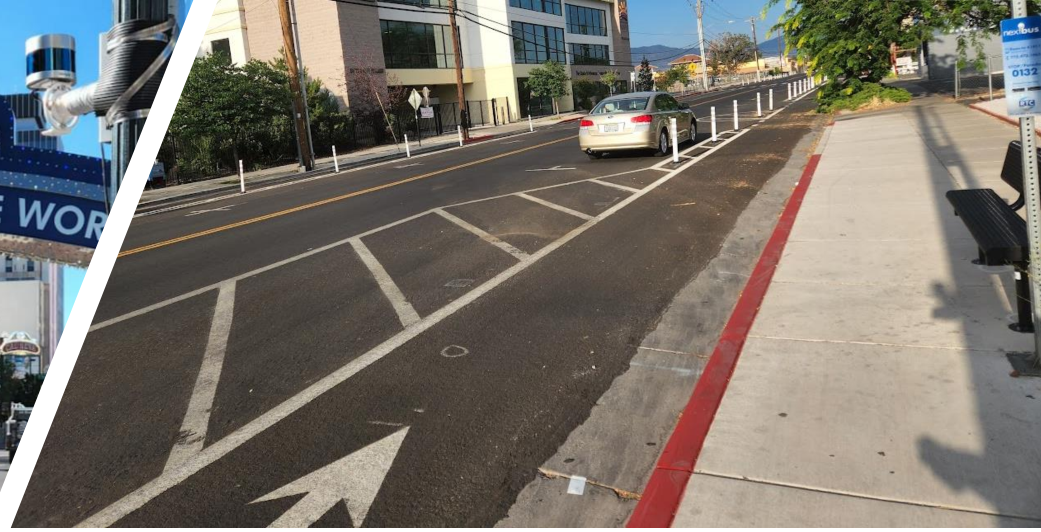

Before-After Study with LiDAR for the Reno Micromobility Pilot Project

For

Regional Transportation Commission of Washoe County (RTC)

Performed By:

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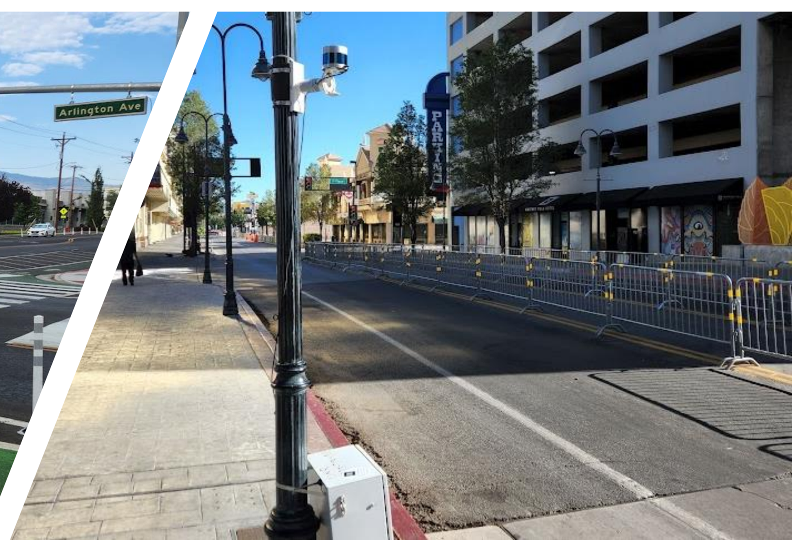

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EXECUTIVE SUMMARY

The Regional Transportation Commission for Washoe County (RTC Washoe) retained the University of Nevada, Reno's (UNR) Center for Advanced Transportation Education and Research (CATER) to provide supporting traffic data for the City of Reno's Micromobility Pilot Project. Data was collected and analyzed at nine sites within the pilot area in three rounds for the purposes of measuring micromobility usage, behavior, safety, and the effectiveness of various micromobility infrastructures. Each of the nine intersection was analyzed separately, but there are also summarized results for the whole study area.

5th St and Keystone Ave: The vehicle volumes and speeds were highest at this signalized intersection, which makes it less inviting for micromobility road users. Furthermore, bicycle infrastructure ended prior to the intersection. The conflict data does not show significant safety concerns however.

5th St and Ralston St: The four-way stop-controlled intersection posed little safety concerns given the low speeds at the approaches and departures and the low number of conflicts. The presence of bicycle lanes reduced the volumes of micromobility road users in the vehicle travel lanes, especially for scooters. Overall, the protected bicycle lanes enhanced the micromobility environment by increasing micromobility activity and decreasing conflict rates, while minimally impacting the vehicle volumes.

5th St and Arlington Ave: This signalized intersection underwent many changes to be converted into a protected intersection. In large part, the changes were a success in causing a majority of micromobility road users to use the protected bicycle lanes in favor of the vehicle travel lanes, with up to 60 percent of bicyclists and up to 80 percent of scooters using the bike lanes over the roadways and sidewalks. These changes improved the safety of the intersection by decreasing the overall conflict frequency and rate by over half from round 1 to round 3. The data suggests that protected intersections such as this one provides a greater degree of separation between micromobility users and vehicles, reducing the conflict rates.

Virginia St and 5th St: Significant changes were made at this intersection with bike lanes extending east-west and a cycle track extending south, as well as a change from two-way to one-way in the south leg. As such, significant increases to micromobility activity came as a result. The micromobility usage of the bicycle infrastructure greatly reduced micromobility volumes on the roadway and sidewalks. Speed decreased as a result of the changes and vehicle-to-vehicle conflicts reduced as a result of the reduced number of conflict points. The only concern is to the increase in the vehicle-to-pedestrian conflicts. The micromobility signal phase is run concurrently with the southbound through and left movements, however, this did not show up as being a safety concern in the conflict data.

Virginia St and 4th St: The signalized intersection has similar trends to the northern intersection at 5th St, with a cycle track extending north-south and bike boxes on the 5th St approaches. The vehicle volumes at this intersection decreased as a result of the change from two-way to one-way. The southbound vehicle volumes between rounds decreased on the weekday, but increased

on the weekend. The pedestrian and micromobility volumes increased with the addition of the infrastructure. Speeds decreased by over 5 MPH on average in the southbound direction. The signal phase configuration in which the southbound phase comes after the micromobility phase seems to slightly discourage red-light running events. Most of the red-light running events are occurring during the southbound movements green (phase 1) rather than the east-west movements (phase 4 and 8) for each direction and round. Vehicle-to-vehicle conflicts decreased as the vehicle-to-pedestrian conflicts increased and other conflicts remained similar.

Virginia St and Commercial Row: This intersection is located just under the Reno Arch; therefore, pedestrian activity is high. Vehicle volumes decreased significantly with the changes made. The southbound vehicle volumes decreased on the weekday and was lowest on round 2 during the weekend. Bicycle and scooter volumes largely migrated from using the roadways and sidewalks to using the cycle track. Speed decreased in the southbound direction and were altogether low at this intersection. The number of conflicts were lower at this intersection with a larger proportion of conflicts being vehicle-to-pedestrian because the high number of crossing pedestrians inside and outside the confines of the crosswalk; however, the conversion of two-way to one-way decreased the number of conflict points overall.

Virginia St and 2nd St: This intersection marked the southern end of the cycle track, of which the infrastructure transitioned into protected bike lanes for the remainder of the study area. As such, this intersection has a unique geometry, which required a learning curve for new micromobility users. Overall, vehicle volumes decreased as the micromobility volumes increased. The micromobility volumes used the bicycle infrastructure the majority of the time during round 2 and round 3, with the remainder split between the sidewalk and roadway. Speeds were at their lowest at this intersection and conflict frequencies and rates decreased. The micromobility red-light running events rates ranged anywhere from 25 to 50 percent. Further, micromobility users were to be more likely to run the red-light on the cycle track. The bike boxes helped alleviate the severity of conflicts and interactions between vehicles and other road users.

Virginia St and Truckee River Walk: The Truckee River Walk encouraged many micromobility users to take advantage of the scenic route, leading to more crossing events as well; however, this did not correlate to high conflict frequencies. For micromobility users traveling along Virginia St, scooters preferred the bike lanes, but the bicyclists were more split between the roadway and sidewalk

Virginia St and Mill St: This uncontrolled intersection saw a decrease in vehicle volumes as pedestrian and micromobility volumes increased. The southernmost intersection had high bike lane utilization. There were no speeding concerns and the conflicts were low at this site.

Overall, reducing the number of through lanes along 5th St did not have a significant affect to vehicle volumes; whereas, changing Virginia St from a two-way to a one-way had a significant affect to the vehicle volumes. However, the southbound vehicle volumes did not change as much along Virginia St. At most sites, particularly along Virginia St, pedestrian and micromobility volumes increased each round. Figure 1 shows the combined breakdown of bicycles and scooters using the roadway, sidewalk, cycle track, and bicycle lanes for all nine sites. “CT/BL” refers to the cycle track and bicycle lanes. In general, the proportion of micromobility road users riding along the roadway and sidewalk decreased with the introduction of the bicycle infrastructure. When breaking this down by infrastructure (Bike lanes versus cycle track) and by street (5th and Virginia), there appears to be no significant difference. This suggests that both bicycle lanes and cycle tracks are good solutions for providing micromobility road users safe and effective travel ways.

There were little speeding concerns at each intersection and speeds generally decreased with the new design configurations. Speeds were lowest along the cycle track and higher otherwise. The weekend most commonly had more vehicle red-light running frequencies, but the rates are usually similar. The micromobility red-light running frequencies and rates were highest at the Virginia and 2nd St intersection. The combined conflict data showed a decrease in vehicle-to-vehicle conflict rates and a slight decrease in the vehicle-to-micromobility conflict rates. Vehicle-to-pedestrian conflict rates decreased significantly along 5th St, but were the same in round 1 and round 3 along Virginia St. Micromobility-to-pedestrian conflicts were much less frequent and occurred largely on Virginia St where rates did increase through the rounds. The study data indicates that micromobility focused infrastructure that separates vehicles and micromobility road users can be effectively extended to other areas of the city, particularly where there is high mixed traffic.

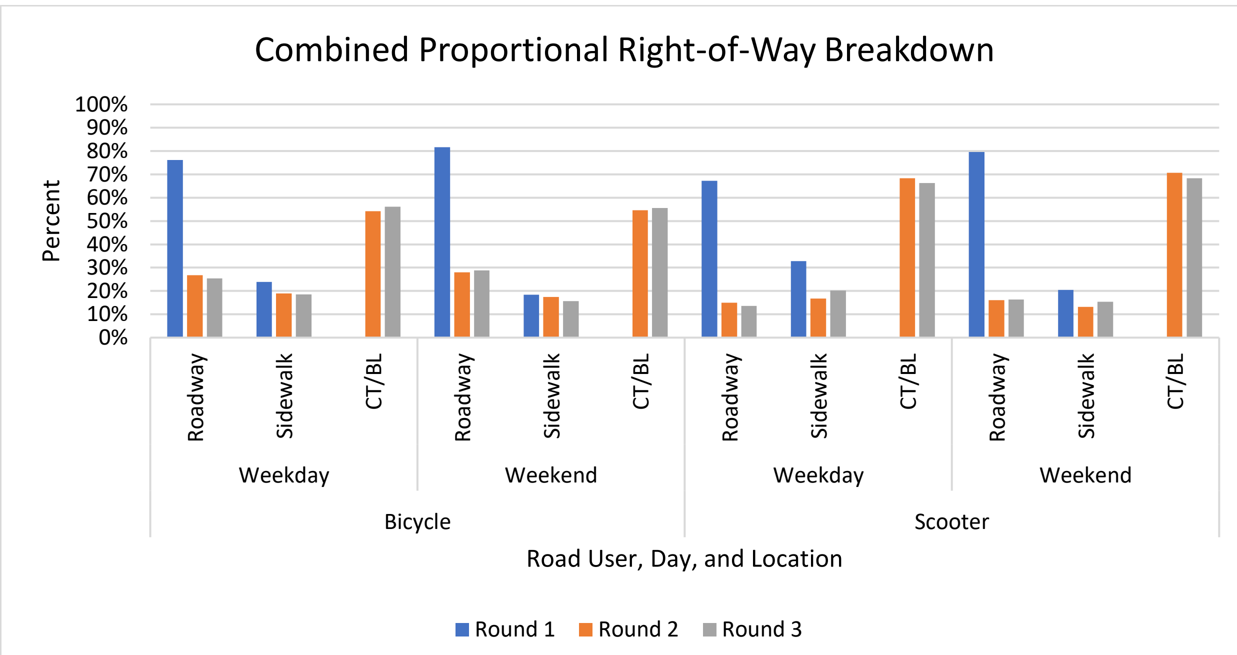


Figure 1 Combined proportion right-of-way breakdown

1 Introduction

The Regional Transportation Commission of Washoe County (RTC) retained the University of Nevada, Reno’s (UNR) Center for Advanced Transportation Education and Research (CATER) to provide supporting traffic data for the City of Reno’s Micromobility Pilot Project.

1.1 Project Background

The Micromobility Pilot Project aims to improve access and connectivity for residents and visitors through micromobility-specific infrastructure in Reno's downtown. Micromobility refers to a range of small, lightweight vehicles such as bicycles or scooters that typically operate at speeds of less than 20 mph and are driven by the user. The pilot project installed facilities such as protected bicycle lanes, bicycle boxes, a two-way cycle track, and a protected intersection along 5th St from Keystone Ave to Evans Ave and along Virginia St from 5th St to Liberty St in downtown Reno, Nevada. Furthermore, there were lane reductions on 5th St and a change from two-way to one-way along Virginia St to accommodate the bicycle infrastructure. This project comes after the city recently implemented Bird’s electric scooter ride-sharing platform, in which electric scooters are stationed throughout the city for purposes of passer-by users to activate via the Bird app on their phone. The ride-sharing platform is increasing the micromobility activity across the city, particularly in Reno’s downtown.

1.2 Study Objectives

The purpose of this study is to measure the before-after multimodal traffic performance of this pilot project, which is essential to understanding how the micromobility-specific infrastructure influences safety and facilitates micromobility road users. The traffic performance includes multimodal traffic volumes, usage of the installed micromobility infrastructures, vehicles and micromobility road users' speeds, and conflicts between vehicles and other road users.

1.3 Study Data

UNR used roadside light detection and ranging (LiDAR) data collection platforms to collect data at nine sites along 5th St and Virginia St during three separate rounds. LiDAR sensors generate cloud points of surrounding objects through 32 pulsed lasers 360 degrees at a frequency of 0.1 seconds. The cloud points collected in the field are run through UNR’s artificial intelligence (AI) software to filter out the background, classify the road user type, and track the road users’ movement. Figure 2 shows the roadside LiDAR platform used to collect the data, the cloud points generated by the LiDAR sensor, and the trajectories of each road user for a 30-minute sample period. During data collection, the sensor is placed 10-12 feet high on a signal or streetlight pole connected to a computer with a hard drive and powered by lithium batteries, which can last anywhere from 3-5 days continuously. The cloud points shown in the bottom of Figure 2 shows what the various road user types look like, as well as other stationary objects such as ground points and buildings. The trajectories on the top right show the movements of each road users’ every 0.1 second. For this study, the vehicles, bicycles, scooters, and pedestrians were classified. The primary focus of this study is the micromobility users, bicyclists and scooters. The traffic data gleaned from these trajectories for the purposes of this study include the following:

- Multi-modal traffic counts
- Vehicle speeds
- Red-light running events
- Conflicts and interactions between road users
- Traffic compliance and behavior

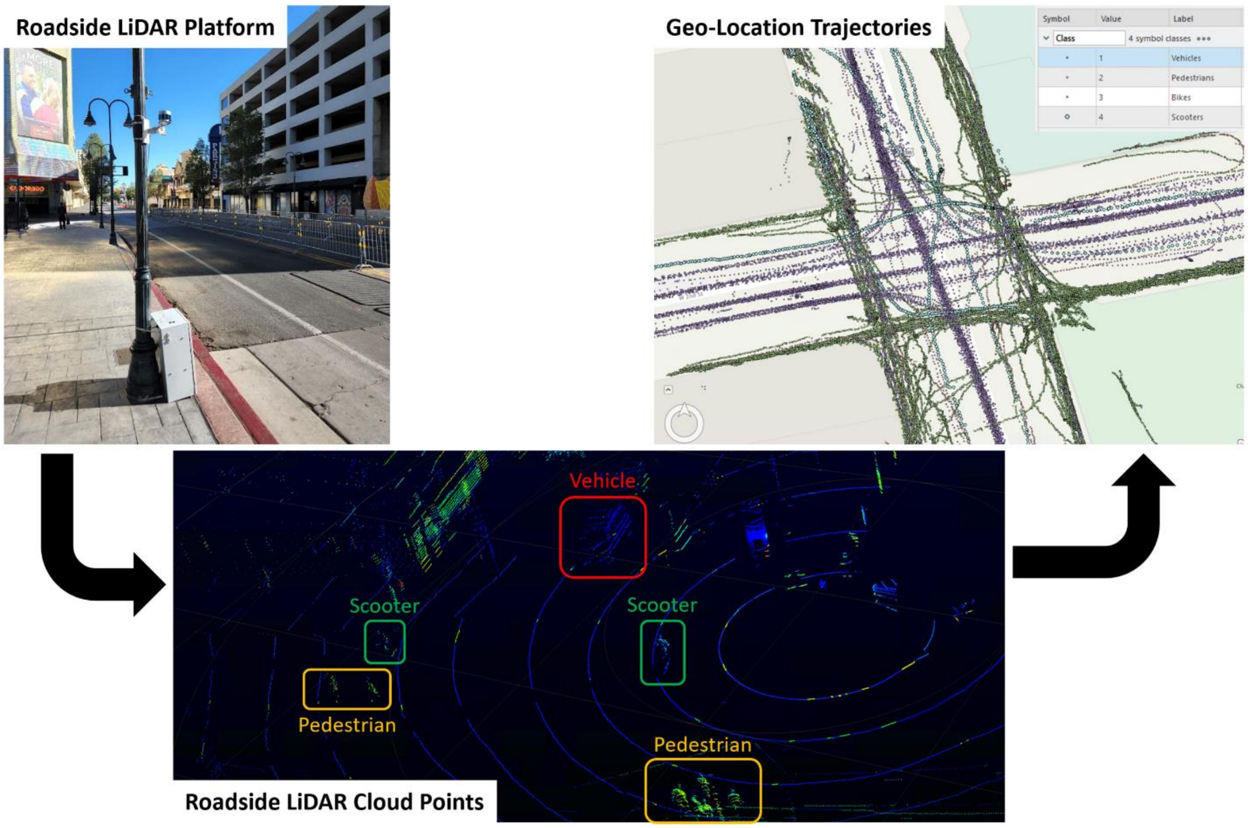


Figure 2 Stages of roadside LiDAR data processing

Each data collection site is shown in Figure 3. Data collection started April 2022 and ended in October 2022, as shown in Table 1. Each site has at least one full weekday and one full weekend day. Round 1 data was collected before any changes were made to the infrastructure. Round 2 data collection occurred once the new infrastructure was installed and during the height of summer. Finally, round 3 data collection also occurred after the new infrastructure was installed but after UNR was back in session and more students occupied the region. Table 1 outlines the site description and the changes that were made. Events that occurred during the data collection period include the Biggest Little Marathon on May 1st, 2022, and Northern Nevada Pride Parade on July 23, 2022. While the analysis days chosen and shown in Table 1 do not overlap with these events, they may have some impact to round 1 Virginia St / Commercial Row and Virginia St / 2nd St, and round 2 Virginia St / 5th St, Virginia St / 4th St, and Virginia St / Commercial Row.

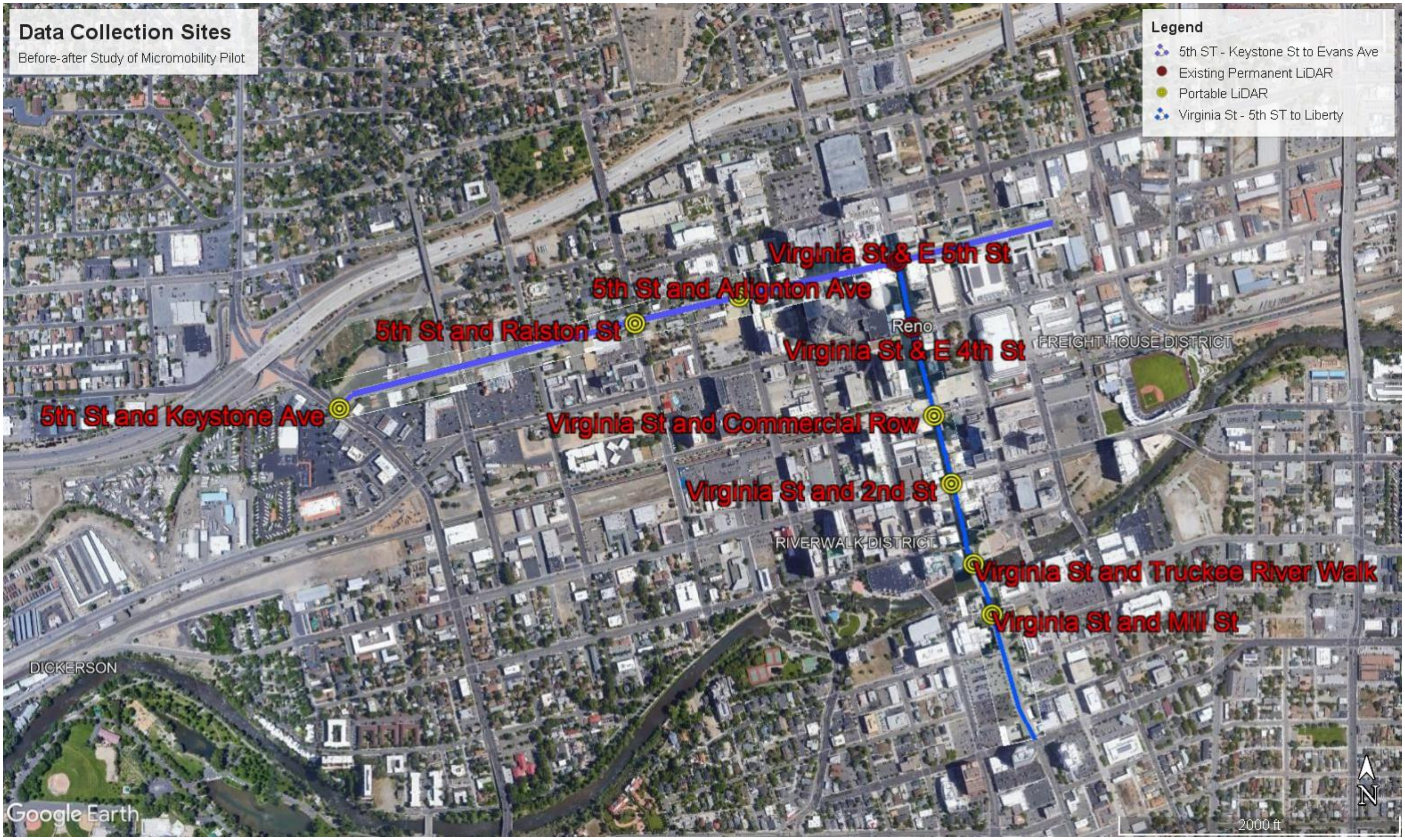


Figure 3 Map of data collection sites and study area

Table 1 Site, analysis days, and site information

Site	Round	Weekday	Weekend	Intersection Type	Changes
5th St and Keystone Ave	1	Tuesday, April 26, 2022	Sunday, April 24, 2022	Signalized	Eastbound Bicycle Lane, Westbound Sharrows
	2	Friday, July 29, 2022	Saturday, July 30, 2022		
	3	Friday, September 30, 2022	Saturday, October 1, 2022		
5th St and Ralston St	1	Tuesday, May 10, 2022	Sunday, May 8, 2022	Four-Way Stop-Controlled	Bicycle Lanes, Reduced Lanes
	2	Friday, July 29, 2022	Saturday, July 30, 2022		
	3	Thursday, September 29, 2022	Saturday, October 1, 2022		
5th St and Arlington Ave	1	Tuesday, April 26, 2022	Saturday, April 23, 2022	Signalized	Protected Intersection, Reduced Lanes
	2	Thursday, July 28, 2022	Saturday, July 30, 2022		
	3	Friday, September 30, 2022	Saturday, October 1, 2022		
Virginia St and 5th St	1	Tuesday, May 10, 2022	Sunday, May 8, 2022	Signalized	Bicycle Lanes, Cycle Track, Bicycle Box, Two-Way to One Way
	2	Friday, July 22, 2022	Sunday, July 24, 2022		
	3	Thursday, September 22, 2022	Saturday, September 24, 2022		
Virginia St and 4th St	1	Tuesday, May 10, 2022	Sunday, May 8, 2022	Signalized	Cycle Track, Bicycle Box, Two-Way to One Way
	2	Friday, July 22, 2022	Sunday, July 24, 2022		
	3	Tuesday, September 27, 2022	Saturday, September 24, 2022		
Virginia St and Commercial Row	1	Monday, April 28, 2022	Saturday, April 30, 2022	One-Way Stop-Controlled	Cycle Track, Two-Way to One Way
	2	Thursday, July 21, 2022	Sunday, July 24, 2022		
	3	Thursday, September 22, 2022	Saturday, September 24, 2022		
Virginia St and 2nd St	1	Thursday, April 28, 2022	Saturday, April 30, 2022	Signalized	Bicycle Lanes, Cycle Track, Bicycle Box, Two-Way to One Way
	2	Tuesday, July 19, 2022	Saturday, July 16, 2022		
	3	Tuesday, September 27, 2022	Sunday, September 25, 2022		
Virginia St and Truckee River Walk	1	Tuesday, May 10, 2022	Sunday, May 8, 2022	Mid-Block Crosswalk	Bicycle Lanes
	2	Tuesday, July 19, 2022	Saturday, July 16, 2022		
	3	Monday, September 26, 2022	Sunday, September 25, 2022		
Virginia St and Mill St	1	Tuesday, May 10, 2022	Sunday, May 8, 2022	Unsignalized T Intersection	Bicycle Lanes
	2	Tuesday, July 19, 2022	Saturday, July 16, 2022		
	3	Monday, September 26, 2022	Sunday, September 25, 2022		

1.3.1 Traffic Counts

Multi-modal traffic counts are extracted from the trajectory data. Total vehicle, pedestrian, bicycle, and scooter volumes are reported. The counts are validated through a sample of raw LiDAR data that can be viewed in the Veloview visualization software, and the GIS trajectory data. Size of the road user and speed profiles are used to further classify road users in regions of high mixed traffic, i.e., sidewalks. The Micromobility volumes are extracted at the approach of each site on the roadways, sidewalks, cycle tracks, and bike lanes to determine the utilization of various rights-of-way locations for each site and round.

1.3.2 Vehicle Speeds

Vehicle speeds are extracted for each vehicle's speed along Virginia St and 5th St each site, round, and intersection approach. Speeds are extracted through geofence detection zones at the through approach of each leg of the intersections. The detection zone is placed just before the stop bar at each intersection except at 5th St and Ralston St, Virginia St and Truckee River Walk, and Virginia St and Mill St. Since 5th St and Ralston St is a four-way stop-controlled intersection, the detection zones are placed approximately 150 feet east and west of the intersection for both directions; therefore, providing free flow speed conditions along 5th St. At Virginia St and Truckee River Walk, the zones are places just before the crosswalk in each direction. At Virginia St and Mill St, the southbound detection zone is placed just before the crosswalk, and the northbound detection zone is placed just before the yield striping. The overall speed data provides information on where there might be speeding concerns, and how speeds change across the three rounds.

1.3.3 Red-Light Running

The vehicle and micromobility red-light running events are extracted at each of the five signalized intersections along 5th St and Virginia St for each round and intersection approach. The vehicle and micromobility users are detected through geofence detection zones at each through and left turn approach and at the bicycle infrastructure along Virginia St. The detection zones are placed past the stop bar and into the intersection. Speed and direction are used to extract only those road users traveling in the desired direction. The timestamps for which the road users are detected in these zones is paired with the signal logs provided by RTC Washoe for the same date and time. If a vehicle or micromobility road user is detected during a red interval for their respective direction or movement, then that road user is flagged as running a red-light. The majority of red-light running events occur within a second to two after the red interval starts, which makes them less severe red-light running events. The larger the time that elapses after the red interval starts, the more dangerous the red-light running event is. The red-light running events are extracted at each through and left-turn vehicle at each signalized intersection. There are bicycle signals along Virginia St for round 2 and round 3. As such, red-light running events for micromobility users in the northbound and southbound direction are extracted at the cycle track and bicycle lane. The total red-light running events and the frequency of red-light running events past the red clearance is included. All the sites and their phases have a red clearance of 1.5 seconds. Additionally, the red-light running rate is reported, which considers the volumes of traffic for the corresponding movements.

Figure 4 shows four unique ring-and -barrier diagrams across the five signalized intersection and three rounds. The ring-and-barrier diagram shows the sequence of traffic signal phases as they occur in time, from left to right. The phases with the through and left together means that the left turn is permissive; whereas, a left turn on its own phase is a protected left turn. The green arrows refer to the bike (micromobility) signal phase. Table 2 designates which diagram goes for to which site and round. For 5th St at Keystone and Arlington Ave, the diagram does not change. For the Virginia St intersections, the diagram changes to accommodate the cycle track. For the Virginia St and 5th St intersection the micromobility phase is concurrent with the southbound through and left. Conversely, at 2nd St and 4th St, they are not concurrent. Also, the order of phase is different between round 2 and round 3 for the Virginia St and 4th St intersection.

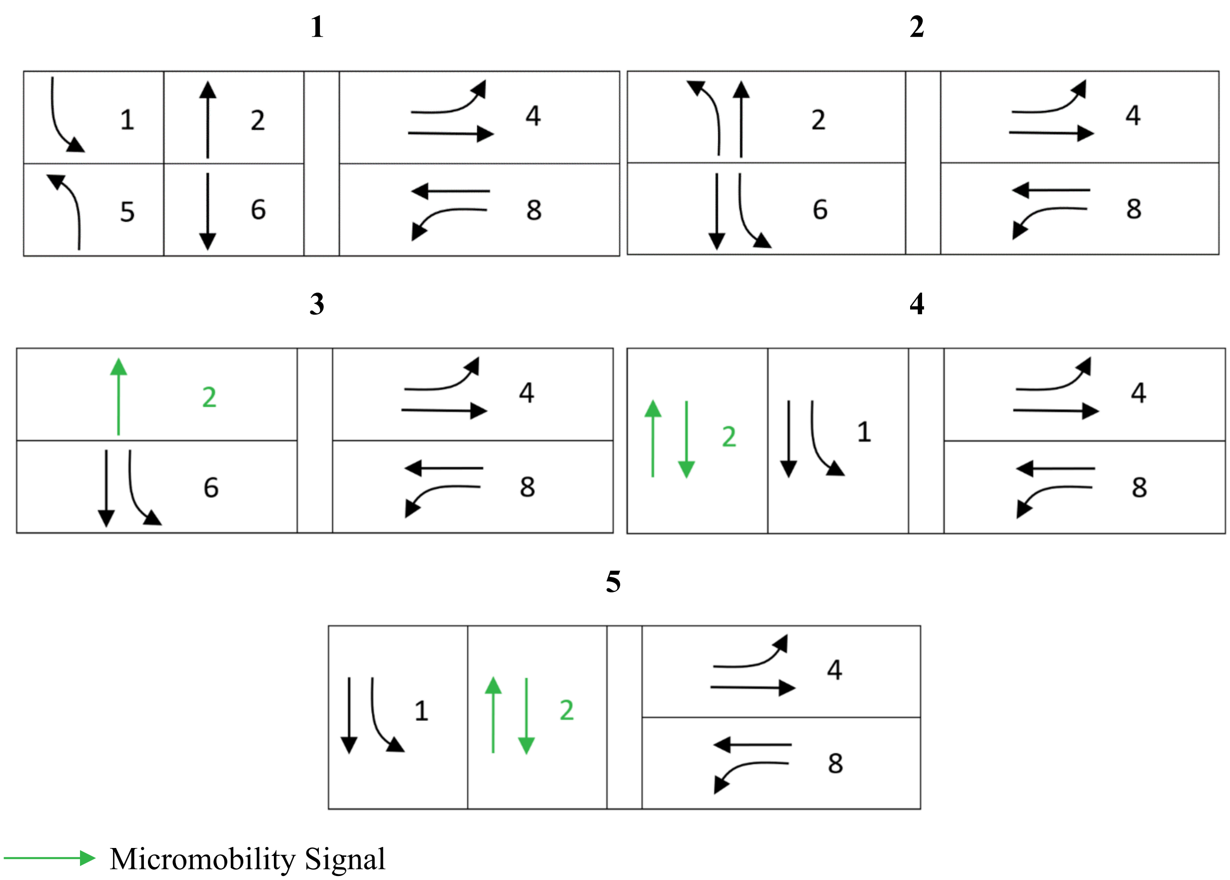


Figure 4 Each unique ring-and-barrier diagram within the study area

Table 2 Each site and rounds ring-and-barrier diagram as presented in Figure 4

Intersection	5th St / Keystone Ave			5th St / Arlington Ave			Virginia St / 5th St			Virginia St / 4th St			Virginia St / 2nd St		
Round	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Diagram	1	1	1	2	2	2	2	3	3	2	4	5	2	4	4

1.3.4 Conflicts

Through the trajectory data extracted from roadside LiDAR sensors, interactions and conflicts between road users can be extracted and used as surrogate safety measures (SSM). The methodology used in this report is extracting interactions for which two road users' trajectories cross each other within a certain time difference, otherwise known as post-encroachment time (PET). In other words, if a vehicle makes a left turn in front of an oncoming through vehicle, the time difference in which the two vehicles occupied the same space is the PET. The same situation applies to other road users such as pedestrians, bicyclists, and scooters. The time difference, or PET, will be referenced throughout this study to indicate the level of severity the conflicts are at each intersection. A number closer to zero suggests a more severe conflict, whereas a higher value suggests a less severe conflict or perhaps just a close interaction. In the literature, two seconds or less is a common interval to consider the interaction as a conflict. Speed at the moment of conflict for each road user is another important factor in determining if the interaction is truly dangerous, and is therefore considered in this study. The angle at which the two road users pass each other is another important factor in determining how severe an interaction is, particularly for vehicle-to-vehicle conflicts.

The following criteria is used to extract conflicts for this study:

- Vehicle-to-vehicle:
  - Time difference less than 2 seconds
  - Conflict angles of 90 degrees or greater: Left/thru and thru/thru conflicts
- Vehicle-to-pedestrian, vehicle-to-bicycle, vehicle-to-scooter, and micromobility-to-pedestrian conflicts
  - Time difference less than 2 seconds
  - Vehicle/micromobility speed greater than or equal to 10 MPH

Once the conflicts are extracted, the conflict frequency, rate and severity are analyzed and compared across rounds. The frequency shows the total number of conflicts and will be displayed on a map to see where conflicts are occurring at each site for each round. The conflict rate takes into consideration the volume of road users. For vehicle-to-vehicle conflicts it is the number of conflicts divided by the total number of vehicles at the intersection. This is number is multiplied by one hundred to be in conflicts per one hundred vehicles. The same is applied to the other conflict types but the most vulnerable road user count is considered. For example, the vehicle-to-bicycle conflict will be in conflicts per one hundred bicycles. Finally, the severity will be analyzed by the distribution of PET.

Figure 5 shows an example of a vehicle-to-vehicle, vehicle-to-pedestrian, vehicle-to-bicycle, and micromode-to-pedestrian conflicts. The vehicle-to-vehicle conflict example is a left turn and opposing through conflict, which is the most common vehicle-to-vehicle conflict at intersections in which yield or permissive left turns exist. These conflicts typically have a conflict angle between 120 and 130, making them more severe. The vehicle-to-pedestrian conflict example is of a through vehicle and a crossing pedestrian at an uncontrolled crosswalk. The vehicle-to-bicycle conflict example is between a westbound vehicle and a bicyclist making an eastbound left onto the cycle track. Lastly, the scooter-to-pedestrian conflict is between a scooter riding through the cycle track and a crossing pedestrian at an uncontrolled crosswalk. A total of two days of data are used for each site and round, one weekday and one weekend.

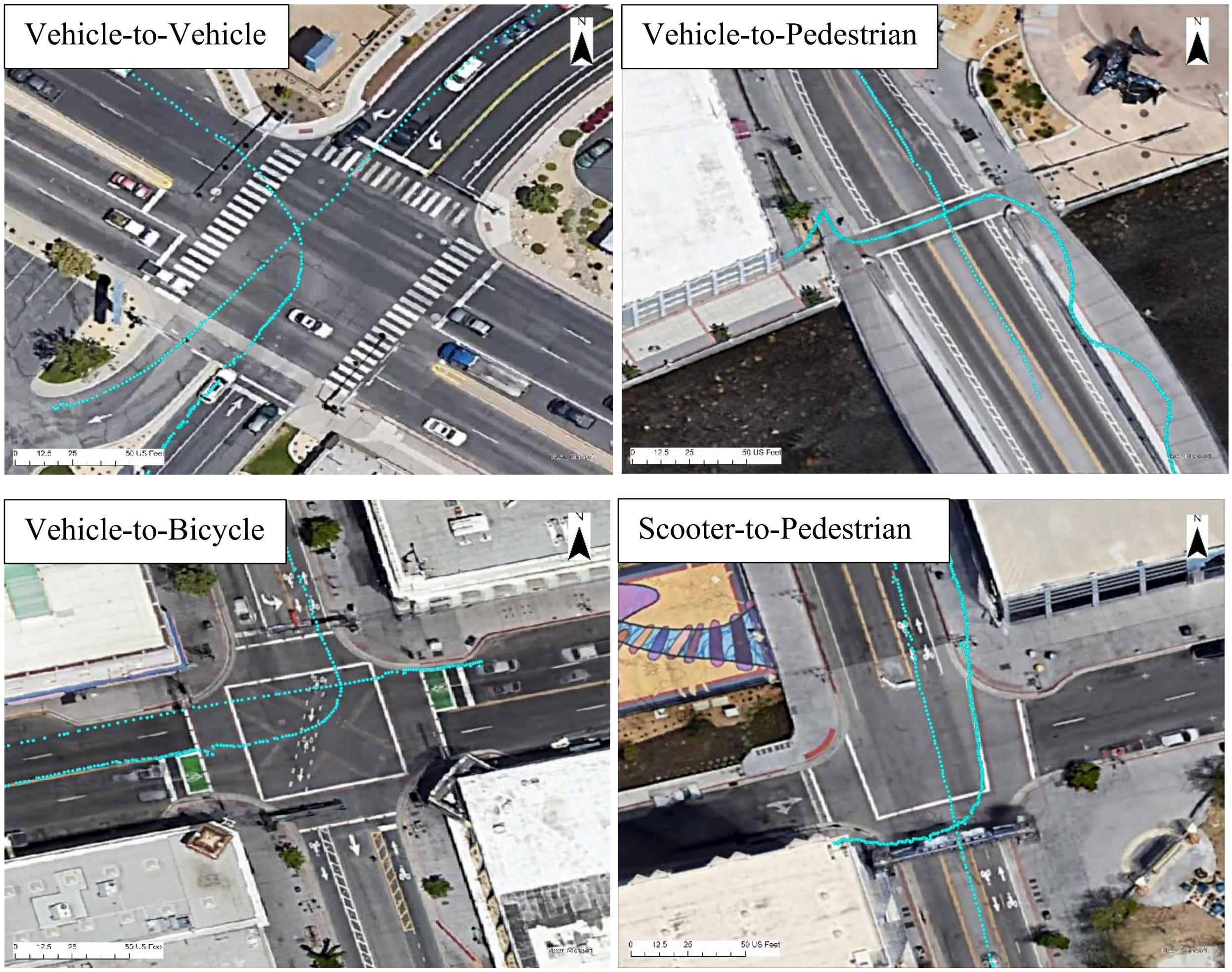


Figure 5 Example of different conflict types

2 Intersection Analysis

Each of the nine intersections are analyzed separately, which includes before-after comparative analyses based on the three rounds of data collection. The purpose of this is to see how road users at each intersection changed as a result of the temporary infrastructure installation. Data that was used includes multi-modal traffic counts, vehicle speeds, red-light running events, and conflicts between different road users. The goal is to determine whether micromobility volumes increased, whether micromobility road users are using the new infrastructure as intended, and whether any safety concerns arose as a result of the changes. Further, an evaluation of the effectiveness of each new infrastructure type will be analyzed to determine which are most beneficial to locals and tourists.

2.1 5th St and Keystone Ave

The 5th St and Keystone Ave intersection is a signalized intersection just south of the I-80 on-ramp. As such, vehicle volumes were much greater than other sites. There are three through lanes and one left-turn lane in the northbound direction; one left-turn, one through, and one right-turn lane in the westbound direction; two through lanes and one left-turn lane in the southbound direction; and one left-turn, one through, and one right-turn lane in the eastbound direction. The west leg of the intersection provides access to the Keystone Square shopping mall. There is a curve on the westbound approach on 5th St. The infrastructure changes to this intersection were minor. On the westbound approach, a bike lane turned into a shared lane marking (Sharrows) on the through lane. On the east leg going eastbound, the bike lane began and extended along the study area on 5th St. The rest of the intersection was unchanged. Figure 6 (a) shows the intersection before changes were made and Figure 6 (b) shows the intersection after changes were made.

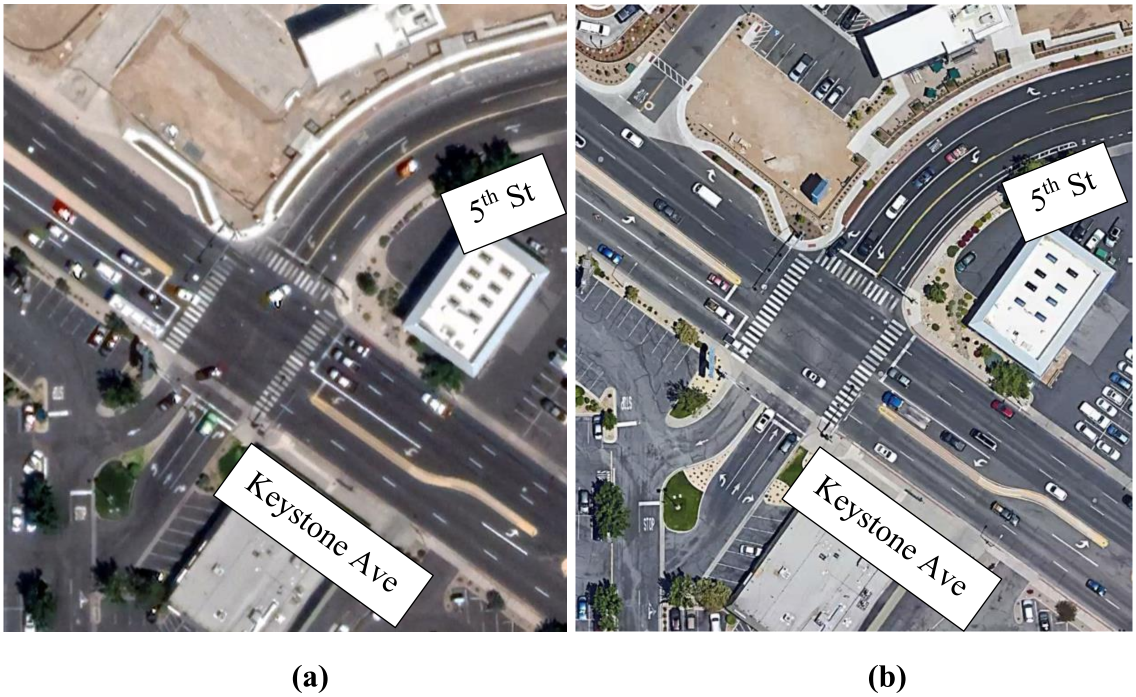


Figure 6 5th St and Keystone Ave before-after infrastructure changes

2.1.1 Counts

The counts for the different road users at the 5th St and Keystone Ave intersection is analyzed. Overall, the vehicle volumes were unaffected by the changes in infrastructure, as shown in Table 3. Further, the vehicles volumes were higher during the weekday than weekend day. The pedestrian volumes increased each round with higher volumes occurring during the weekend, as shown in Table 4. Bicycle volumes were highest during round 2 and scooter volumes increased each round, as shown in Table 5. Further, bicycles made up a slightly higher proportion of the micromobility volumes.

Table 3 5th St and Keystone Ave daily vehicle volumes

Round	Weekday Vehicles	Weekend Vehicles
1	32985	30752
2	36542	27631
3	33097	29871

Table 4 5th St and Keystone Ave daily pedestrian volumes

Round	Weekday Pedestrian	Weekend Pedestrian
1	246	299
2	311	320
3	367	377

Table 5 5th St and Keystone Ave daily micromobility volumes

Round	Weekday Bicycle	Weekend Bicycle	Weekday Scooter	Weekend Scooter
1	47	69	33	48
2	93	77	73	58
3	80	51	80	79

2.1.2 Micromobility Behavior

The behavior and compliance of the micromobility road users at the 5th St and Keystone Ave intersection is analyzed. Figure 7 and Figure 8 shows the right-of-way utilization of the micromobility road users during a given weekday and weekend day, respectively. In other words, the extent to which micromobility road users use the roadway, bike lane, cycle track, and the sidewalks. "CT/BL" refers to the cycle track and bicycle lanes. For the 5th St and Keystone Ave intersection, the only change to the infrastructure for round 2 and 3 was that there was a bike lane on the east leg intend for eastbound travel; therefore, any micromobility road user that is counted in this section is traveling in the wrong direction. Furthermore, only the east leg is considered in this section.

Based on Figure 7 and Figure 8, bicyclists and scooters both favored using the roadway for each round, but scooters were more likely to use the sidewalks than the bicycles.

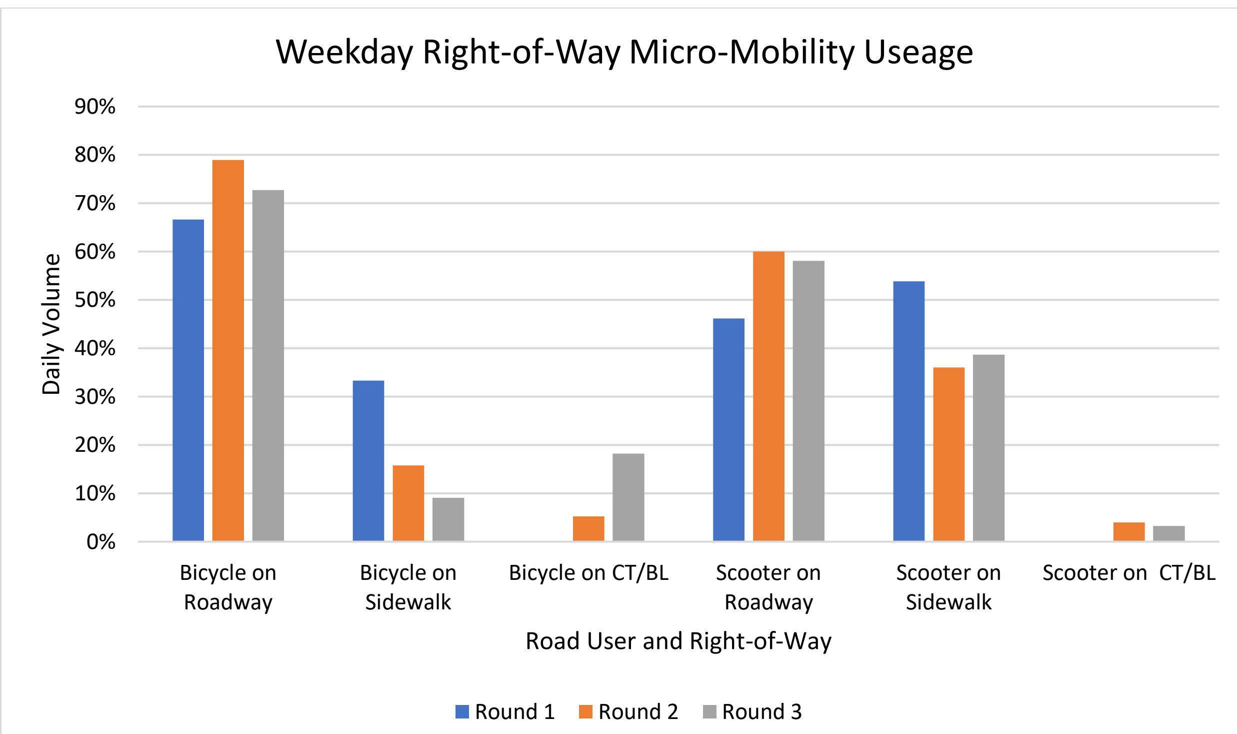


Figure 7 5th St and Keystone Ave weekday right-of-way micromobility usage

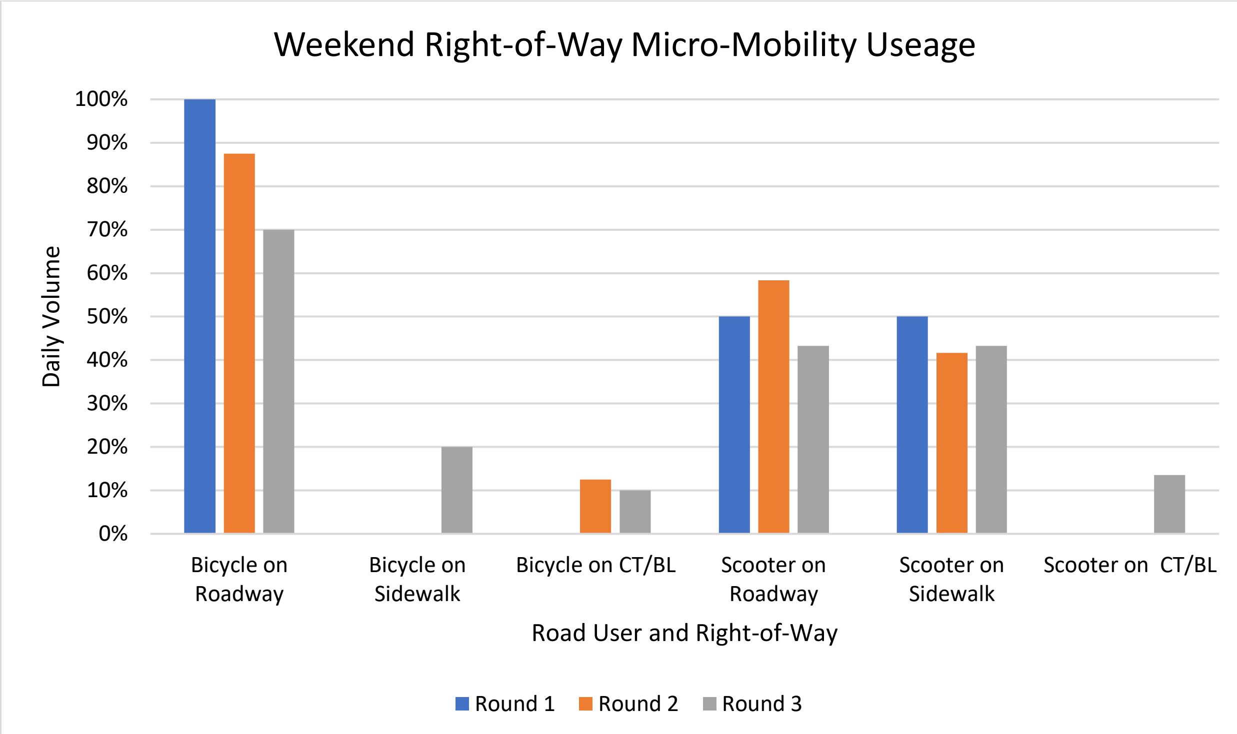


Figure 8 5th St and Keystone Ave weekend right-of-way micromobility usage

2.1.3 Speed

The vehicle speeds at the 5th St and Keystone Ave intersection are analyzed. The through speeds of each individual vehicle is extracted and the distribution of the speed is shown in Figure 9 for each round and each direction. The detection zones used to extract the speeds were placed just before the stop bar in each direction. The Xs mark the mean, the horizontal lines mark the median, and the lower and upper boundaries of the box represent the 25th and 75th percentile speeds, respectively. The speed limit is 30 MPH along Keystone Ave and 25 MPH along 5th St. Overall, a majority of vehicles were under the speed limit. Speeds were generally higher in the north-south direction where there were also some outlier speeds. This may be because of the proximity to the I-80 freeway. Furthermore, there appears to be no change to the speeds over the three rounds.

Figure 9 5th St and Keystone Ave vehicle speeds

2.1.4 Red-Light Running

The red-light running at the 5th St and Keystone Ave intersection are analyzed. The through and left turn vehicles detected past the stop bar over a speed of 10 MPH going in the correct direction during the red-interval for their respective direction and movement are flagged as red-light running events. Figure 10 shows the ring-and-barrier diagram of the intersection, which did not change with the rounds. Figure 11 and Figure 12 shows the frequency of red-light running events based on the total and after red clearance, respectively. Figure 13 and Figure 14 shows the rate of red-light running events based on the total and after red clearance, respectively. Most red-light running events occurred in the northbound and southbound directions where there was more traffic, but the rates were higher in the eastbound and westbound directions, particularly during the weekend. Round 2 saw a spike in the number of red-light running events after the red clearance time. Overall, there was no significant difference in the frequency of red-light running events across the three rounds.

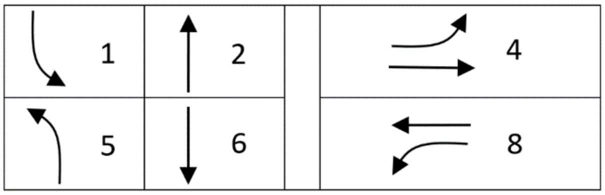


Figure 10 5th St and Keystone Ave ring-and-barrier diagram

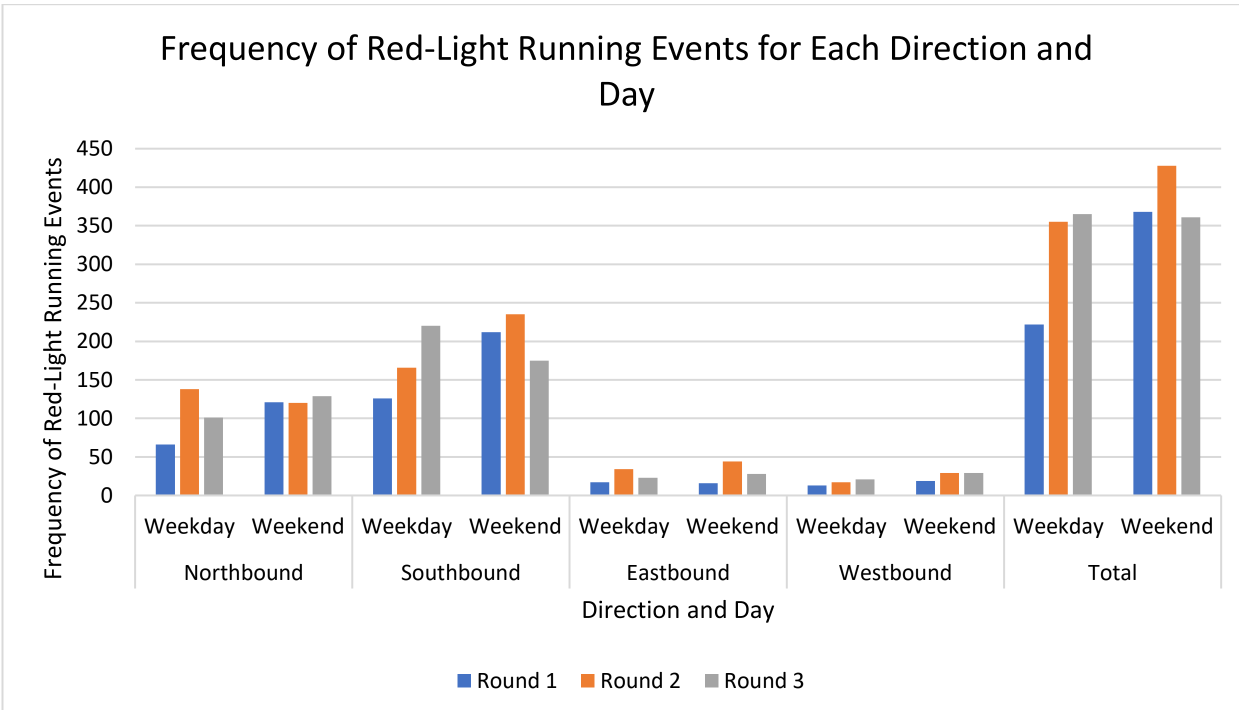


Figure 11 5th St and Keystone Ave frequency of vehicle red-light running events

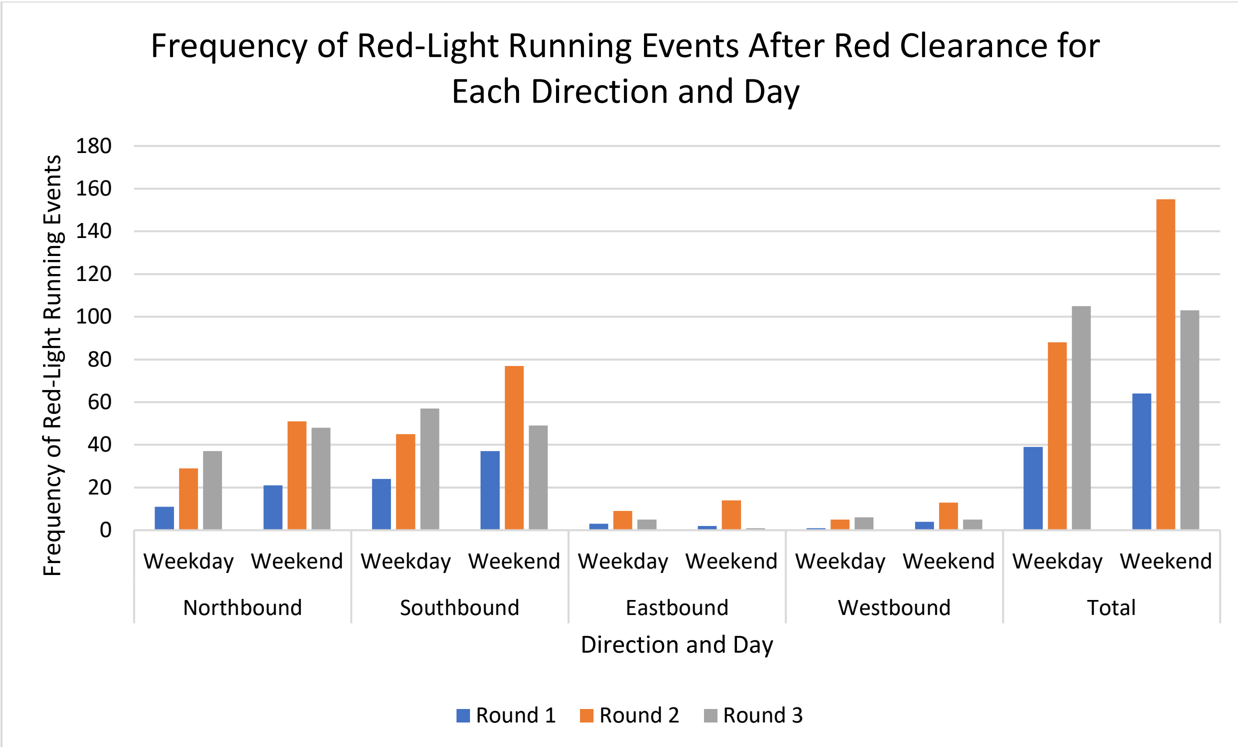


Figure 12 5th St and Keystone Ave frequency of vehicle red-light running events after red clearance

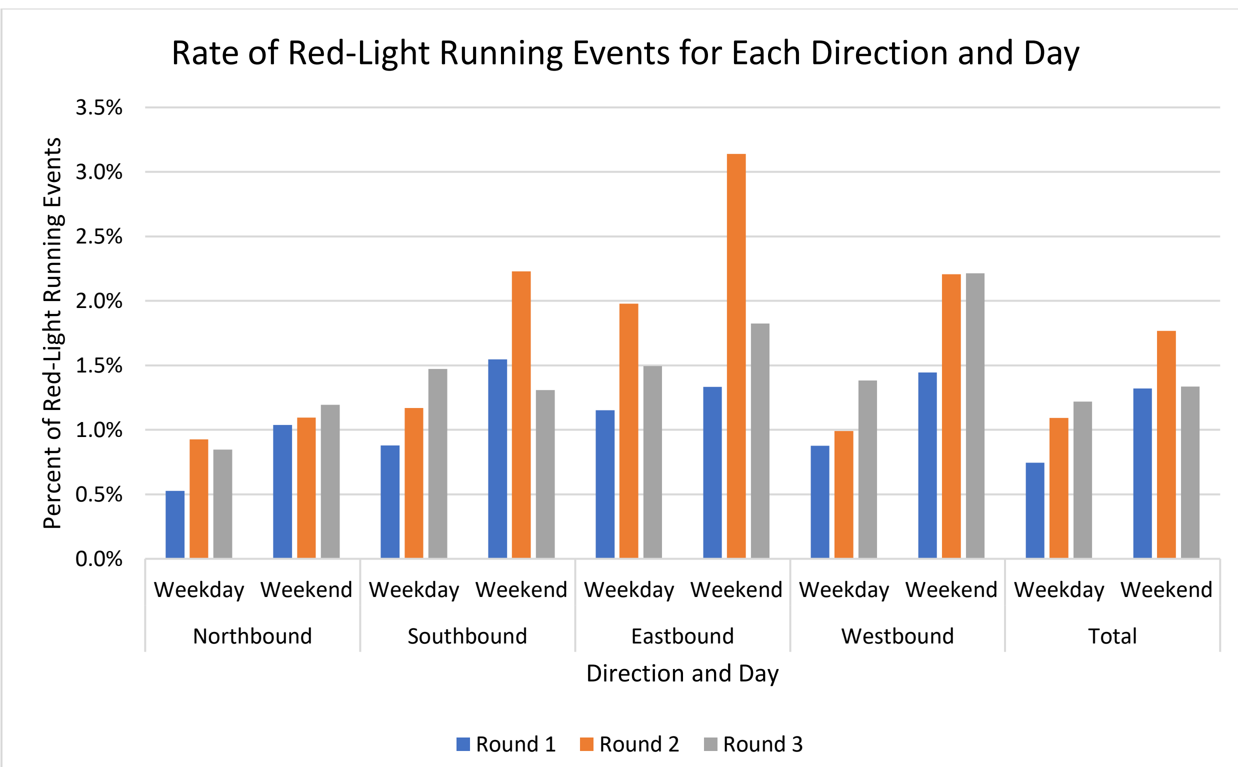


Figure 13 5th St and Keystone Ave percent of vehicle red-light running events

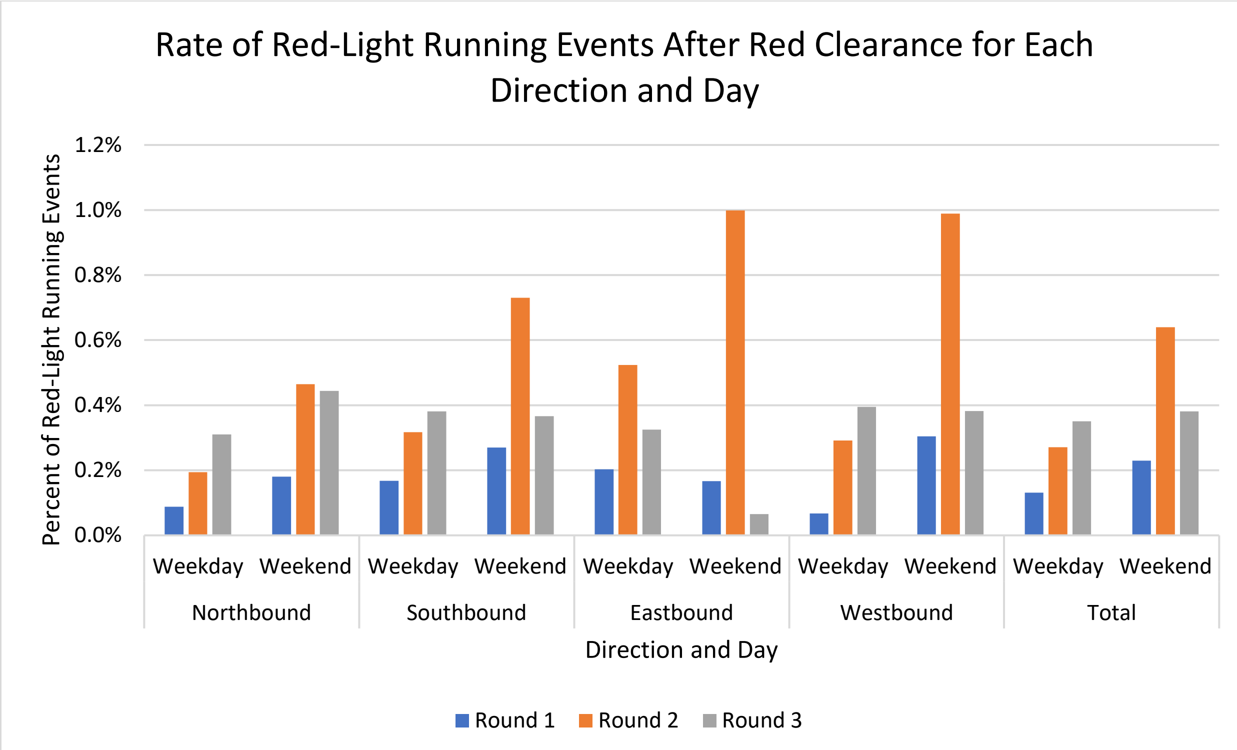


Figure 14 5th St and Keystone Ave percent of vehicle red-light running events after red clearance

2.1.5 Conflicts

The conflicts between road users at the 5th St and Keystone Ave intersection is analyzed. Figure 15 illustrates the conflicts by showing a map of each conflict's location within the site, along with the conflict frequency and severity in PET. Considering that few changes have been made the infrastructure, it makes sense to see that the number of conflicts has remained steady. Furthermore, most of the conflicts are between vehicles, with very few conflicts involving vulnerable road users. Table 6 shows the conflict rate, which normalizes the number of conflicts by the volumes of the most vulnerable road user. The only trend that differs from the overall numbers is that the conflict rate decreased for vehicle-to-bicycle conflicts. Overall, the safety of the intersection has not changed.

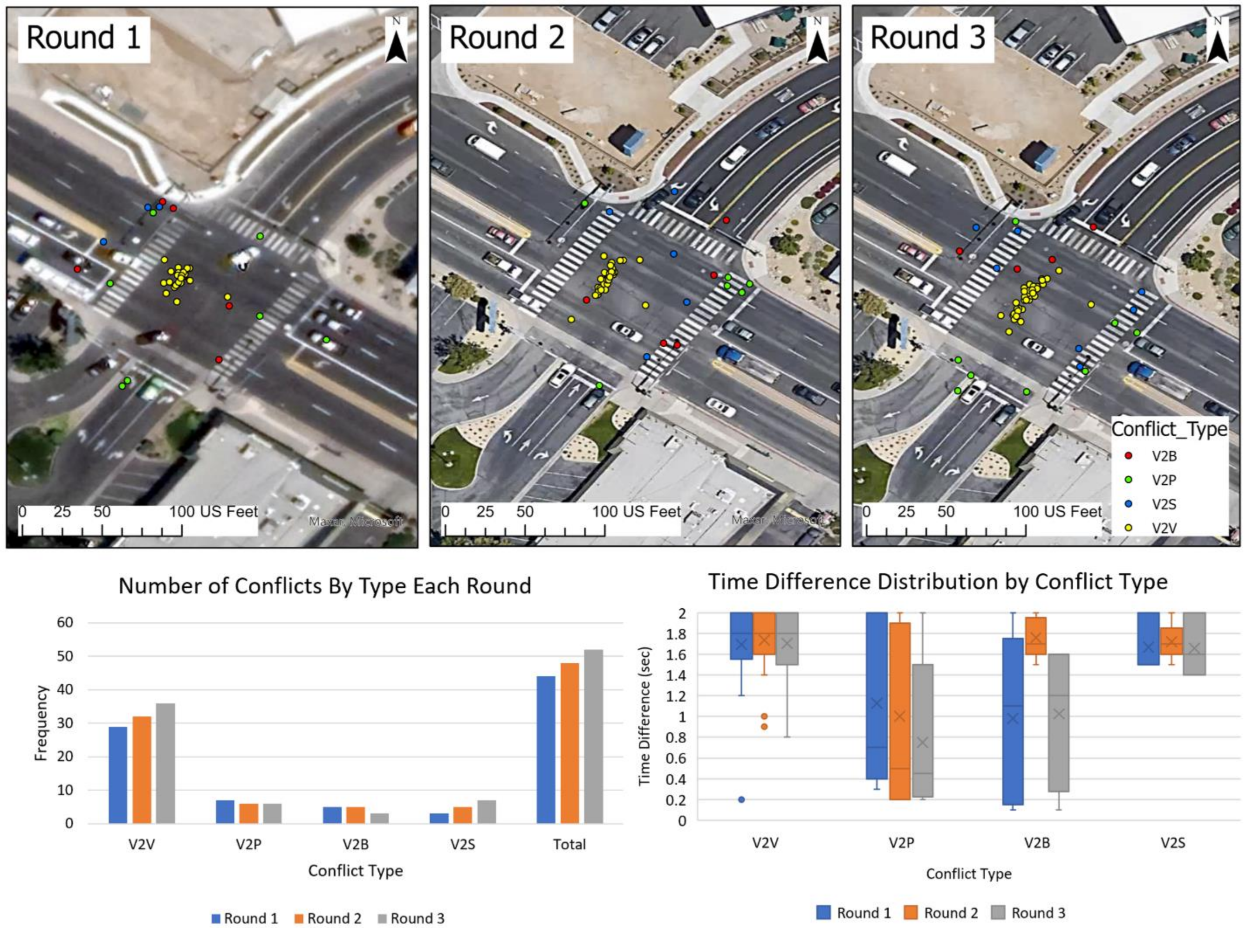


Figure 15 5th St and Keystone Ave conflict locations, frequencies, and severities

Table 6 5th St and Keystone Ave conflict rates

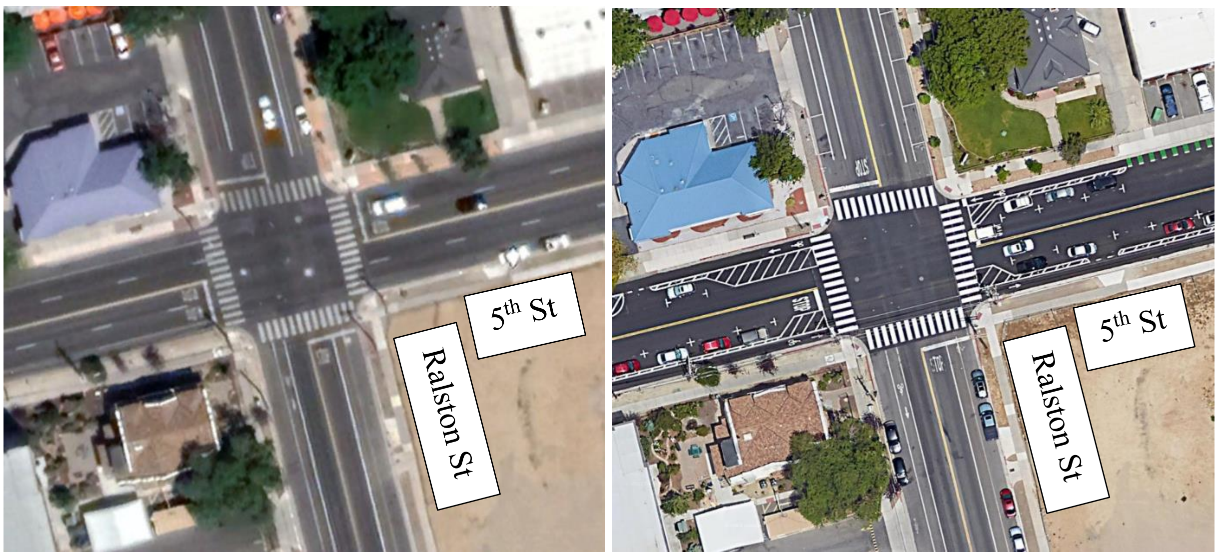
Round	Vehicle-to-vehicle conflicts per 100 vehicles	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
1	0.05	1.28	4.31	3.70	0.07
2	0.05	0.95	2.94	3.82	0.07
3	0.06	0.81	2.29	4.40	0.08

2.1.6 Summary

The overall findings of the 5th St and Keystone Ave intersection analysis is summarized. Vehicle volumes have remained the same over the three rounds, but the pedestrian and micromobility volumes increased. Vehicle volumes were higher on the weekday versus the weekend, whereas the pedestrian and micromobility volumes were similar on the weekday versus weekend. Bicycles and scooters favored using the roadway; however, scooters were more likely to use the sidewalk. Speeds were generally higher in the north-south direction where there were also some outlier speeds. Furthermore, there is no increase in speeds across the three rounds. There was no significant difference in the frequency of red-light running events across the three rounds. The number of conflicts has remained steady over the three rounds. Furthermore, a large proportion of conflicts did not involve vulnerable road users. Overall, the safety of the intersection has not changed.

2.2 5TH ST AND RALSTON ST

The 5th St and Ralston St intersection is a four-way stop-controlled intersection between Keystone Ave and Arlington Ave. During round 1, there were two lanes each direction in the east-west direction and one lane each direction in the north-south directions. There are crosswalks and street parking at each leg of the intersection and existing bike lanes in the north-south directions. The infrastructure changes that occurred along 5th St include adding a protected bicycle lane between the sidewalk and street parking with marked boundaries which extended along 5th St. To make room for the bicycle lanes, the through lanes were reduced to one lane in each direction. Figure 16 (a) shows the intersection before changes were made and Figure 16 (b) shows the intersection after changes were made.



(a) **(b)**

Figure 16 5th St and Ralston St before-after infrastructure changes

2.2.1 Counts

The counts for the different road users at the 5th St and Ralston St intersection is analyzed. Overall, the vehicle volumes increased between round 1 and 2 and decreased between round 2 and 3, as shown in Table 7. Further, the vehicles volumes were higher during the weekday than weekend day. The pedestrian volumes remained steady on the weekday and increased on the weekend, with higher volumes occurring during the weekday, as shown in Table 8. Bicycle volumes increased while scooters saw a peak during round 2, as shown in Table 9.

Table 7 5th St and Ralston St daily vehicle volumes

Round	Weekday Vehicles	Weekend Vehicles
1	8309	5432
2	10771	8524
3	9410	7113

Table 8 5th St and Ralston St daily pedestrian volumes

Round	Weekday Pedestrian	Weekend Pedestrian
1	418	202
2	423	371
3	419	399

Table 9 5th St and Ralston St daily micromobility volumes

Round	Weekday Bicycle	Weekend Bicycle	Weekday Scooter	Weekend Scooter
1	92	94	180	143
2	163	155	273	278
3	171	125	191	182

2.2.2 Micromobility Behavior

The behavior and compliance of the micromobility road users at the 5th St and Ralston St intersection is analyzed. Figure 17 and Figure 18 shows the right-of-way utilization of the micromobility road users during a given weekday and weekend day, respectively. In other words, the extent to which micromobility road users use the roadway, bike lane, cycle track, and the sidewalks. "CT/BL" refers to the cycle track and bicycle lanes. For the Ralston intersection, the bike lanes were installed along 5th St, therefore, only the east and west legs are considered in this section.

Overall, the numbers of micromobility users riding on the roadway decreased by over half after round 1 while the bike lane volumes increased. During round 2 and round 3, the proportion of bicycles using the roadway was less than to that of the bike lanes; whereas, up to 80 percent of scooter users used the bike lanes. Overall, sidewalks were less utilized for bicycle, but similar to roadway volumes for scooters. Also, there was no significant difference between the weekday versus weekend. Overall, it appears that the introduction of bike lanes took micromobility users off the roadways.

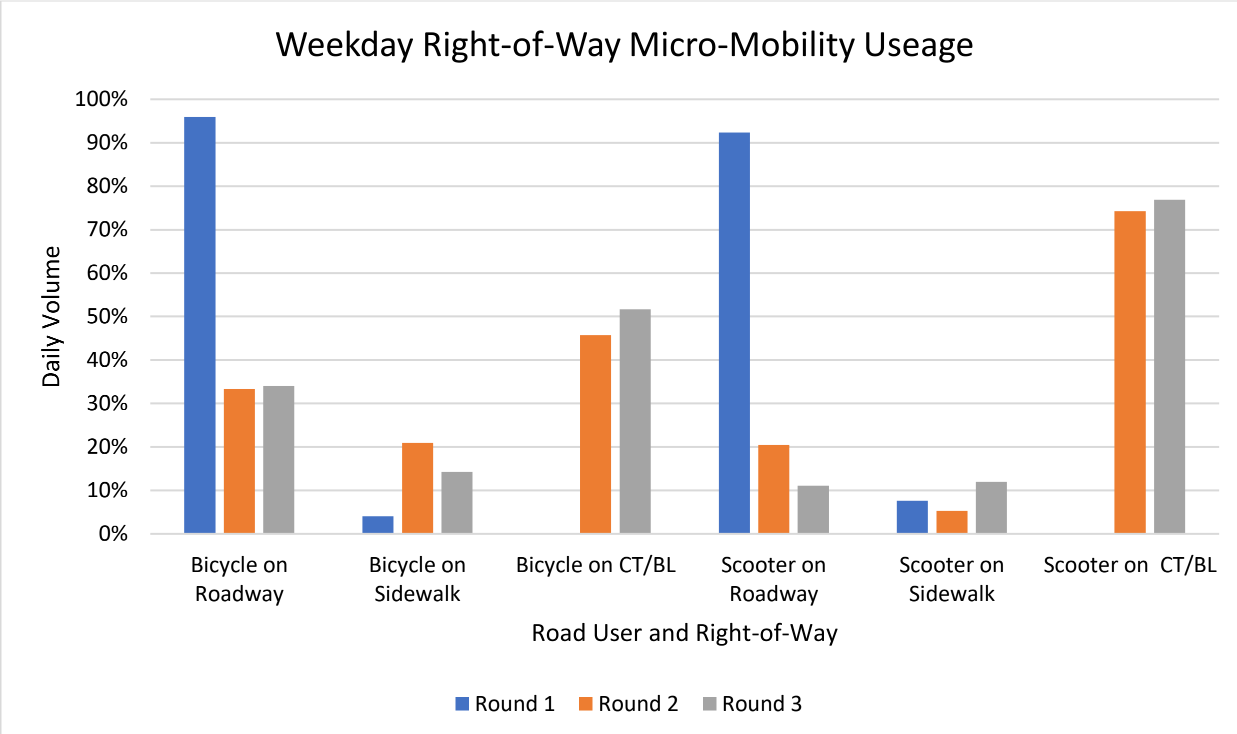


Figure 17 5th St and Ralston weekday right-of-way micromobility usage

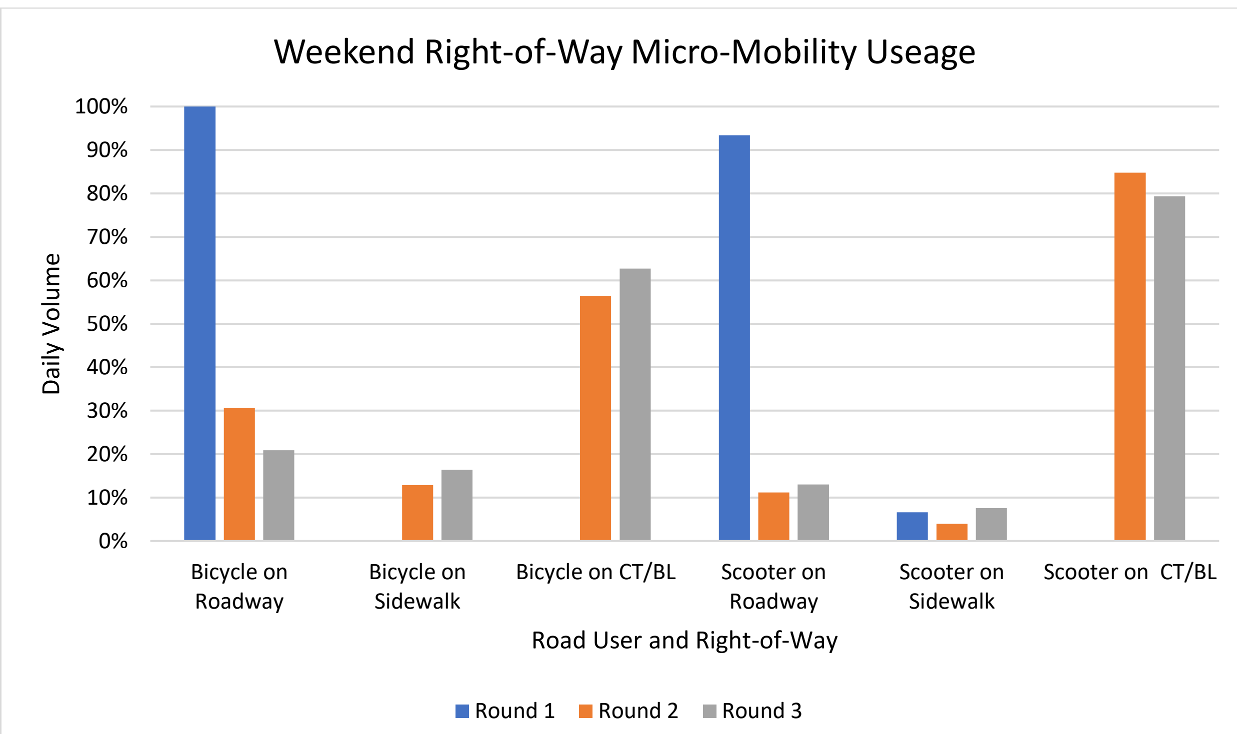


Figure 18 5th St and Ralston weekend right-of-way micromobility usage

2.2.3 Speed

The vehicle speeds at the 5th St and Ralston St intersection are analyzed. Given that this intersection is a stop-controlled intersection, speeds approximately 150 feet east and west of the intersection were extracted to get an idea of 5th St free flow speeds. The through speeds of each individual vehicle is extracted and the distribution of the speed is shown in Figure 19 for each round and each direction. The Xs mark the mean, the horizontal lines mark the median, and the lower and upper boundaries of the box represent the 25th and 75 percentile speeds, respectively. The speed limit is 25 MPH along 5th St. Overall, a majority of vehicles were under the speed limit with 75-percentile speeds being less than 25 MPH for each leg, direction, and round. Furthermore, the eastbound speeds decreased on the east leg and increased on the west leg. The westbound speed remained the same on the east leg and increased on the west leg. Each of these changes were by 2 to 3 MPH on average.

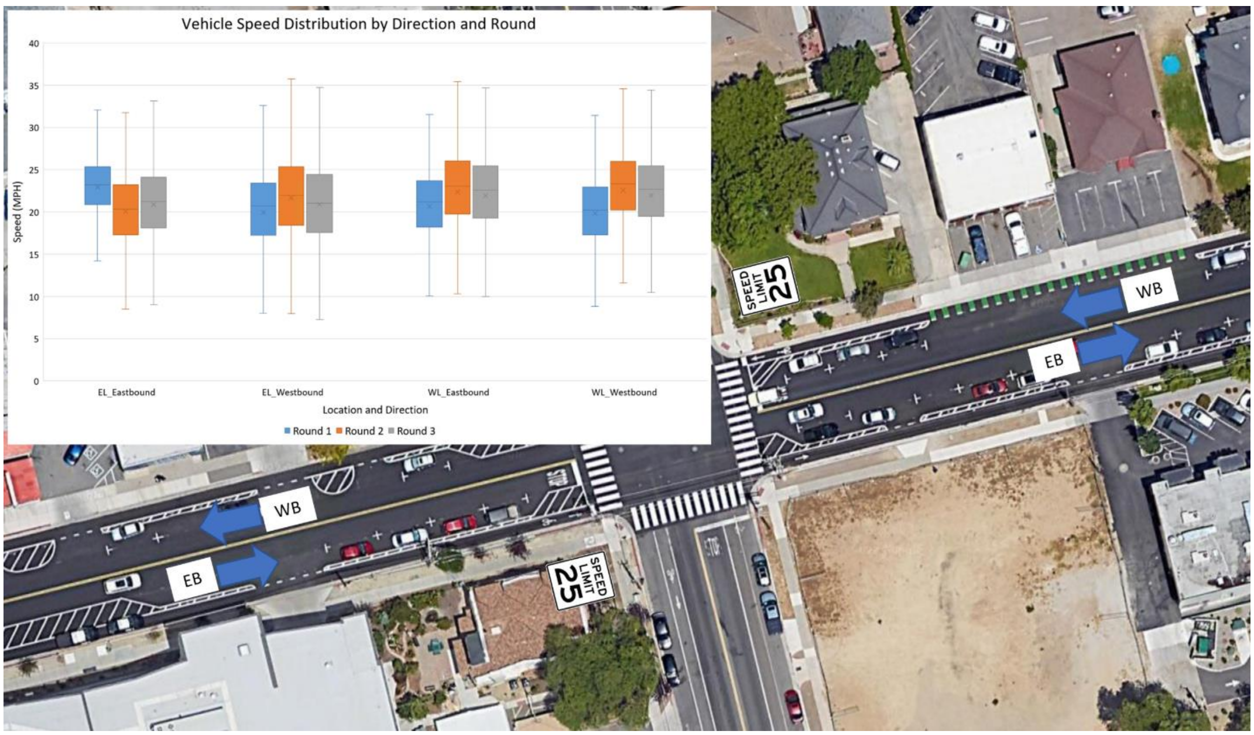


Figure 19 5th St and Ralston vehicle speeds

2.2.4 Conflicts

The conflicts between road users at the 5th St and Ralston St intersection is analyzed. Figure 20 illustrates the conflicts by showing a map of each conflict's location within the site, along with the conflict frequency and severity in PET. Vehicle-to-vehicle conflicts had a spike during round 2 before normalizing to round 1 number in round 3. The other conflict types had relatively lower numbers, meaning there are little safety concerns for the vulnerable road users. Furthermore, the distributions of PET increased through the three rounds for each conflict type.

Table 10 shows the conflict rate, which normalizes the number of conflicts by the volumes of the most vulnerable road user. The conflict rate shows that vehicle-to-bicycle conflicts decreased between round 1 and round 2.

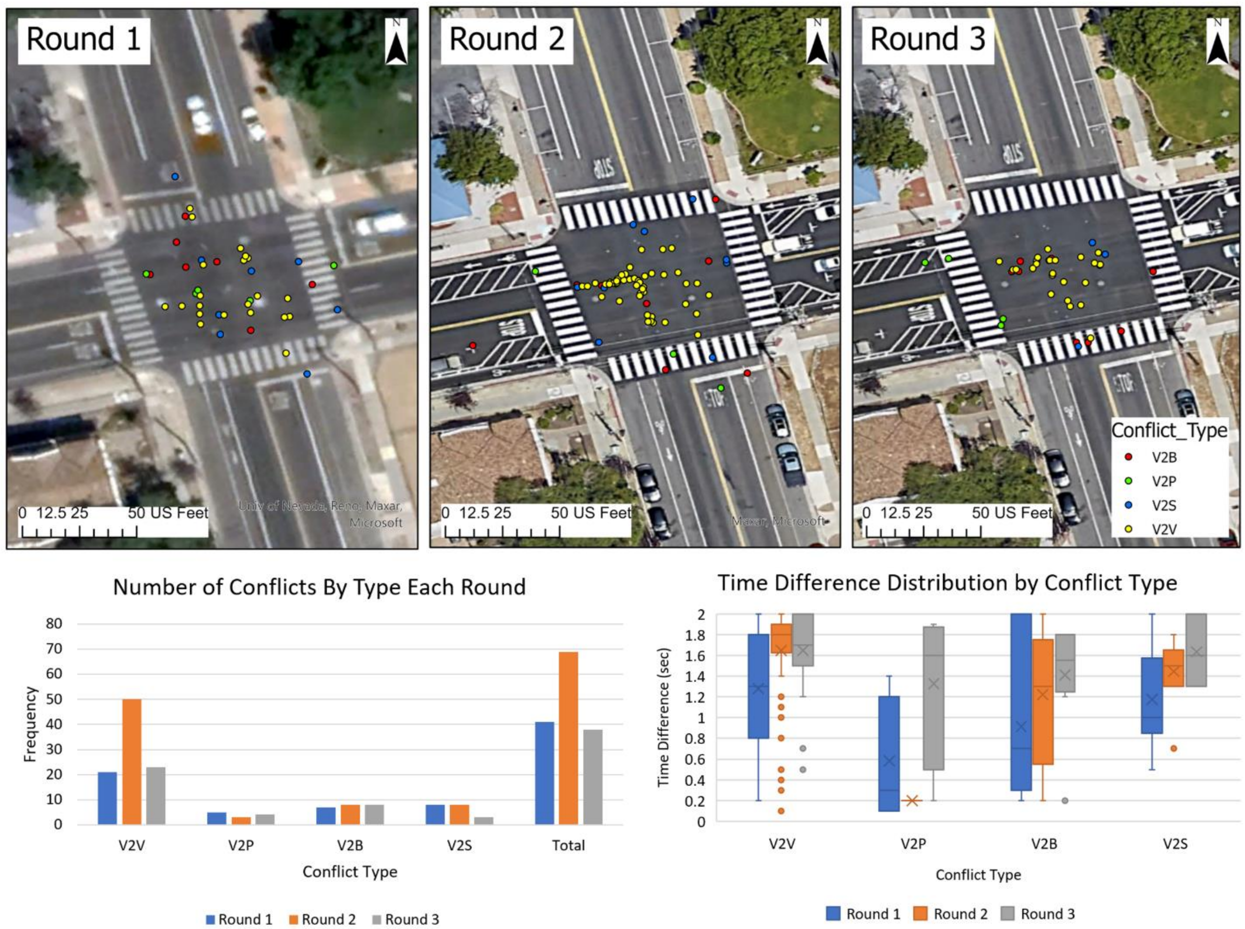


Figure 20 5th St and Ralston conflict locations, frequencies, and severities

Table 10 5th St and Ralston conflict rates

Round	Vehicle-to-vehicle conflicts per 100 vehicles	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
1	0.15	0.81	3.76	2.48	0.28
2	0.26	0.38	2.52	1.45	0.33
3	0.14	0.49	2.70	0.80	0.21

2.2.5 Summary

The overall findings of the 5th St and Ralston St intersection analysis is summarized. Overall, vehicle and bicycle volumes increased, pedestrian volumes decreased over the weekday and increased on the weekend, scooter volumes were highest during round 2. The introduction of bike lanes took micromobility users off the roadways, especially for scooter users. The free flow speeds along 5th St just east and west of the Ralston intersection were well within the speed limit with marginal changes between rounds. The number of conflicts, particularly for those vulnerable road users, was low, which means that there were limited safety concerns.

2.3 5TH ST AND ARLINGTON AVE

The 5th St and Arlington Ave intersection is a signalized intersection between Ralston St and Virginia St. The intersection has crosswalks and street parking at each leg. In the round 1 conditions, there were two lanes at each approach with permissive left turns. In the round 2 and 3 conditions, protected bicycle lanes were installed along 5th St. To make room for the bicycle lanes, the through lanes were reduced to one lane in each direction. At the intersection, a protected intersection was installed which is designed to increase separation between vehicles and micromobility road users. Elements of a protected intersection include a directed path for bicyclists and scooters to traverse the intersection, greater visibility for turning vehicles via a setback between the two road users, a corner island for queueing of bicyclists and scooters, and a waiting zone for turning vehicles to yield for crossing vulnerable road users such as pedestrian, bicyclists, and scooters. The geometry also creates sharper right turn radii for right turn vehicles, which forces them to slow down. Figure 21 (a) shows the intersection before changes were made and Figure 21 (b) shows the intersection after changes were made.

(a) **(b)**

Figure 21 5th St and Arlington Ave before-after infrastructure changes

2.3.1 Counts

The counts for the different road users at the 5th St and Arlington Ave intersection is analyzed. Overall, the vehicle volumes increased between round 1 and 2 and decreased between round 2 and round 3, as shown in Table 11. Further, the vehicles volumes were higher during the weekday in round 1 and round 3, but higher during weekend in round 2. The pedestrian volumes were lowest during round 2 and were similar between round 1 and 2, as shown in Table 12. Furthermore, round 2 during the weekday had the lowest pedestrian volumes. Bicycle volumes increased over the three rounds and scooter volumes were highest during round 2 on the weekday, as shown in Table 13.

Table 11 5th St and Arlington Ave daily vehicle volumes

Round	Weekday Vehicles	Weekend Vehicles
1	8859	6006
2	9492	9890
3	9077	6857

Table 12 5th St and Arlington Ave daily pedestrian volumes

Round	Weekday Pedestrian	Weekend Pedestrian
1	501	470
2	304	444
3	523	477

Table 13 5th St and Arlington Ave daily micromobility volumes

Round	Weekday Bicycle	Weekend Bicycle	Weekday Scooter	Weekend Scooter
1	111	79	114	113
2	124	84	110	250
3	138	82	148	144

2.3.2 Micromobility Behavior

The behavior and compliance of the micromobility road users at the 5th St and Arlington Ave intersection is analyzed. Figure 22 and Figure 23 shows the right-of-way utilization of the micromobility road users during a given weekday and weekend day, respectively. In other words, the extent to which micromobility road users use the roadway, bike lane, cycle track, and the sidewalks. "CT/BL" refers to the cycle track and bicycle lanes. Bike lanes were installed along 5th St for round 2 and 3 as well as a protected intersection at the Arlington intersection. As such, each leg of the intersection is considered.

Overall, the numbers of micromobility users riding on the roadway decreased between round 1 and 2 while bike lane usage increased. This was especially true for the scooter users. In the after conditions, up to 60 percent of bicyclists and up to 80 percent of scooters used the bike lanes in round 2 and round 3. Sidewalks took up anywhere between 5 to 10 percent of micromobility road users. There was no significant difference in trends between the weekday and weekend. Overall, these trends generally match that of the neighboring intersection at Ralston St.

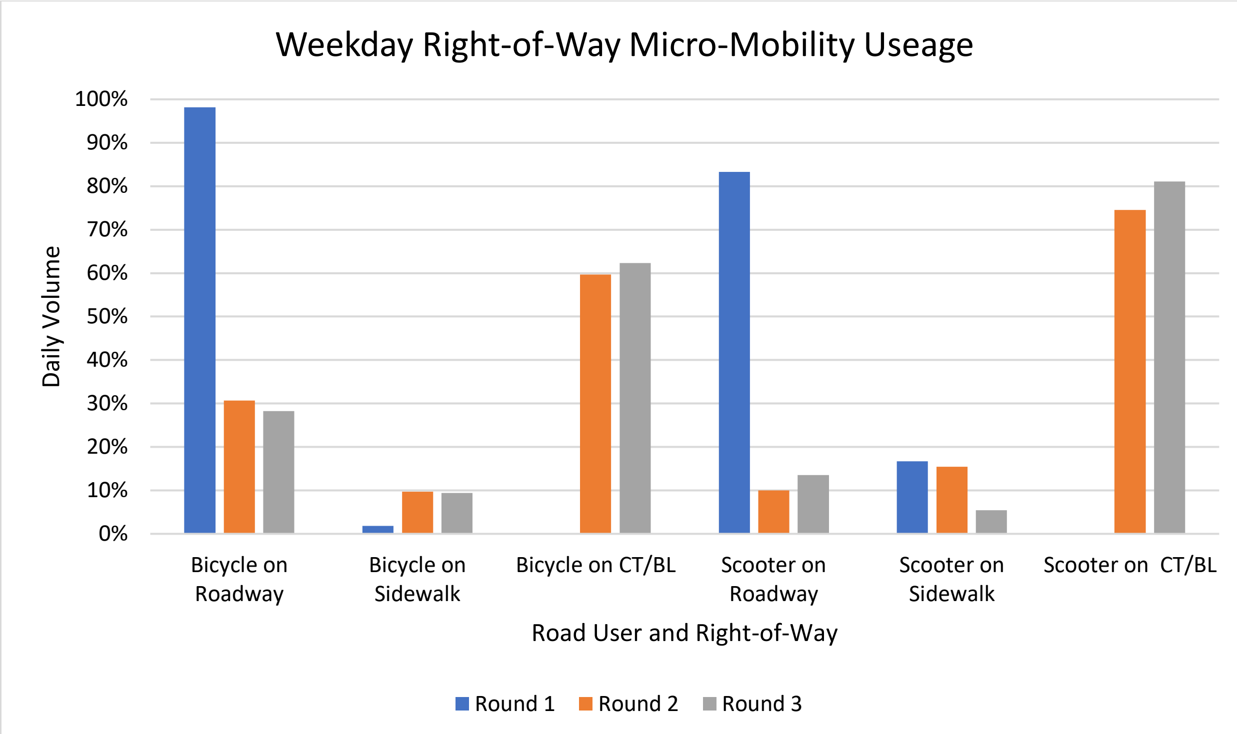


Figure 22 5th St and Arlington Ave weekday right-of-way micromobility usage

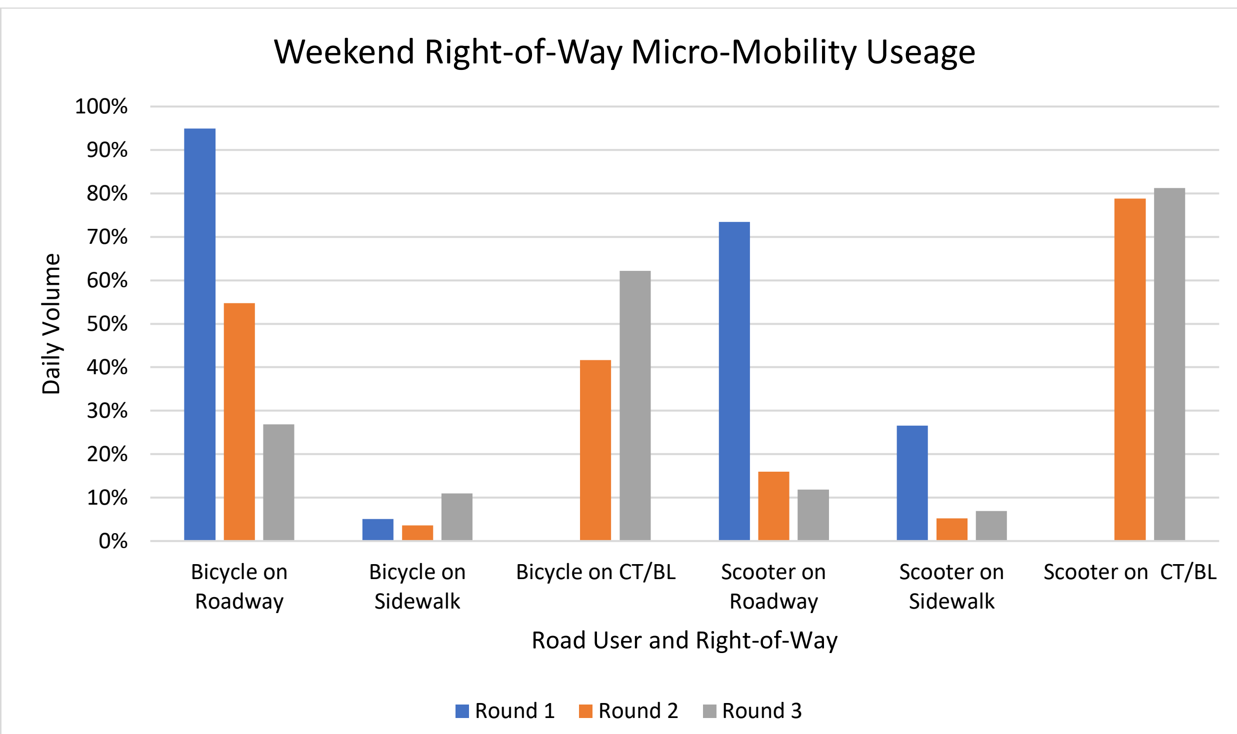


Figure 23 5th St and Arlington Ave weekend right-of-way micromobility usage

2.3.3 Speed

The vehicle speeds at the 5th St and Arlington Ave intersection are analyzed. Vehicle speeds are extracted at the approach of each leg. The through speeds of each individual vehicle is extracted and the distribution of the speed is shown in Figure 24 for each round and each direction. The detection zones used to extract the speeds are placed just before the stop bar in each direction. The Xs mark the mean, the horizontal lines mark the median, and the lower and upper boundaries of the box represent the 25th and 75 percentile speeds, respectively. The speed limit is 30 MPH. Overall, a majority of vehicles were under the speed limit with 75-percentile speeds being less than 25 MPH for each direction and round. Furthermore, there was no significant change to the speeds over the three rounds, except in the northbound direction where the speed decreased after round 1 by 9 MPH on average.

Figure 24 5th St and Arlington Ave vehicle speeds

2.3.4 Red-Light Running

The red-light running at the 5th St and Arlington Ave intersection are analyzed. The through and left turn vehicles detected past the stop bar over a speed of 10 MPH going in the correct direction during the red-interval for their respective direction and movement are flagged as red-light running events. Figure 25 shows the ring-and-barrier diagram of the intersection, which did not change with the rounds. Figure 26 and Figure 27 shows the frequency of red-light running events based on the total and after red clearance, respectively. Figure 28 and Figure 29 shows the rate of red-light running events based on the total and after red clearance, respectively. The frequency of red-light running events increased after round 1, but the rates in Figure 29 suggests that this was a result of lower vehicle volumes. The number of red-light running events increased between round 2 and round 3. The overall frequency trends generally match the after red clearance red-light running events.

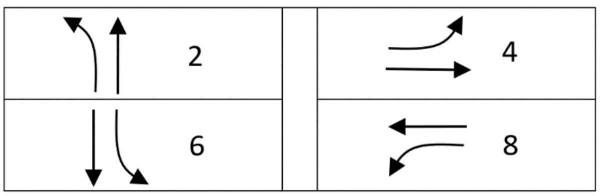


Figure 25 5th St and Arlington Ave ring-and-barrier diagram

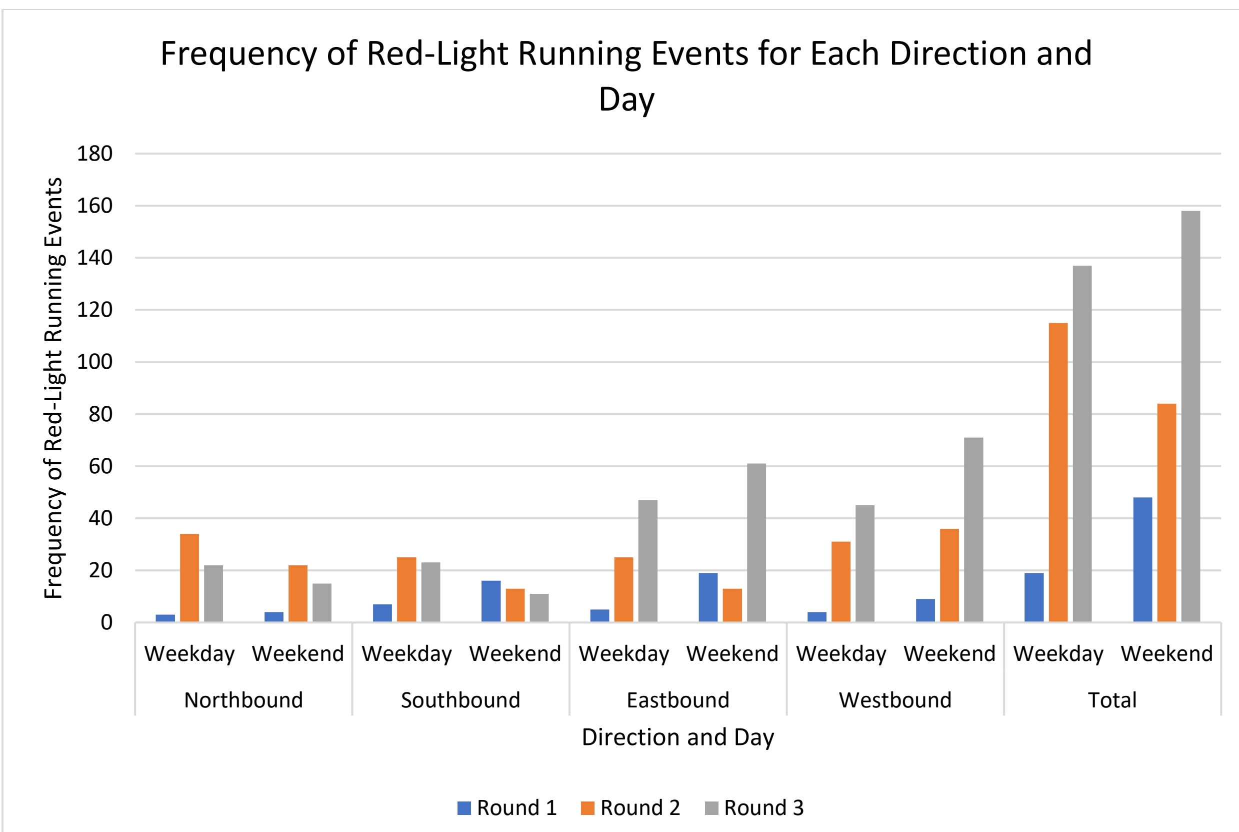


Figure 26 5th St and Arlington Ave frequency of vehicle red-light running events

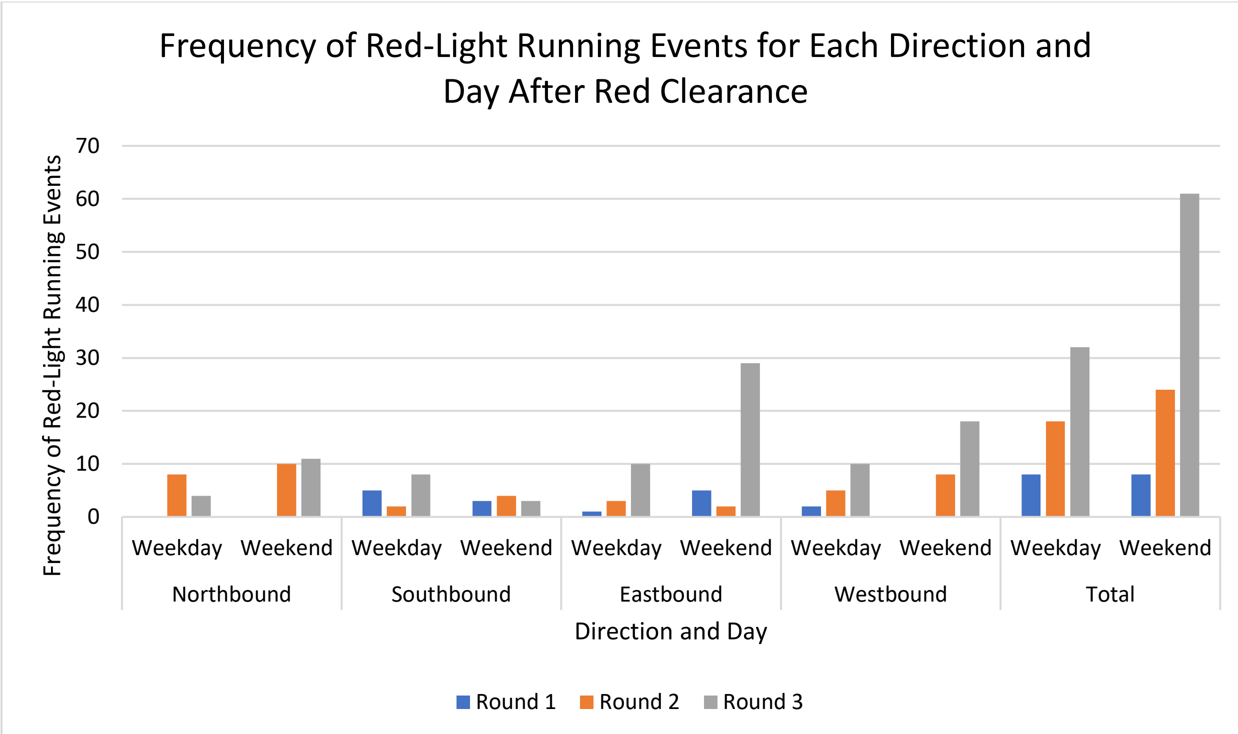


Figure 27 5th St and Arlington Ave frequency of vehicle red-light running events after red clearance

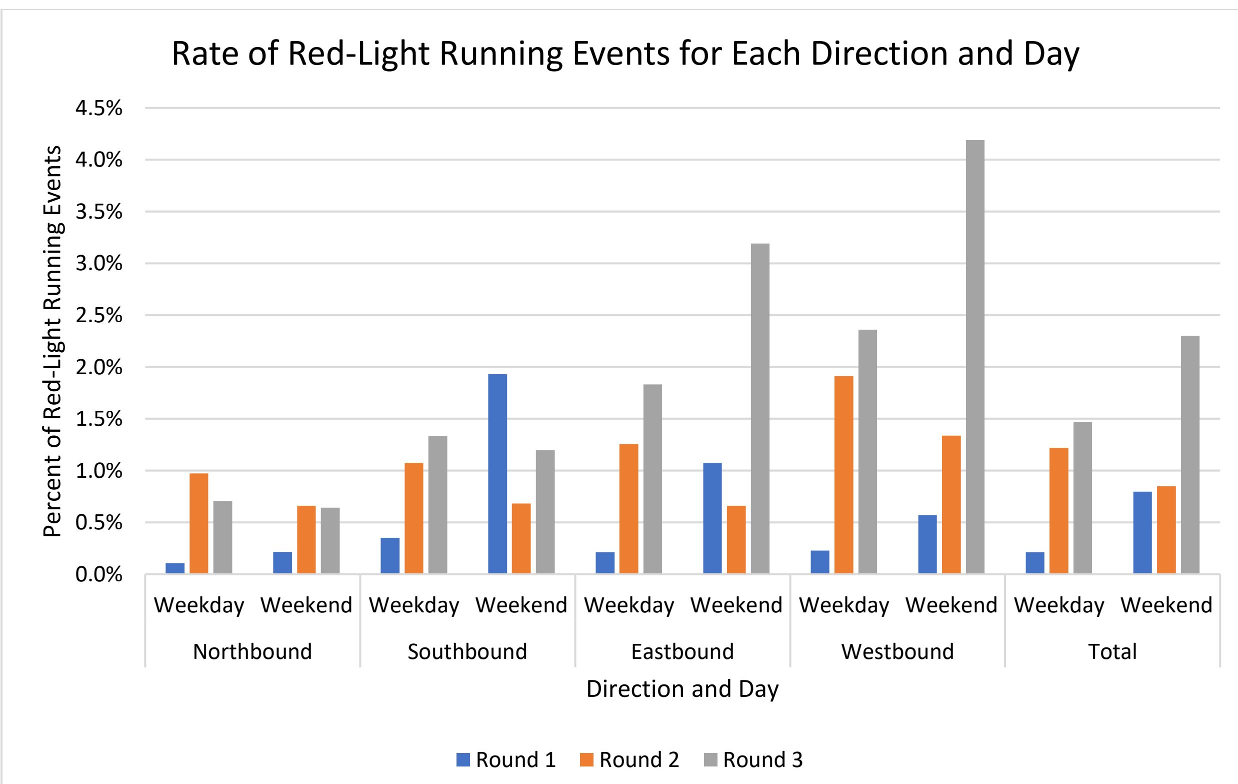


Figure 28 5th St and Arlington Ave percent of vehicle red-light running events

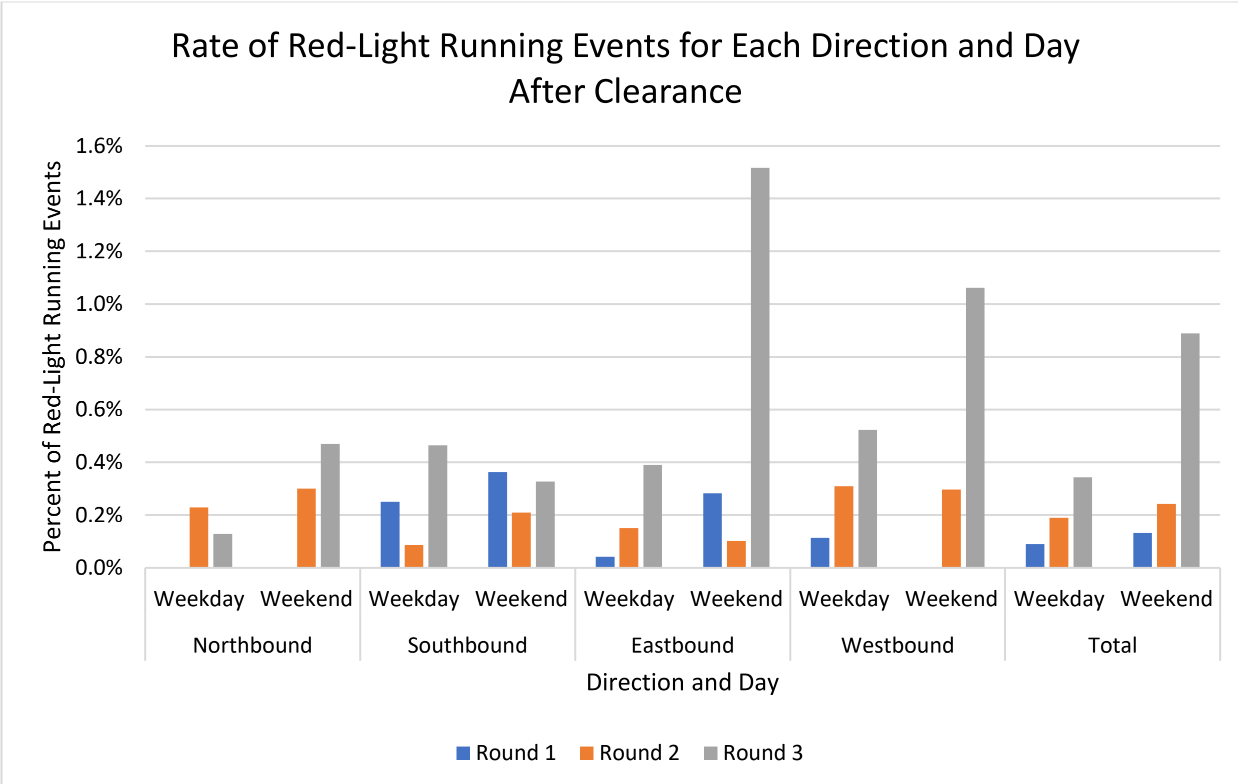


Figure 29 5th St and Arlington Ave percent of vehicle red-light running events after red clearance

2.3.5 Conflicts

The conflicts between road users at the 5th St and Arlington Ave intersection is analyzed. Figure 30 illustrates the conflicts by showing a map of each conflict's location within the site, along with the conflict frequency and severity in PET. Vehicle-to-vehicle conflicts decreased significantly between round 1 and 2 and slightly decreased between round 2 and 3. This was primarily because of the decrease in vehicle lane, which reduces the number of conflict points between vehicles. The other conflict types have relatively lower numbers, meaning there is little safety concerns for the vulnerable road users.

Table 14 shows the conflict rate, which normalizes the number of conflicts by the volumes of the most vulnerable road user. The conflict rate shows a similar trend to the frequencies.

Figure 30 5th St and Arlington Ave conflict locations, frequencies, and severities

Table 14 5th St and Arlington Ave conflict rates

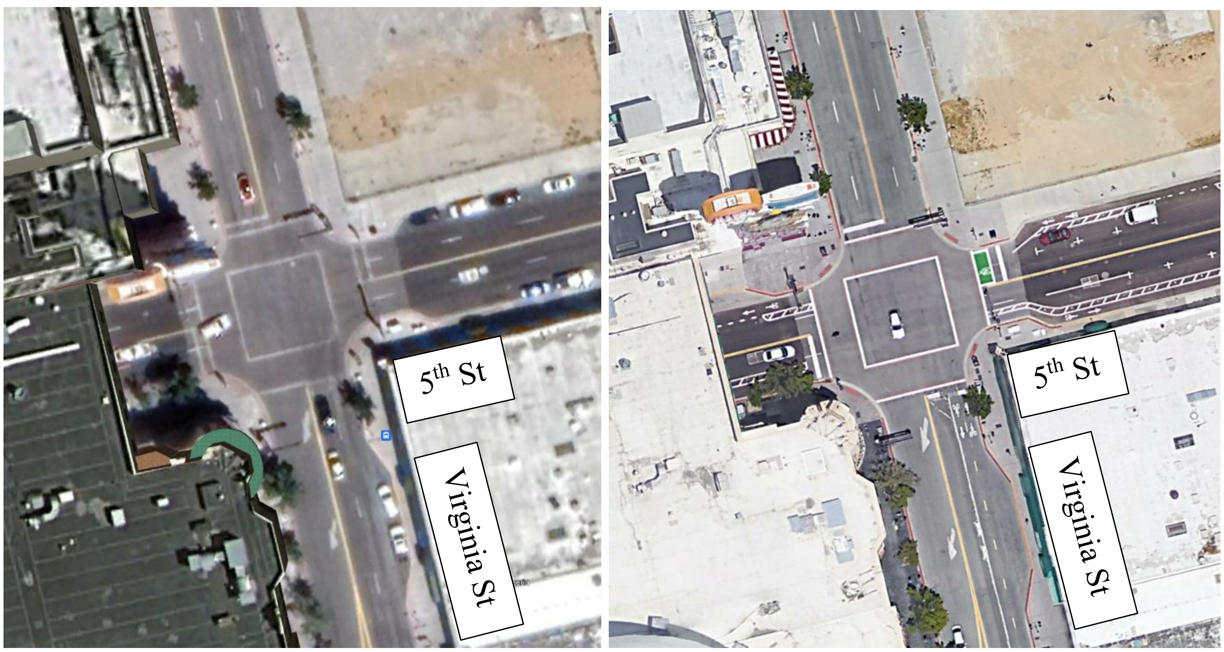
Round	Vehicle-to-vehicle conflicts per 100 vehicles	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
1	0.47	0.51	4.21	3.08	0.55
2	0.16	0.94	3.37	0.83	0.23
3	0.15	0.20	0.91	1.71	0.19

2.3.6 Summary

The overall findings of the 5th St and Arlington Ave intersection analysis is summarized. Overall, vehicle volumes peaked during round 2, but pedestrian volumes were lowest during this round. Bicycle and scooter volumes increased. The introduction of bike lanes took micromobility users off the roadways, especially for scooter users. During round 2 and round 3, a majority of micromobility road users used the bicycle lanes. The number of red-light running events increased across the rounds; however, the rates indicate this was primarily a result of increased vehicle volumes. The speeds at the intersection approaches were largely within the speed limit. The number of vehicle-to-vehicle conflicts decreased significantly from round 1 to round 2 and 3. Other conflict types were relatively low. Overall, the new infrastructure is being utilized correctly and the safety has improved.

2.4 VIRGINIA ST AND 5TH ST

The Virginia St and 5th St intersection is signalized. The intersection has crosswalks at each leg and street parking at the north and east leg. In the round 1 conditions, there were two lanes at each approach with permissive left turns. In the round 2 and 3 conditions, the infrastructure changes along 5th St to include adding a protected bicycle lane between the sidewalk and street parking with marked boundaries. South of the intersection is where the cycle track began and extended south along Virginia St. At this intersection, Virginia St changed from a two-way in the north leg to a one-way going southbound in the south leg. The north leg geometry was unchanged. At the westbound approach, a bike box was installed which is intended to keep stopped micromobility users in the line of sight of vehicles and to provide queue storage. Figure 31 (a) shows the intersection before changes were made and Figure 31 (b) shows the intersection after changes were made.



(a) (b)

Figure 31 Virginia St and 5th St before-after infrastructure changes

2.4.1 Counts

The counts for the different road users at the Virginia St and 5th St intersection is analyzed. Overall, the vehicle volumes were lowest at round 3 during the weekday and at round 2 during the weekend, but volumes were similar otherwise, as shown in Table 15. However, when looking at the southbound movements only, the weekday volumes decreased each round while the weekend volumes increased. The pedestrian volumes have increased over the three rounds, particularly during the weekend, as shown in Table 16. Bicycle volumes increased over the three rounds, particularly on the weekend, as shown in Table 17. Scooter volumes also increased after the implementation of the new infrastructure, especially on the weekend.

Table 15 Virginia St and 5th St daily vehicle volumes

	All		Southbound	
Round	Weekday Vehicles	Weekend Vehicles	Weekday Vehicles	Weekend Vehicles
1	12220	13724	3977	3598
2	12330	9830	3787	4029
3	9274	12887	3316	4287

Table 16 Virginia St and 5th St daily pedestrian volumes

Round	Weekday Pedestrian	Weekend Pedestrian
1	1452	1430
2	1938	2321
3	1887	2841

Table 17 Virginia St and 5th St daily micromobility volumes

Round	Weekday Bicycle	Weekend Bicycle	Weekday Scooter	Weekend Scooter
1	73	59	132	202
2	151	163	349	648
3	121	280	339	624

2.4.2 Micromobility Behavior

The behavior and compliance of the micromobility road users at the Virginia St and 5th St intersection is analyzed. Figure 32 and Figure 33 shows the right-of-way utilization of the micromobility road users during a given weekday and weekend day, respectively. In other words, the extent to which micromobility road users use the roadway, bike lane, cycle track, and the sidewalks. "CT/BL" refers to the cycle track and bicycle lanes. For the Virginia St and 5th St intersection, the bike lanes were installed along 5th St and a cycle track on the south leg. The north leg remained unchanged and is therefore excluded.

Overall, the number of bicycles on the roadway and sidewalks significantly decreased as the bike lane and cycle track volumes increased. Additionally, the number of scooters on the roadway decreased while the bike lane and cycle track increased. Considering there were high pedestrian activity at this intersection, the new infrastructure accomplished the goal of getting micromobility road users off the sidewalks and utilizing the bike lanes and the cycle track.

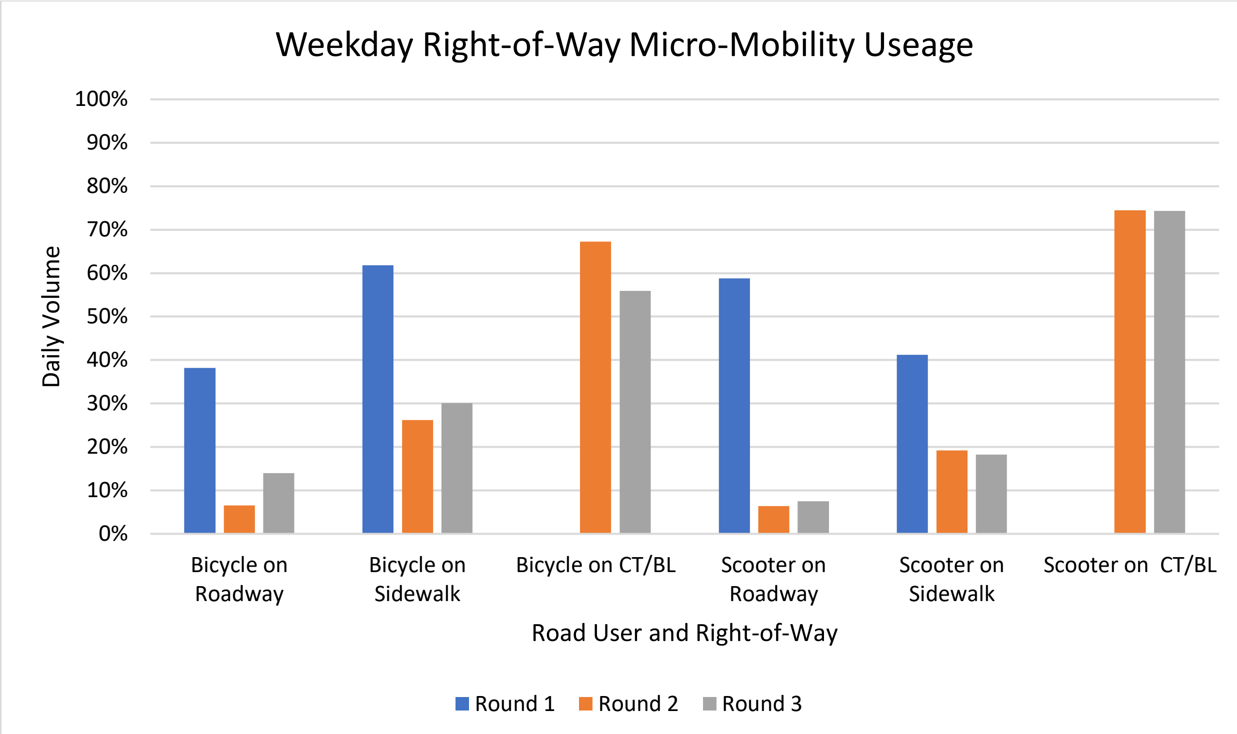


Figure 32 Virginia St and 5th St weekday right-of-way micromobility usage

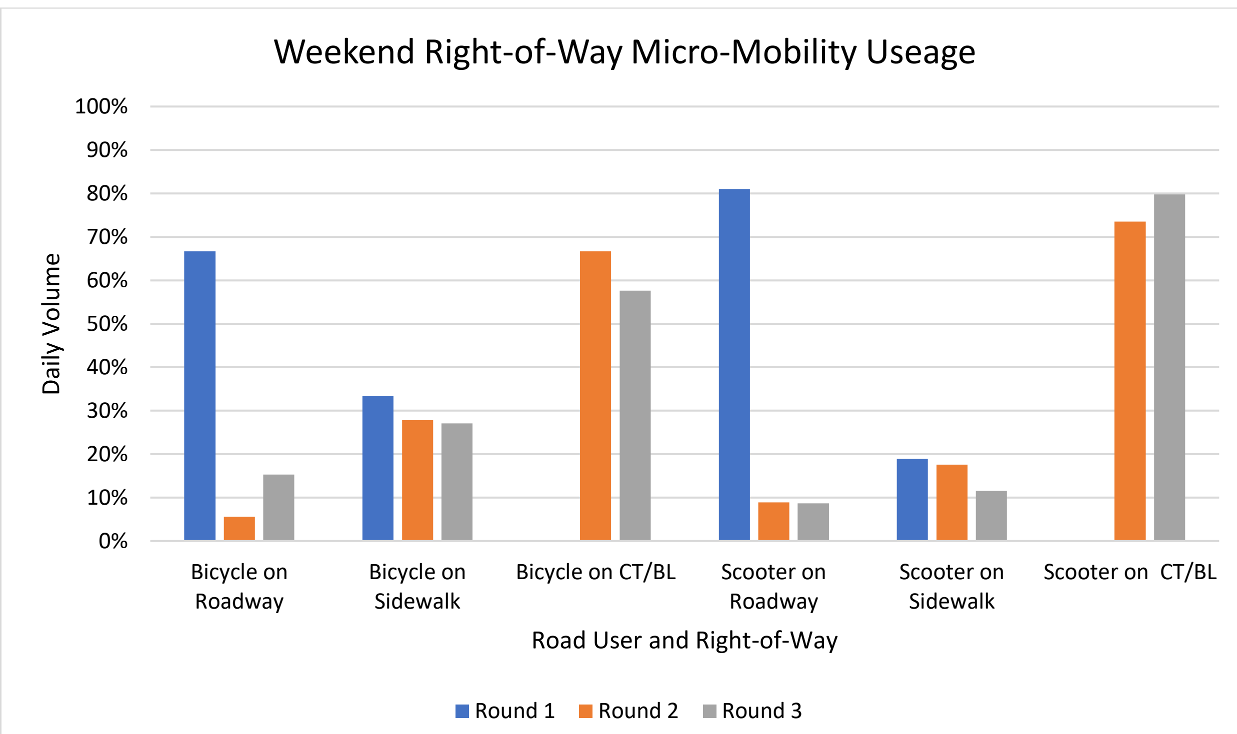


Figure 33 Virginia St and 5th St weekend right-of-way micromobility usage

2.4.3 Speed

The vehicle speeds at the Virginia St and 5th St intersection are analyzed. Vehicle speeds are extracted at the approach of each leg. Since Virginia St changed from two-way to one-way at this intersection, the northbound approach is only available for round 1. The through speeds of each individual vehicle is extracted and the distribution of the speed is shown in Figure 34 for each round and each direction. The detection zones used to extract the speeds are placed just before the stop bar in each direction. The Xs mark the mean, the horizontal lines mark the median, and the lower and upper boundaries of the box represent the 25th and 75 percentile speeds, respectively. The speed limit is 25 MPH. Overall, a majority of vehicles were under the speed limit with 75-percentile speeds being less than 25 MPH for each direction, and round. Furthermore, speeds appear to have decreased slightly over the three rounds, particularly in the southbound direction along Virginia St.

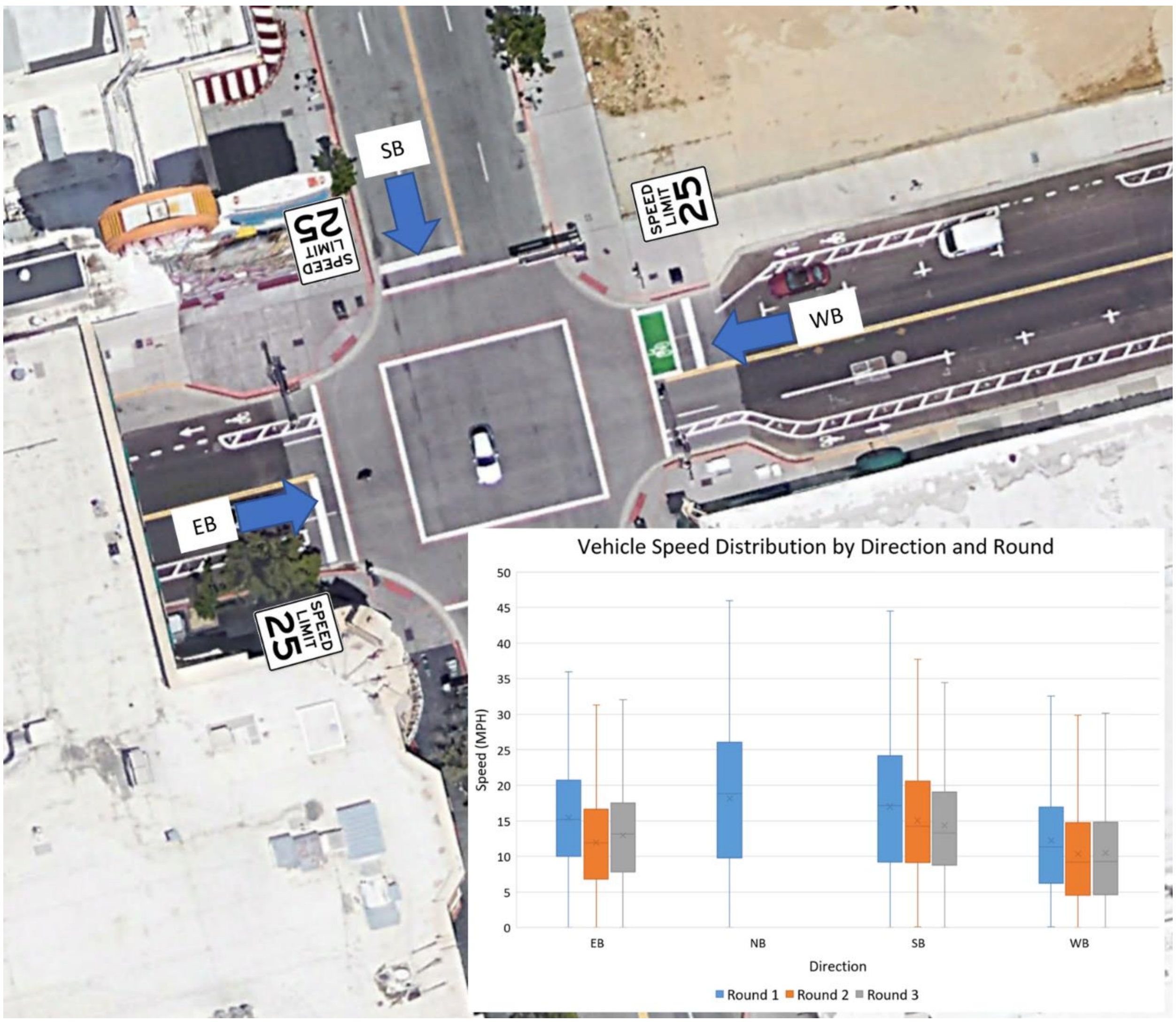


Figure 34 Virginia St and 5th St vehicle speeds

2.4.4 Red-Light Running

The red-light running at the Virginia St and 5th St intersection are analyzed. The through and left turn vehicles detected past the stop bar over a speed of 10 MPH going in the correct direction during the red-interval for their respective direction and movement are flagged as red-light running events. Figure 35 shows the ring-and-barrier diagram of the intersection, which changed after round 1 to accommodate the cycle track. The micromobility phase ran concurrently with the southbound through and left movements, which required that the left turn vehicles yield for oncoming northbound micromobility users. Figure 36 and Figure 37 shows the frequency of red-light running events based on the total and after red clearance, respectively. Figure 38 and Figure 39 shows the rate of red-light running events based on the total and after red clearance, respectively. The red-light running events were most frequent in the eastbound and southbound direction. The frequency and rate trends were generally the same, as was the overall versus the after red clearance. The red-light running events were highest during round 2 and lowest during round 3.

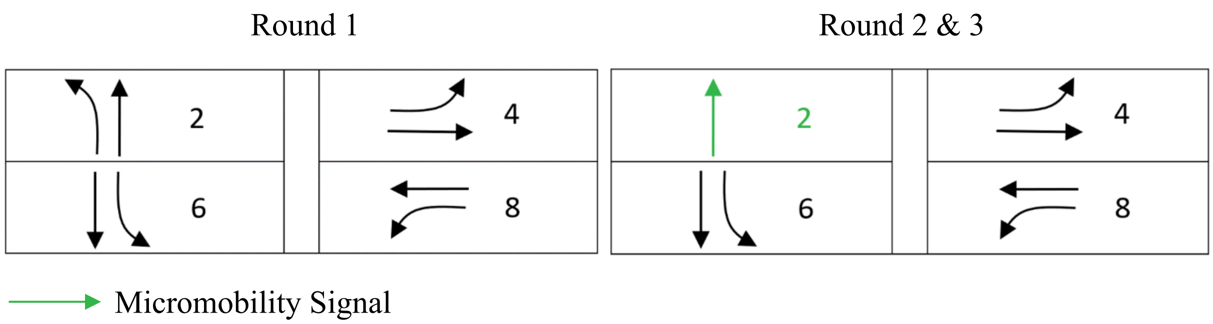


Figure 35 Virginia St and 5th St ring-and-barrier diagrams

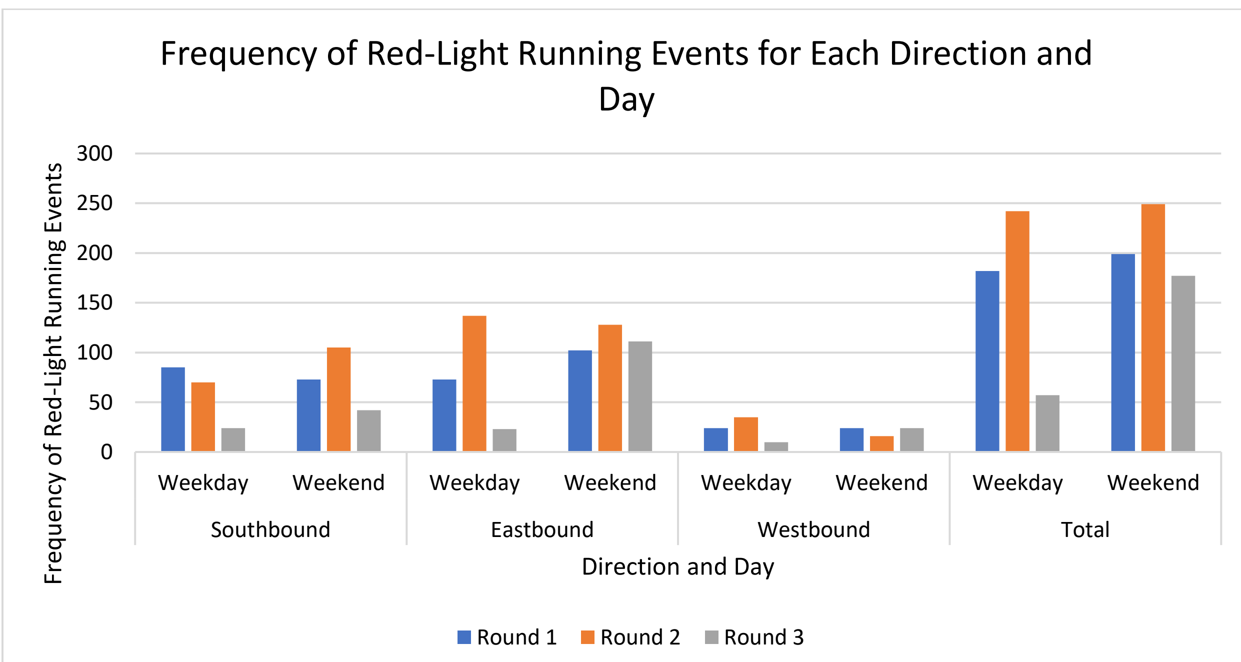


Figure 36 Virginia St and 5th St frequency of vehicle red-light running events

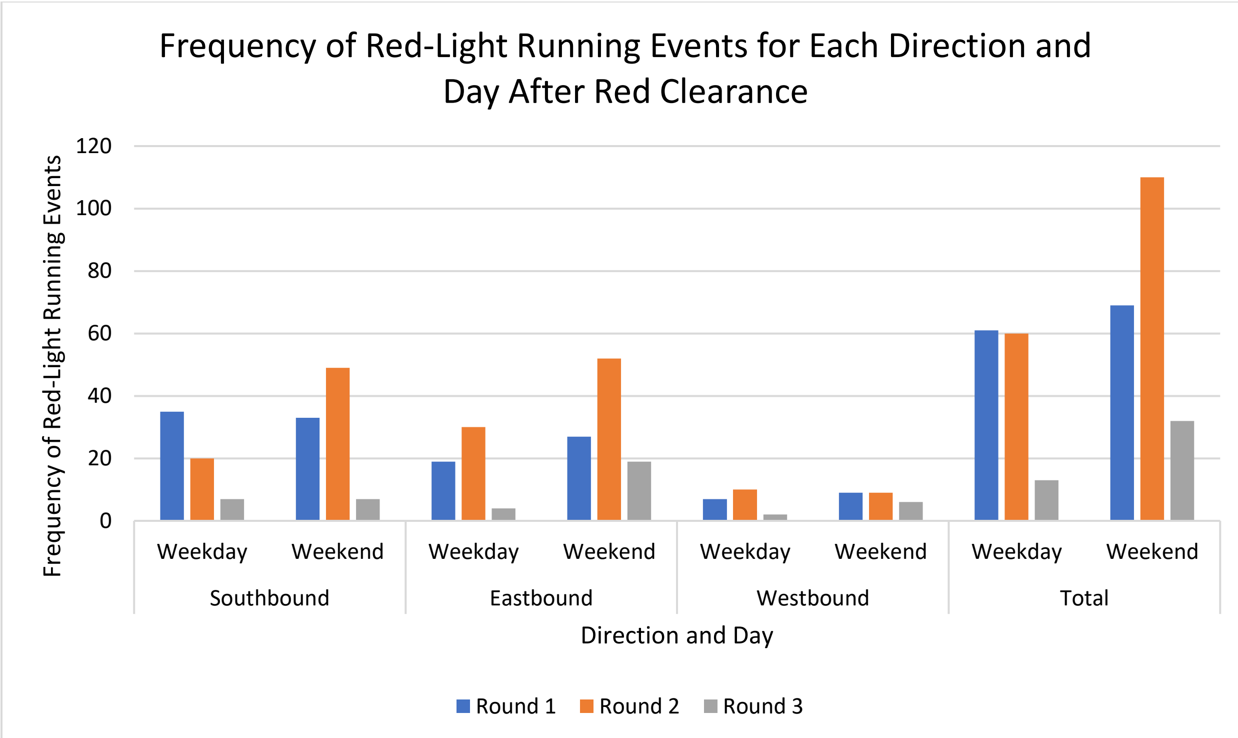


Figure 37 Virginia St and 5th St frequency of vehicle red-light running events after red clearance

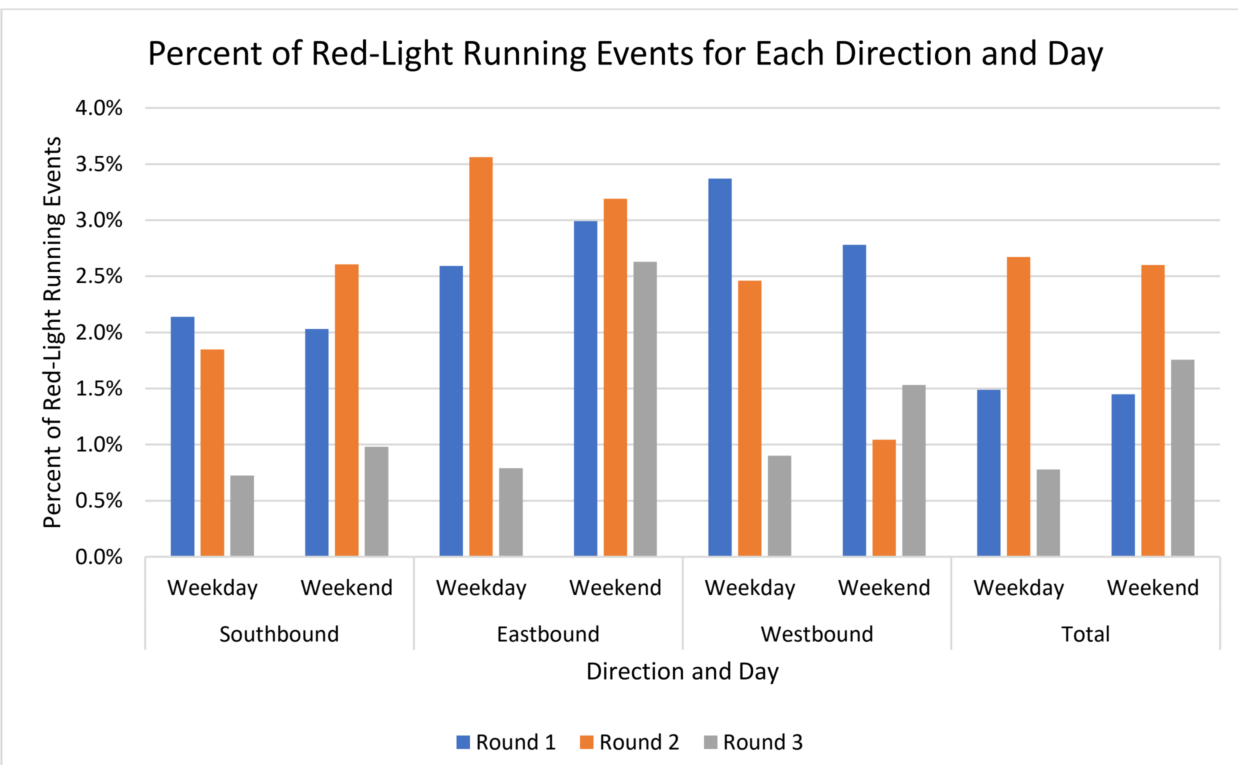


Figure 38 Virginia St and 5th St percent of vehicle red-light running events

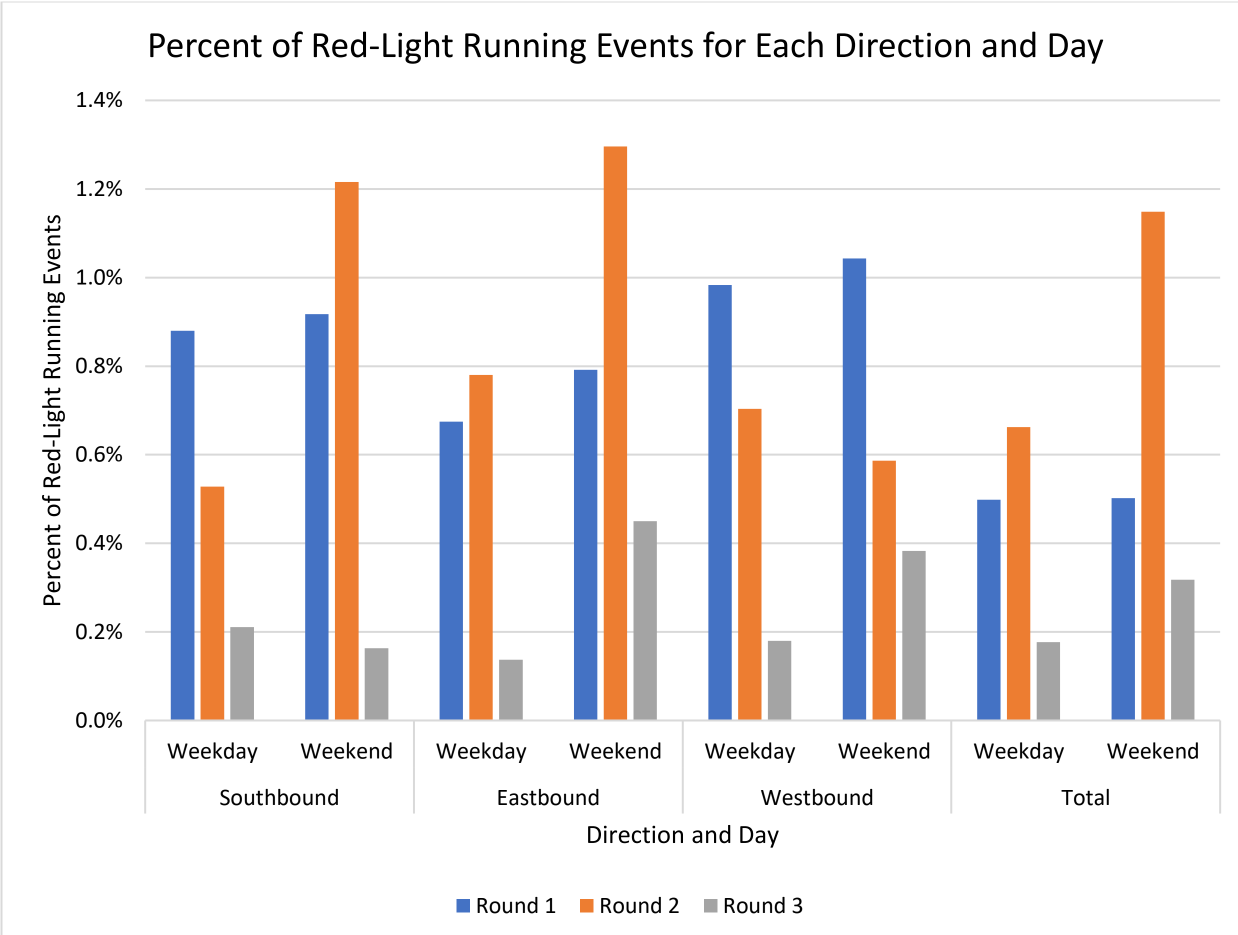


Figure 39 Virginia St and 5th St percent of vehicle red-light running events after red clearance

Figure 40 and Figure 41 shows the frequency and rate of micromobility red-light running events, respectively. The micromobility phase ran concurrently with the southbound through and left movements, which required that the left turn vehicles yield for oncoming northbound micromobility users. During the weekend, the frequency and rate of micromobility red-light running events was highest during round 3. During the weekday, the frequency was similar. The rate of red-light running events was as high as 18 percent on the weekend during round 3 and under 12 percent otherwise.

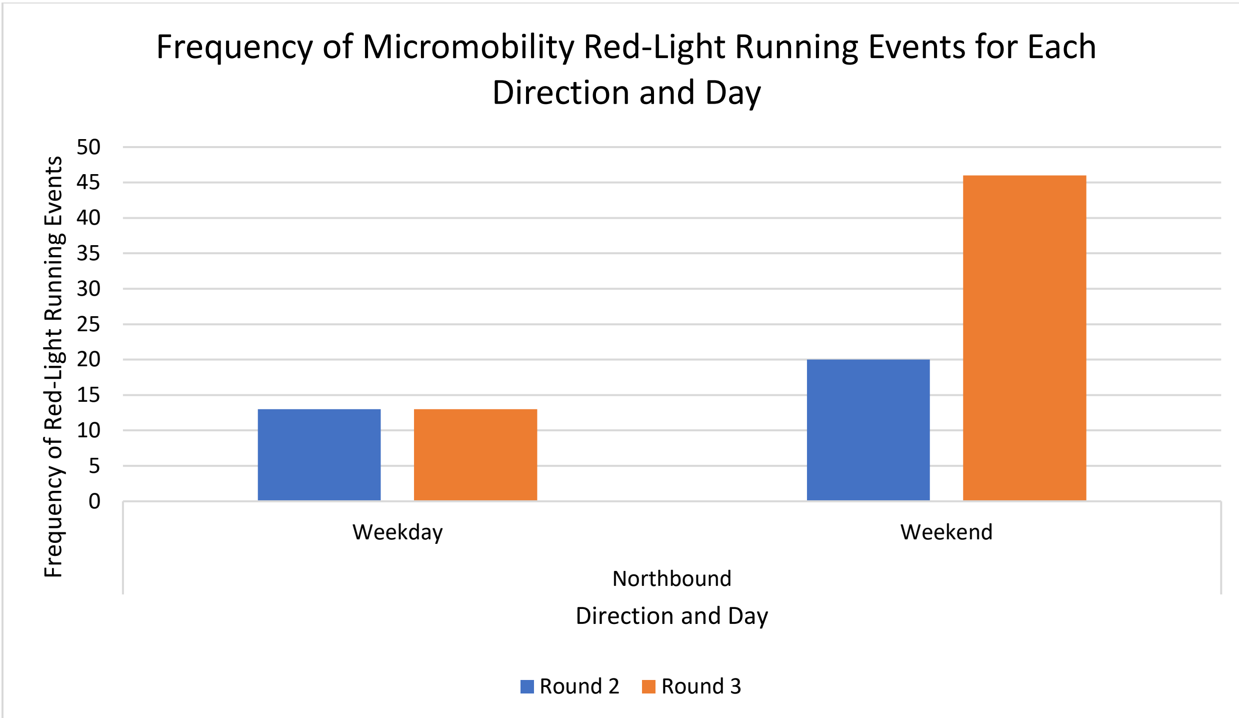


Figure 40 Virginia St and 5th St frequency of micromobility red-light running events

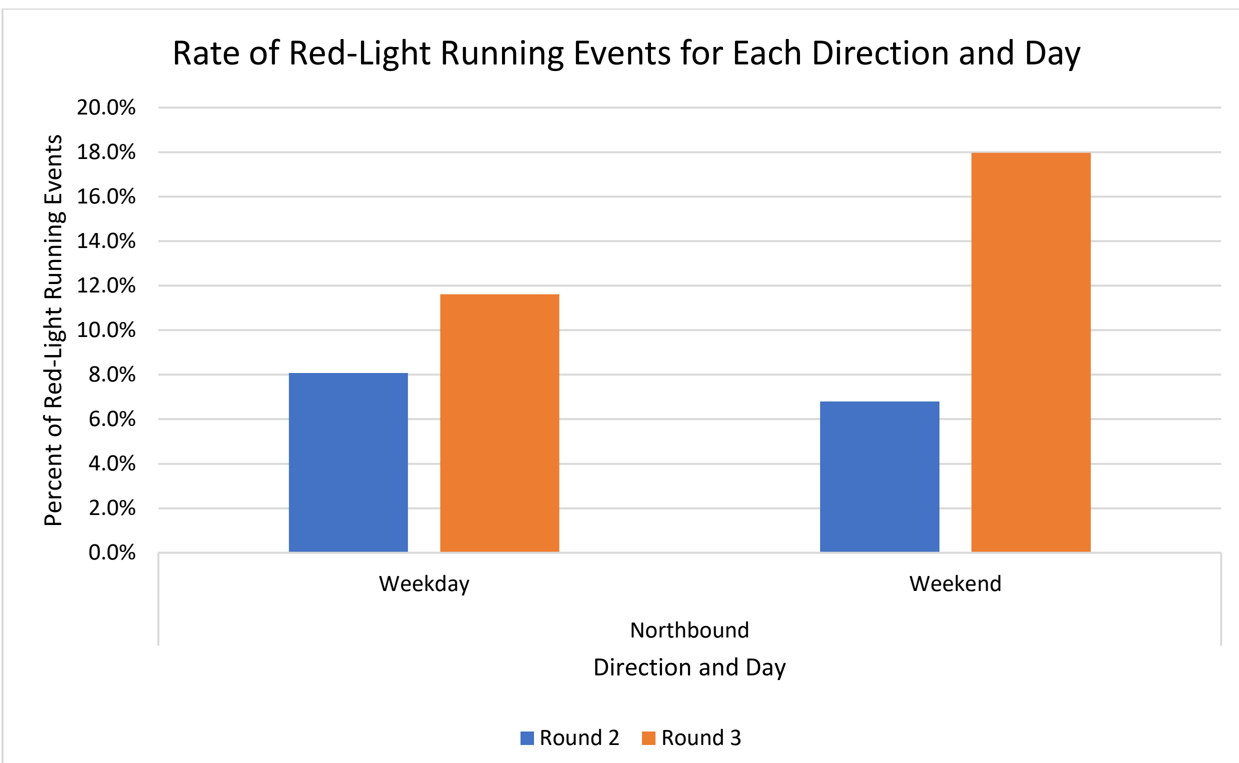


Figure 41 Virginia St and 5th St percent of micromobility red-light running events

2.4.5 Conflicts

The conflicts between road users at the Virginia St and 5th St intersection is analyzed. Figure 42 illustrates the conflicts by showing a map of each conflict's location within the site, along with the conflict frequency and severity in PET. Vehicle-to-vehicle decreased significantly between round 1 and 2 and slightly increased between round 2 and 3. This is primarily because of the decrease in vehicle lanes and the change from two-way to one-way along Virginia St, which reduces the number of conflict points between vehicles. Vehicle to micromobility user conflicts remained relatively steady with a decrease between round 1 and 2 for vehicle-to-bicycle conflicts. The number of vehicle-to-pedestrian conflicts increased over the three rounds. The average PETs have remained the same across the rounds for each conflict type. Figure 42 shows that the majority of vehicle to vulnerable road user conflicts were occurring at the west and south crosswalk and that vehicle-to-micromobility conflicts were lower around the bike box. The conflict point between the permissive southbound left and opposing micromobility northbound through movement did not appear to be a major safety concern based on the conflict map.

Table 12 shows the conflict rate, which normalizes the number of conflicts by the volumes of the most vulnerable road user. The conflict rate shows that safety for vehicle-to-bicycle and vehicle-to-scooter safety improved with the addition of the new infrastructure. Also, the conflict rate for vehicle-to-pedestrian conflicts decreased between round 1 and 2, but was at its highest during round 3. Figure 43 shows the micromobility-to-pedestrian conflicts, which are low at this intersection and tend to occur along the west crosswalk. The conflict rate in conflicts per 100 pedestrians for round 1, 2, and 3 are 0.03, 0.09, and 0.21, respectively.

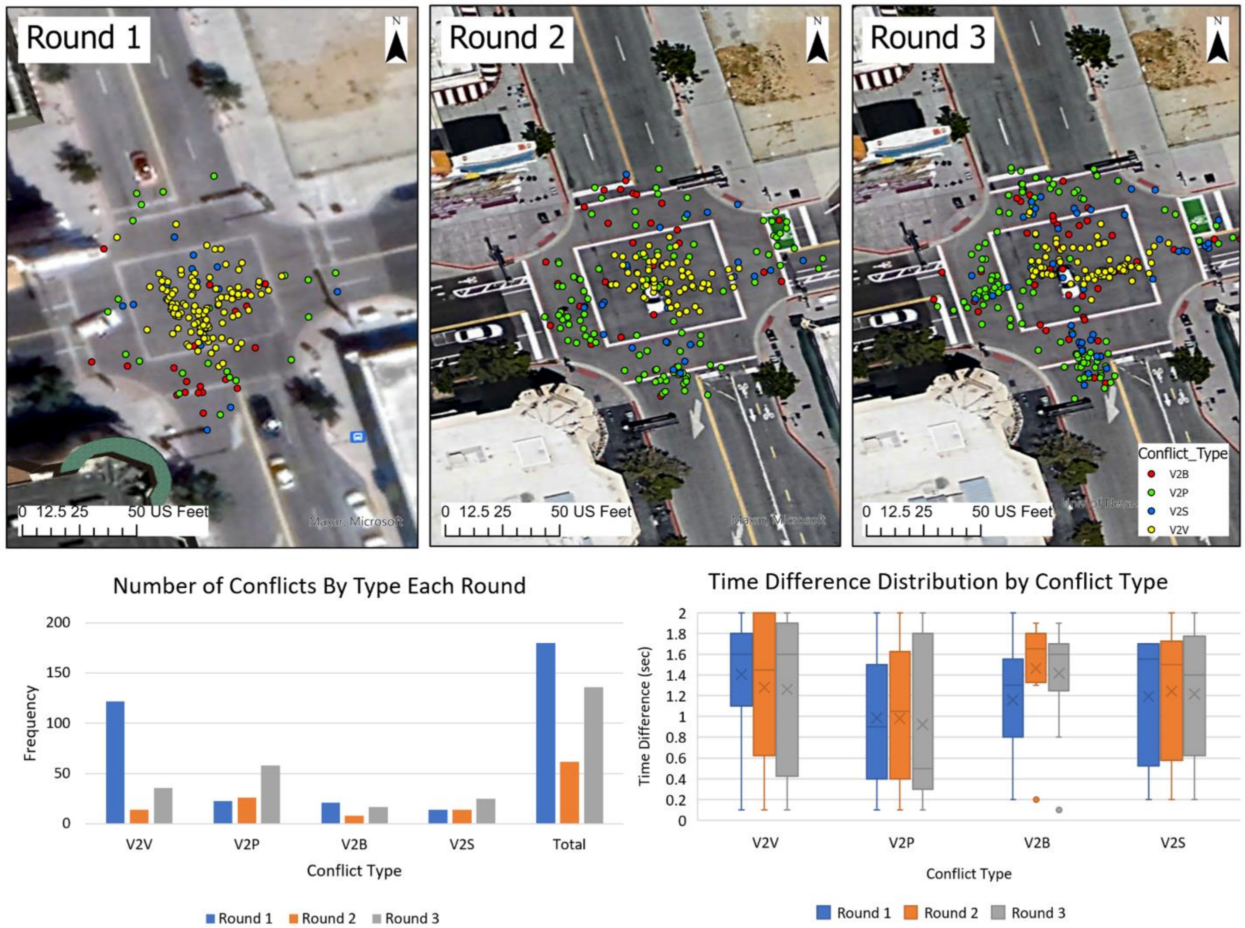


Figure 42 Virginia St and 5th St conflict locations, frequencies, and severities

Table 18 Virginia St and 5th St conflict rates

Round	Vehicle-to-vehicle conflicts per 100 vehicles	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
1	0.47	0.80	15.91	4.19	0.61
2	0.06	0.61	2.55	1.40	0.22
3	0.16	1.23	4.24	2.60	0.48

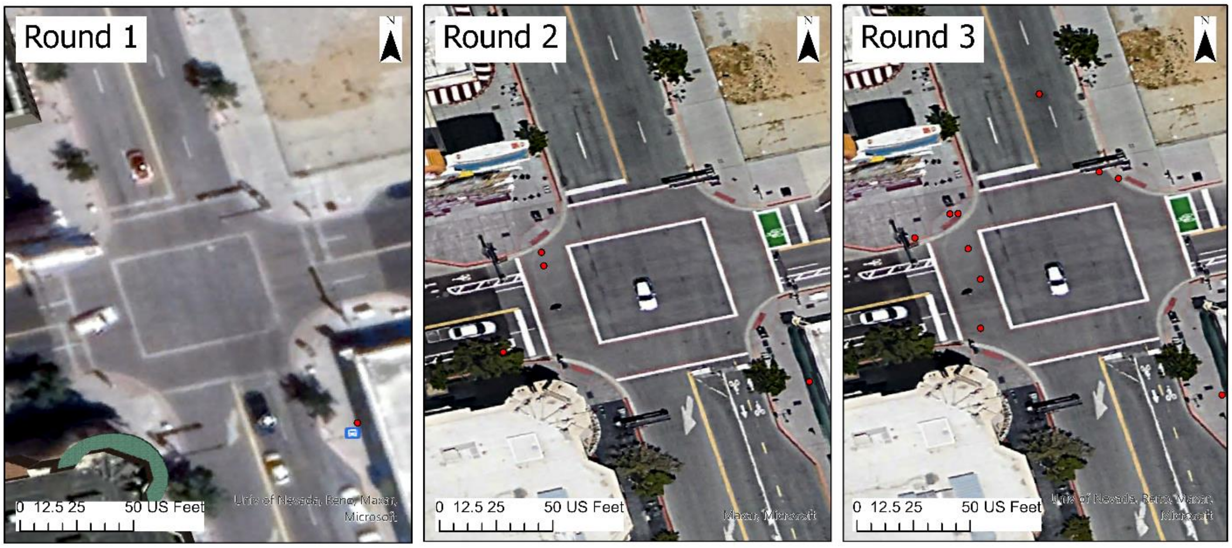


Figure 43 Virginia St and 5th St micromobility-to-pedestrian conflicts

2.4.6 Summary

The overall findings of the Virginia St and 5th St intersection analysis is summarized. Overall, vehicle volumes were lower on round 3 during the weekday and on round 2 during the weekend. The pedestrian and micromobility volumes increased from the before conditions to after. The addition of the bicycle infrastructure decreased the number of bicycles on the sidewalk and the number of scooters on the roadway. There does not appear to be any speeding issues and speeds have decreased slightly over the three rounds, particularly in the southbound direction along Virginia St. The vehicle red-light running events were most frequent in the eastbound and southbound direction. The vehicle red-light running events were highest during round 2 and lowest during round 3. The rate of micromobility red-light running events were as high as 18 percent on the weekend during round 3 and under 12 percent otherwise. Vehicle-to-vehicle conflicts decreased as the conflict rate of vehicle to micromobility users also decreased. However, vehicle-to-pedestrian conflict frequency and rate were highest at round 3. These conflicts appear to be clustering around the west and south crosswalks.

2.5 VIRGINIA ST AND 4TH ST

The Virginia St and 4th St intersection is signalized. The intersection has crosswalks at each leg. In the round 1 conditions, there were two lanes at each approach with permissive left turns. In the round 2 and 3 conditions, a cycle track was added along Virginia St. At this intersection, Virginia St changed from a two-way to a one-way going southbound. Bike boxes were added to the eastbound and westbound approaches, which is intended to keep stopped micromobility users in the line of sight of vehicles and to provide queue storage. Figure 44 (a) shows the intersection before changes were made and Figure 44 (b) shows the intersection after changes were made.

(a) **(b)**

Figure 44 Virginia St and 4th St before-after infrastructure changes

2.5.1 Counts

The counts for the different road users at the Virginia St and 5th St intersection is analyzed. Overall, the vehicle volumes decreased over the three rounds, as shown in Table 19. The southbound vehicle volumes decreased each round on the weekday and increased after round 1 on the weekend. The pedestrian volumes have increased over the three rounds, particularly the weekend, as shown in Table 20. Bicycle volumes increased between round 1 and round 2, as shown in Table 17. Scooter volumes also increased after the implementation of the new infrastructure, especially on the weekend.

Table 19 Virginia St and 4th St daily vehicle volumes

	All		Southbound Movements	
Round	Weekday Vehicles	Weekend Vehicles	Weekday Vehicles	Weekend Vehicles
1	17836	17832	4115	3809
2	16308	11424	4056	4228
3	11737	13928	3346	4124

Table 20 Virginia St and 4th St daily pedestrian volumes

Round	Weekday Pedestrian	Weekend Pedestrian
1	1841	1776
2	2273	2732
3	2365	3829

Table 21 Virginia St and 4th St daily micromobility volumes

Round	Weekday Bicycle	Weekend Bicycle	Weekday Scooter	Weekend Scooter
1	62	83	238	259
2	172	172	490	770
3	90	176	462	671

2.5.2 Micromobility Behavior

The behavior and compliance of the micromobility road users at the Virginia St and 4th St intersection is analyzed. Figure 45 and Figure 46 shows the right-of-way utilization of the micromobility road users during a given weekday and weekend day, respectively. In other words, the extent to which micromobility road users use the roadway, bike lane, cycle track, and the sidewalks. “CT/BL” refers to the cycle track and bicycle lanes. For the Virginia St and 4th St intersection, a cycle track was installed along Virginia St and, therefore, only the north-south directions are considered.

Overall, bicycle volumes on the roadway and sidewalk decreased marginally as the cycle track volumes increased; however, bicyclist volumes were split amongst the three right-of-way locations on the weekday, but the weekend saw an increase in cycle track usage. Scooters, on the other hand, had a significant decrease in roadway and sidewalk usage and a significant increase in cycle track volumes. During round 2 and round 3, over 70 percent of scooters used the cycle track with the remainder split between roadway and sidewalk usage. In general, the cycle track was primarily utilized by scooters, but bicyclist used the cycle track more on the weekends.

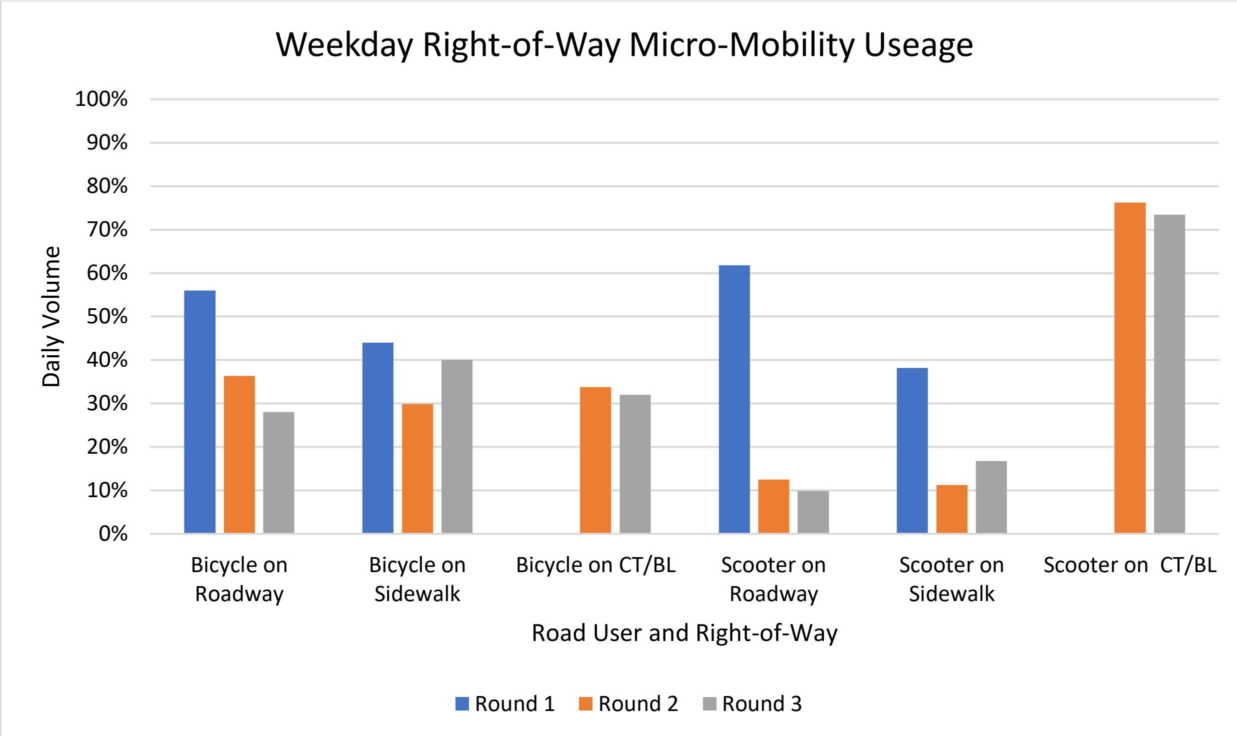


Figure 45 Virginia St and 4th St weekday right-of-way micromobility usage

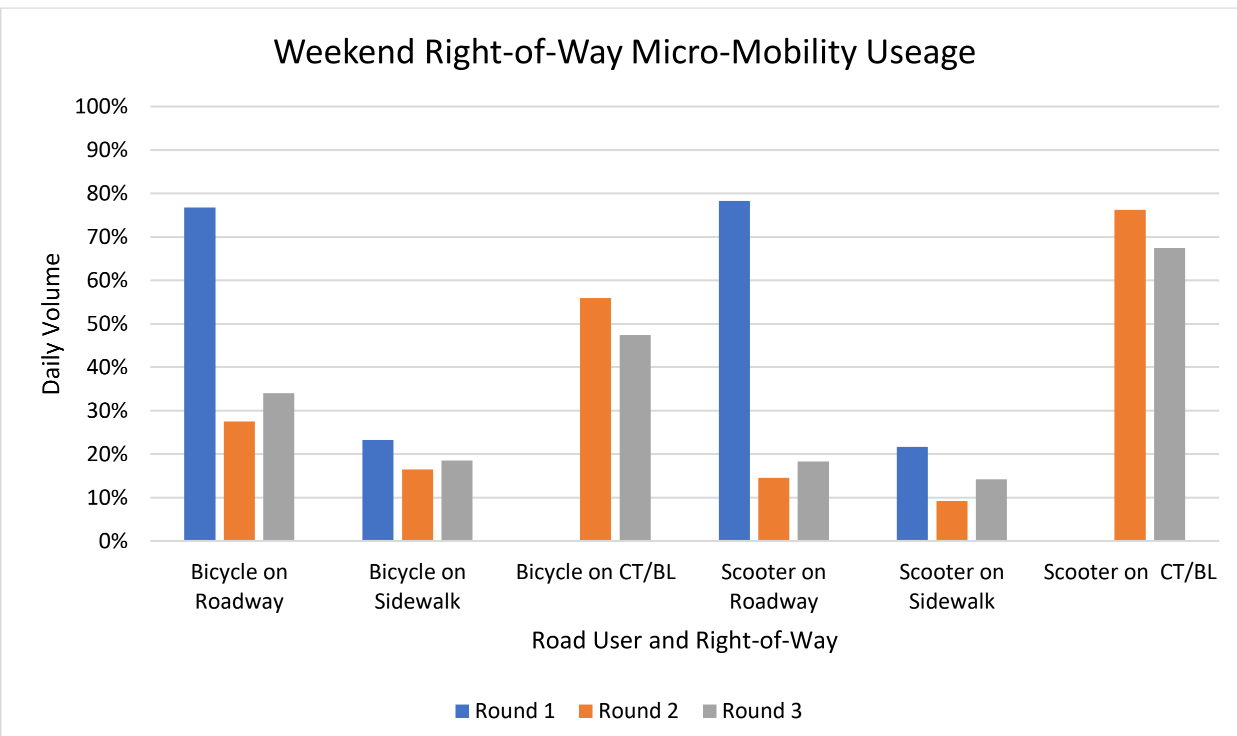


Figure 46 Virginia St and 4th St weekend right-of-way micromobility usage

2.5.3 Speed

The vehicle speeds at the Virginia St and 4th St intersections are analyzed. Vehicle speeds were extracted at the approach of each leg. Since Virginia St changed from two-way to one-way at this intersection, the northbound approach is only available for round 1. The through speeds of each individual vehicle is extracted and the distribution of the speed is shown in Figure 47 for each round and each direction. The detection zones used to extract the speeds are placed just before the stop bar in each direction. The Xs marks the mean, the horizontal lines mark the median, and the lower and upper boundaries of the box represent the 25th and 75 percentile speeds, respectively. The speed limit is 25 MPH. Overall, a majority of vehicles were under the speed limit with 75-percentile speeds being less than 25 MPH for each direction, and round. Furthermore, speeds decreased by over 5 MPH on average between round 1 and 2 for the southbound and westbound directions.

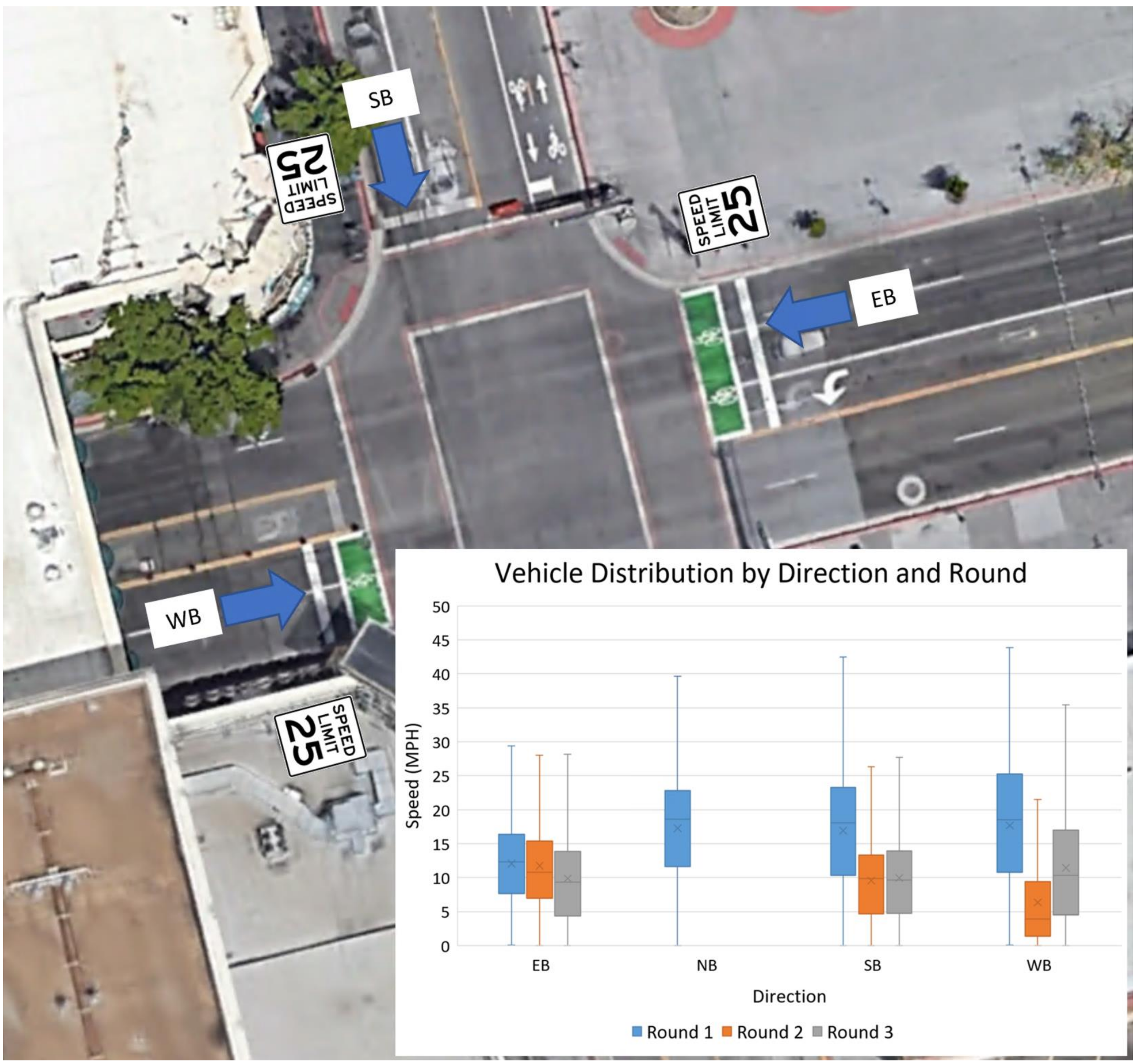


Figure 47 Virginia St and 4th St vehicle speeds

2.5.4 Red-Light Running

The red-light running at the Virginia St and 4th St intersection are analyzed. The through and left turn vehicles detected past the stop bar over a speed of 10 MPH going in the correct direction during the red-interval for their respective direction and movement are flagged as red-light running events. Figure 48 shows the ring-and-barrier diagram of the intersection, which changed after round 1 to accommodate the cycle track. The micromobility phase ran only with north-south pedestrians and did not come into conflict with vehicle, unless during a red-light running event. Furthermore, the order of phase was different between round 2 and round 3. During round 2, the micromobility phase preceded the southbound phase, but for round 3, preceded the east-west phases. Figure 49 and Figure 50 shows the frequency of red-light running events based on the total and after red clearance, respectively. Figure 51 and Figure 52 shows the rate of red-light running events based on the total and after red clearance, respectively. Overall, there was a sharp increase in the frequency and rate of red-light running events after round 1 for the total and after red clearance events.; whereas, the difference between round 2 and round 3 was smaller. The frequency was relatively split between the different directions and there was no difference between the days.

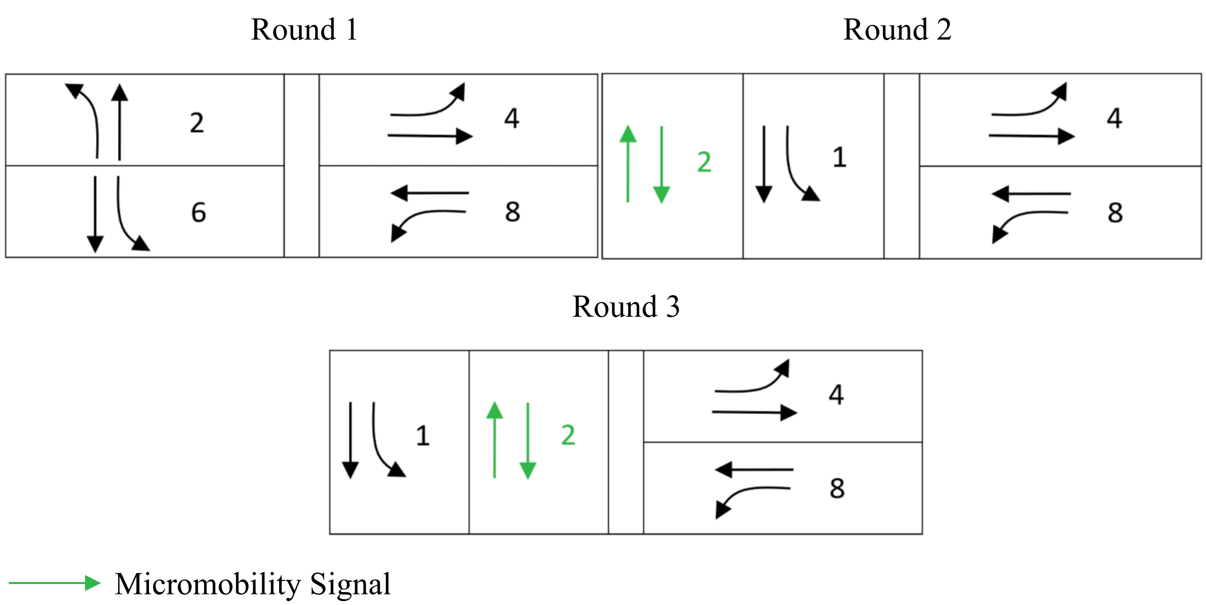


Figure 48 Virginia St and 4th St ring-and-barrier diagrams

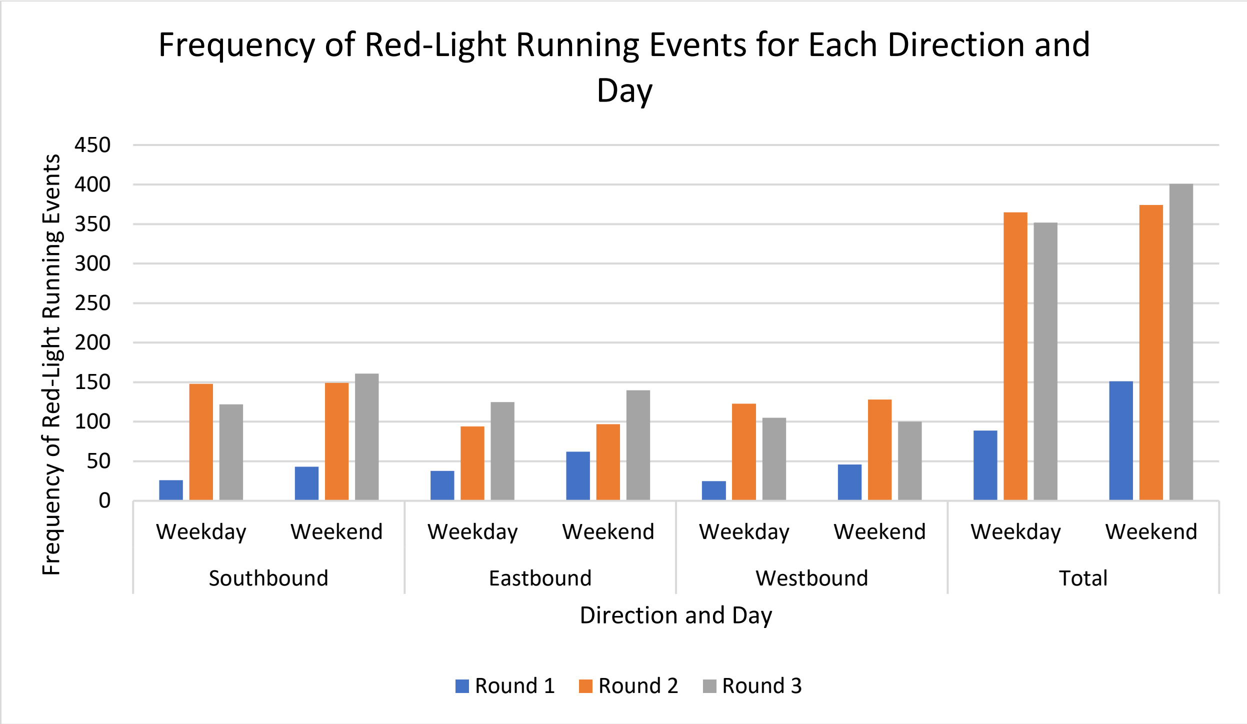


Figure 49 Virginia St and 4th St frequency of vehicle red-light running events

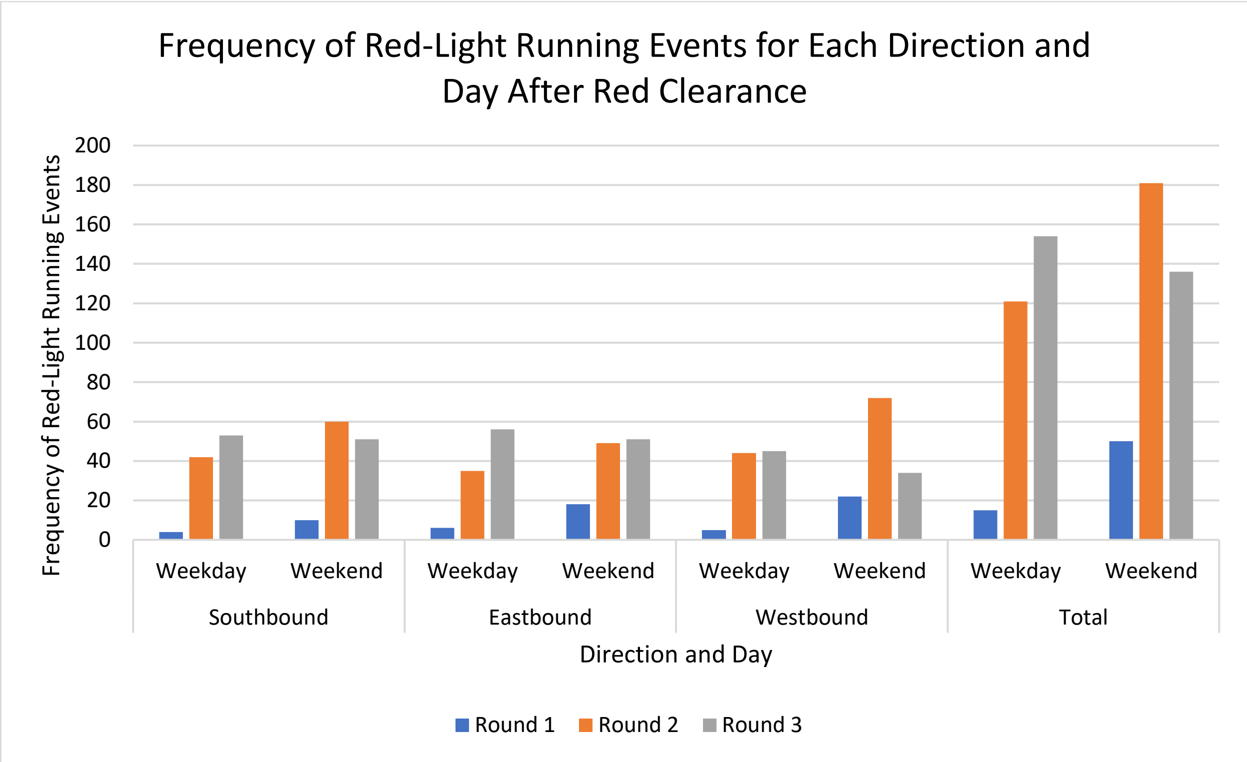


Figure 50 Virginia St and 4th St frequency of vehicle red-light running events after red clearance

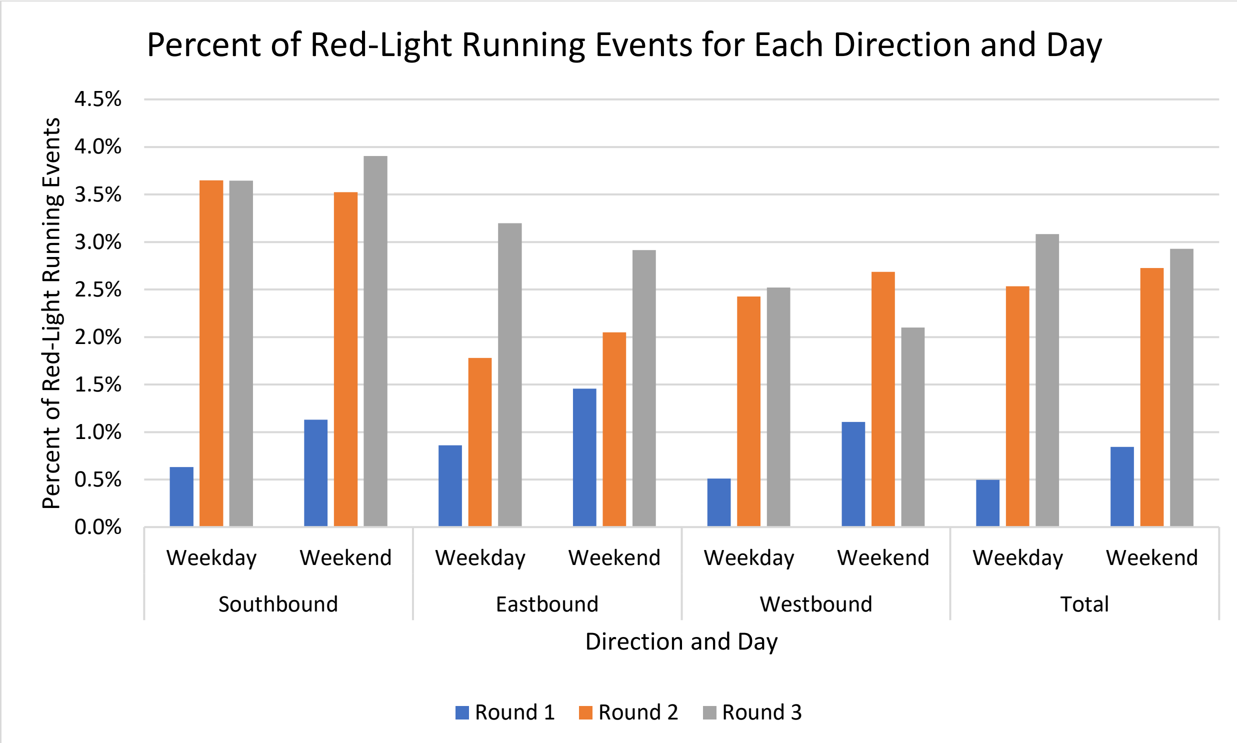


Figure 51 Virginia St and 4th St percent of vehicle red-light running events

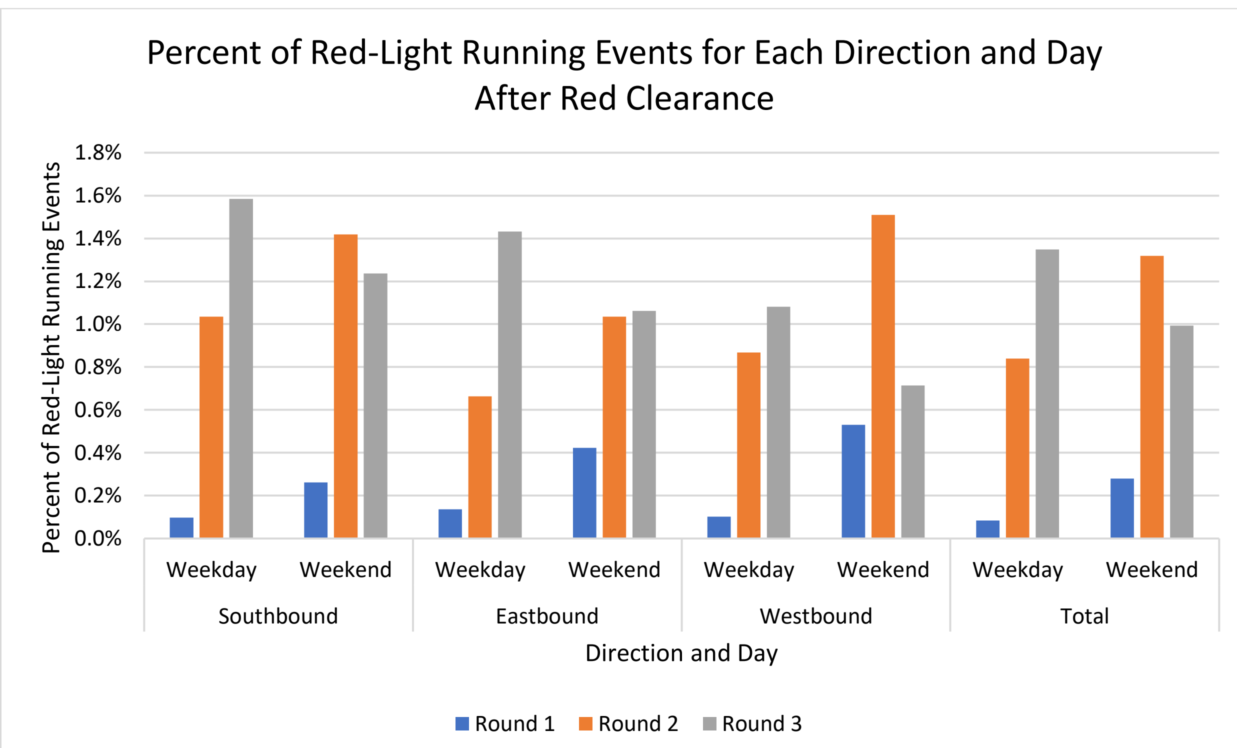


Figure 52 Virginia St and 4th St percent of vehicle red-light running events after red clearance

Figure 53 and Figure 54 shows the frequency and rate of micromobility red-light running events, respectively. Table 22 and Table 23 shows the breakdown of micromobility red-light running events by conflicting phase for the frequency and percent, respectively. The micromobility phase ran only with north-south pedestrians and does not come into conflict with vehicle, unless during red-light running events. Furthermore, the order of phase was different between round 2 and round 3. During round 2, the micromobility phase preceded the southbound phase, but for round 3, preceded the east-west phases. The frequency and rate of red-light running events were higher during round 3 when the east-west movement phases came after the micromobility phase. The frequency was similar between the two directions, but the rate was higher in the southbound direction, with 45 percent being the highest. Most of the red-light running events were occurring during the southbound movements green (phase 1) rather than the east-west movements (phase 4 and 8) for each direction and round. The northbound direction for each round had a higher proportion of red-light running events concurrent with the opposing east-west movement phases.

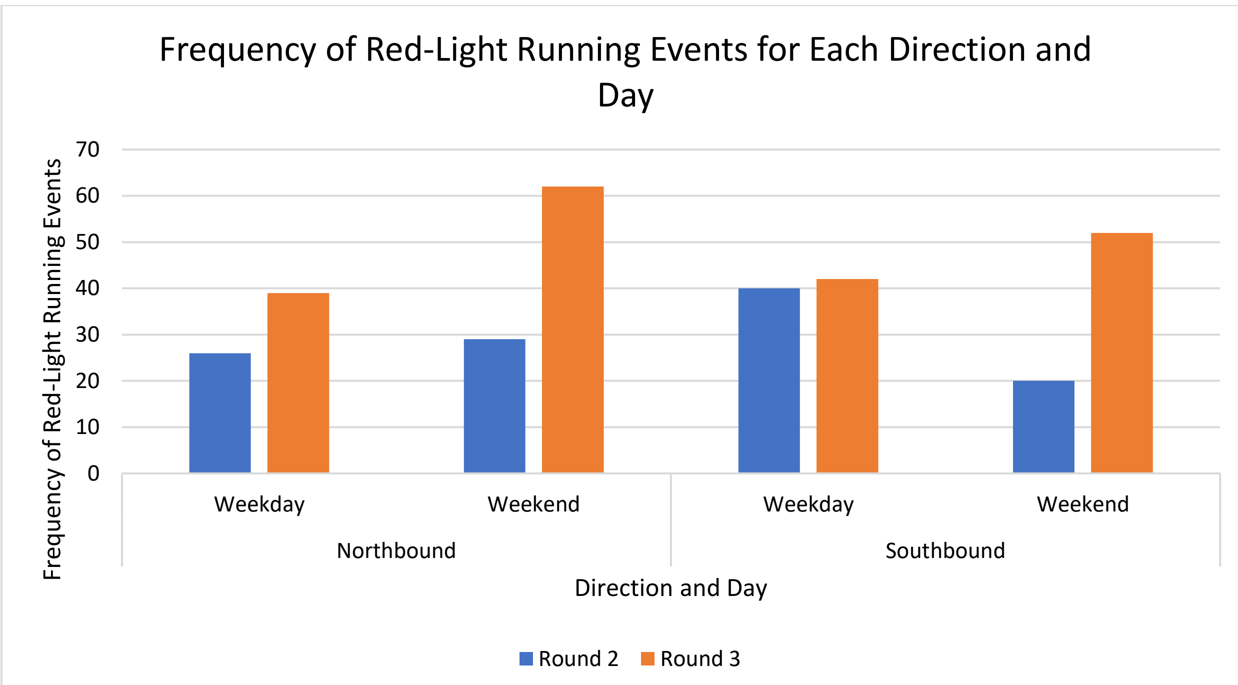


Figure 53 Virginia St and 4th St frequency of micromobility red-light running events

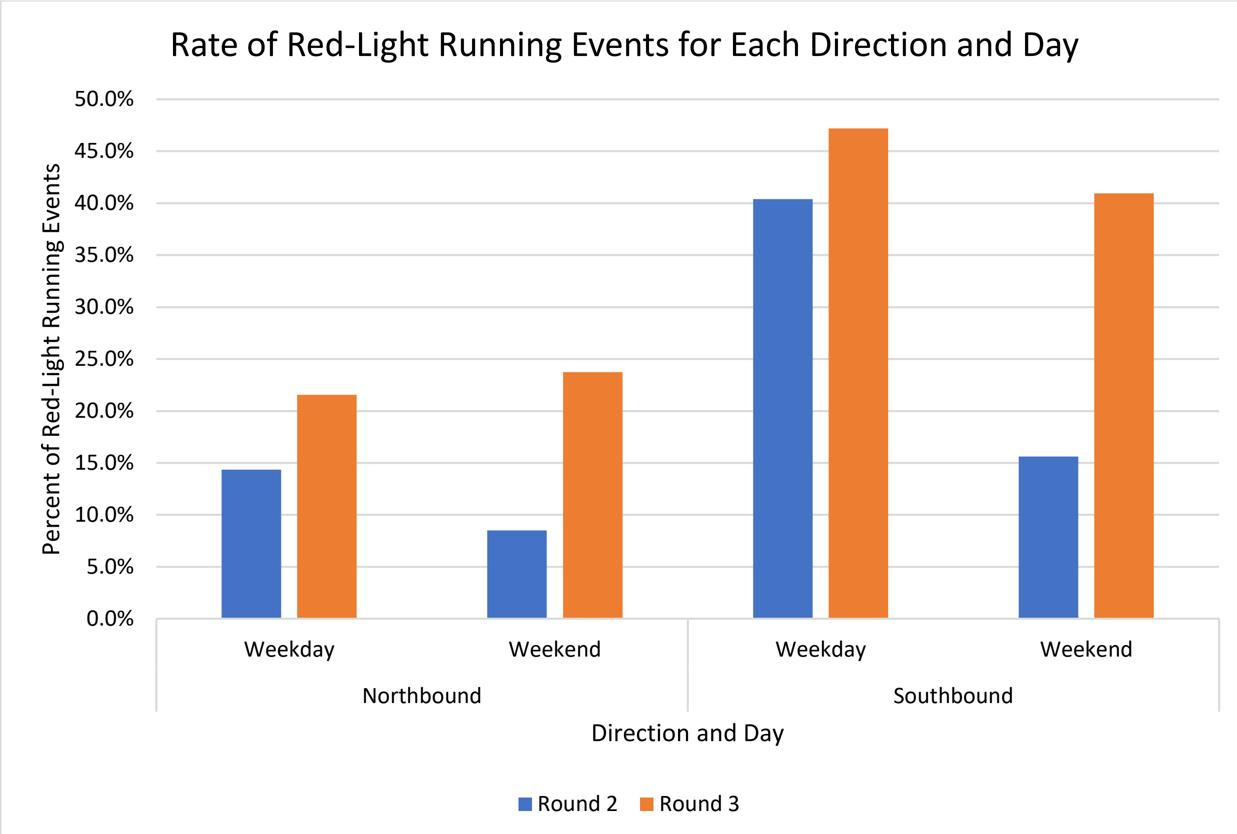


Figure 54 Virginia St and 4th St percent of micromobility red-light running events

Table 22 Virginia St and 4th St frequency of micromobility red-light running by conflicting phase

Round	Direction	Southbound		East-West		Red Clearance	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
2	Northbound	14	16	10	14	3	1
	Southbound	33	12	2	3	5	5
3	Northbound	29	43	9	15	2	4
	Southbound	24	39	1	5	17	8

Table 23 Virginia St and 4th percent of micromobility red-light running by conflicting phase

Round	Direction	Southbound		East-West		Red Clearance	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
2	Northbound	52%	52%	37%	45%	11%	3%
	Southbound	83%	60%	5%	15%	13%	25%
3	Northbound	73%	69%	23%	24%	5%	6%
	Southbound	57%	75%	2%	10%	40%	15%

2.5.5 Conflicts

The conflicts between road users at the Virginia St and 4th St intersection is analyzed. Figure 55 illustrates the conflicts by showing a map of each conflict's location within the site, along with the conflict frequency and severity in PET. Vehicle-to-vehicle decreased significantly between round 1 and 2 and increased between round 2 and 3. This was primarily because of the decrease in vehicle lanes and the change from two-way to one-way along Virginia St, which reduces the number of conflict points between vehicles. Vehicle to micromobility user conflicts remained relatively steady with a decrease between round 1 and 2 for vehicle-to-bicycle conflicts. The number of vehicle-to-pedestrian conflicts increased over the three rounds. The average PET for each conflict type did not change significantly. Figure 55 shows that the majority of vehicle to vulnerable road user conflicts occurred at the west and south crosswalk. Vehicle to micromobility conflicts were lower around the bike box. The conflict trends for Virginia St and 4th St are similar to the Virginia St and 5th St intersection.

Table 12 shows the conflict rate, which normalizes the number of conflicts by the volumes of the most vulnerable road user. The conflict rate shows that safety for vehicle-to-scooter safety improved with the addition of the new infrastructure. Vehicle-to- bicycle conflict rates were lowest during round 2, but were high during round 1 and round 3. Vehicle-to-pedestrian conflict rates increased over the three rounds. Figure 56 shows the micromobility-to-pedestrian conflicts, which increase each round and tend to occur at the corners of the intersection and at the cycle track/crosswalk conflict point. The conflict rate in conflicts per 100 pedestrians for round 1, 2, and 3 are 0.11, 0.30, and 0.71, respectively.

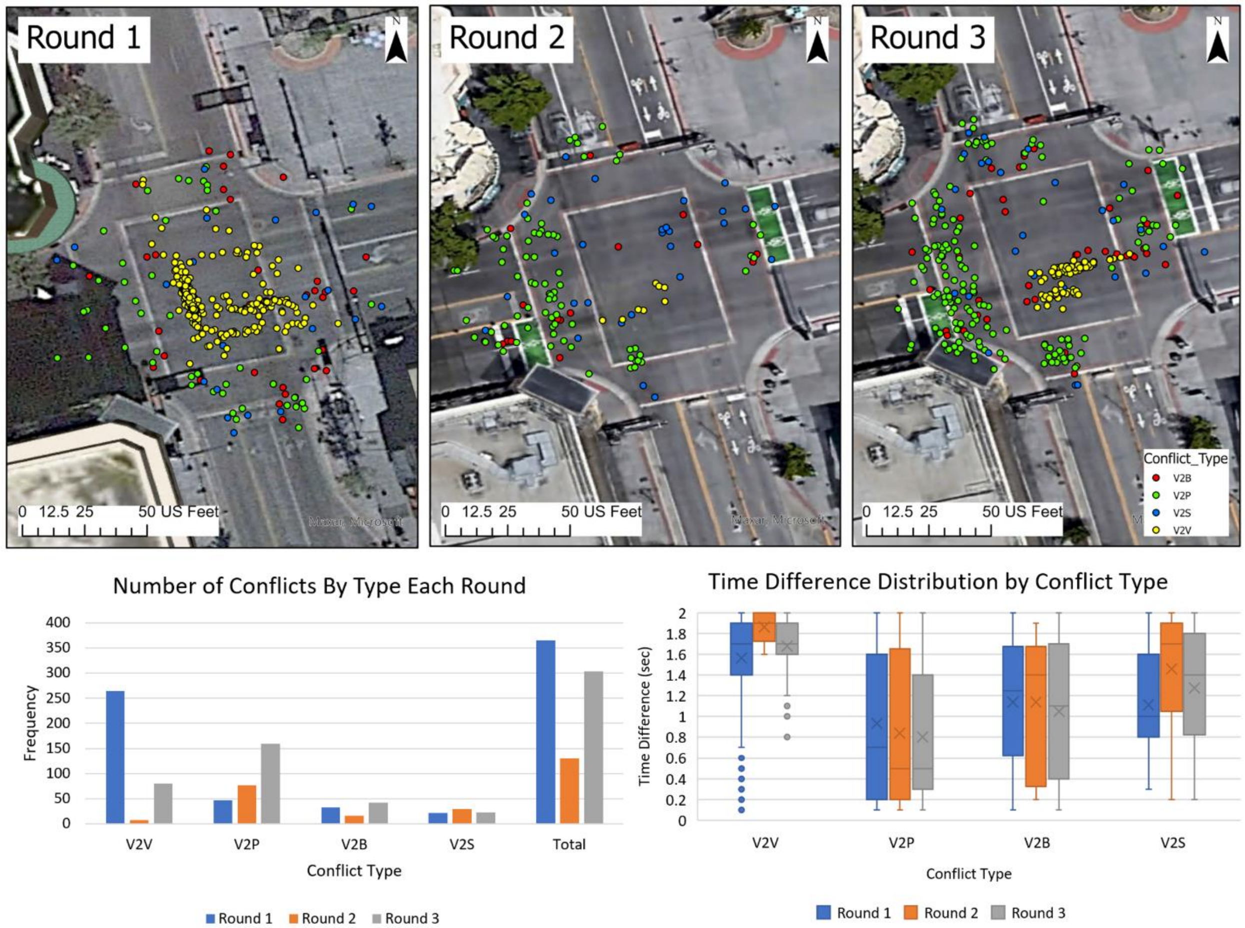


Figure 55 Virginia St and 4th St conflict locations, frequencies, and severities

Table 24 Virginia St and 4th St conflict rates

Round	Vehicle-to-vehicle conflicts per 100 vehicles	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
1	0.74	1.30	22.07	4.43	0.91
2	0.03	1.54	4.65	2.30	0.38
3	0.31	2.57	15.79	2.03	0.91

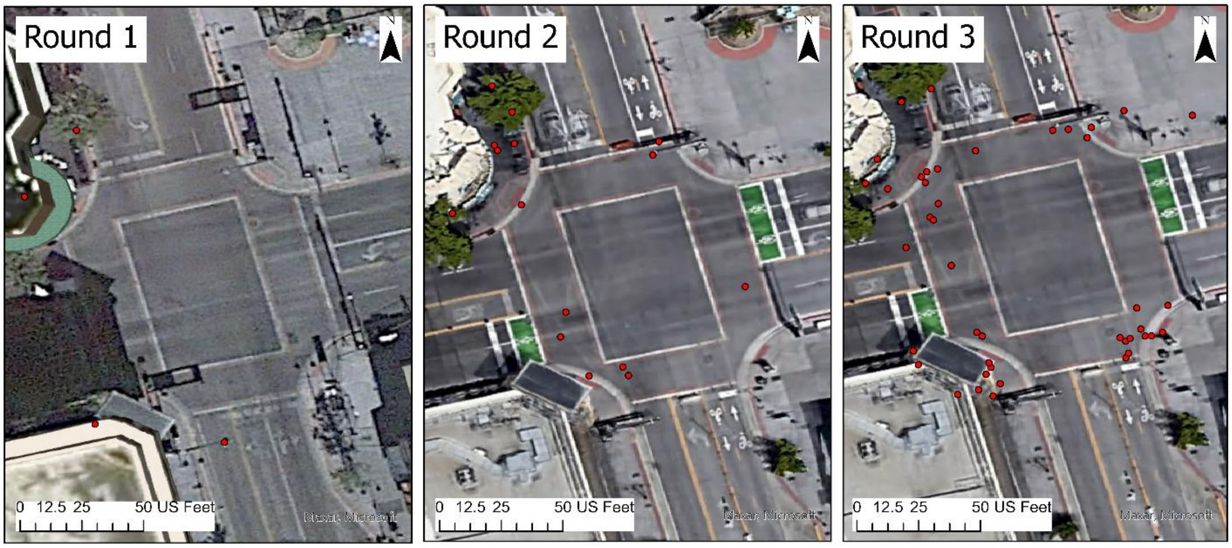


Figure 56 Virginia and 4th St micromobility-to-pedestrian conflicts

2.5.6 Summary

The overall findings of the Virginia St and 4th St intersection analysis is summarized. Overall, vehicle volumes were lower on round 3 during the weekday and on round 2 during the weekend. The pedestrian and micromobility volumes increased from the before conditions to after. The addition of the cycle track caused more scooters to use it in favor of the roadway or sidewalk; whereas the bicycles were still split amongst the right-of-way locations.

There does not appear to be any speeding issues and speeds have decreased significantly between round 1 and 2 in the southbound and westbound directions. Overall, there was a sharp increase in the frequency and rate of vehicle red-light running events after round 1 for the total and after red clearance events; whereas, the difference between round 2 and round 3 was smaller. The frequency and rate of micromobility red-light running events were higher during round 3 when the east-west movement phases come after the micromobility phases. The configuration in which the southbound phase came after the micromobility phase slightly discouraged red-light running events. Most of the red-light running events occurred during the southbound movements green (phase 1) rather than the east-west movements (phase 4 and 8) for each direction and round; however, the northbound micromobility users were more likely to run the red-light during the east-west phase.

Vehicle-to-vehicle conflicts decreased as the conflict rate of vehicle-to-pedestrian and micromobility-to-pedestrian conflicts increased. Vehicle-to-scooter conflicts decreased while vehicle-to-bicycle conflicts were lowest during round 2. These conflicts are clustered around the west and south crosswalk.

2.6 VIRGINIA ST AND COMMERCIAL ROW

The Virginia St and Commercial Row is a one-way side street stop-controlled intersection. The intersection has crosswalks at the east, west, and south legs. Commercial Row is one-way in the eastbound direction. In the round 1 conditions, there was one lane at each approach with a left turn pocket. In the round 2 and 3 conditions, a cycle track was added along Virginia St. At this intersection, Virginia St changed from a two-way to a one-way going southbound. The Commercial Row geometry was unchanged. Figure 57 (a) shows the intersection before changes were made and Figure 57 (b) shows the intersection after changes were made.

(a) (b)

Figure 57 Virginia St and Commercial Row before-after infrastructure changes

2.6.1 Counts

The counts for the different road users at the Virginia St and Commercial Row intersection are analyzed. Overall, the vehicle volumes decreased significantly between round 1 and 2 and increased slightly from round 2 to 3, as shown in Table 25. The southbound vehicle volumes decreased on the weekday and was lowest on round 2 during the weekend. The pedestrian volumes increased, particularly during the weekend, as shown in Table 20. Bicycle volumes increased over the three rounds with a peak in volumes during round 3, as shown in Table 17. Scooter volumes also increased after the implementation of the new infrastructure and volumes were much higher during the weekend.

Table 25 Virginia St and Commercial Row daily vehicle volumes

	All		Southbound Movements	
Round	Weekday Vehicles	Weekend Vehicles	Weekday Vehicles	Weekend Vehicles
1	9739	11417	4359	4701
2	3957	4146	3579	3730
3	4037	4970	3430	4046

Table 26 Virginia St and Commercial Row daily pedestrian volumes

Round	Weekday Pedestrian	Weekend Pedestrian
1	2519	3444
2	3068	3480
3	3187	3867

Table 27 Virginia St and Commercial Row daily micromobility volumes

Round	Weekday Bicycle	Weekend Bicycle	Weekday Scooter	Weekend Scooter
1	113	165	254	790
2	108	160	783	1123
3	217	324	419	758

2.6.2 Micromobility Behavior

The behavior and compliance of the micromobility road users at the Virginia St and Commercial Row intersection is analyzed. Figure 58 and Figure 59 shows the right-of-way utilization of the micromobility road users during a given weekday and weekend day, respectively. In other words, the extent to which micromobility road users use the roadway, bike lane, cycle track, and the sidewalks is shown. "CT/BL" refers to the cycle track and bicycle lanes. For the Virginia St and Commercial Row intersection, a cycle track extends along Virginia St. The Commercial Row geometry was unchanged so only the Virginia St approaches are considered.

Overall, bicycle volumes on the roadway decreased as the cycle track volumes increased. During round 3, at least half of the bicycles used the cycle track. Scooter on the other hand, had a large decrease in roadway and slight decrease in sidewalk usage with a large increase in cycle track volumes. During round 2 and 3, half of scooters used the cycle track with the remainder split between roadway and sidewalks. In general, the cycle track was used by all micromobility users.

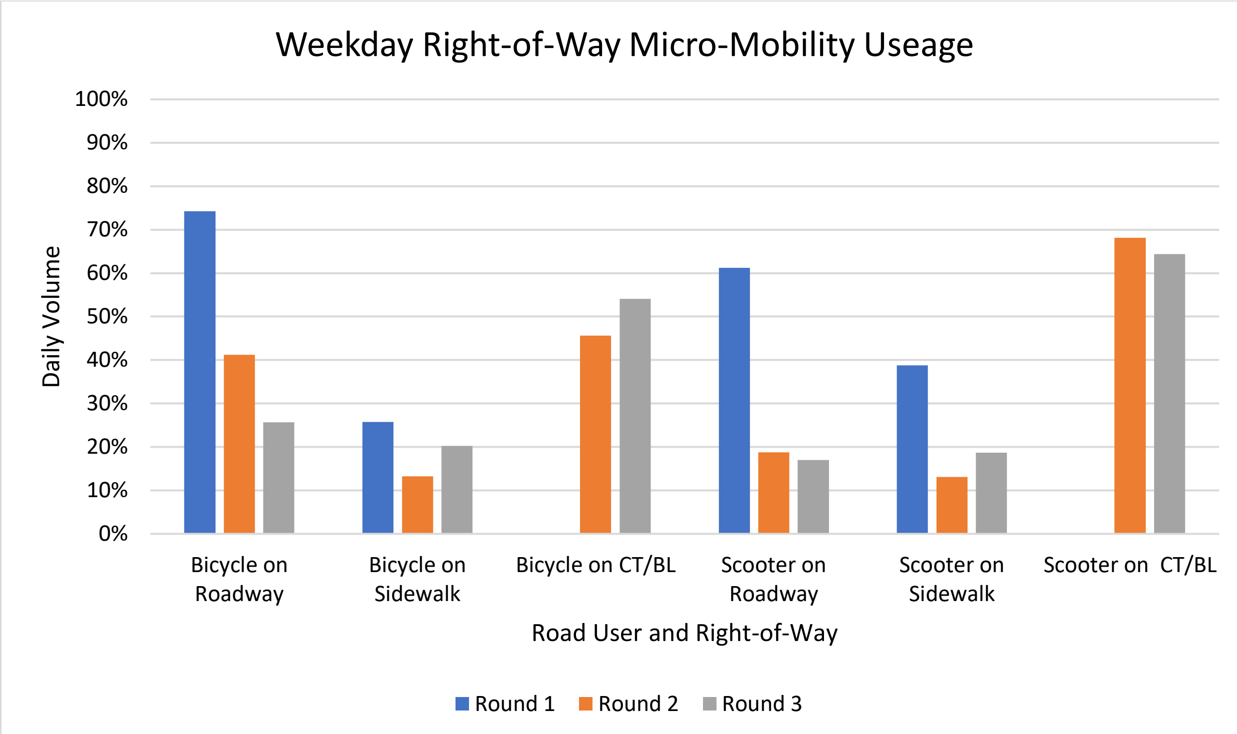


Figure 58 Virginia St and Commercial Row weekday right-of-way micromobility usage

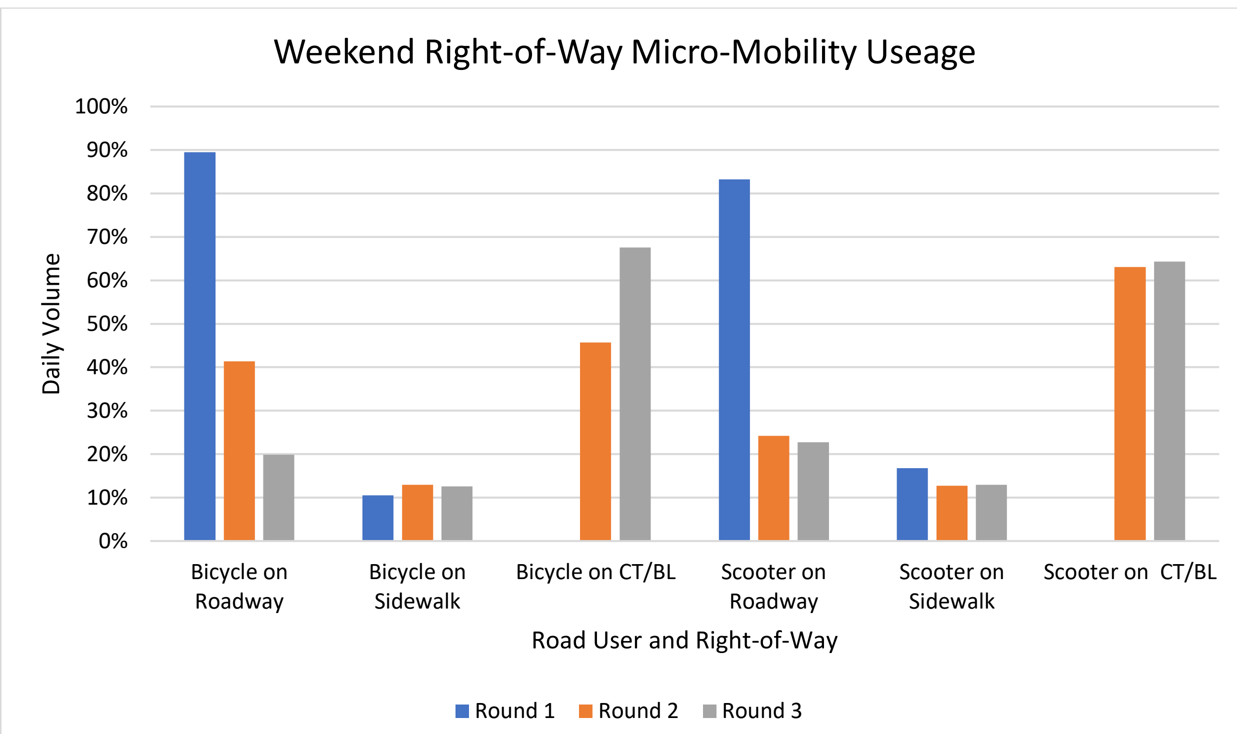


Figure 59 Virginia St and Commercial Row weekend right-of-way micromobility usage

2.6.3 Speed

The vehicle speeds at the Virginia St and Commercial Row intersection are analyzed. Vehicle speeds were extracted at the approach of each leg. Since Virginia changed from two-way to one-way, the northbound approach is only available for round 1. The through speeds of each individual vehicle is extracted and the distribution of the speed is shown in Figure 60 for each round and each direction. The detection zones used to extract the speeds are placed just before the stop bar in the westbound and northbound (round 1) directions, and just before the intersection in the southbound direction. The Xs marks the mean, the horizontal lines mark the median, and the lower and upper boundaries of the box represent the 25th and 75 percentile speeds, respectively. The speed limit is 25 MPH. Overall, a majority of vehicles were under the speed limit with 75-percentile speeds being less than 20 MPH for each direction and round. Furthermore, speeds decreased between round 1 and 2 for the southbound direction.

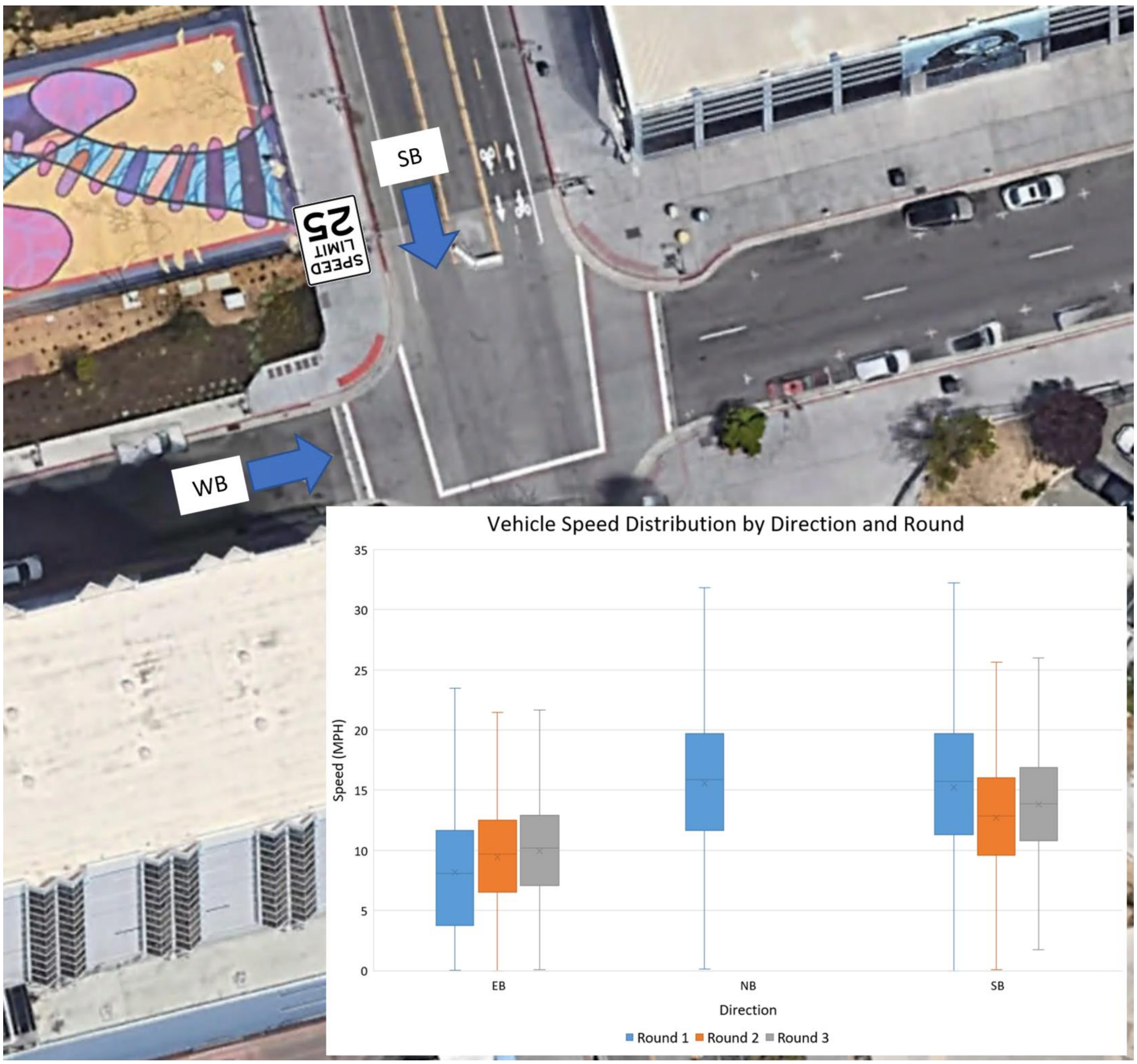


Figure 60 Virginia St and Commercial Row vehicle speeds

2.6.4 Conflicts

The conflicts between road users at the Virginia St and Commercial Row intersection is analyzed. Figure 61 illustrates the conflicts by showing a map of each conflict's location within the site, along with the conflict frequency and severity in PET. Vehicle-to-vehicle conflicts decreased between round 1 and 2 and increased marginally between round 2 and 3. There were lower vehicle-to-vehicle conflicts at this intersection considering the lower number of conflict points, especially during round 2 and 3 conditions. Vehicle to vulnerable road user conflicts were much lower in frequency at this intersection when compared to 4th and 5th St. Vehicle-to-pedestrian conflicts had the highest frequencies at this intersection; however, that was because of the higher number so pedestrian crossing activity because of the Reno Arch tourist attraction. Also, the average PET decreased for vehicle-to-pedestrian conflicts.

Table 28 shows the conflict rate, which normalizes the number of conflicts by the volumes of the most vulnerable road user. The conflict rate indicates vehicle-to-pedestrian safety actually improved. Trends of other conflict types mimics that of the frequency. Figure 62 shows the micromobility-to-pedestrian conflicts, which increase each round and tend to occur at the Virginia St crosswalk, especially at the cycle track/crosswalk conflict point. The conflict rate in conflicts per 100 pedestrians for round 1, 2, and 3 are 0.12, 0.21, and 0.40, respectively.

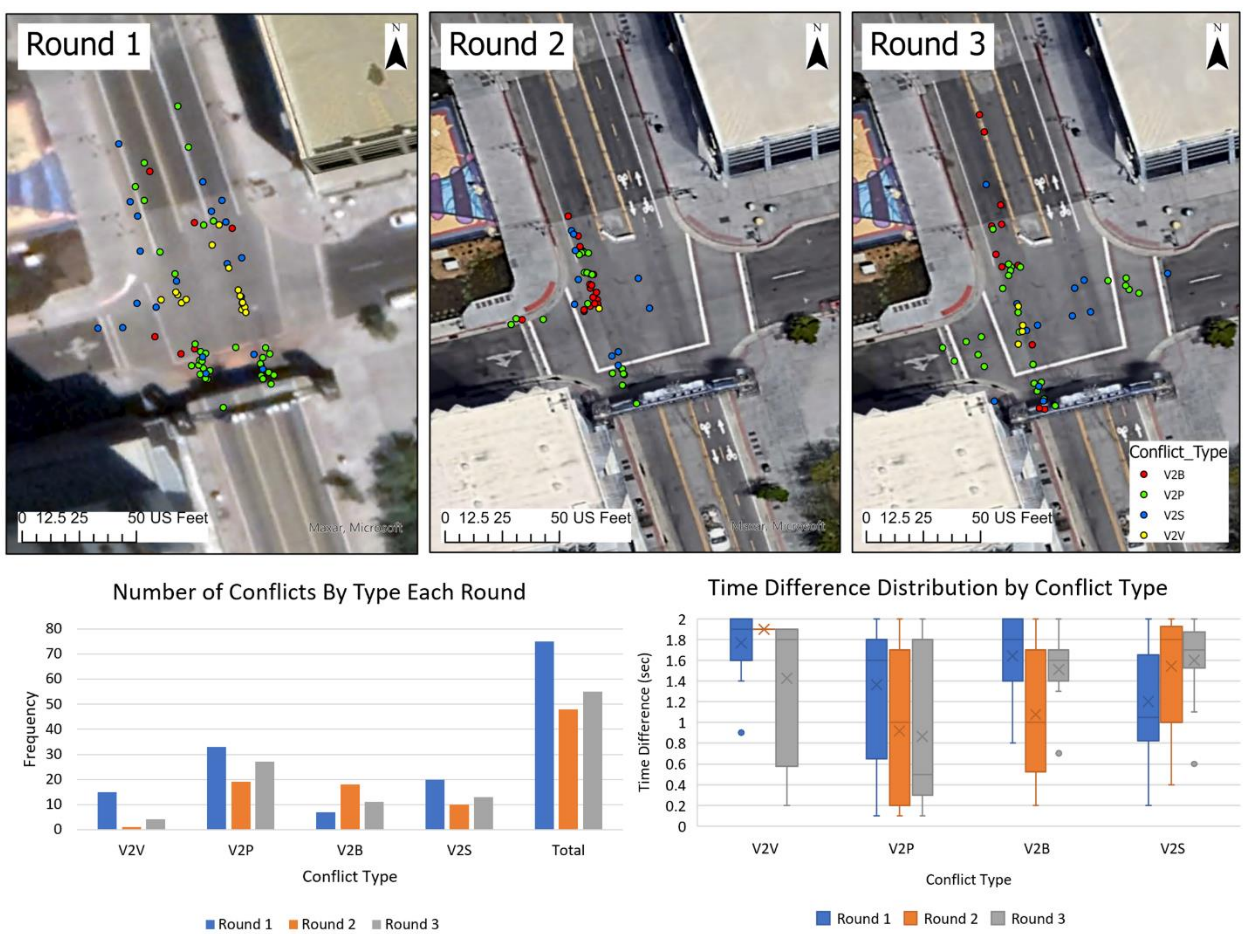


Figure 61 Virginia St and Commercial Row conflict locations, frequencies, and severities

Table 28 Virginia St and Commercial Row conflict rates

Round	Vehicle-to-vehicle conflicts per 100 vehicles	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
1	0.07	0.55	2.52	1.92	0.26
2	0.01	0.26	5.81	0.54	0.29
3	0.04	0.38	2.03	1.10	0.31

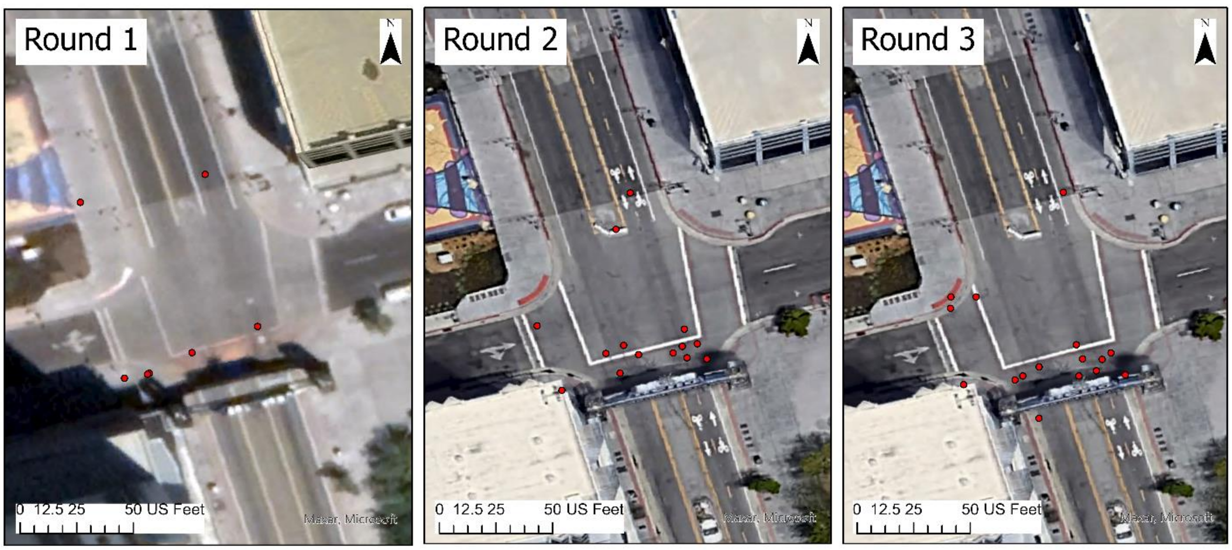


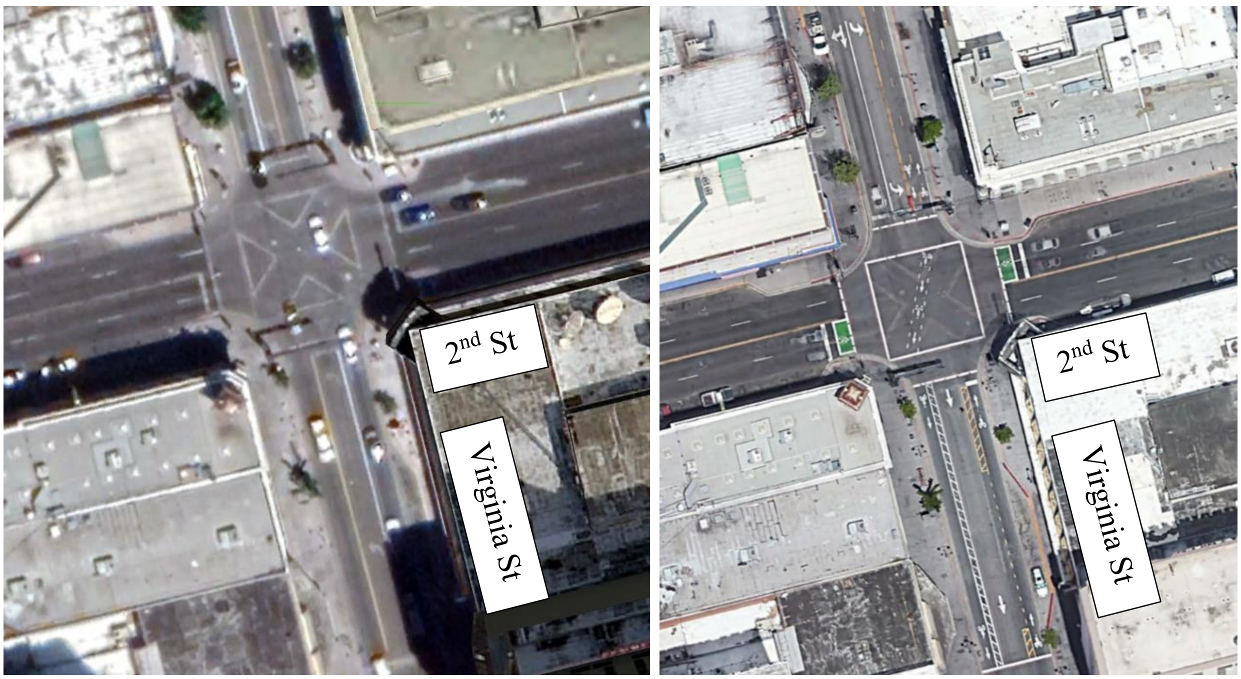
Figure 62 Virginia St and Commercial Row micromobility-to-pedestrian conflicts

2.6.5 Summary

The overall findings of the Virginia St and Commercial Row intersection analysis is summarized. Overall, vehicle volumes decreased with the new infrastructure while the pedestrian and micromobility volumes increased. The appearance of the cycle track caused more scooters to use it in favor of the roadway or sidewalk; whereas the bicycles still favored the roadway. There were no speeding issues and speeds decreased between round 1 and 2 in the southbound direction. The conflicts at this intersection were low. The vehicle-to-pedestrian conflicts were highest, but the conflict rate showed a decreasing trend.

2.7 VIRGINIA ST AND 2ND ST

The Virginia St and 2nd St intersection is signalized. The intersection has crosswalks at each leg and diagonal crossings in round 1 conditions. Also in round 1 conditions, there were two lanes at the eastbound and westbound approaches and one lane in the northbound and southbound direction with left turn pockets. In the round 2 and 3 conditions, the north leg had the two-way cycle track, but the south leg had protected bicycle lanes. This means there was a transition in the bicycle infrastructure. At this intersection, Virginia St changed from a two-way to a one-way going southbound. Bike boxes were added to the eastbound and westbound approaches, which is intended to keep stopped micromobility users in the line of sight of vehicles and to provide queue storage. Figure 63 (a) shows the intersection before changes were made and Figure 63 (b) shows the intersection after changes were made.



(a) **(b)**

Figure 63 Virginia St and 2nd St before-after infrastructure changes

2.7.1 Counts

The counts for the different road users at the Virginia St and 2nd St intersection is analyzed. Overall, the total and southbound vehicle volumes decreased over the three rounds, as shown in Table 29. The pedestrian volumes increased between round 1 and round 2, as shown in Table 30. Bicycle volumes increased over the three rounds, as shown in Table 31. Scooter volumes increased after the implementation of the new infrastructure, especially on the weekend. Micromobility volumes were higher on the weekend.

Table 29 Virginia St and 2nd St daily vehicle volumes

	All		Southbound Movements	
Round	Weekday Vehicles	Weekend Vehicles	Weekday Vehicles	Weekend Vehicles
1	14004	16426	4093	4920
2	8872	10263	3456	4489
3	8529	8366	3297	3512

Table 30 Virginia St and 2nd St daily pedestrian volumes

Round	Weekday Pedestrian	Weekend Pedestrian
1	2596	3509
2	3397	3957
3	3277	3672

Table 31 Virginia St and 2nd St daily micromobility volumes

Round	Weekday Bicycle	Weekend Bicycle	Weekday Scooter	Weekend Scooter
1	142	216	172	395
2	203	343	471	853
3	292	357	377	519

2.7.2 Micromobility Behavior

The behavior and compliance of the micromobility road users at the Virginia St and 2nd St intersection is analyzed. Figure 64 and Figure 65 shows the right-of-way utilization of the micromobility road users during a given weekday and weekend day, respectively. In other words, the extent to which micromobility road users use the roadway, bike lane, cycle track, or the sidewalks. "CT/BL" refers to the cycle track and bicycle lanes. For the Virginia St and 2nd St intersection, the north leg had a cycle track but the infrastructure transitioned to bike lanes in the south leg.

Overall, bicycle volumes on the roadway decreased as the cycle track and bike lane volumes increased such that up to half the bicycles used the bike infrastructure. Similarly, scooters had a decrease in roadway and sidewalk usage and increase in cycle track and bike lane volumes. During round 2 and 3, at least half of micromobility road users used the cycle track with the remainder split between roadway and sidewalk usage. The bicycle and scooter trends were similar at this site.

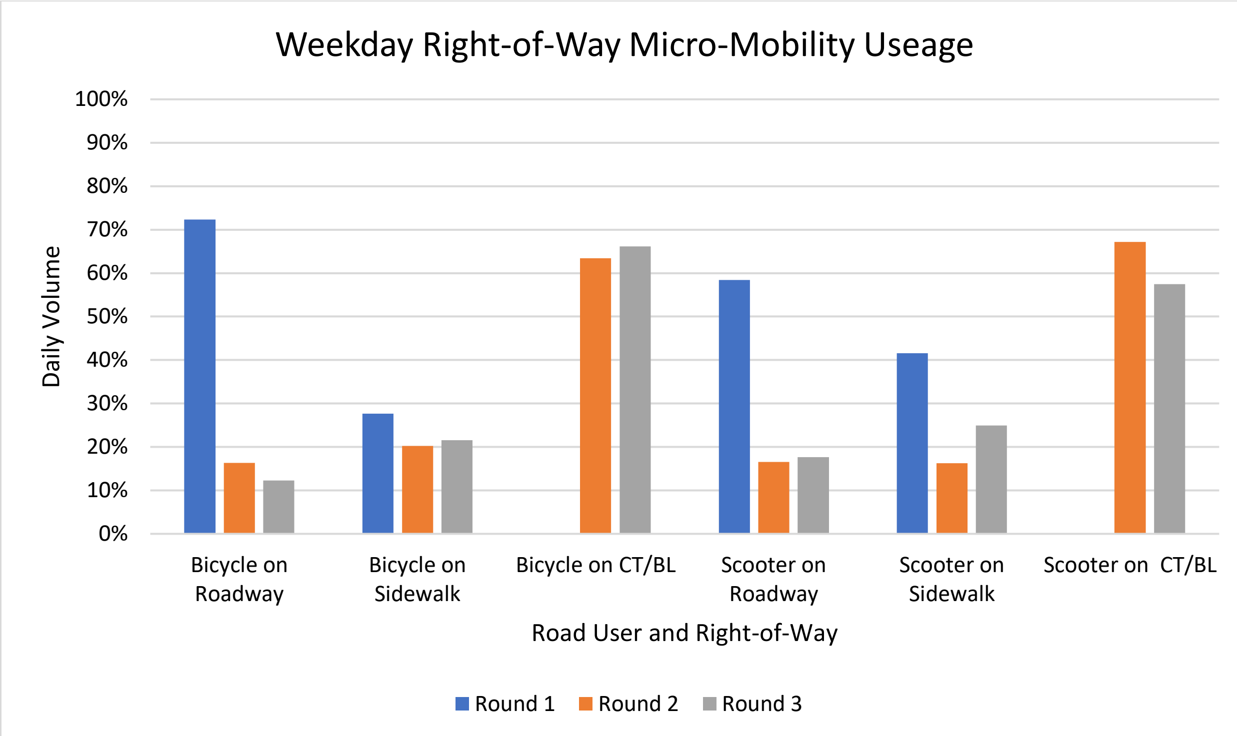


Figure 64 Virginia St and 2nd St weekday right-of-way micromobility usage

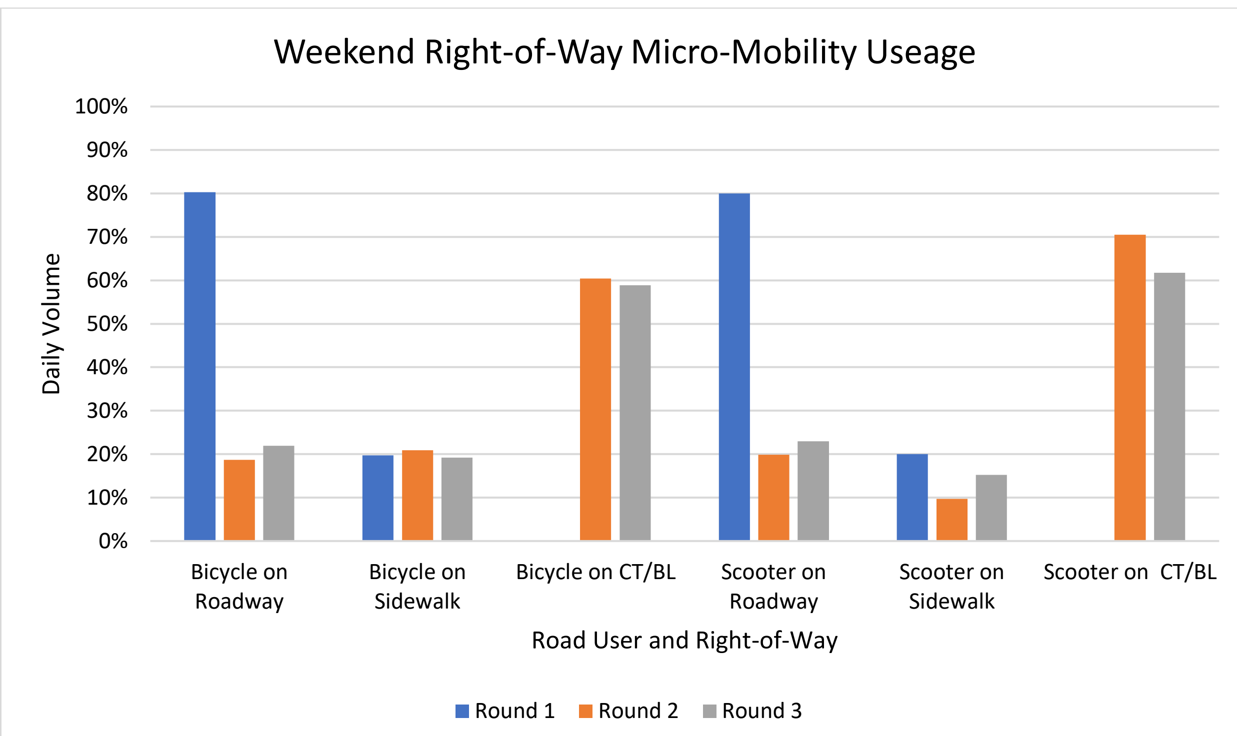


Figure 65 Virginia St and 2nd St weekend right-of-way micromobility usage

2.7.3 Speed

The vehicle speeds at the Virginia St and 2nd St intersection are analyzed. Vehicle speeds are extracted at the approach of each leg. Since Virginia St changed from two-way to one-way, the northbound approach is only available for round 1. The through speeds of each individual vehicle is extracted and the distribution of the speed is shown in Figure 66 for each round and each direction. The detection zones used to extract the speeds are placed just before the stop bar in each direction. The Xs mark the mean, the horizontal lines mark the median, and the lower and upper boundaries of the box represent the 25th and 75 percentile speeds, respectively. The speed limit is 25 MPH. Overall, a majority of vehicles were under the speed limit with 75-percentile speeds being less than 15 MPH for each direction and round. Furthermore, speeds decreased slightly between round 1 and 2 for the southbound directions.

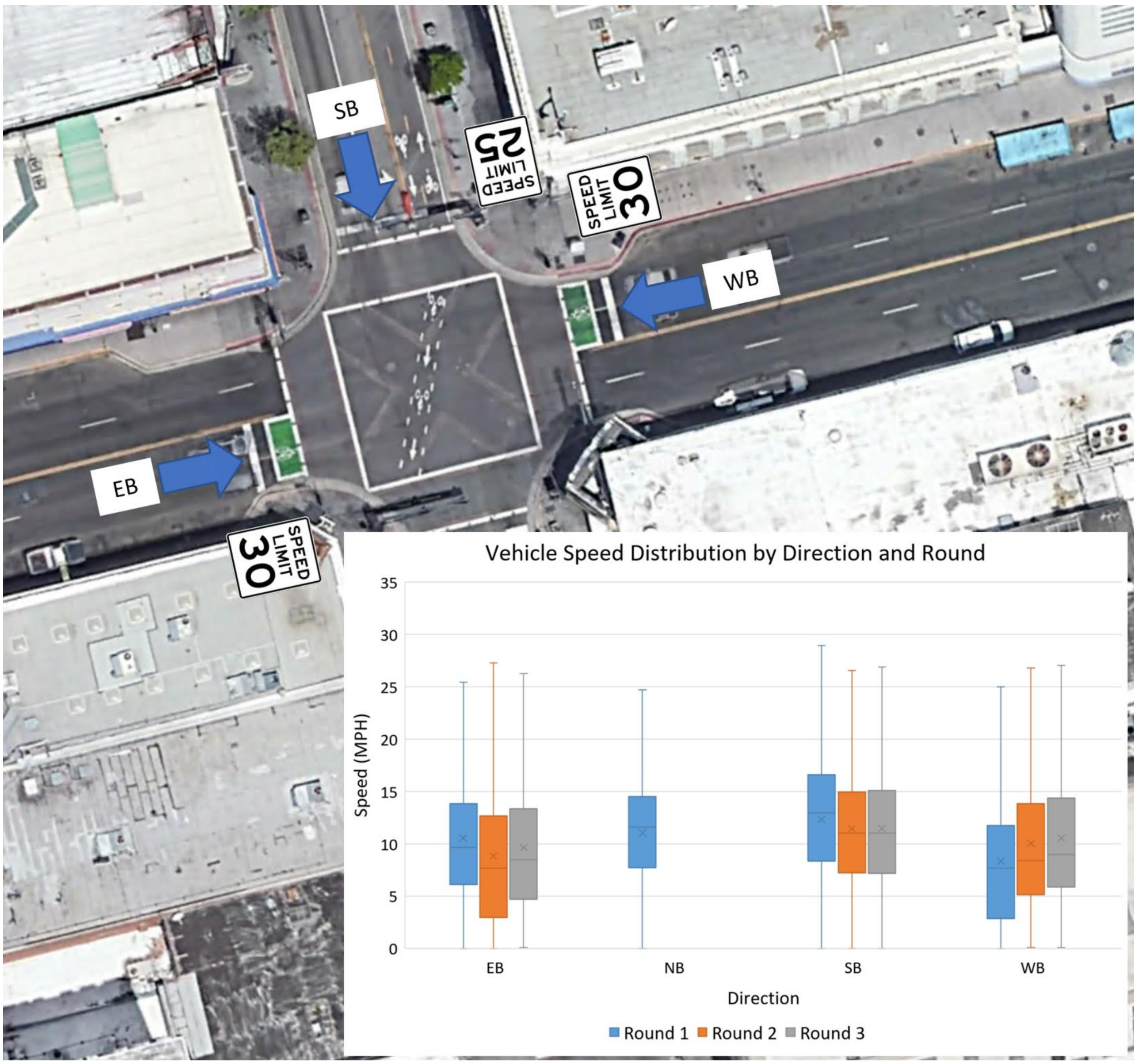


Figure 66 Virginia St and 2nd St vehicle speeds

2.7.4 Red-Light Running

The red-light running at the Virginia St and 2nd St intersection are analyzed. The through and left turn vehicles detected past the stop bar over a speed of 10 MPH going in the correct direction during the red-interval for their respective direction and movement are flagged as red-light running events. Figure 67 shows the ring-and-barrier diagram of the intersection, which changed after round 1 to accommodate the cycle track. The micromobility phase ran only with north-south pedestrians and do not come into conflict with vehicle, unless during red-light running events. Figure 68 and Figure 69 shows the frequency of red-light running events based on the total and after red clearance, respectively. Figure 70 and Figure 71 shows the rate of red-light running events based on the total and after red clearance, respectively. The micromobility red-light running events primarily occurred in the southbound direction, which was highest during round 2 and lowest during round 1. The total frequency trends were similar to the after red clearance and the rates.

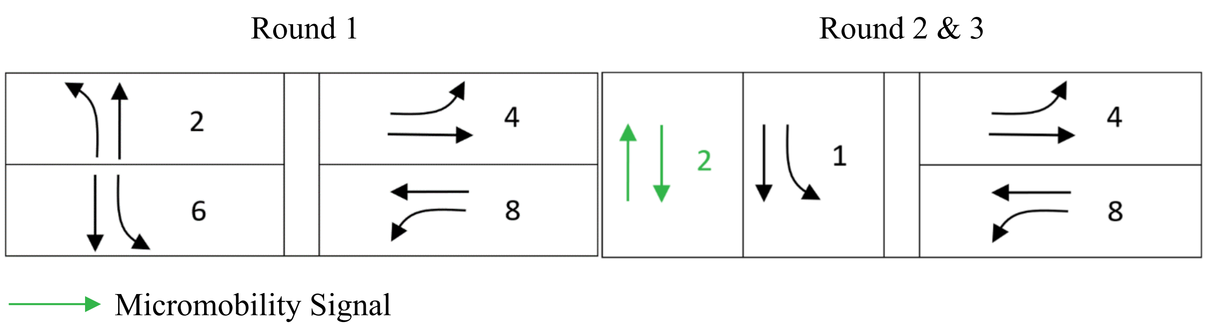


Figure 67 Virginia St and 2nd St ring-and-barrier diagrams

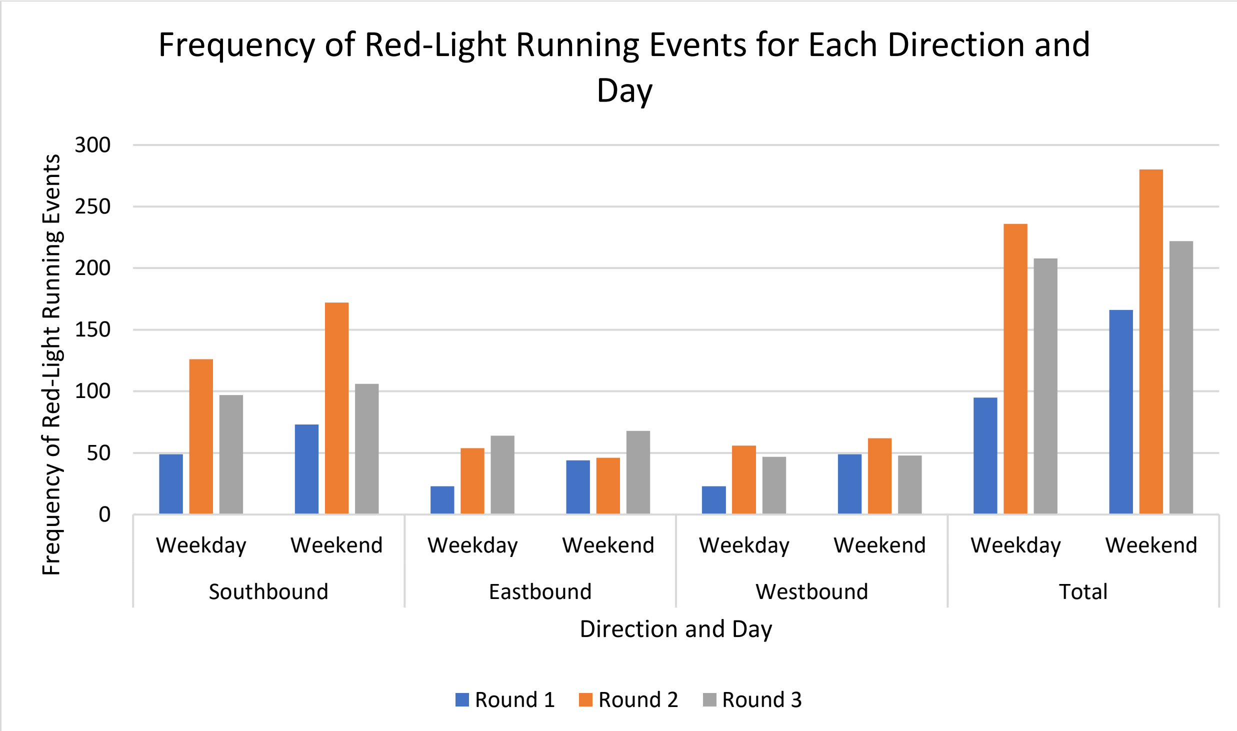


Figure 68 Virginia St and 2nd St frequency of vehicle red-light running events

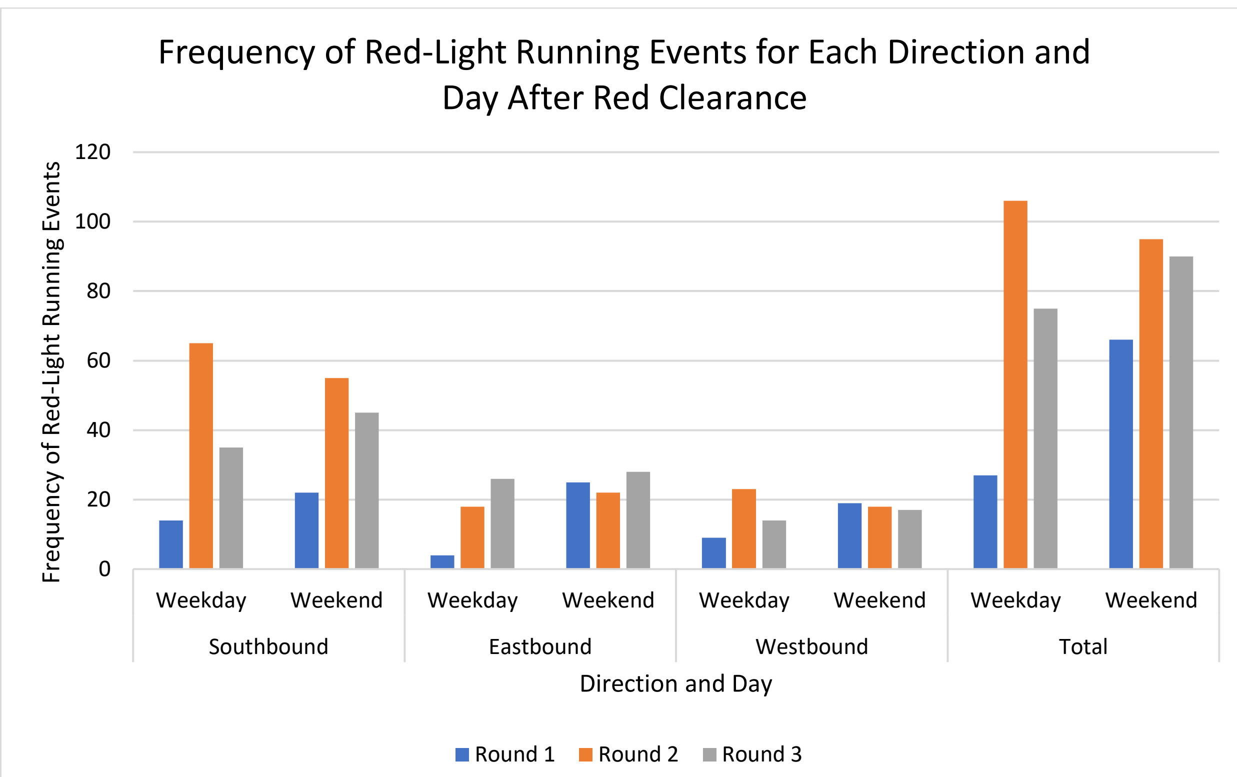


Figure 69 Virginia St and 2nd St frequency of vehicle red-light running events after red clearance

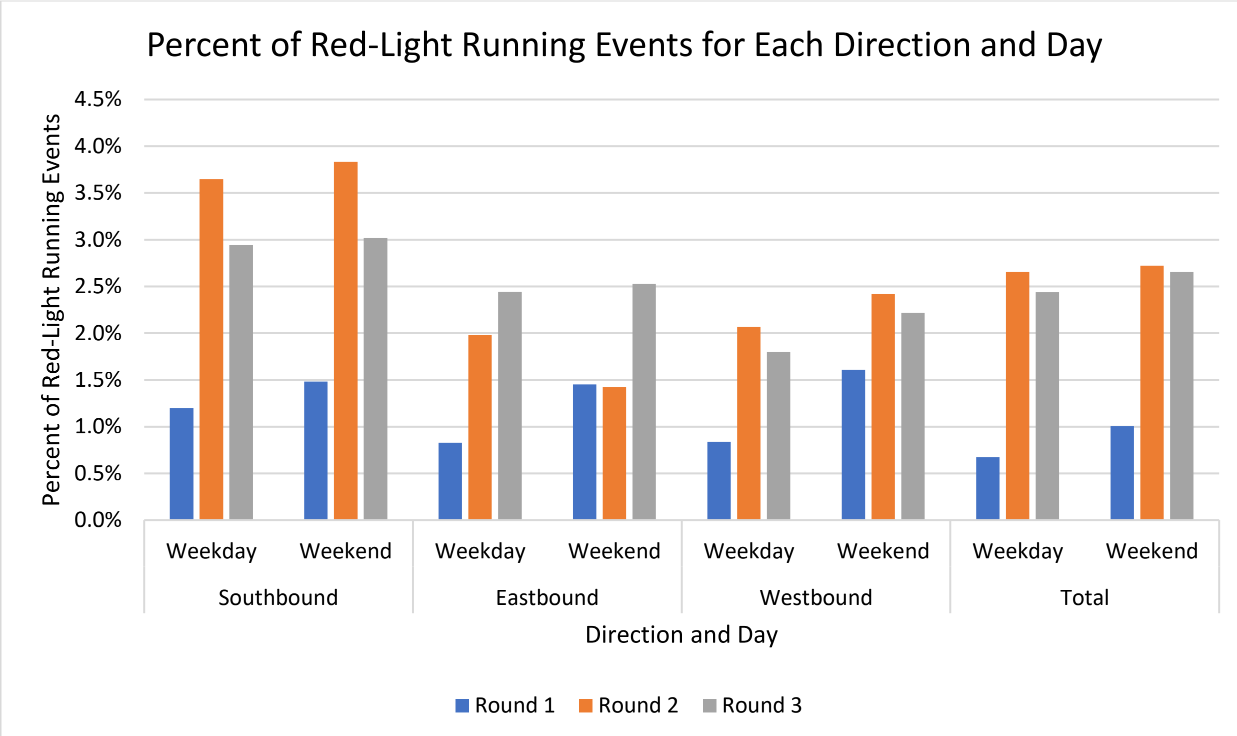


Figure 70 Virginia St and 2nd St percent of vehicle red-light running events

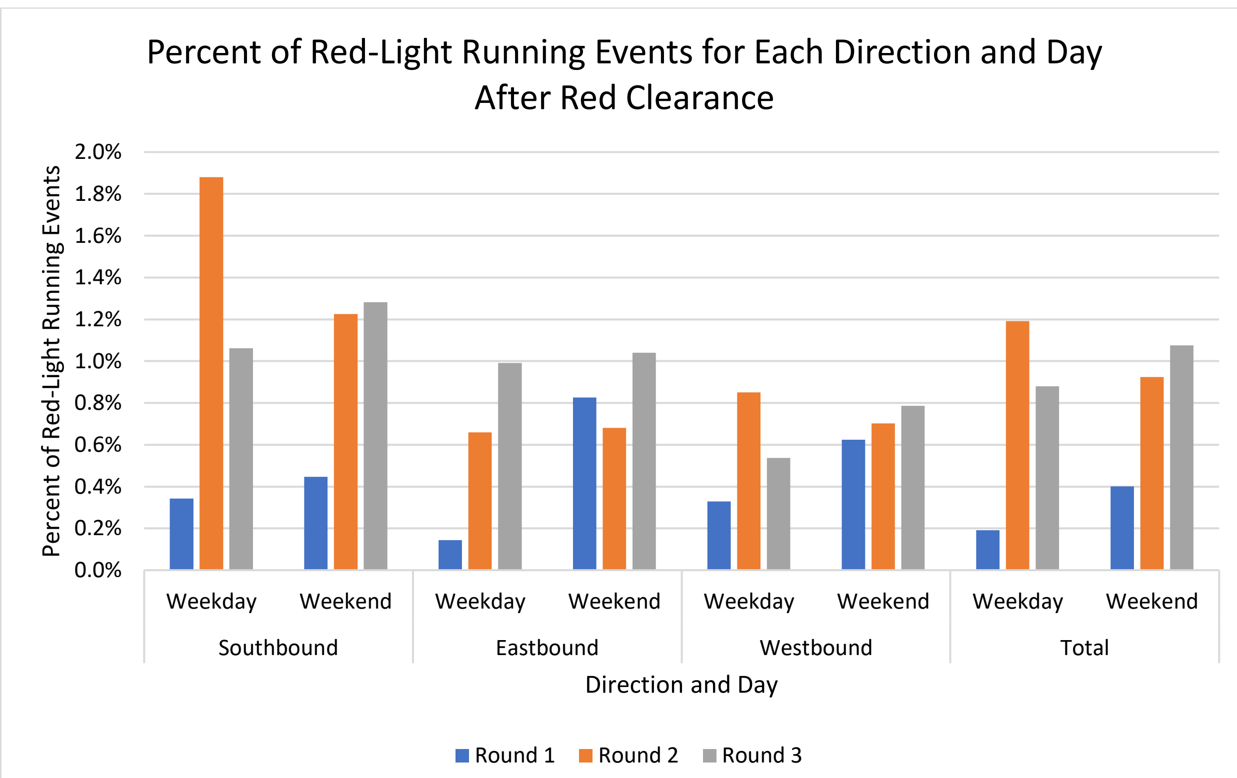


Figure 71 Virginia St and 2nd St percent of vehicle red-light running events after red clearance

Figure 72 and Figure 73 shows the frequency and rate of micromobility red-light running events, respectively. The micromobility phase ran only with north-south pedestrians and do not come into conflict with vehicle, unless during red-light running events. There was little difference in the frequency and rate of micromobility red-light running events between round 2 and round 3. The frequency and rate of red-light running events were slightly higher on the cycle track side in the southbound direction, with rates as high as 50 percent.

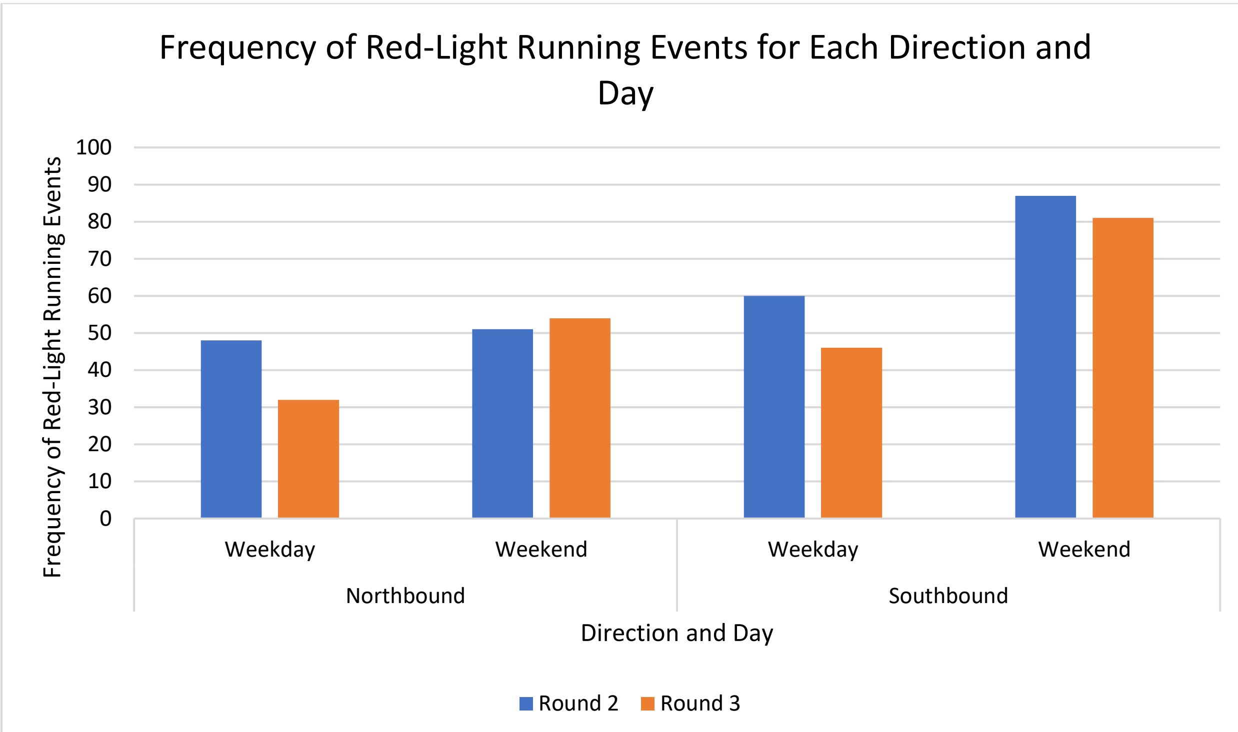


Figure 72 Virginia St and 2nd St frequency of micromobility red-light running events

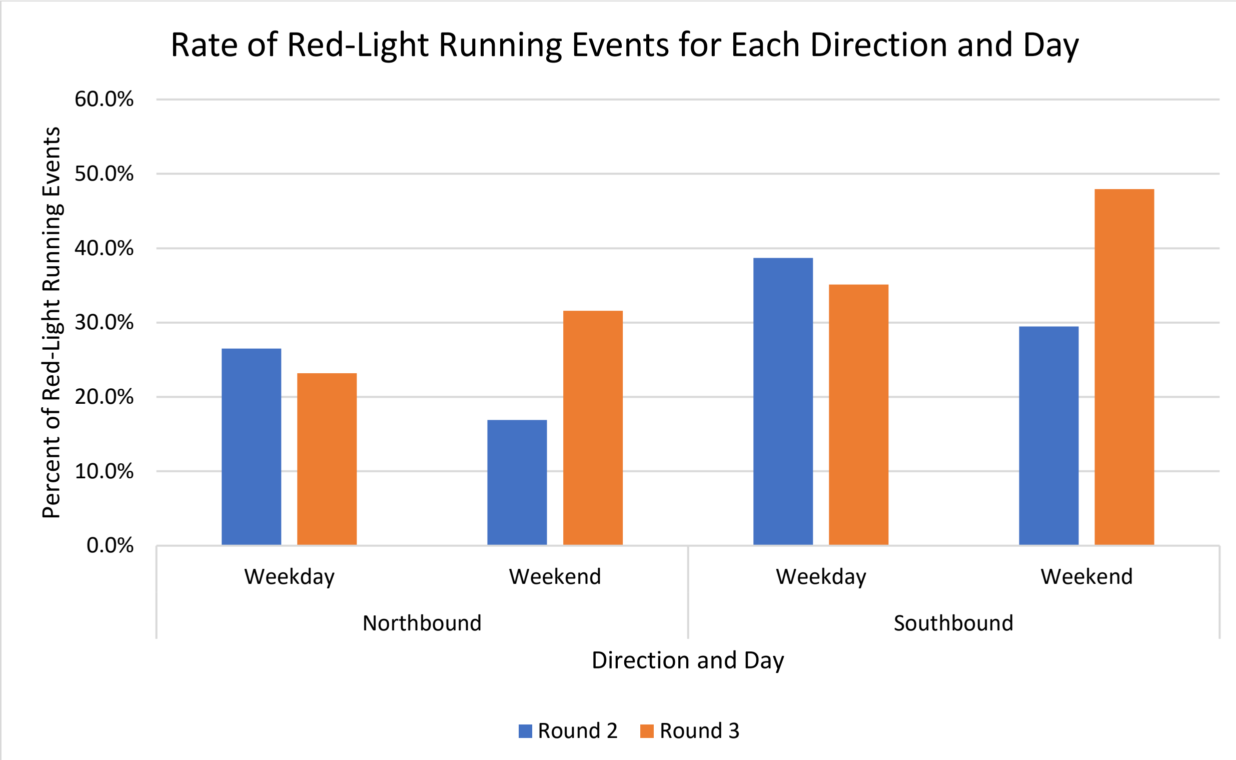


Figure 73 Virginia St and 2nd St percent of micromobility red-light running events

2.7.5 Conflicts

The conflicts between road users at the Virginia St and 2nd St intersection is analyzed. Figure 74 illustrates the conflicts by showing a map of each conflict's location within the site, along with the conflict frequency and severity in PET. Vehicle-to-vehicle decreased significantly between round 1 and 2. This was primarily because of the change from two-way to one-way along Virginia St, which reduces the number of conflict points between vehicles. Vehicle-to-bicycle conflicts remained relatively steady while vehicle-to-scooter and vehicle-to-pedestrian conflicts decreased. The average PET for each conflict type did not change significantly. Figure 74 shows that the majority of vehicle-to-pedestrian conflicts were occurring at the west and south crosswalks.

Table 32 shows the conflict rate, which normalizes the number of conflicts by the volumes of the most vulnerable road user. The conflict rate shows decreasing trends for all conflict types and a decrease in the overall conflict rate. Figure 75 shows the micromobility-to-pedestrian conflicts, which increase each round and tend to occur at the Virginia St crosswalk, especially at the cycle track/crosswalk conflict point. The conflict rate in conflicts per 100 pedestrians for round 1, 2, and 3 are 0.21, 0.48, and 0.46, respectively.

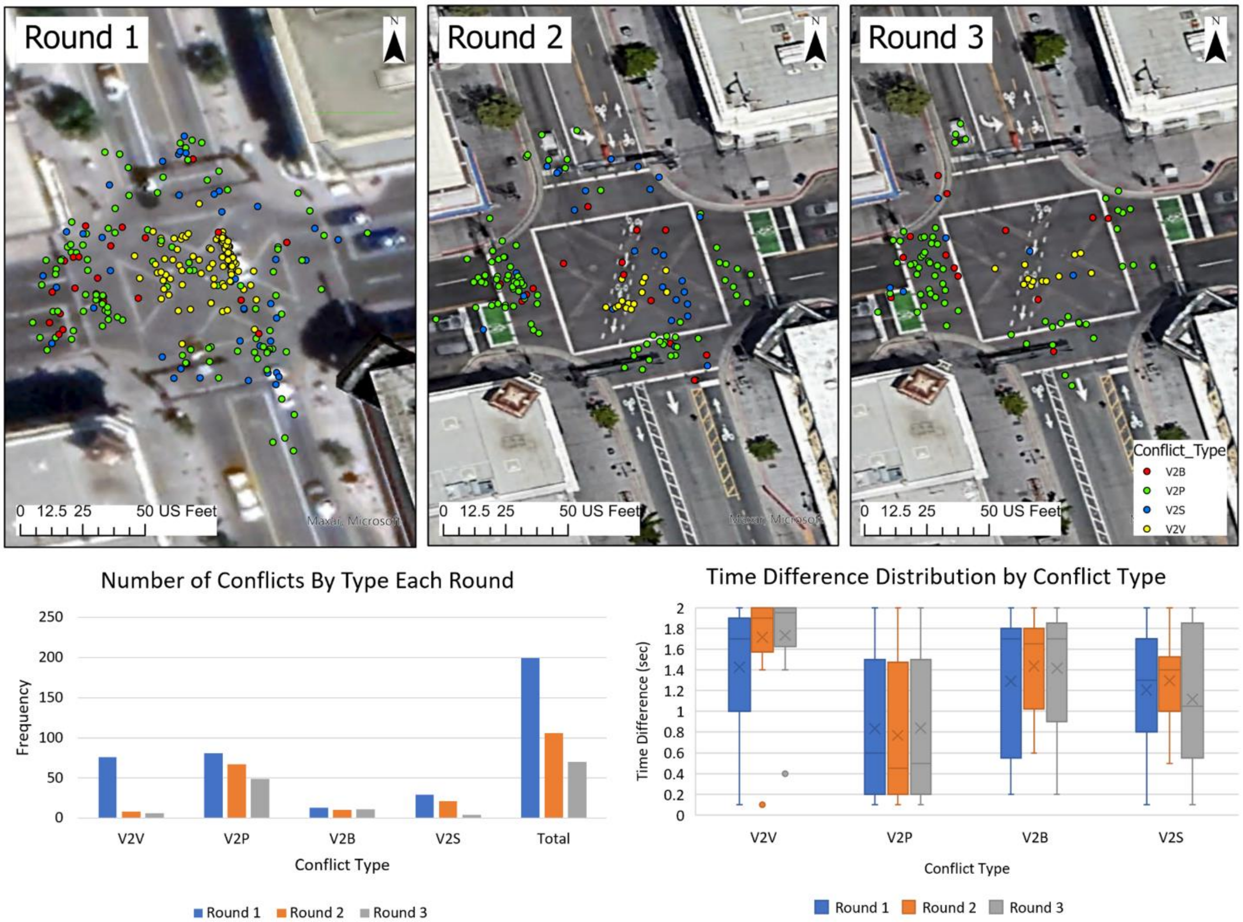


Figure 74 Virginia St and 2nd St conflict locations, frequencies, and severities

Table 32 Virginia St and 2nd St conflict rates

Round	Vehicle-to-vehicle conflicts per 100 vehicles	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
1	0.25	1.33	3.63	5.11	0.53
2	0.04	0.91	1.83	1.59	0.37
3	0.04	0.71	1.69	0.45	0.28

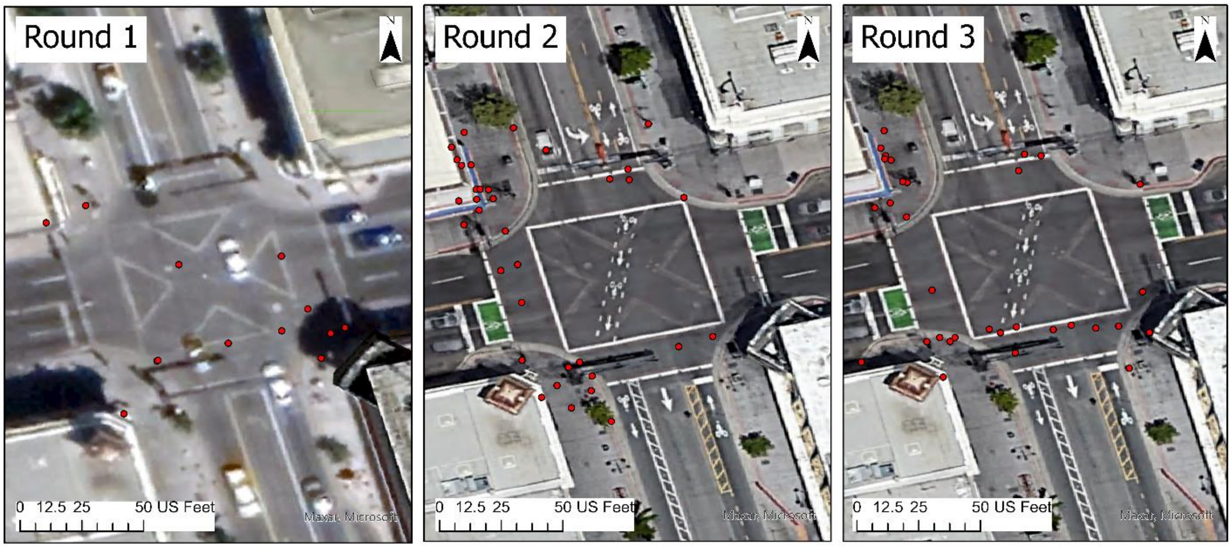


Figure 75 Virginia and 2nd St micromobility-to-pedestrian conflicts

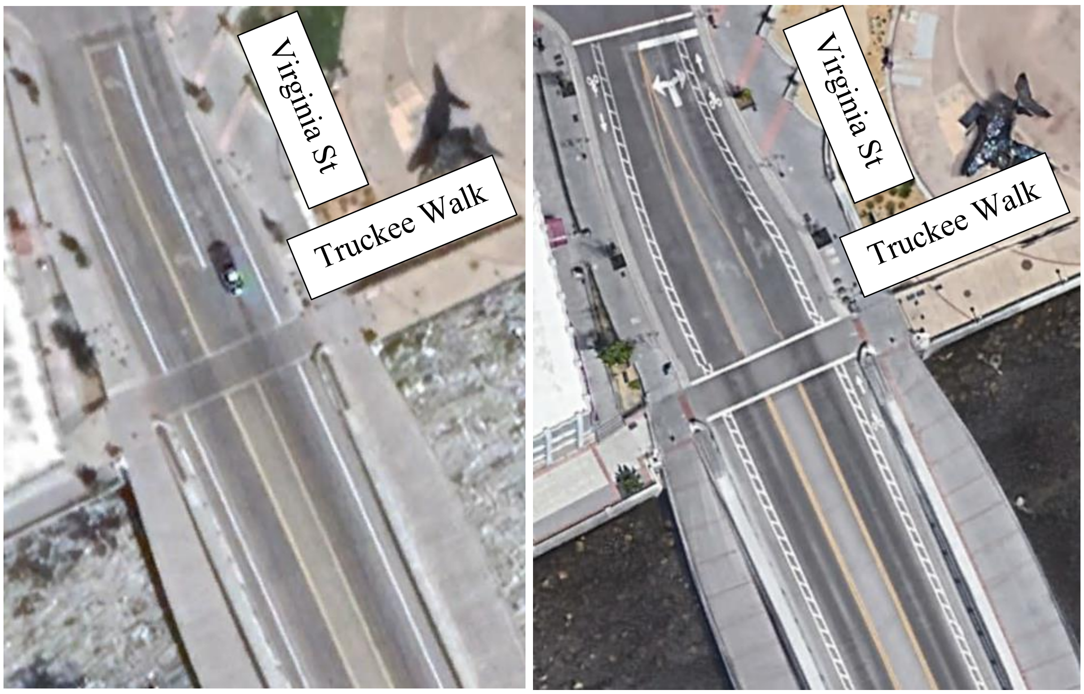
2.7.6 Summary

The overall findings of the Virginia and 2nd St intersection analysis is summarized. Overall, vehicle volumes decreased with the new infrastructure while the pedestrian and micromobility volumes increased. Upon the implementation of the new infrastructure, both bicyclists and scooters migrated to using the cycle track and bike lanes in favor of the roadway and sidewalks.

There are no speeding issues and speeds have decreased significantly between round 1 and round 2 in the southbound direction. The red-light running events primarily occurred in the southbound direction, which was highest during round 2 and lowest during round 1. There was little difference in the frequency and rate of micromobility red-light running events between round 2 and round 3. The micromobility red-light running events rates ranged anywhere from 25 to 50 percent. Further, micromobility users were to be more likely to run the red-light on the north leg where there is the two-way cycle track. Vehicle-to-vehicle conflicts have decreased significantly between round 1 and 2. The vehicle-to-pedestrian conflicts made up the highest frequency of total conflicts, however, the frequency and rates show a decreasing trend. Further, a majority of these conflicts occurred at the west crosswalk where vehicle speeds are low. Vehicle to micromobility user conflicts were relatively low, with a decreasing trend for vehicle-to-scooters. The conflict rate over the three rounds shows a decreasing trend for each conflict type, meaning safety improved.

2.8 VIRGINIA ST AND TRUCKEE RIVER WALK

The Virginia St and Truckee River Walk is a mid-block crosswalk along the Truckee River just to the south. Therefore, there was large number of crossing vulnerable road users. In round 1 conditions, there was one through lane in each direction with a center median. In the round 2 and round 3 conditions, protected bike lanes with striped buffers were added. This is also where Virginia St transitioned from one-way back to two-way. Figure 76 (a) shows the site before changes were made and Figure 76 (b) shows the site after changes were made.



(a) **(b)**

Figure 76 Virginia St and Truckee River Walk before-after infrastructure changes

2.8.1 Counts

The counts for the different road users at Virginia St and the Truckee River Walk are analyzed. Overall, the vehicle volumes decreased each round, as shown in Table 33. The pedestrian volumes have increased after round 1, particularly the weekend, as shown in Table 34. Bicycle volumes were highest during round 2, as shown in Table 35. Scooter volumes also increased after the implementation of the new infrastructure, with the highest daily volume occurring during round 2 on the weekend.

Table 33 Virginia St and Truckee River Walk daily vehicle volumes

Round	Weekday Vehicles	Weekend Vehicles
1	9144	9521
2	6685	8072
3	5937	6913

Table 34 Virginia St and Truckee River Walk daily pedestrian volumes

Round	Weekday Pedestrian	Weekend Pedestrian
1	1077	798
2	1606	1866
3	1584	1734

Table 35 Virginia St and Truckee River Walk daily micromobility volumes

Round	Weekday Bicycle	Weekend Bicycle	Weekday Scooter	Weekend Scooter
1	46	41	209	132
2	151	198	541	958
3	90	165	612	746

2.8.2 Micromobility Behavior

The behavior and compliance of the micromobility road users at Virginia St and the Truckee River Walk is analyzed. Figure 77 and Figure 78 shows the right-of-way utilization of the micromobility road users during a given weekday and weekend day, respectively. In other words, the extent to which micromobility road users use the roadway, bike lane, cycle track, or the sidewalks. “CT/BL” refers to the cycle track and bicycle lanes. For this site, protected bike lanes were installed. The Truckee River Walk volumes are not considered in this section.

Overall, bicycle and scooter volumes on the sidewalk and roadways decreased as the bike lanes were installed. Scooter roadway volumes decreases significantly after round 1, with about ten percent utilization, however, bicycles still utilized the roadway. Overall, the bike lanes encouraged the micromobility road users to utilize the sidewalk and roadways less.

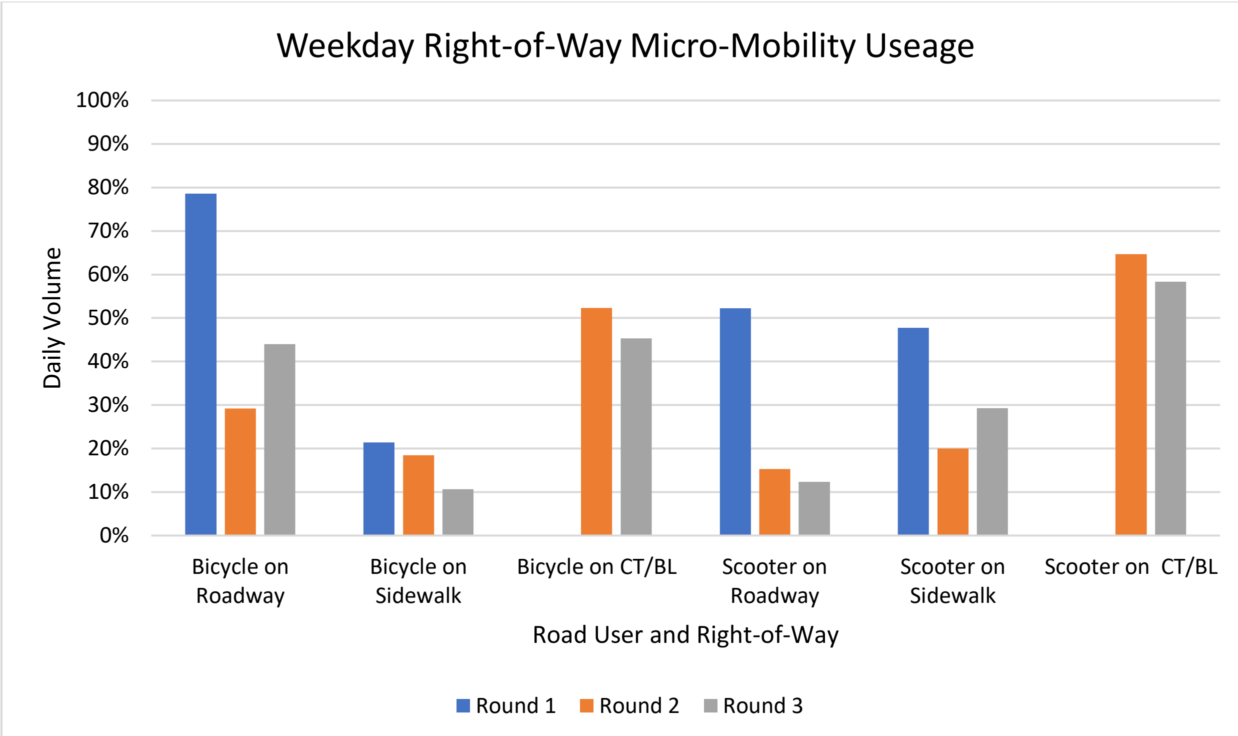


Figure 77 Virginia St and Truckee River Walk weekday right-of-way micromobility usage

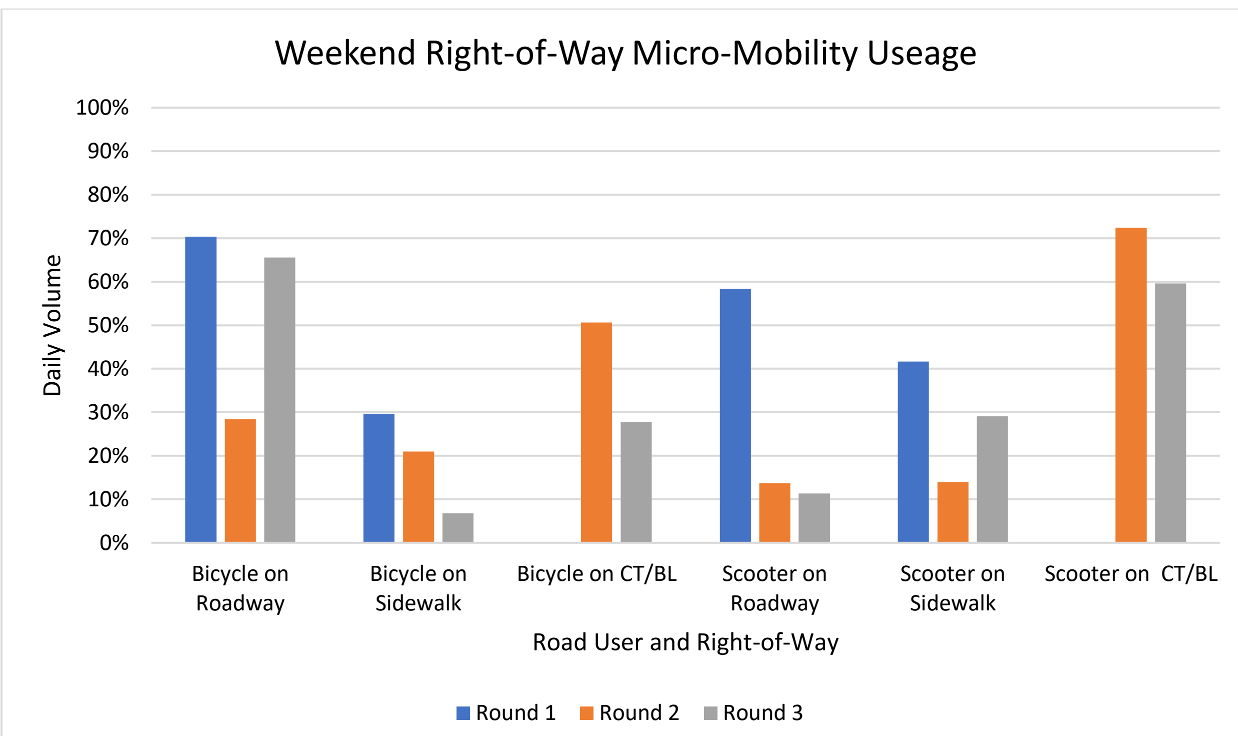


Figure 78 Virginia St and Truckee River Walk weekend right-of-way micromobility usage

2.8.3 Speed

The vehicle speeds at Virginia St and the Truckee River Walk are analyzed. Vehicle speeds are extracted at the approach of each leg. The through speeds of each individual vehicle is extracted and the distribution of the speed is shown in Figure 79 for each round and each direction. The zones are places just before the crosswalk in each direction. The Xs mark the mean, the horizontal lines mark the median, and the lower and upper boundaries of the box represent the 25th and 75 percentile speeds, respectively. The speed limit is 25 MPH. Overall, a majority of vehicles were under the speed limit with 75-percentile speeds being less than 25 MPH for each direction, and round. Furthermore, speeds decreased in the after condition for each direction.

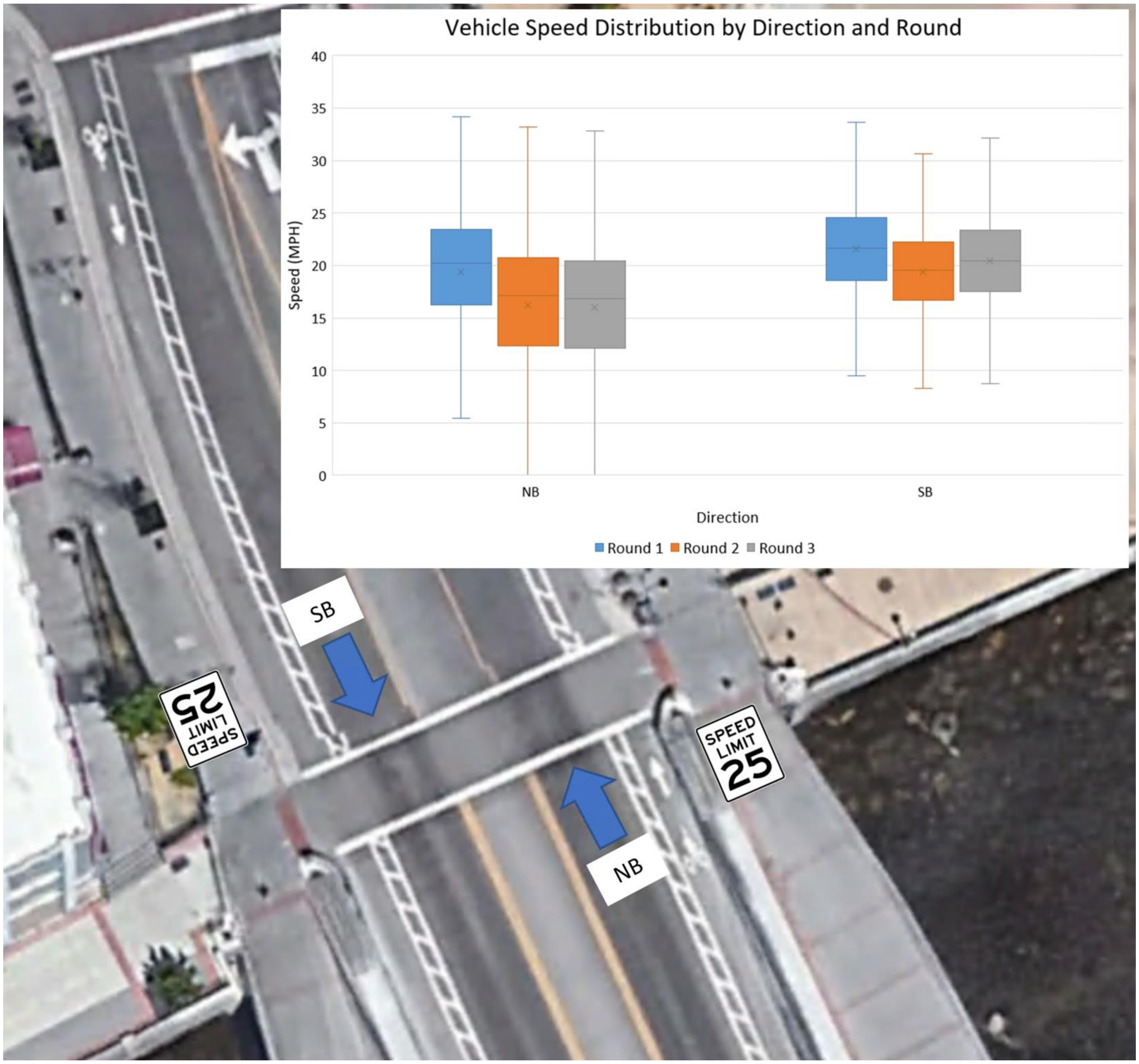


Figure 79 Virginia St and Truckee River Walk vehicle speeds

2.8.4 Conflicts

The conflicts between road users at Virginia St and the Truckee River Walk is analyzed. Figure 80 illustrates the conflicts by showing a map of each conflict's location within the site, along with the conflict frequency and severity in PET. There were no vehicle-to-vehicle conflicts with critical conflict angles, therefore, they are not considered. Vehicle-to-pedestrian and vehicle-to-scooter conflicts remained steady across the three rounds, but vehicle-to-bicycle conflicts decreased between round 1 and 2. The conflict rates shown in Table 36 generally match this trend. Overall, the frequency of conflicts at this crossing location were generally lower and the number of conflicts reduced by 50 percent between round 1 and 2 and remained that way in round 3. Lastly, the locations of conflicts appear to be more concentrated around the crosswalk during round 2 and round 3.

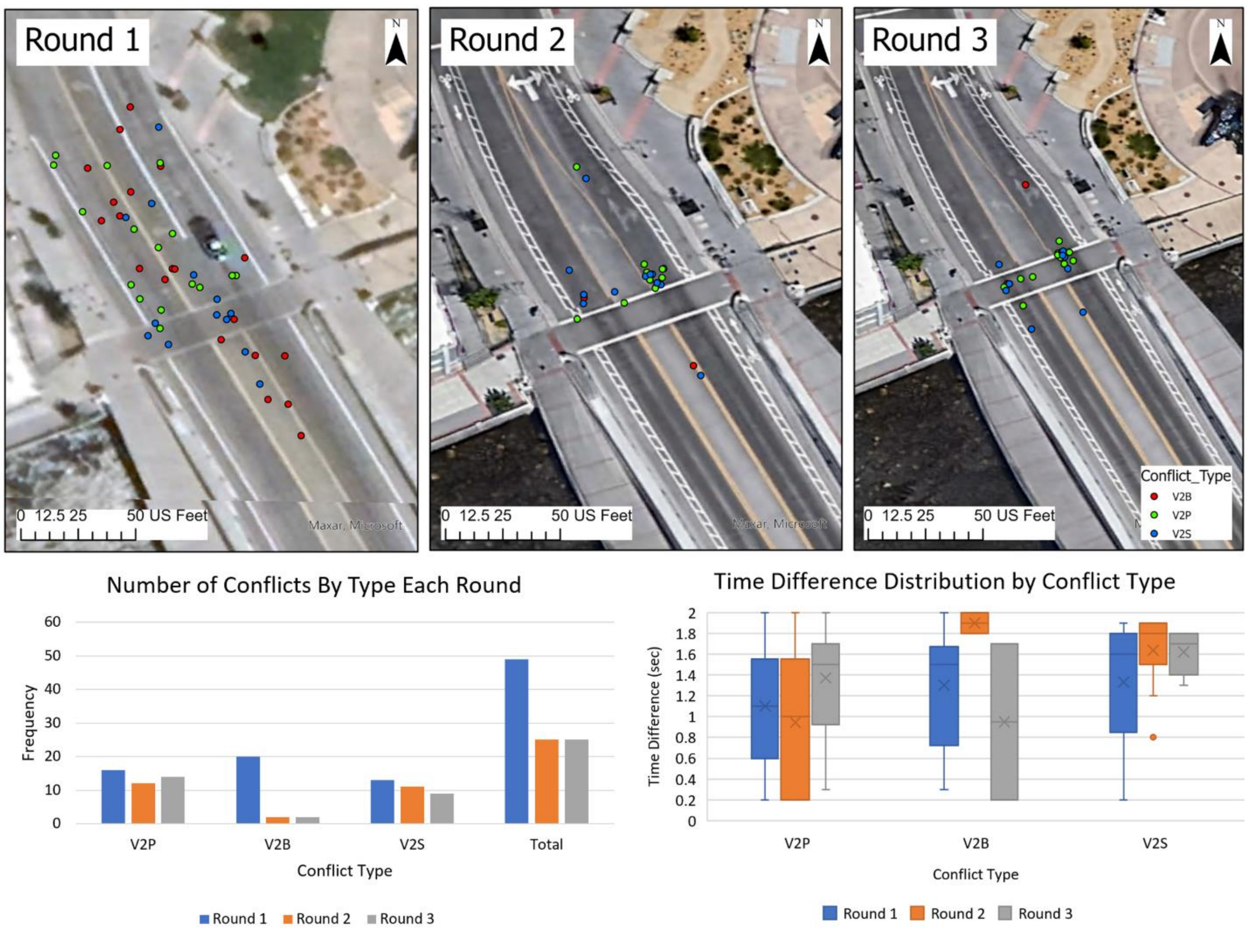


Figure 80 Virginia St and Truckee River Walk conflict locations, frequencies, and severities

Table 36 Virginia St and Truckee River Walk conflict rates

Round	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
1	0.85	22.99	3.81	0.23
2	0.35	0.57	0.73	0.12
3	0.42	0.78	0.66	0.14

2.8.5 Summary

The overall findings of Virginia St and the Truckee Riverwalk analysis is summarized. Overall, vehicle volumes decreased with the new infrastructure while the pedestrian and micromobility volumes increased. Overall, the bike lanes encouraged the micromobility road users to utilize the sidewalk and roadways less.

There were no speeding issues and speeds decreased between each round. The conflicts at this intersection were low and overall conflict frequencies decreased by half from round 1 to round 2.

2.9 VIRGINIA ST AND MILL ST

The Virginia St and Mill St has a crosswalk crossing Virginia St and one crossing Mill St. Mill St is one-way on the eastbound direction. There is one through lane in each approach with a left turn pocket in the southbound approach. In the round 2 and 3 conditions, protected bike lanes with striped buffers were added. Figure 81 (a) shows the intersection before changes were made and Figure 81 (b) shows the intersection after changes were made.

(a) (b)

Figure 81 Virginia St and Mill St before-after infrastructure changes

2.9.1 Counts

The counts for the different road users at the Virginia St and Mill St intersection is analyzed. Overall, the vehicle volumes decreased between round 1 and 2, but increased slightly between round 2 and 3, as shown in Table 37. The pedestrian volumes increased after round 1, particularly on the weekend, as shown in Table 38. Bicycle and scooter volumes increased over the three rounds with large scooter volumes in round 2 and round 3 over the weekend, as shown in Table 39.

Table 37 Virginia St and Mill St daily vehicle volumes

Round	Weekday Vehicles	Weekend Vehicles
1	9326	11696
2	6902	8822
3	7229	9645

Table 38 Virginia St and Mill St daily pedestrian volumes

Round	Weekday Pedestrian	Weekend Pedestrian
1	774	701
2	1123	1323
3	1069	1013

Table 39 Virginia St and Mill St daily micromobility volumes

Round	Weekday Bicycle	Weekend Bicycle	Weekday Scooter	Weekend Scooter
1	41	53	172	92
2	161	199	345	801
3	178	228	268	640

2.9.2 Micromobility Behavior

The behavior and compliance of the micromobility road users at the Virginia St and Mill St intersection is analyzed. Figure 82 and Figure 83 shows the right-of-way utilization of the micromobility road users during a given weekday and weekend day, respectively. In other words, the extent to which micromobility road users use the roadway, bike lane, cycle track, or the sidewalks. "CT/BL" refers to the cycle track and bicycle lanes. For this site, protected bike lanes were installed along Virginia St and therefore only the north-south approaches are considered.

Overall, micromobility road users favored the bike lanes in round 2 and round 3, especially for scooters. Usage of roadways and especially sidewalks decreased between round 1 and round 2.

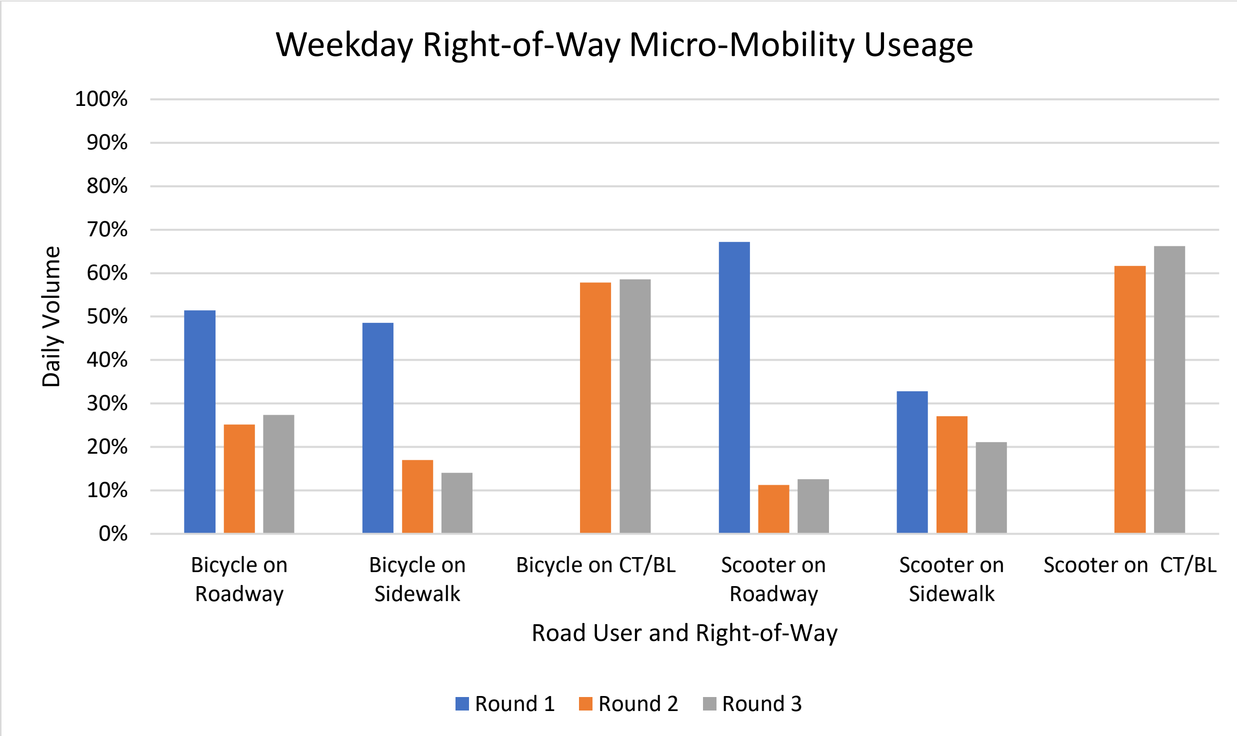


Figure 82 Virginia St and Mill St weekday right-of-way micromobility usage

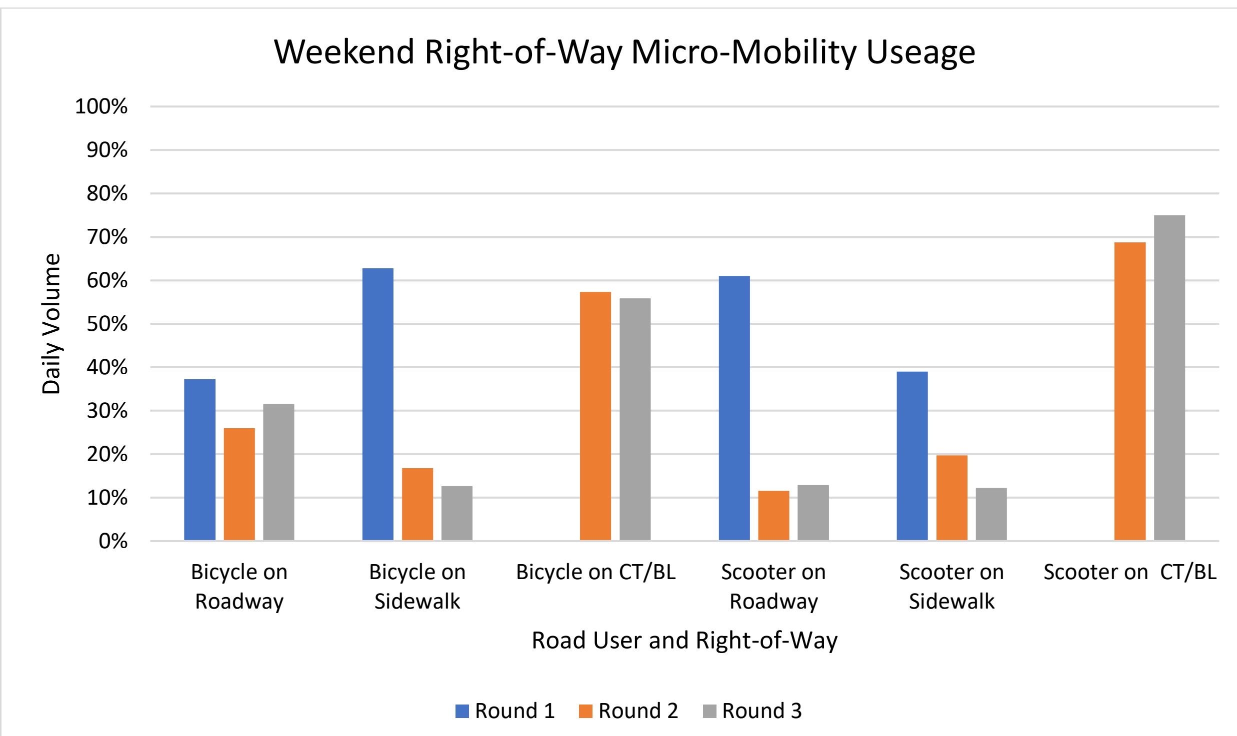


Figure 83 Virginia St and Mill St weekend right-of-way micromobility usage

2.9.3 Speed

The vehicle speeds at the Virginia St and Mill St intersection are analyzed. Vehicle speeds are extracted at the approach of each leg. The through speeds of each individual vehicle is extracted and the distribution of the speed is shown in Figure 84 for each round and each direction. The southbound detection zone is placed just before the crosswalk, and the northbound detection zone is placed just before the yield striping. The X's marks the mean, the horizontal lines mark the median, and the lower and upper boundaries of the box represent the 25th and 75 percentile speeds, respectively. The speed limit is 25 MPH. Overall, a majority of vehicles were under the speed limit with 75-percentile speeds being less than 25 MPH for each direction, and round. Furthermore, speeds decreased in the after condition for each direction, especially in the northbound direction.

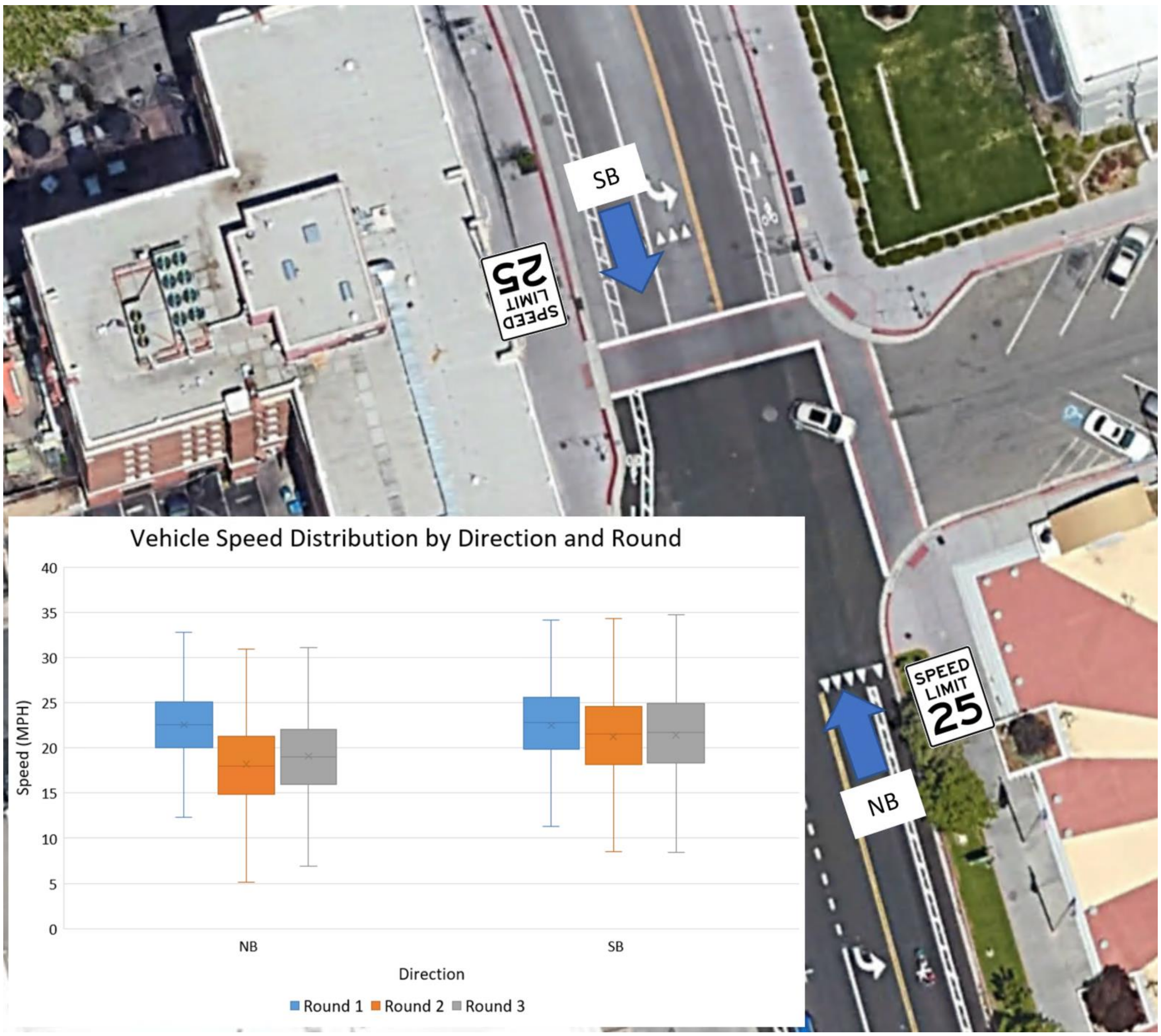


Figure 84 Virginia St and Mill St vehicle speeds

2.9.4 Conflicts

The conflicts between road users at the Virginia St and Mill St intersection is analyzed. Figure 85 illustrates the conflicts by showing a map of each conflict's location within the site, along with the conflict frequency and severity in PET. Vehicle-to-vehicle conflicts were low at this intersection and are therefore not included. Vehicle-to-pedestrian and vehicle-to-bicycle conflicts reduced significantly between round 1 and round 2 while vehicle-to-scooter conflicts were very low and remained the same over the three rounds. The conflict rates shown in Table 40 generally match this trend. Overall, the frequency of conflicts at this intersection were lower and the number of conflicts reduced by over 50 percent between round 1 and 2 and remained that way in round 3. Further, the average PET values increased each round.

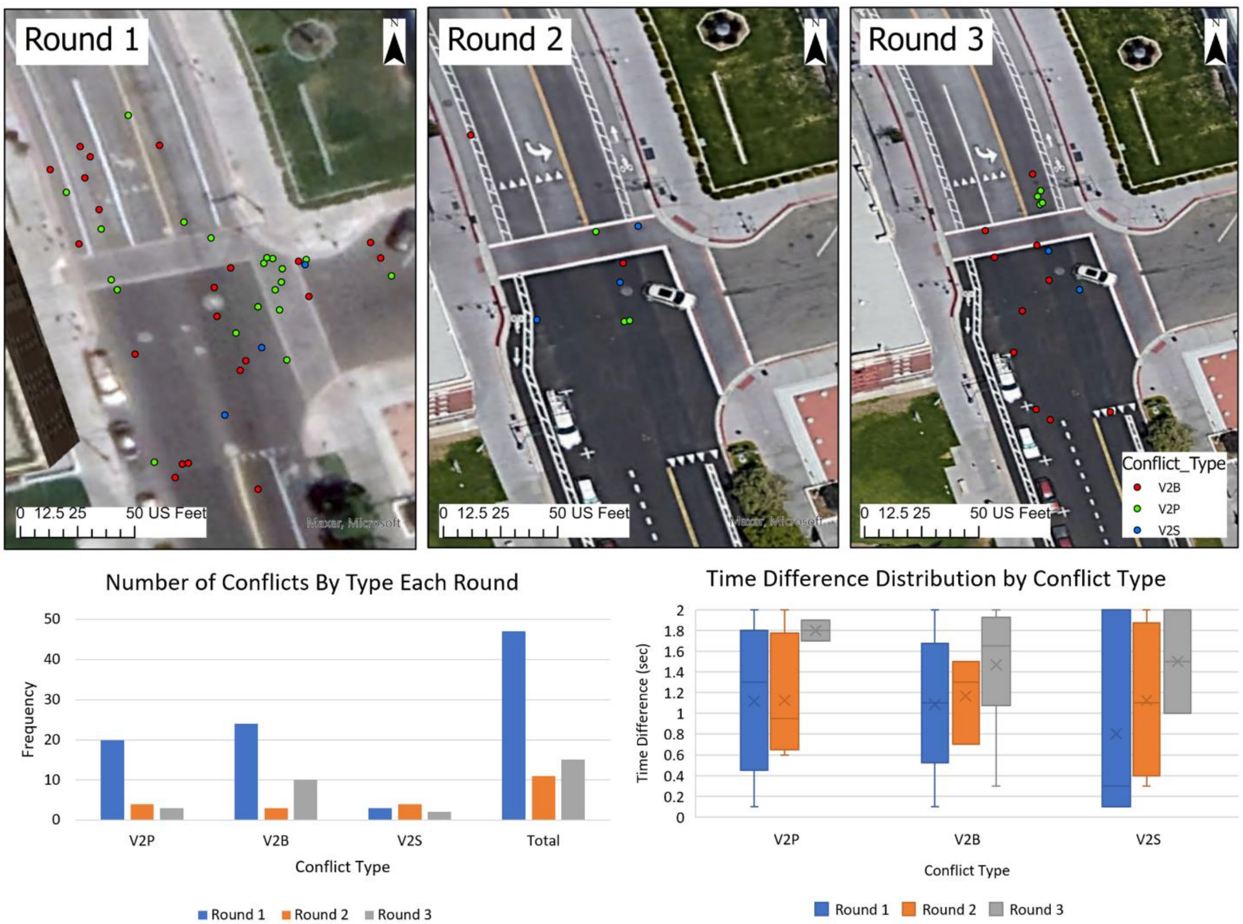


Figure 85 Virginia St and Mill St conflict locations, frequencies, and severities

Table 40 Virginia St and Mill St conflict rates

Round	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
1	1.36	25.53	1.14	0.21
2	0.16	0.83	0.35	0.06
3	0.14	2.46	0.22	0.07

2.9.5 Summary

The overall findings of the Virginia St and Mill St intersection analysis is summarized. Overall, vehicle volumes decreased with the new infrastructure while the pedestrian and micromobility volumes increased. The bike lanes were more heavily utilized at this intersection in round 2 and 3, especially for scooters.

There were no speeding issues and speeds have decreased between each round. The conflicts at this intersection are low and overall conflict frequencies decreased by over half from round 1 to round 2.

3 SUMMARY

The summarized data across the nine sites and three rounds is provided. The summary includes the multi-modal daily counts, the micromobility right-of-way utilization, speed, and conflicts.

3.1 COUNTS

The summarized multi-modal counts are outlined. Table 41 and Figure 86 shows the southbound vehicle volumes on Virginia St from 5th to 2nd St for each round. Table 42 tabulates the daily volumes of each road user at each site for each round. Figure 87, Figure 88, Figure 89, and Figure 90 shows the corresponding bar charts of the daily volumes each site and round for vehicles, pedestrians, bicyclists, and scooters, respectively. The 5th St and Keystone Ave intersection had by far the most vehicle volumes, with the Virginia St and 4th intersection at a distant second. Along 5th St, weekday vehicle volumes were higher; whereas along Virginia St, weekend vehicle volumes were higher. Along 5th St, the vehicle volumes were similar across the rounds, but along Virginia St, the vehicle volumes tended to decrease. Therefore, reducing the number of through lanes along 5th St did not have a significant affect to vehicle volumes; whereas, changing Virginia St from a two-way to a one-way had a significant affect to the vehicle volumes. However, the southbound volumes along Virginia St were more consistent between rounds with a slightly decreasing trend at Commiercial Ave and 2nd St, as shown in Table 41 and Figure 86.

The pedestrian volumes were by far the highest along Virginia St, particularly at 4th St, Commercial Row, and 2nd St. Pedestrian volumes were typically higher on the weekend. The pedestrian volumes typically increased after the implementation of the new infrastructure in round 2 and round 3. Bicycle volumes were also highest along Virginia St; however, there were hot spots during round 3 on the weekend at 5th St, Commercial Row, and 2nd St. Along Virginia St, there was an increasing trend of bicycle volumes across the three rounds. Scooter volumes made up the majority of the micromobility volumes. Scooter volumes increased, especially on the weekends.

Table 41 All sites and rounds daily southbound vehicle volumes

Intersection	Round	Weekday Vehicles	Weekend Vehicles
Virginia St / 5th St	1	3977	3598
	2	3787	4029
	3	3316	4287
Virginia St / 4th St	1	4115	3809
	2	4056	4228
	3	3346	4124
Virginia St \ Commercial Row	1	4359	4701
	2	3579	2767
	3	3430	4046
Virginia St \ 2nd St	1	4093	4920
	2	3456	4489
	3	3297	3512

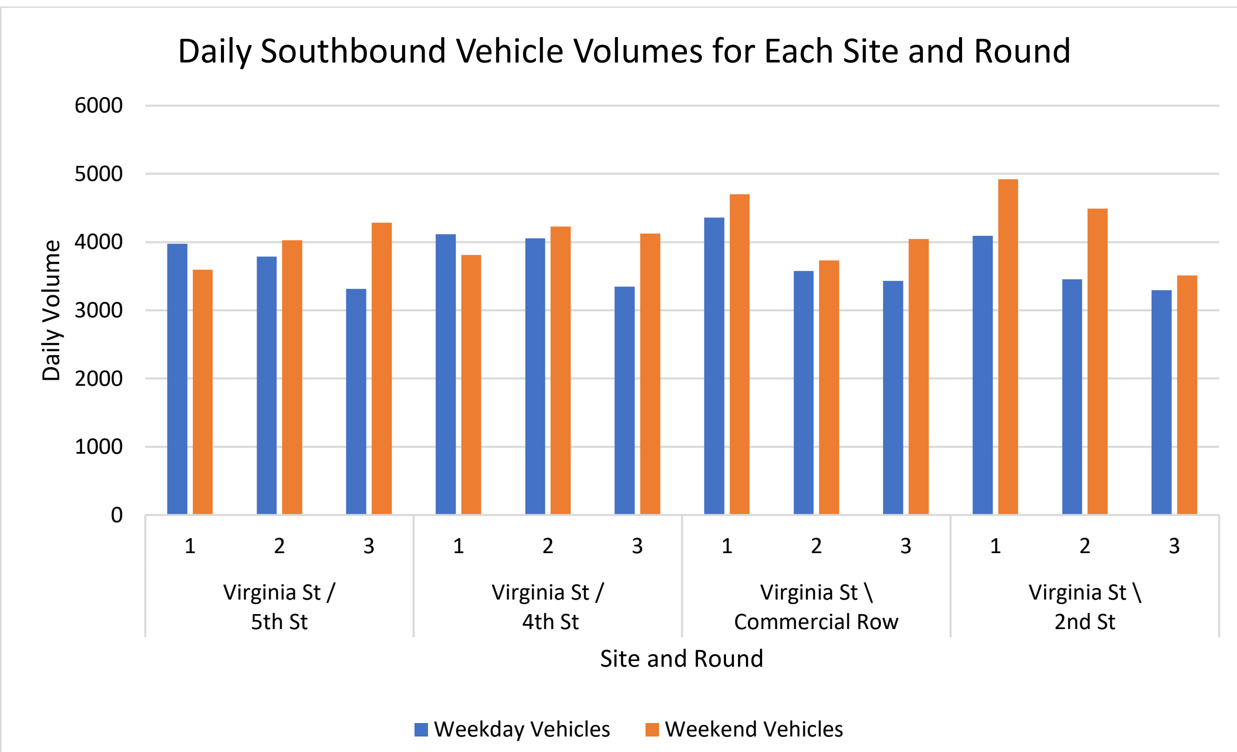


Figure 86 All sites and rounds daily southbound vehicle volumes

Table 42 All sites and rounds daily multi-modal traffic volumes

Intersection	Round	Weekday Vehicles	Weekend Vehicles	Weekday Pedestrian	Weekend Pedestrian	Weekday Bicycle	Weekend Bicycle	Weekday Scooter	Weekend Scooter
5th St / Keystone Ave	1	32985	30752	246	299	47	69	33	48
	2	36542	27631	311	320	93	77	73	58
	3	33097	29871	367	377	80	51	80	79
5th St / Ralston St	1	8309	5432	418	202	92	94	180	143
	2	10771	8524	423	371	163	155	273	278
	3	9410	7113	419	399	171	125	191	182
5th St / Arlington Ave	1	8859	6006	501	470	111	79	114	113
	2	9492	9890	304	444	124	84	110	250
	3	9077	6857	523	477	138	82	148	144
Virginia St / 5th St	1	12220	13724	1452	1430	73	59	132	202
	2	12330	9830	1938	2321	151	163	349	648
	3	9274	12887	1887	2841	121	280	339	624
Virginia St / 4th St	1	17836	17832	1841	1776	62	83	238	259
	2	16308	11424	2273	2732	172	172	490	770
	3	11737	13928	2365	3829	90	176	462	671
Virginia St \ Commercial Row	1	9739	11417	2519	3444	113	165	254	790
	2	3957	3302	3068	4353	108	202	783	1068
	3	4037	4970	3187	3867	217	324	419	758
Virginia St \ 2nd St	1	14004	16426	2596	3509	142	216	172	395
	2	8872	10263	3397	3957	203	343	471	853
	3	8529	8366	3277	3672	292	357	377	519
Virginia St \ Truckee River Walk	1	9144	9521	1077	798	46	41	209	132
	2	6685	8072	1606	1866	151	198	541	958
	3	5937	6913	1584	1734	90	165	612	746
Virginia St \ Mill St	1	9326	11696	774	701	41	53	172	92
	2	6902	8822	1123	1323	161	199	345	801
	3	7229	9645	1069	1013	178	228	268	640

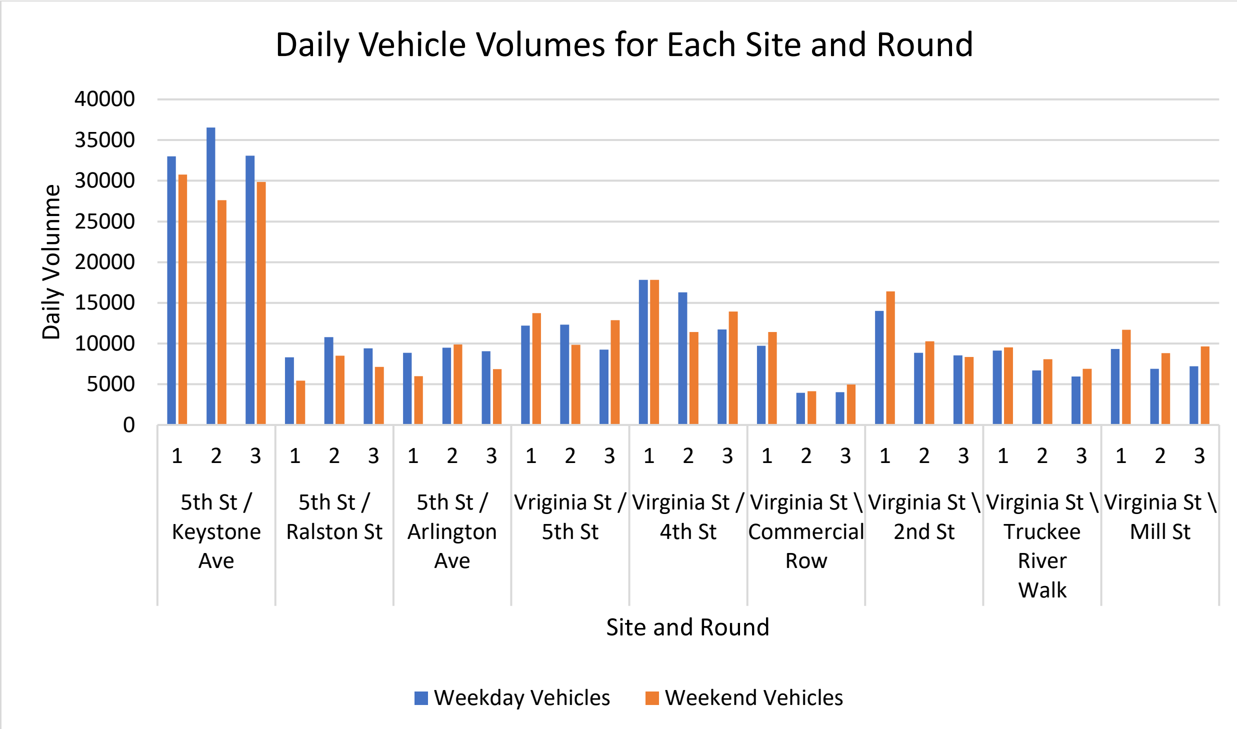


Figure 87 All sites and rounds Daily vehicle volumes

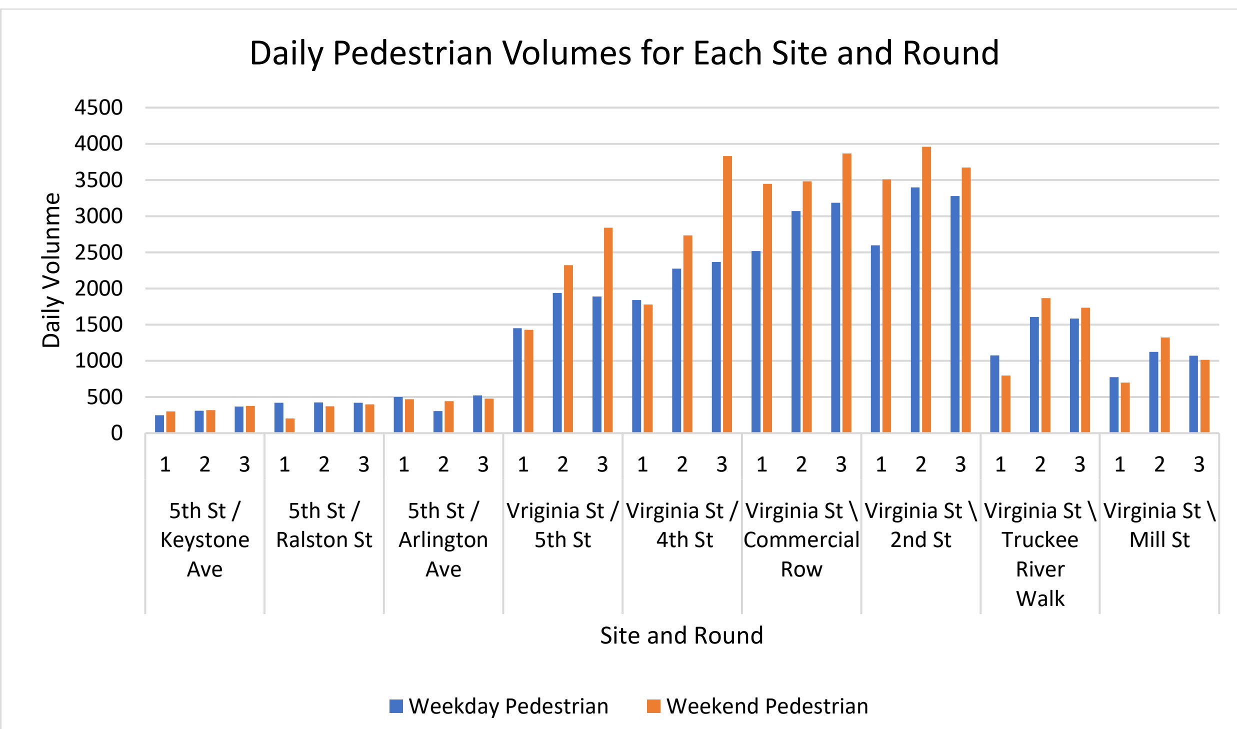


Figure 88 All sites and rounds Daily pedestrian volumes

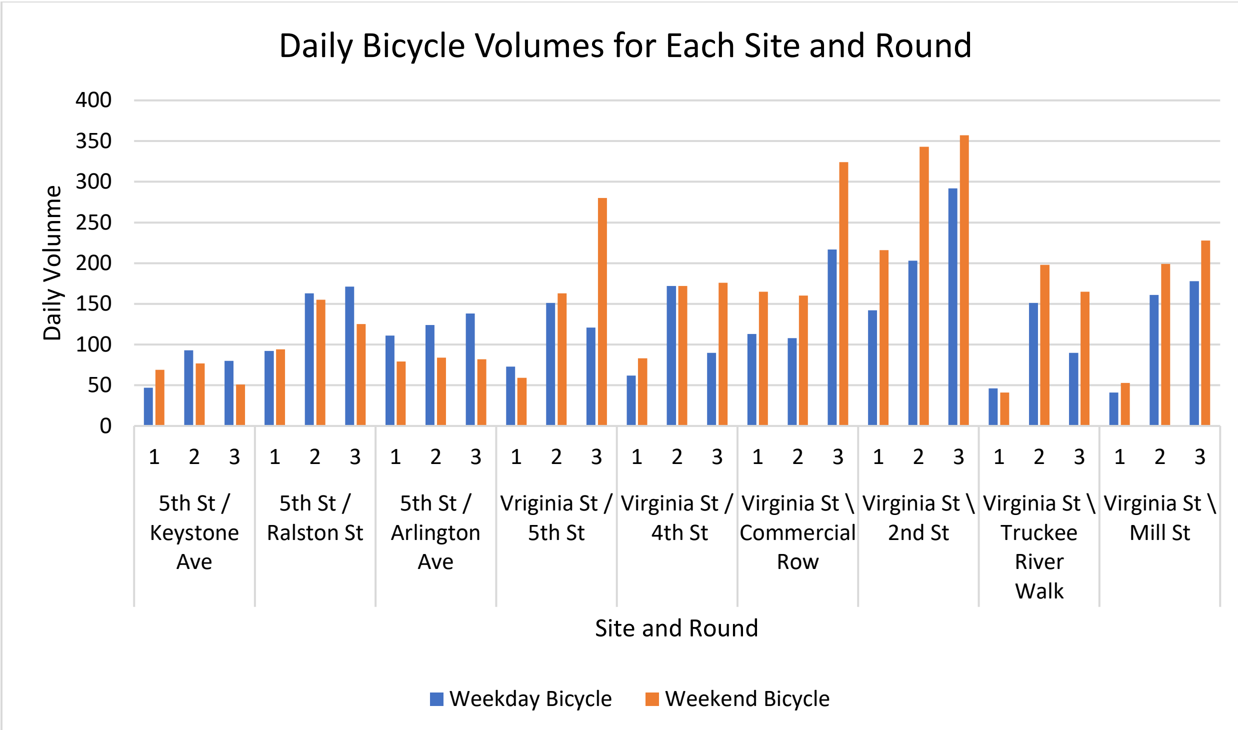


Figure 89 All sites and rounds Daily Bicycle volumes

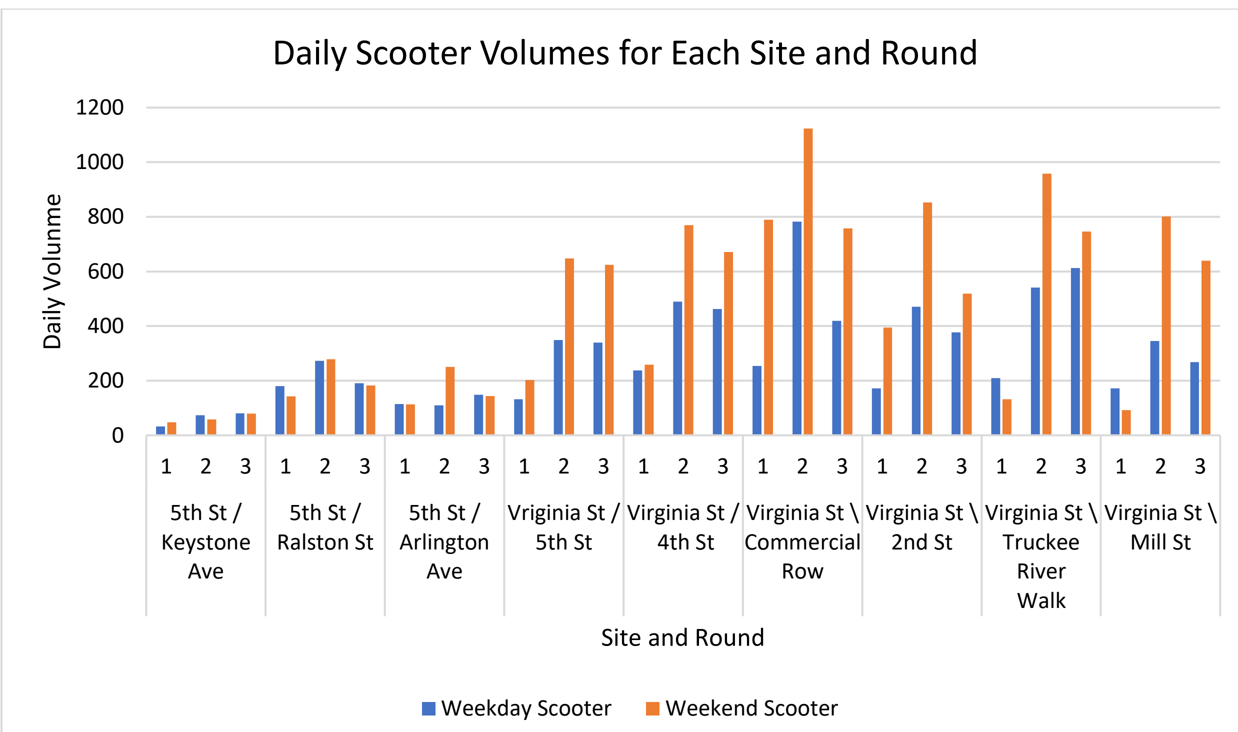


Figure 90 All sites and rounds Daily Scooter volumes

3.2 Micromobility Behavior

The summarized micromobility behavior and compliance are outlined. Figure 91 shows the total combined breakdown of bicycles and scooters using the roadway, sidewalk, cycle track, and bicycle lanes. "CT/BL" refers to the cycle track and bicycle lanes. Table 43 and Table 44 show the breakdown of volumes on the roadway, sidewalk, cycle track, and bicycle lanes for each site and round for bicycles and scooters, respectively. Figure 92 and Figure 93 shows the total combined breakdown of bicycles and scooters using the roadway, sidewalk, cycle track, and bicycle lanes broken down by the study street for the weekday and weekend, respectively. Figure 94 and Figure 95 shows the total combined breakdown of bicycles and scooters using the roadway, sidewalk, cycle track, and bicycle lanes broken down by the bicycle infrastructure for the weekday and weekend, respectively.

Up to 55 percent of bicyclists and 70 percent of scooters favored using the cycle track and bike lanes during round 2 and round 3. Roadway volumes were generally higher for bicycles than scooters; whereas, sidewalks were roughly the same. Figure 92 and Figure 93 shows that there is little difference between 5th St and Virginia when looking at the round 2 and round 3 conditions. There is also no significant difference between the bicycle infrastructure on right-of-way utilization, as shown in Figure 94 and Figure 95. This suggests that both bicycle lanes and cycle tracks are good solutions for providing micromobility road users safe and effective right-of-way locations.

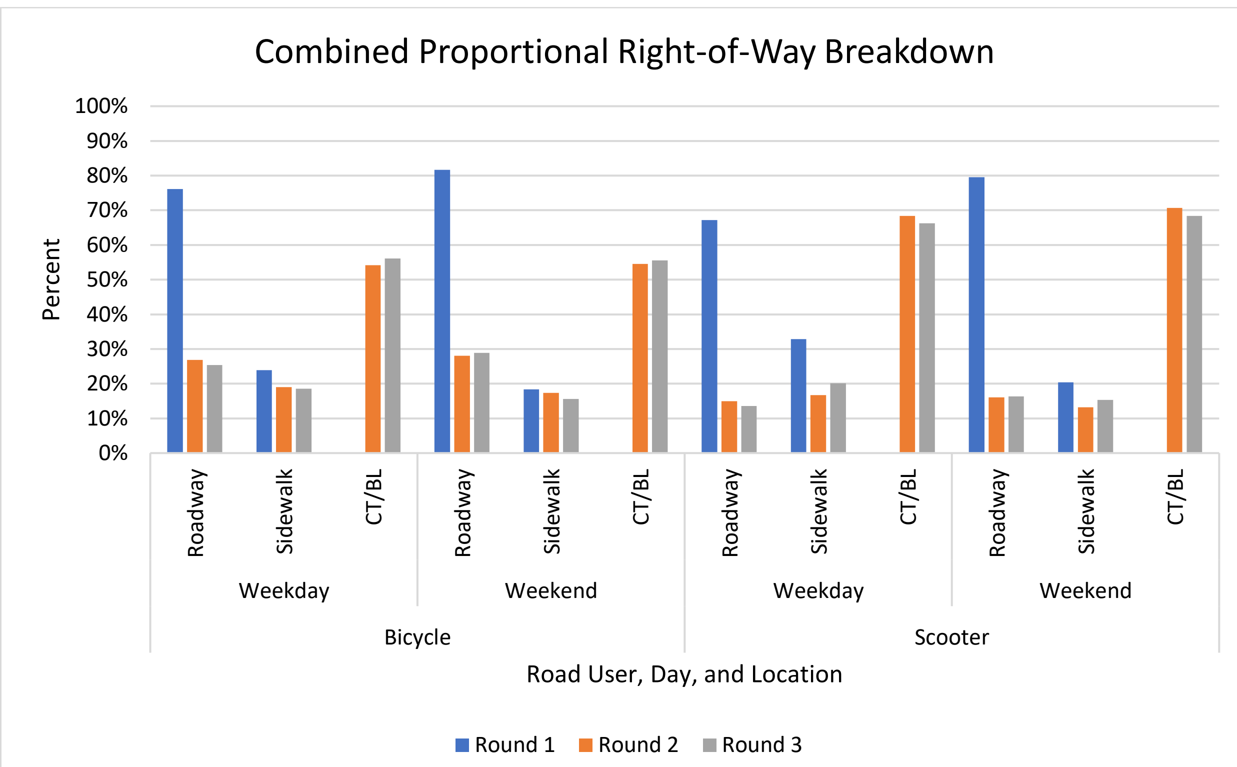


Figure 91 Combined proportion right-of-way breakdown

Table 43 All sites and rounds proportional bicycle right-of-way breakdown

Intersection	Round	Weekday			Weekend		
		Bicycle on Roadway	Bicycle on Sidewalk	Bicycle on Cycle Track/Bike Lane	Bicycle on Roadway	Bicycle on Sidewalk	Bicycle on Cycle Track/Bike Lane
5th St / Keystone Ave	1	67%	33%	N/A	100%	0%	N/A
	2	79%	16%	5%	88%	0%	13%
	3	73%	9%	18%	70%	20%	10%
5th St / Ralston St	1	96%	4%	N/A	100%	0%	N/A
	2	33%	21%	46%	31%	13%	56%
	3	34%	14%	52%	21%	16%	63%
5th St / Arlington Ave	1	98%	2%	N/A	95%	5%	N/A
	2	31%	10%	60%	55%	4%	42%
	3	28%	9%	62%	27%	11%	62%
Virginia St / 5th St	1	38%	62%	N/A	67%	33%	N/A
	2	7%	26%	67%	6%	28%	67%
	3	14%	30%	56%	15%	27%	58%
Virginia St / 4th St	1	56%	44%	N/A	77%	23%	N/A
	2	36%	30%	34%	28%	17%	56%
	3	28%	40%	32%	34%	19%	47%
Virginia St \ Commercial Row	1	74%	26%	N/A	89%	11%	N/A
	2	41%	13%	46%	31%	17%	52%
	3	26%	20%	54%	20%	13%	68%
Virginia St \ 2nd St	1	72%	28%	0%	80%	20%	N/A
	2	16%	20%	63%	19%	21%	60%
	3	12%	22%	66%	22%	19%	59%
Virginia St \ Truckee River Walk	1	79%	21%	N/A	70%	30%	N/A
	2	29%	18%	52%	28%	21%	51%
	3	44%	11%	45%	66%	7%	28%
Virginia St \ Mill St	1	51%	49%	N/A	37%	63%	N/A
	2	25%	17%	58%	26%	17%	57%
	3	27%	14%	59%	32%	13%	56%

Table 44 All sites and rounds proportional scooter right-of-way breakdown

Intersection	Round	Weekday			Weekend		
		Scooter on Roadway	Scooter on Sidewalk	Scooter on Cycle Track/Bike Lane	Scooter on Roadway	Scooter on Sidewalk	Scooter on Cycle Track/Bike Lane
5th St / Keystone Ave	1	46%	54%	N/A	50%	50%	N/A
	2	60%	36%	4%	58%	42%	0%
	3	58%	39%	3%	43%	43%	14%
5th St / Ralston St	1	92%	8%	N/A	93%	7%	N/A
	2	20%	5%	74%	11%	4%	85%
	3	11%	12%	77%	13%	8%	79%
5th St / Arlington Ave	1	83%	17%	N/A	73%	27%	N/A
	2	10%	15%	75%	16%	5%	79%
	3	14%	5%	81%	12%	7%	81%
Virginia St / 5th St	1	59%	41%	N/A	81%	19%	N/A
	2	6%	19%	74%	9%	18%	74%
	3	7%	18%	74%	9%	12%	80%
Virginia St / 4th St	1	62%	38%	N/A	78%	22%	N/A
	2	12%	11%	76%	15%	9%	76%
	3	10%	17%	73%	18%	14%	67%
Virginia St \ Commercial Row	1	61%	39%	N/A	83%	17%	N/A
	2	19%	13%	68%	16%	23%	61%
	3	17%	19%	64%	23%	13%	64%
Virginia St \ 2nd St	1	58%	42%	N/A	80%	20%	N/A
	2	17%	16%	67%	20%	10%	70%
	3	18%	25%	57%	23%	15%	62%
Virginia St \ Truckee River Walk	1	52%	48%	N/A	58%	42%	N/A
	2	15%	20%	65%	14%	14%	72%
	3	12%	29%	58%	11%	29%	60%
Virginia St \ Mill St	1	67%	33%	N/A	61%	39%	N/A
	2	11%	27%	62%	12%	20%	69%
	3	13%	21%	66%	13%	12%	75%

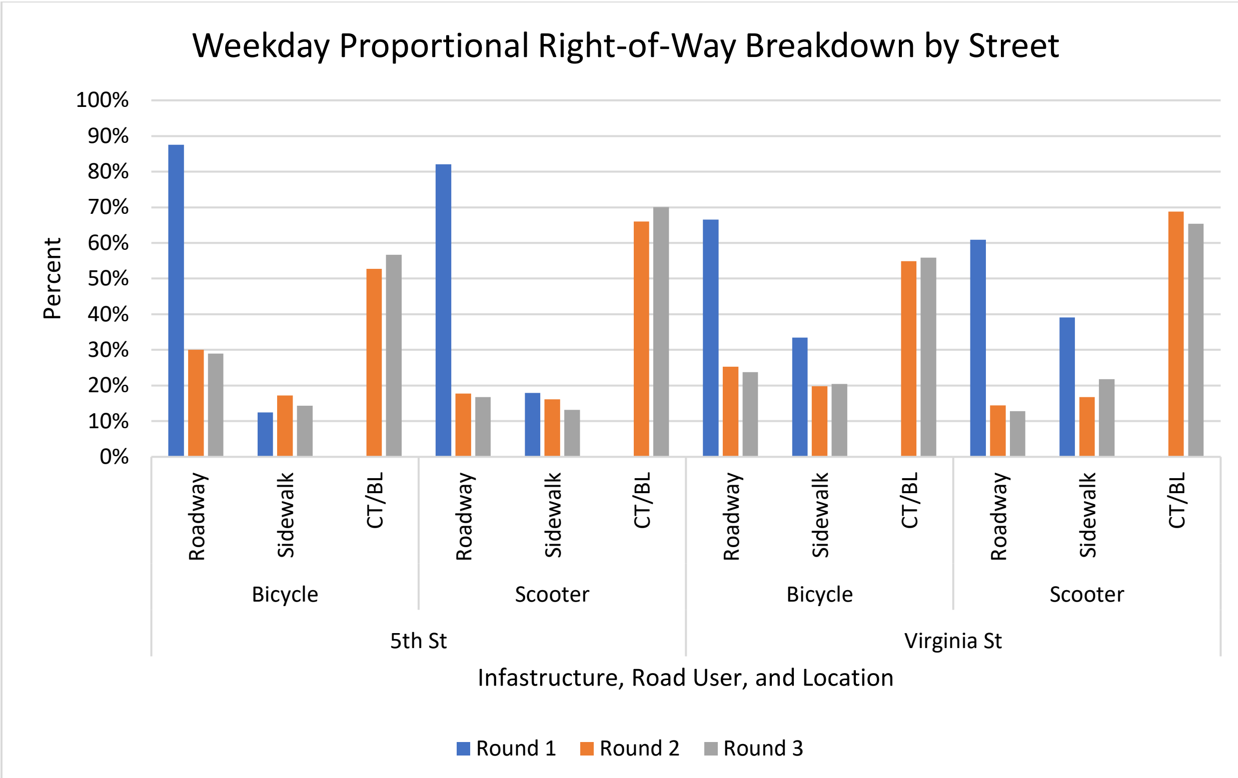


Figure 92 Weekday combined proportion right-of-way breakdown by street

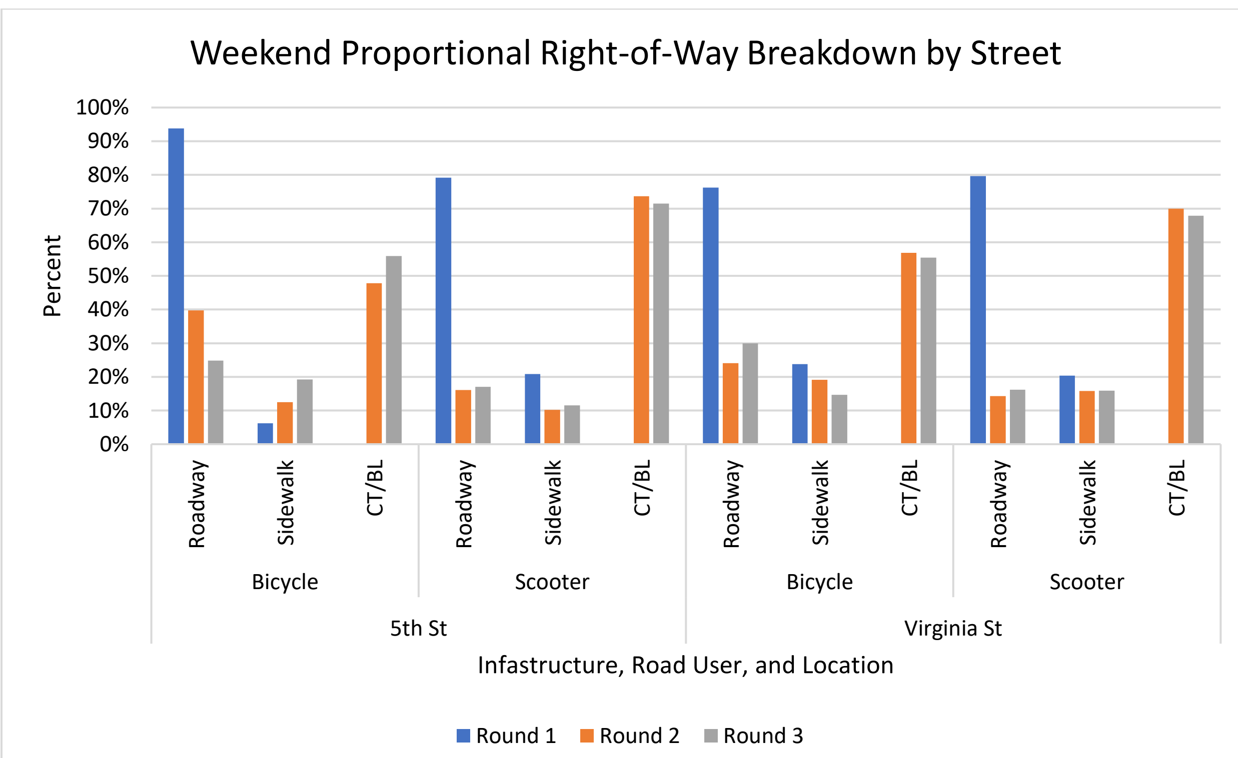


Figure 93 Weekend combined proportion right-of-way breakdown by street

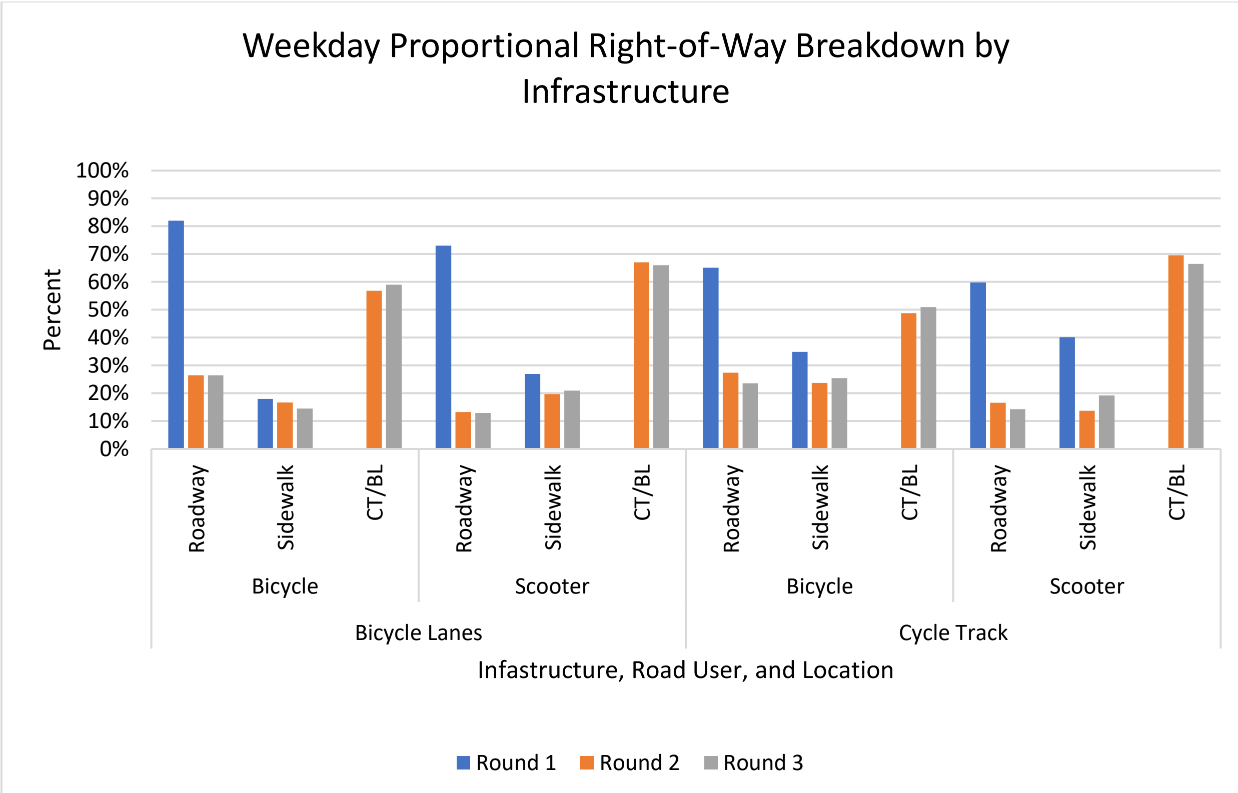


Figure 94 Weekday combined proportion right-of-way breakdown by infrastructure

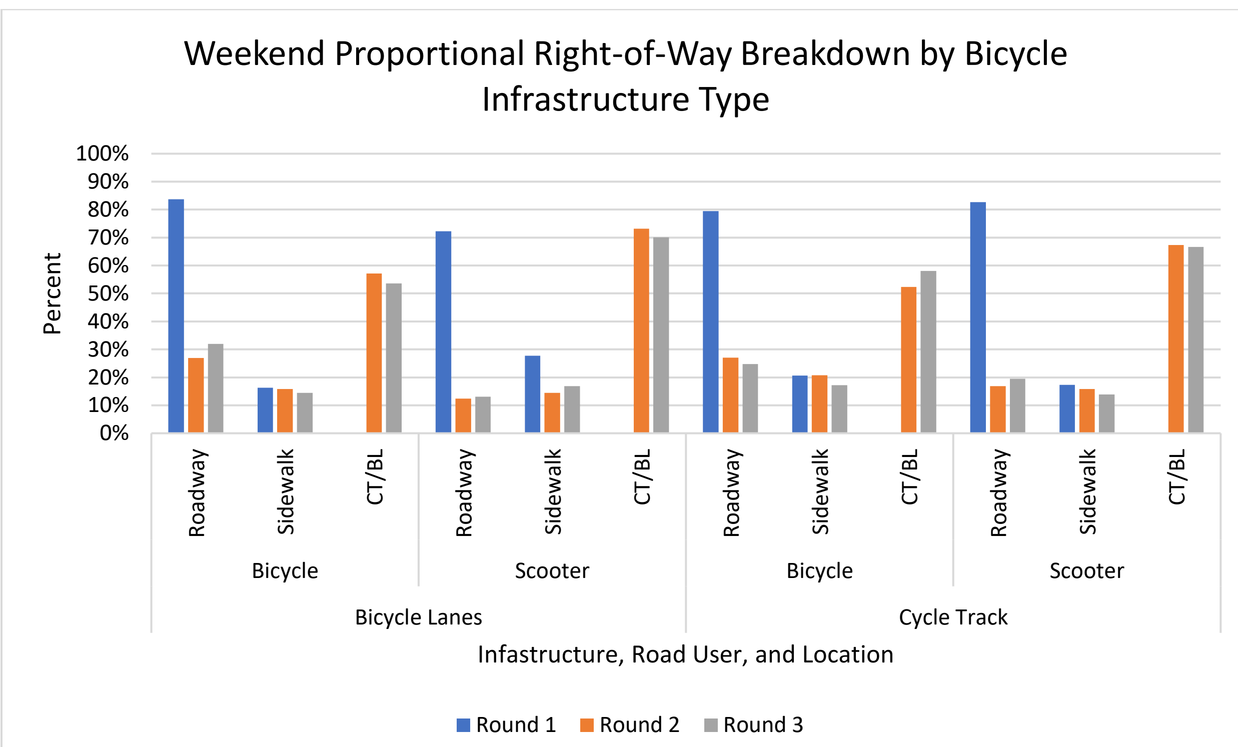


Figure 95 Weekend combined proportion right-of-way breakdown by infrastructure

3.3 Speed

The vehicle speeds are outlined. Figure 96 shows the 85th and 95th percentile speeds each site and round. Table 45 Shows the speed statistics each site and round, which include 15th, 50th, 85th,95th, and mean speeds. Speeds were highest along 5th St and at the Truckee River Walk and Mill St on Virginia. Speeds were lowest at 4th St, Commercial Row, and 2nd St along Virginia St. Along Virginia St, speeds decreased with the installment of bike infrastructure and with the change from two-way to one-way. Overall, the 95th percentile speeds show that the vast majority of vehicle in the study area were traveling less than 35 MPH. Therefore, speeding is not a significant issue for this study from a safety perspective.

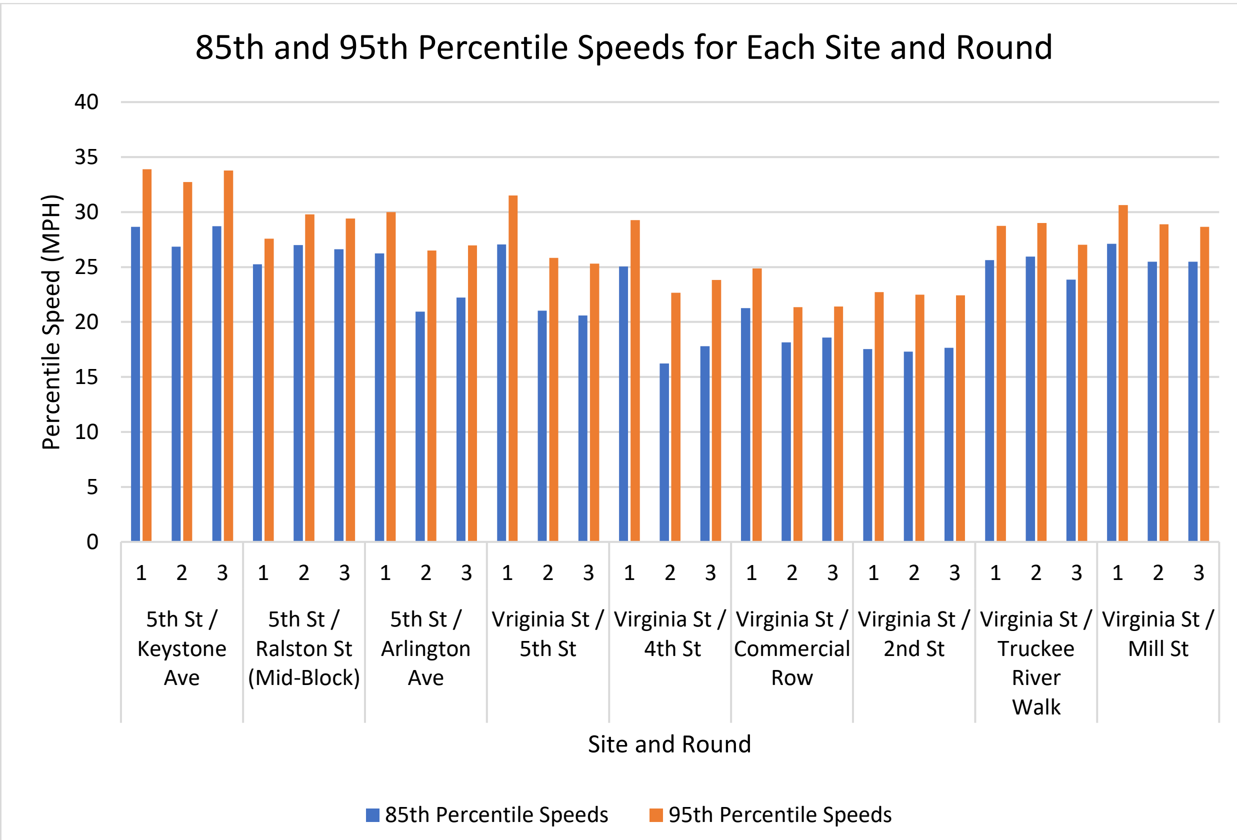


Figure 96 Summarized 85th and 95th percentile speeds for each site and round

Table 45 Summarized speed statistics for each site and round

Intersection	Round	15th Percentile Speeds	50th Percentile Speeds	85th Percentile Speeds	95th Percentile Speeds	Mean Speeds
5th St / Keystone Ave	1	7.3	15.8	28.6	33.9	17.1
	2	6.7	14.9	26.9	32.7	16.1
	3	7.1	15.7	28.7	33.8	17.0
5th St / Ralston St (Mid-Block)	1	16.3	21.2	25.3	27.6	20.7
	2	16.7	22.3	27.0	29.8	21.8
	3	16.3	21.9	26.6	29.4	21.5
5th St / Arlington Ave	1	5.2	14.0	26.2	30.0	15.2
	2	3.1	10.6	20.9	26.5	11.8
	3	4.0	10.8	22.2	27.0	12.3
Virginia St / 5th St	1	6.4	16.4	27.1	31.5	16.9
	2	4.5	12.3	21.0	25.8	12.9
	3	5.1	12.5	20.6	25.3	12.9
Virginia St / 4th St	1	6.6	17.3	25.1	29.3	16.5
	2	2.0	9.4	16.2	22.7	9.9
	3	2.4	9.7	17.8	23.8	10.5
Virginia St / Commercial Row	1	7.4	15.0	21.3	24.9	14.7
	2	7.4	13.0	18.2	21.3	13.0
	3	8.3	13.6	18.6	21.4	13.5
Virginia St / 2nd St	1	3.5	11.4	17.5	22.7	11.5
	2	4.0	10.0	17.3	22.5	10.7
	3	4.5	10.2	17.7	22.4	11.0
Virginia St / Truckee River Walk	1	15.0	20.9	25.6	28.7	20.4
	2	12.1	21.5	25.9	29.0	21.1
	3	12.5	18.9	23.8	27.0	18.3
Virginia St / Mill St	1	17.6	22.6	27.1	30.6	22.5
	2	14.2	20.1	25.5	28.9	19.9
	3	14.9	20.2	25.5	28.6	20.2

3.4 RED-LIGHT RUNNING

The red-light running events at the signalized intersections are outlined. Table 46 and Table 47 shows the frequency of red-light running events based on the total and after red clearance for each site and round, respectively. Table 48 and Table 49 shows the rate of red-light running events based on the total and after red clearance for each site and round, respectively. Table and Table 51 shows the frequency and rate of micromobility red-light running events for each site and round, respectively. Vehicle red-light running frequencies were highest at the 5th St and Keystone Ave intersection and lowest at the 5th St and Arlington Ave intersection. The after red clearance red-light running events generally mimic the trends seen for the overall. The weekend most commonly had more red-light running frequencies, but the rates were generally similar. The micromobility red-light running frequencies and rates were highest at the Virginia and 2nd St intersection and lowest at the Virginia St and 5th St intersection. Round 3 had highest frequencies except at Virginia St and 2nd St.

Table 46 Frequency of red-light running events

Intersection	Round	Northbound		Southbound		Eastbound		Westbound		Total	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
5th St / Keystone Ave	1	66	121	126	212	17	16	13	19	222	368
	2	138	120	166	235	34	44	17	29	355	428
	3	101	129	220	175	23	28	21	29	365	361
5th St / Arlington Ave	1	3	4	7	16	5	19	4	9	19	48
	2	34	22	25	13	25	13	31	36	115	84
	3	22	15	23	11	47	61	45	71	137	158
Virginia St / 5th St	1	N/A	N/A	85	73	73	102	24	24	182	199
	2	N/A	N/A	70	105	137	128	35	16	242	249
	3	N/A	N/A	24	42	23	111	10	24	57	177
Virginia St / 4th St	1	N/A	N/A	26	43	38	62	25	46	89	151
	2	N/A	N/A	148	149	94	97	123	128	365	374
	3	N/A	N/A	122	161	125	140	105	100	352	401
Virginia St / 2nd St	1	N/A	N/A	49	73	23	44	23	49	95	166
	2	N/A	N/A	126	172	54	46	56	62	236	280
	3	N/A	N/A	97	106	64	68	47	48	208	222

Table 47 Frequency of red-light running events after red clearance

Intersection	Round	Northbound		Southbound		Eastbound		Westbound		Total	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
5th St / Keystone Ave	1	11	21	24	37	3	2	1	4	39	64
	2	29	51	45	77	9	14	5	13	88	155
	3	37	48	57	49	5	1	6	5	105	103
5th St / Arlington Ave	1	0	0	5	3	1	5	2	0	8	8
	2	8	10	2	4	3	2	5	8	18	24
	3	4	11	8	3	10	29	10	18	32	61
Virginia St / 5th St	1	N/A	N/A	35	33	19	27	7	9	61	69
	2	N/A	N/A	20	49	30	52	10	9	60	110
	3	N/A	N/A	7	7	4	19	2	6	13	32
Virginia St / 4th St	1	N/A	N/A	4	10	6	18	5	22	15	50
	2	N/A	N/A	42	60	35	49	44	72	121	181
	3	N/A	N/A	53	51	56	51	45	34	154	136
Virginia St / 2nd St	1	N/A	N/A	14	22	4	25	9	19	27	66
	2	N/A	N/A	65	55	18	22	23	18	106	95
	3	N/A	N/A	35	45	26	28	14	17	75	90

Table 48 Rate of red-light running events

Intersection	Round	Northbound		Southbound		Eastbound		Westbound		Total	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
5th St / Keystone Ave	1	0.5%	1.0%	0.9%	1.5%	1.2%	1.3%	0.9%	1.4%	0.7%	1.3%
	2	0.9%	1.1%	1.2%	2.2%	2.0%	3.1%	1.0%	2.2%	1.1%	1.8%
	3	0.8%	1.2%	1.5%	1.3%	1.5%	1.8%	1.4%	2.2%	1.2%	1.3%
5th St / Arlington Ave	1	0.1%	0.2%	0.4%	1.9%	0.2%	1.1%	0.2%	0.6%	0.2%	0.8%
	2	1.0%	0.7%	1.1%	0.7%	1.3%	0.7%	1.9%	1.3%	1.2%	0.8%
	3	0.7%	0.6%	1.3%	1.2%	1.8%	3.2%	2.4%	4.2%	1.5%	2.3%
Virginia St / 5th St	1	N/A	N/A	2.1%	2.0%	2.6%	3.0%	3.4%	2.8%	1.5%	1.4%
	2	N/A	N/A	1.8%	2.6%	3.6%	3.2%	2.5%	1.0%	2.7%	2.6%
	3	N/A	N/A	0.7%	1.0%	0.8%	2.6%	0.9%	1.5%	0.8%	1.8%
Virginia St / 4th St	1	N/A	N/A	0.6%	1.1%	0.9%	1.5%	0.5%	1.1%	0.5%	0.8%
	2	N/A	N/A	3.6%	3.5%	1.8%	2.0%	2.4%	2.7%	2.5%	2.7%
	3	N/A	N/A	3.6%	3.9%	3.2%	2.9%	2.5%	2.1%	3.1%	2.9%
Virginia St / 2nd St	1	N/A	N/A	1.2%	1.5%	0.8%	1.5%	0.8%	1.6%	0.7%	1.0%
	2	N/A	N/A	3.6%	3.8%	2.0%	1.4%	2.1%	2.4%	2.7%	2.7%
	3	N/A	N/A	2.9%	3.0%	2.4%	2.5%	1.8%	2.2%	2.4%	2.7%

Table 49 Rate of red-light running events after red clearance

Intersection	Round	Northbound		Southbound		Eastbound		Westbound		Total	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
5th St / Keystone Ave	1	0.1%	0.2%	0.2%	0.3%	0.2%	0.2%	0.1%	0.3%	0.1%	0.2%
	2	0.2%	0.5%	0.3%	0.7%	0.5%	1.0%	0.3%	1.0%	0.3%	0.6%
	3	0.3%	0.4%	0.4%	0.4%	0.3%	0.1%	0.4%	0.4%	0.4%	0.4%
5th St / Arlington Ave	1	0.0%	0.0%	0.3%	0.4%	0.0%	0.3%	0.1%	0.0%	0.1%	0.1%
	2	0.2%	0.3%	0.1%	0.2%	0.2%	0.1%	0.3%	0.3%	0.2%	0.2%
	3	0.1%	0.5%	0.5%	0.3%	0.4%	1.5%	0.5%	1.1%	0.3%	0.9%
Virginia St / 5th St	1	N/A	N/A	0.9%	0.9%	0.7%	0.8%	1.0%	1.0%	0.5%	0.5%
	2	N/A	N/A	0.5%	1.2%	0.8%	1.3%	0.7%	0.6%	0.7%	1.1%
	3	N/A	N/A	0.2%	0.2%	0.1%	0.5%	0.2%	0.4%	0.2%	0.3%
Virginia St / 4th St	1	N/A	N/A	0.1%	0.3%	0.1%	0.4%	0.1%	0.5%	0.1%	0.3%
	2	N/A	N/A	1.0%	1.4%	0.7%	1.0%	0.9%	1.5%	0.8%	1.3%
	3	N/A	N/A	1.6%	1.2%	1.4%	1.1%	1.1%	0.7%	1.3%	1.0%
Virginia St / 2nd St	1	N/A	N/A	0.3%	0.4%	0.1%	0.8%	0.3%	0.6%	0.2%	0.4%
	2	N/A	N/A	1.9%	1.2%	0.7%	0.7%	0.8%	0.7%	1.2%	0.9%
	3	N/A	N/A	1.1%	1.3%	1.0%	1.0%	0.5%	0.8%	0.9%	1.1%

Table 50 Frequency of micromobility red-light running events

Intersection	Round	Northbound		Southbound	
		Weekday	Weekend	Weekday	Weekend
Virginia St / 5th St	1	N/A	N/A	N/A	N/A
	2	13	20	N/A	N/A
	3	13	46	N/A	N/A
Virginia St / 4th St	1	N/A	N/A	N/A	N/A
	2	26	29	40	20
	3	39	62	42	52
Virginia St / 2nd St	1	N/A	N/A	N/A	N/A
	2	48	51	60	87
	3	32	54	46	81

Table 51 Rate of micromobility red-light running events

Intersection	Round	Northbound		Southbound	
		Weekday	Weekend	Weekday	Weekend
Virginia St / 5th St	1	N/A	N/A	N/A	N/A
	2	8.1%	6.8%	N/A	N/A
	3	11.6%	18.0%	N/A	N/A
Virginia St / 4th St	1	N/A	N/A	N/A	N/A
	2	14.4%	8.5%	40.4%	15.6%
	3	21.5%	23.8%	47.2%	40.9%
Virginia St / 2nd St	1	N/A	N/A	N/A	N/A
	2	26.5%	16.9%	38.7%	29.5%
	3	23.2%	31.6%	35.1%	47.9%

3.5 Conflicts

The summarized conflicts are outlined. Table 52 shows the conflict rate for each conflict type breakdown by road segment for each conflict type. The road segments include Keystone to Arlington Ave along 5th St, 5th to 2nd St along Virginia St, and Truckee River Walk to Mill St along Virginia St. There is also segmentation of 5th St and Virginia St, with the overlap of Virginia and 5th St. Figure 97 shows the overall conflict rate each site and round. Table 53 shows the conflict frequency and rate for micromobility-to-pedestrian conflicts. Table 54 shows the conflict rate for each conflict type for each site.

Conflict rates are higher from 5th to 2nd St along Virginia St, with the highest occurring at 4th St. Conflict rates decreased after the implementation of new infrastructure for all sites. Some sites saw an increase from round 2 to round 3, but was still lower than round 1. On Virginia St at 5th and 4th St, the vehicle-to-pedestrian conflict rate increased each round. Vehicle-to-vehicle conflicts saw the largest reductions overall as a result of the decreased conflict points. Vehicle-to- micromobility conflicts also decreased after the implementation of bicycle infrastructure. Micromobility-to-pedestrian conflicts occurred primarily on Virginia St, particularly from 4th to 2nd St, and generally did increase, as shown in Table 53. Overall, conflicts decreased after round 1 and stayed lower through round 3, which suggests that safety improved.

Table 52 Conflict rates breakdown by road segment characteristic for each conflict type

Street Segment	Round	Vehicle-to-vehicle conflicts per 100 vehicles	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
Virginia St - 5th to 2nd St	1	0.42	0.99	8.00	3.48	0.61
	2	0.04	0.79	3.43	1.36	0.32
	3	0.17	1.18	4.36	1.56	0.54
Virginia St - Truckee to Mill St	1	N/A	1.07	24.31	2.64	0.22
	2	N/A	0.27	0.71	0.57	0.09
	3	N/A	0.31	1.82	0.49	0.11
5th St - Keystone to Virginia	1	0.20	0.80	6.57	3.32	0.28
	2	0.10	0.65	2.77	1.47	0.17
	3	0.07	0.21	0.95	0.55	0.13
Total	1	0.24	0.99	8.64	3.81	0.40
	2	0.07	0.69	2.64	1.14	0.22
	3	0.11	0.98	3.35	1.36	0.30

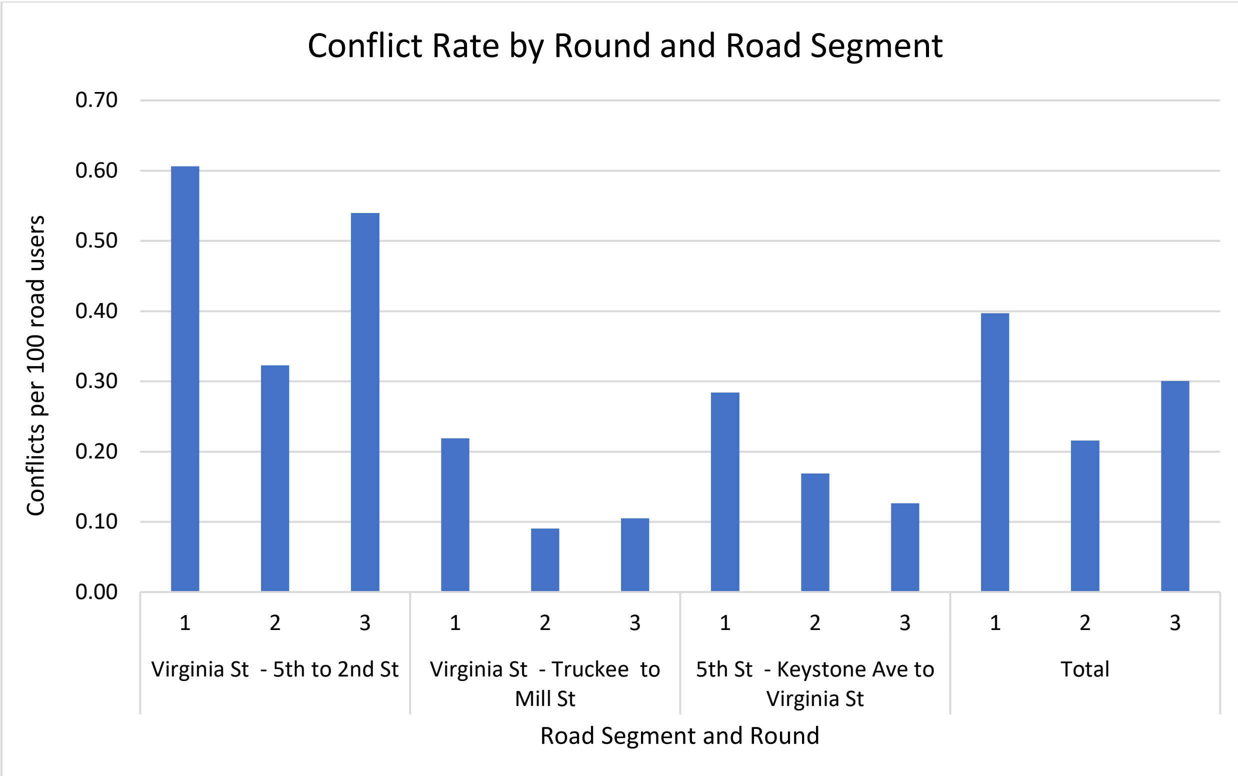


Figure 97 Conflict rate by round and road segment for each site and round

Table 53 Conflict frequency and rate of micromobility-to-pedestrian conflicts

Intersection	Round	Micromobility-to-pedestrian conflicts	Micromobility-to-pedestrian conflicts per 100 pedestrians
5th St / Keystone Ave	1	0	0.00
	2	0	0.00
	3	0	0.00
5th St / Ralston St	1	0	0.00
	2	0	0.00
	3	1	0.12
5th St / Arlington Ave	1	3	0.31
	2	1	0.13
	3	1	0.10
Virginia St / 5th St	1	1	0.03
	2	4	0.09
	3	10	0.21
Virginia St / 4th St	1	4	0.11
	2	15	0.30
	3	44	0.71
Virginia St \ Commercial Row	1	7	0.12
	2	14	0.21
	3	28	0.40
Virginia St \ 2nd St	1	13	0.21
	2	35	0.48
	3	32	0.46
Virginia St \ Truckee River Walk	1	1	0.05
	2	10	0.29
	3	8	0.24
Virginia St \ Mill St	1	2	0.14
	2	7	0.29
	3	6	0.29

Table 54 All sites and rounds conflict rates over a two-day period

Intersection	Round	Vehicle-to-vehicle conflicts per 100 vehicles	Vehicle-to-pedestrian conflicts per 100 pedestrians	Vehicle-to-bicycle conflicts per 100 bicycles	Vehicle-to-scooter conflicts per 100 scooters	Conflicts per 100 road users
5th St / Keystone Ave	1	0.05	1.28	4.31	3.70	0.07
	2	0.05	0.95	2.94	3.82	0.07
	3	0.06	0.81	2.29	4.40	0.08
5th St / Ralston St	1	0.15	0.81	3.76	2.48	0.28
	2	0.26	0.38	2.52	1.45	0.33
	3	0.14	0.49	2.70	0.80	0.21
5th St / Arlington Ave	1	0.47	0.51	4.21	3.08	0.55
	2	0.16	0.94	3.37	0.83	0.23
	3	0.15	0.20	0.91	1.71	0.19
Virginia St / 5th St	1	0.47	0.80	15.91	4.19	0.61
	2	0.06	0.61	2.55	1.40	0.22
	3	0.16	1.23	4.24	2.60	0.48
Virginia St / 4th St	1	0.74	1.30	22.07	4.43	0.91
	2	0.03	1.54	4.65	2.30	0.38
	3	0.31	2.57	15.79	2.03	0.91
Virginia St \ Commercial Row	1	0.07	0.55	2.52	1.92	0.26
	2	0.01	0.26	5.81	0.54	0.29
	3	0.04	0.38	2.03	1.10	0.31
Virginia St \ 2nd St	1	0.25	1.33	3.63	5.11	0.53
	2	0.04	0.91	1.83	1.59	0.37
	3	0.04	0.71	1.69	0.45	0.28
Virginia St \ Truckee River Walk	1	-	0.85	22.99	3.81	0.23
	2	-	0.35	0.57	0.73	0.12
	3	-	0.42	0.78	0.66	0.14
Virginia St \ Mill St	1	-	1.36	25.53	1.14	0.21
	2	-	0.16	0.83	0.35	0.06
	3	-	0.14	2.46	0.22	0.07

4 CONCLUSIONS

The concluding remarks for the Before-After Study with LiDAR for the Reno Micromobility Pilot Program is outlined. Roadside LiDAR data was collected at nine intersections for three separate rounds for the purposes of providing supporting analytics for the City of Reno's Micromobility Pilot Program. Each site's round 1 data provides information of the before conditions, and round 2 and round 3 provides information for the after conditions. The purpose of this study is to see how the traffic patterns changed as a result of the new infrastructure. In particular, how the micromobility users adapted to the changes. This was measured through multi-modal counts, speeds, red-light running events, and conflicts. These measures allowed for a better understanding of how micromobility usage changed, where the micromobility users preferred to ride, and whether any safety concerns arose.

At 5th St and Keystone Ave, the high vehicle volumes and relatively higher speeds means that further micromobility improvements should be made to encourage safer micromobility activity. 5th St and Ralston St had little concern in terms of safety. The protected bicycle lanes greatly enhanced the micromobility environment by reducing roadway and sidewalk volumes, with little to no impact to vehicles. The protected intersection at 5th St and Arlington Ave greatly improved the micromobility infrastructure utilization and overall safety. Protected intersections such as this one would be a great permanent addition to this and other signalized intersection with high mixed traffic.

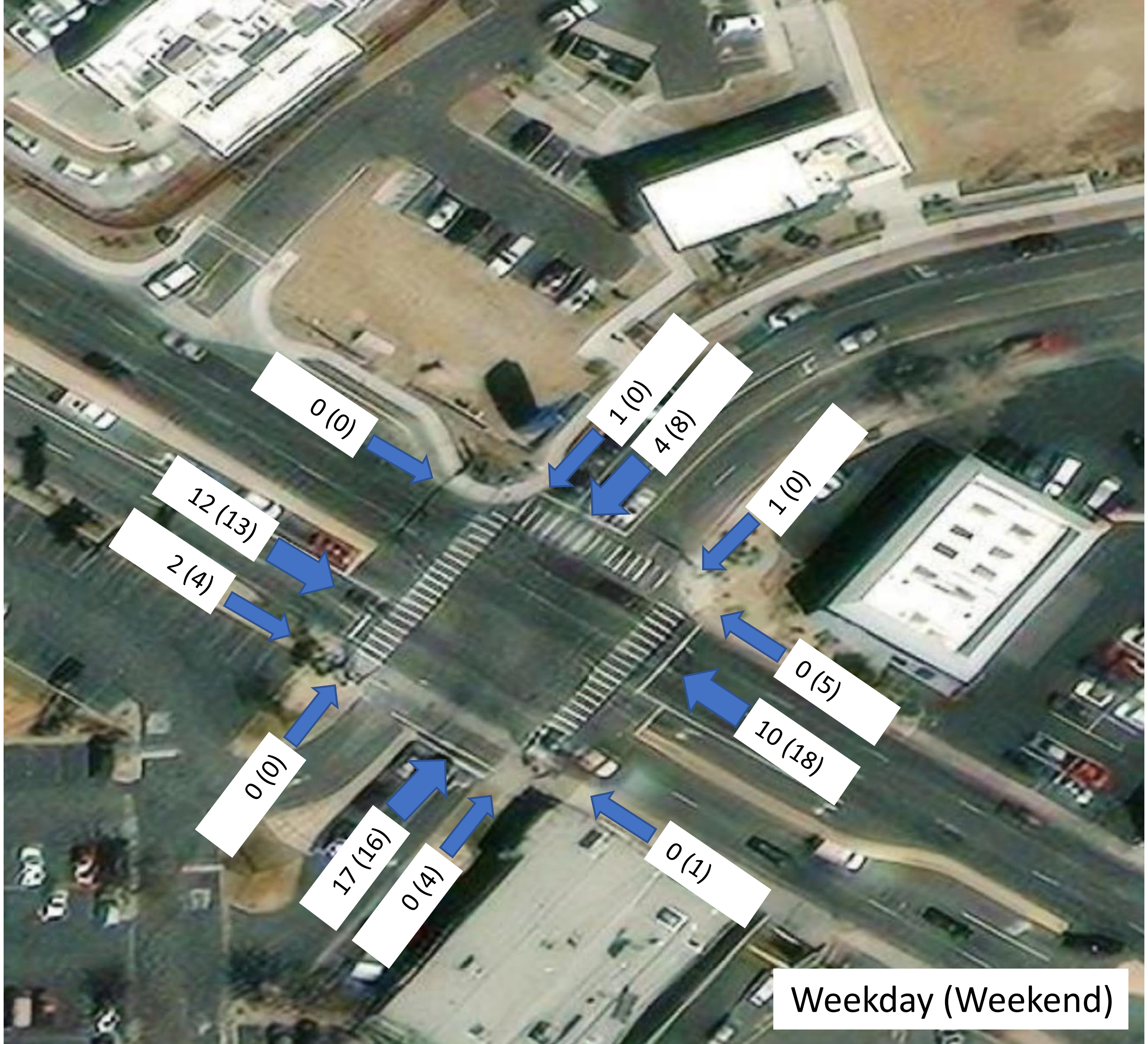
Virginia St and 5th St showcased the great utility of both the bike lanes and cycle tracks in getting micromobility users off the roadways and sidewalks. Virginia St and 4th St and the cycle track that extends across it had a similar affect to the micromobility users. The signal phase configuration in which the southbound phase comes after the micromobility phase slightly discouraged red-light running events. This signal phase configuration is therefore preferred; however, more data is required to say with certainty that it is safer. Virginia St and Commercial Row, again with a cycle track running through it, shortened the crossing length and reduced conflict points between vehicles and crossing vulnerable road users.

Virginia St and 2nd St was a transition point for the bike infrastructure, for which the cycle track changed to protected bicycle lanes. This transition needed to be navigated by the micromobility users, which means there was a learning curve for such users. The bike boxes helped alleviate the severity of conflicts and interactions between vehicles and other road users. The micromobility red-light running events rates ranged anywhere from 25 to 50 percent. Further, micromobility users were to be more likely to run the red-light on the cycle track. The Truckee River Walk encouraged many micromobility users to take advantage of the scenic route. For micromobility users traveling along Virginia St, scooters preferred the bike lanes, but the bicyclists were more split between the roadway and sidewalk. Lastly, Virginia St and Mill St had high bike lane utilization and little safety concerns.

Overall, reducing the number of through lanes along 5th St did not have a significant affect to vehicle volumes. The change from two-way to one-way along Virginia St did not have a significant effect to the southbound vehicle volumes. In general, the proportion of micromobility using riding along the roadway and sidewalk decreased with the introduction of the bicycle infrastructure. This is true for sites with bicycle lanes and cycle tracks. There were little speeding concerns at each intersection and speeds generally decreased with the new design configurations. The weekend most commonly had more vehicle red-light running frequencies, but the rates are usually similar. The micromobility red-light running frequencies and rates were highest at the Virginia and 2nd St intersection and lowest at the Virginia St and 5th St intersection. Conflict frequencies and rates decreased after round 1. The study data indicates that micromobility focused infrastructure that separates vehicles and micromobility road users can be extended to other areas of the city, particularly where there is high mixed traffic.

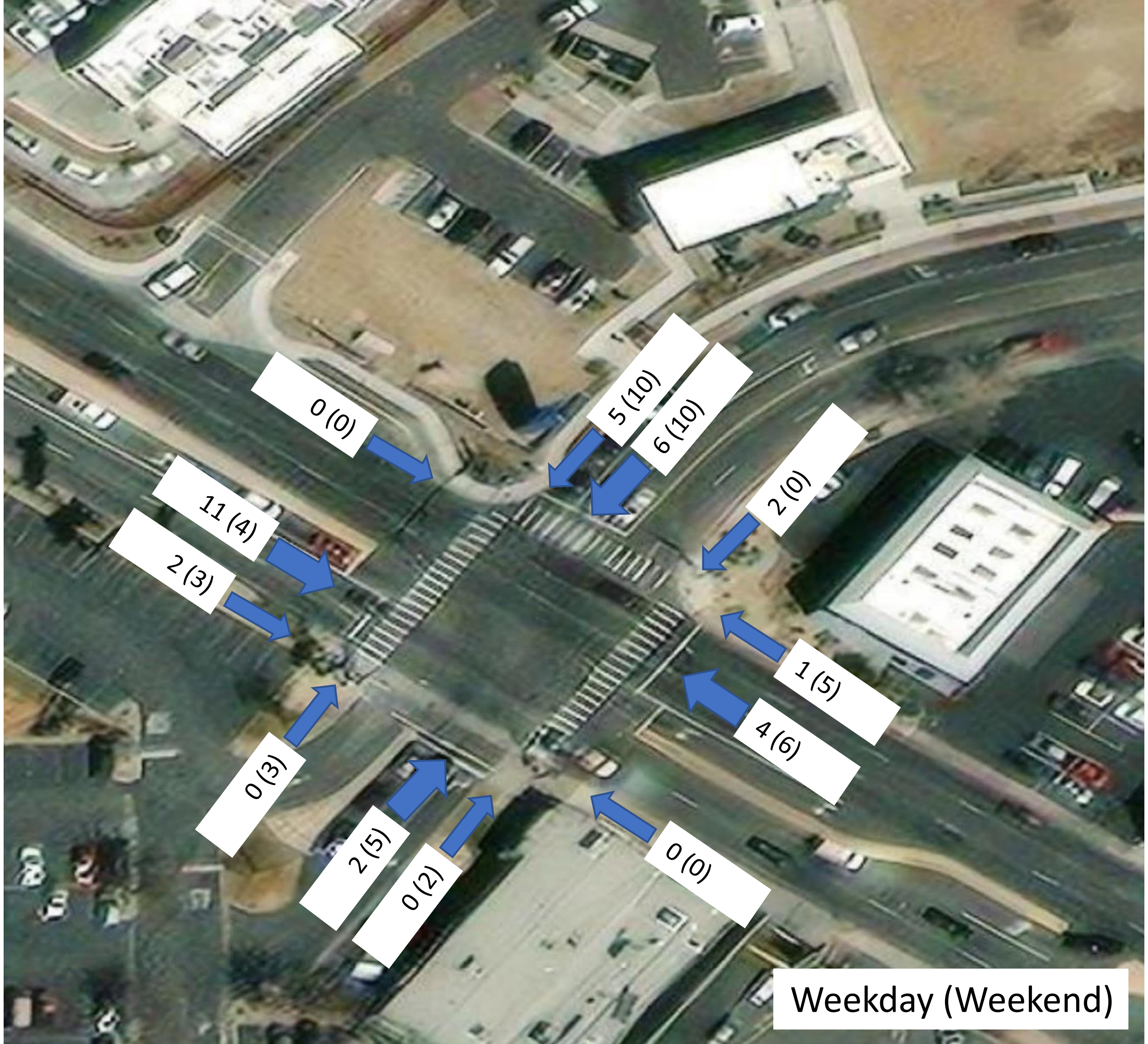
APPENDIX A: 5TH ST AND KEYSTONE AVE MICROMOBILITY

Round 1



Bicycles

Round 1

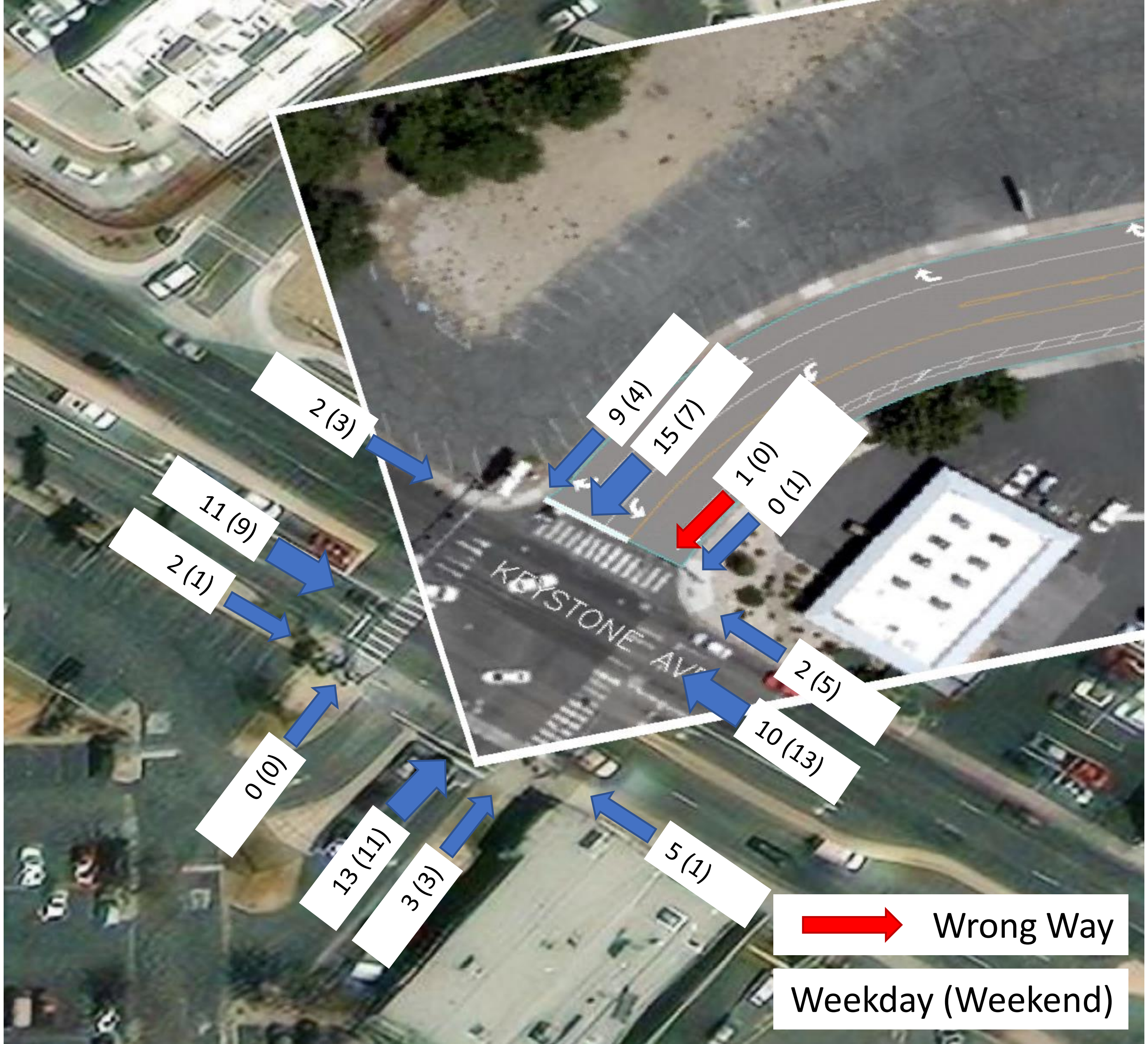


Scooters

Round 2

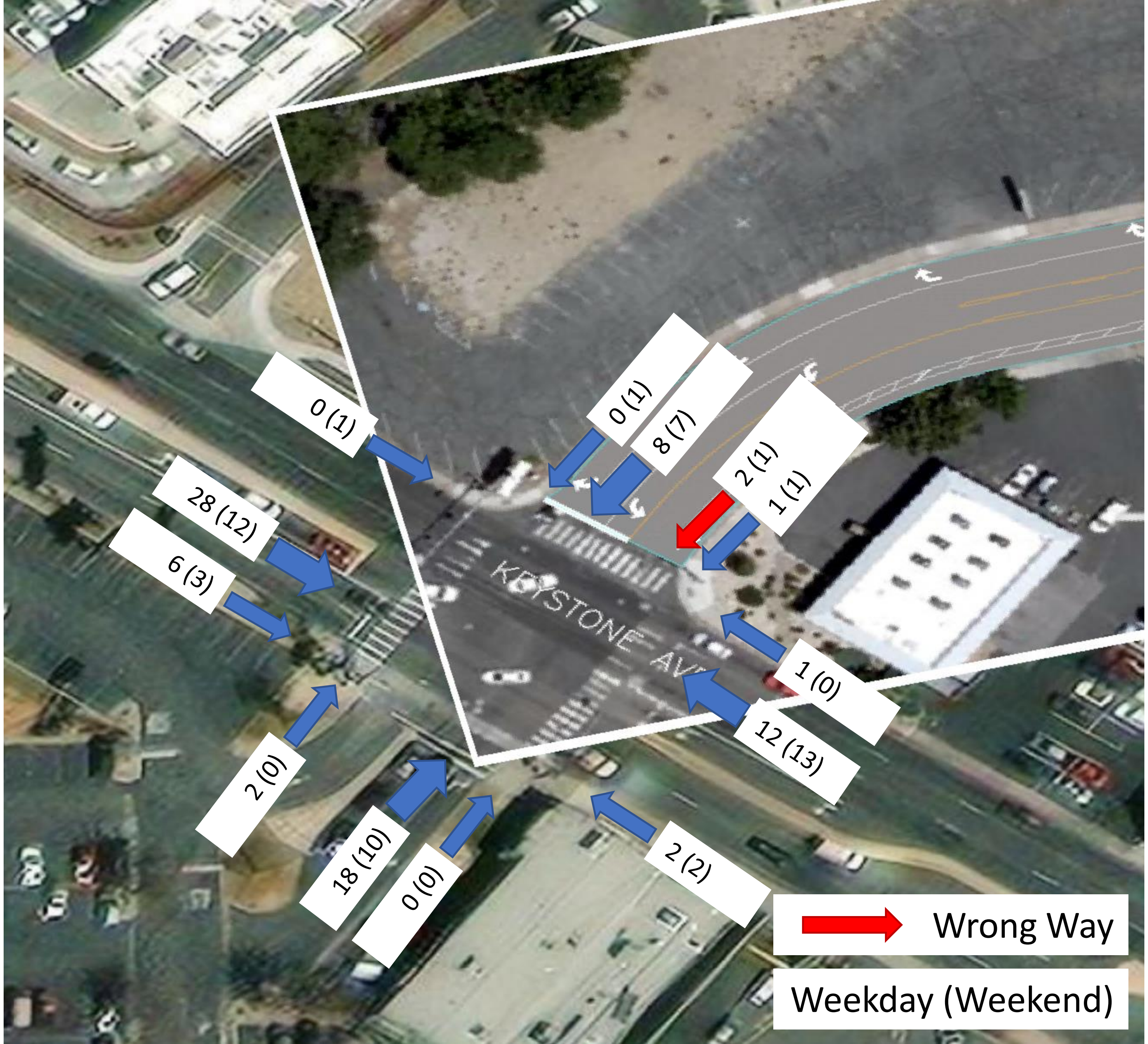
Bicycles

Round 2



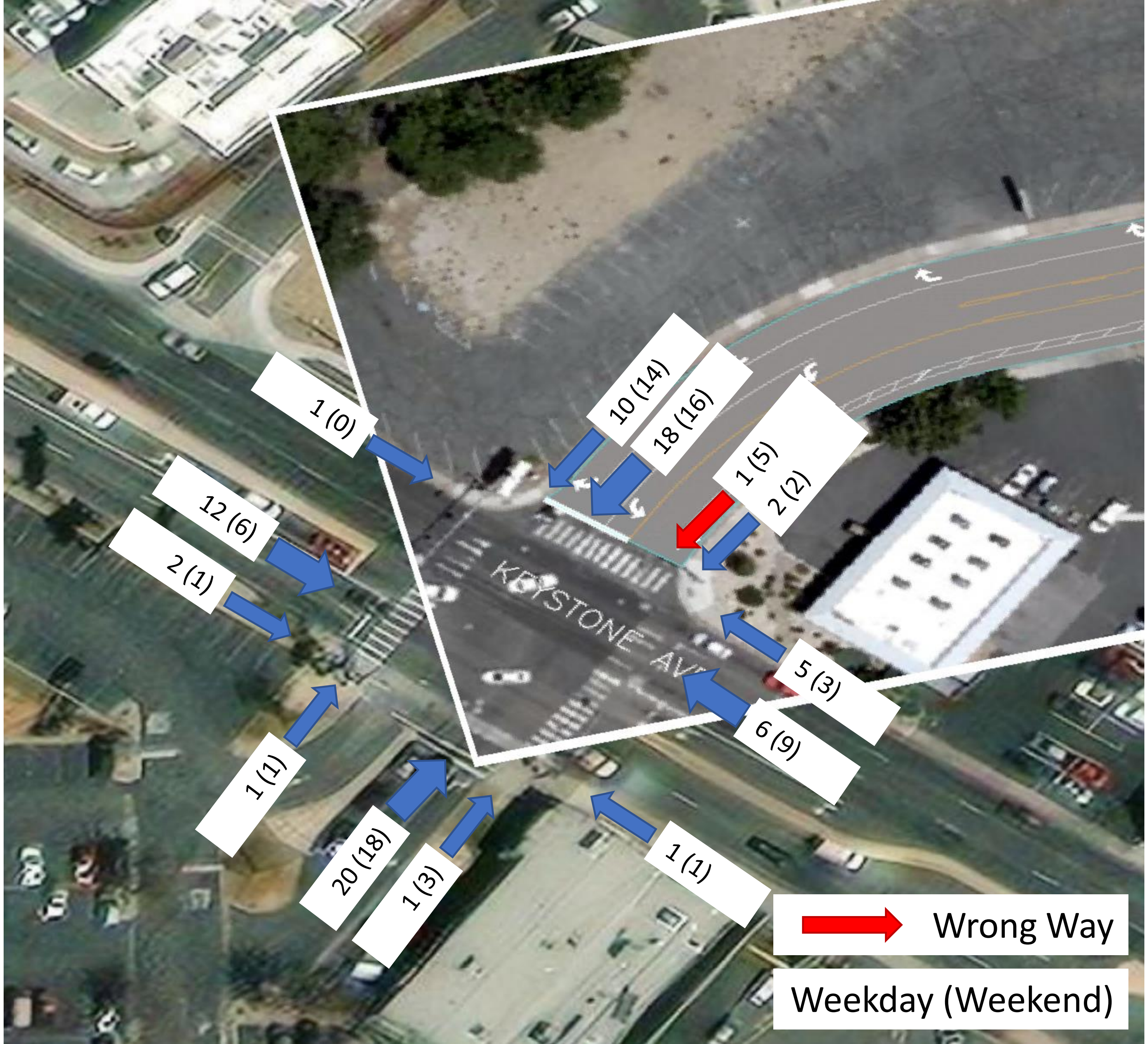
Scooters

Round 3



Bicycles

Round 3



Scooter

APPENDIX B: 5TH ST AND RALSTON ST MICROMOBILITY

Round 1

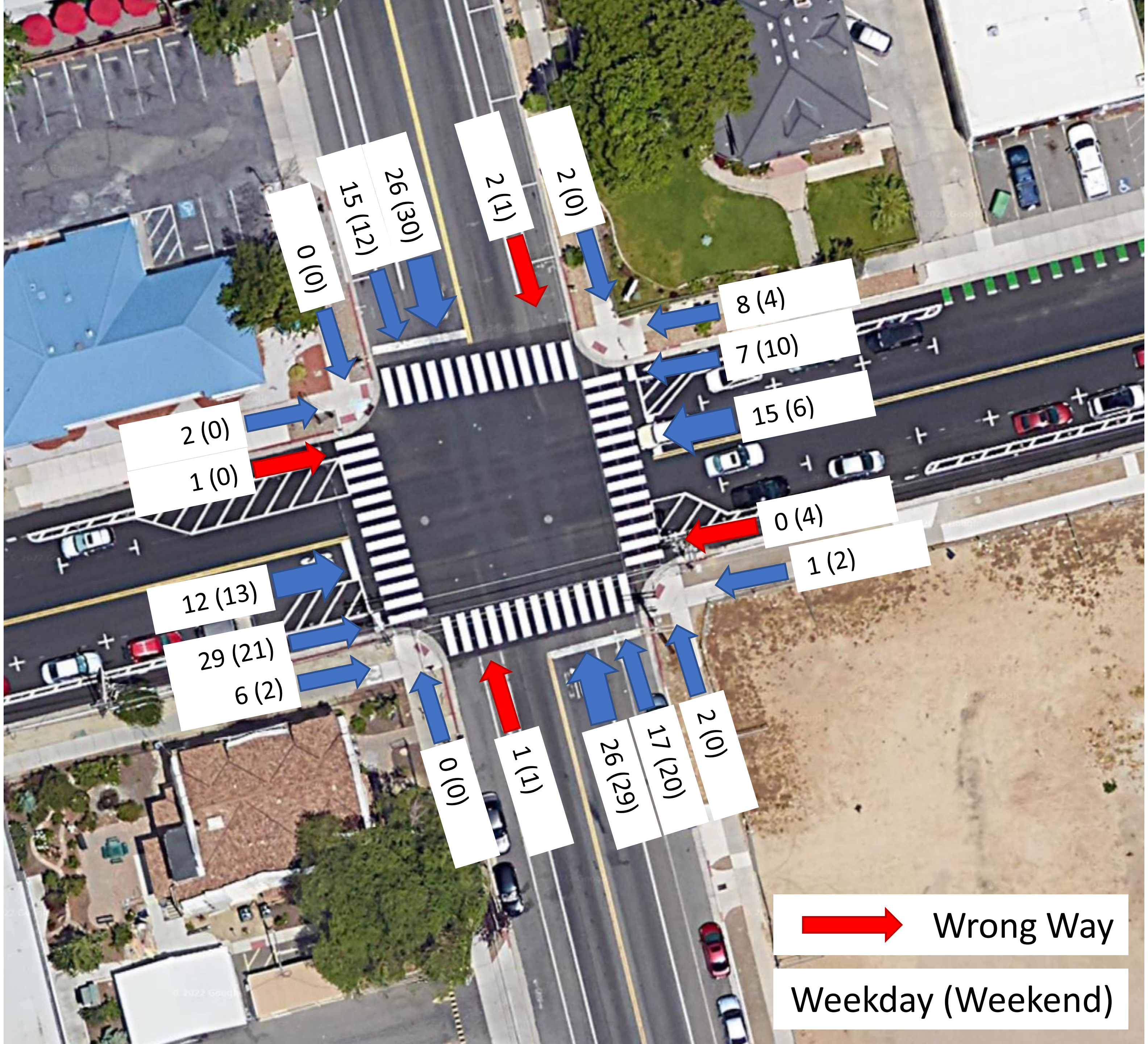
Bicycles

Round 1

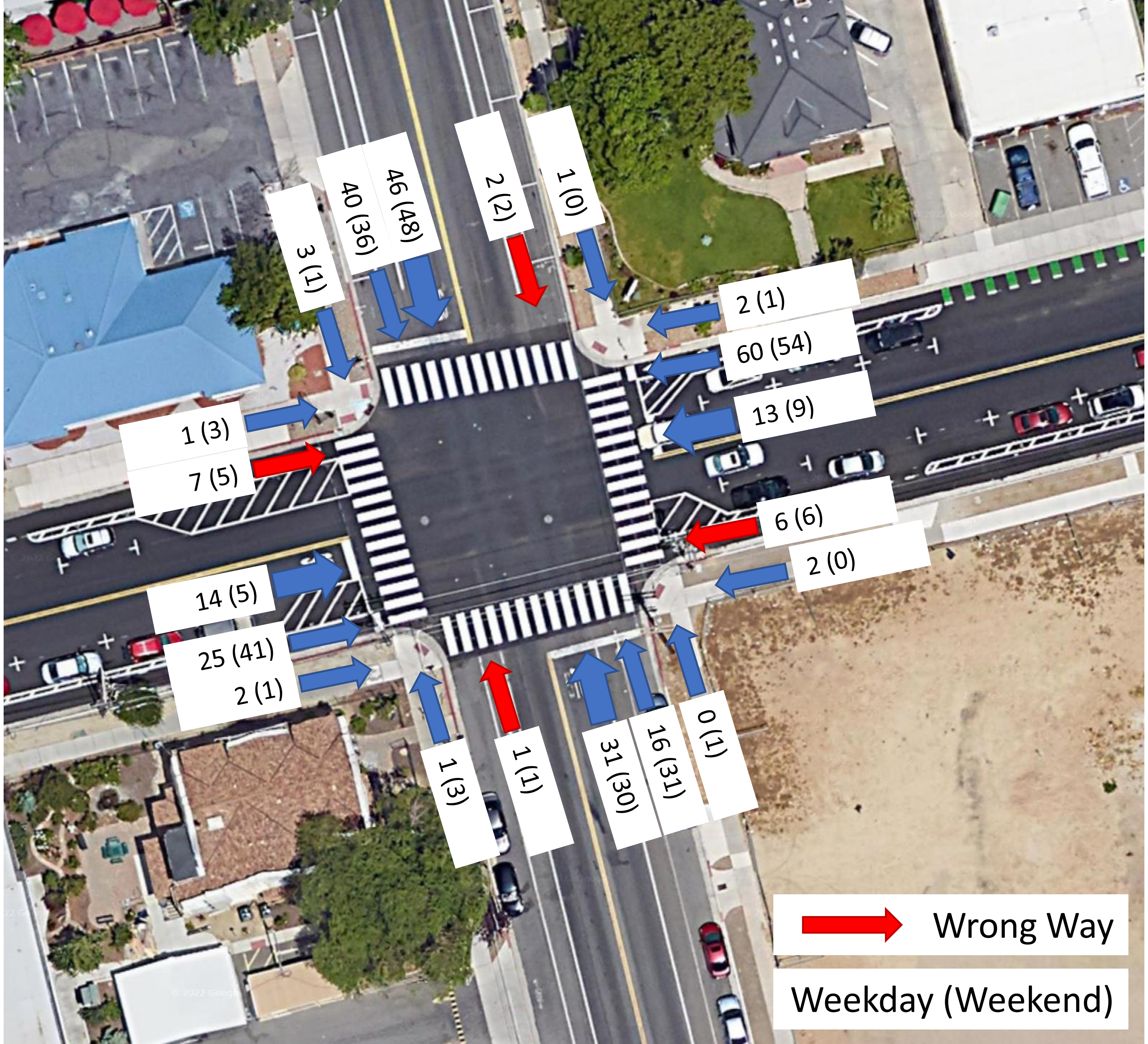
Scooters

Round 2

Bicycles



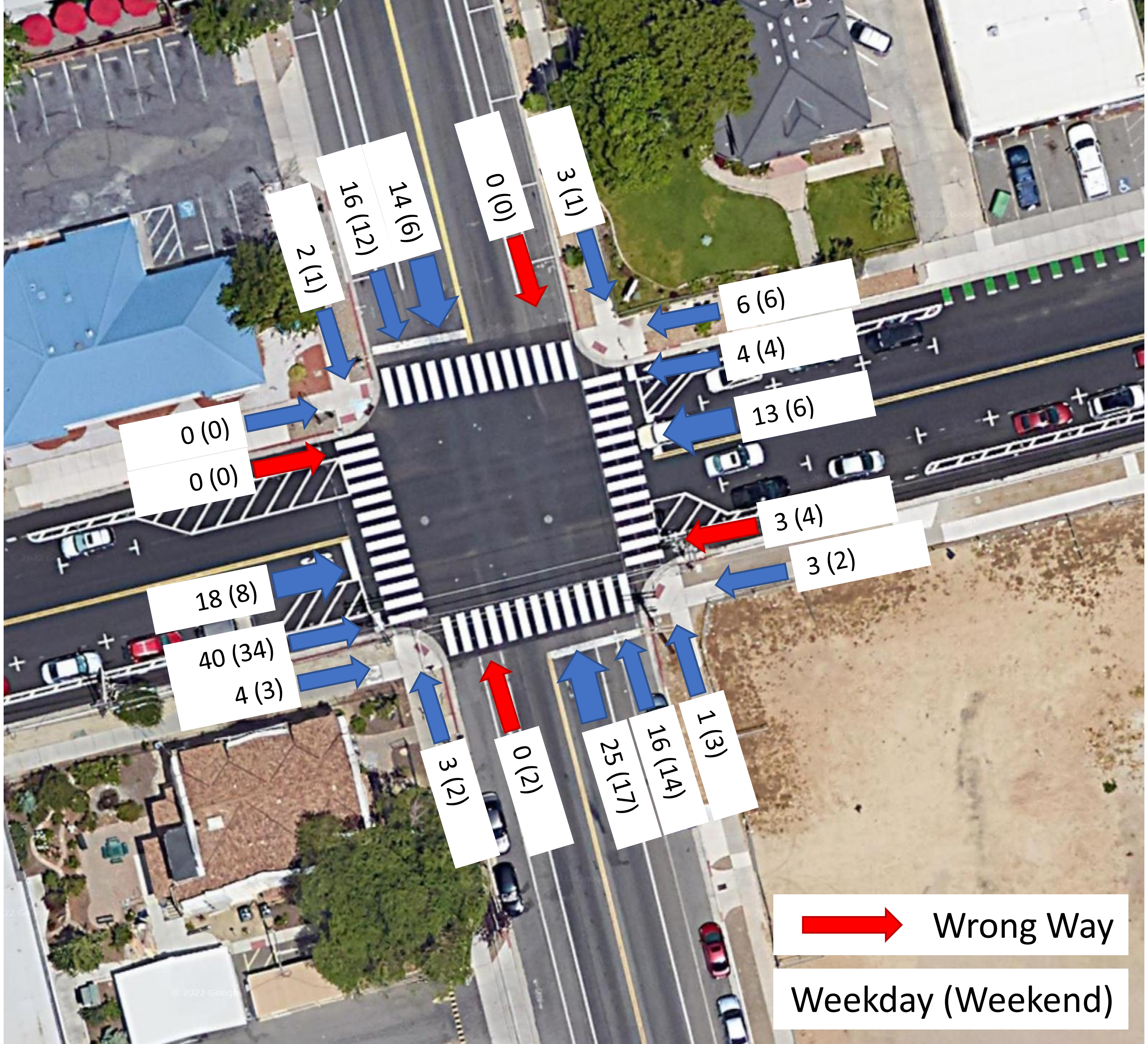
Round 2



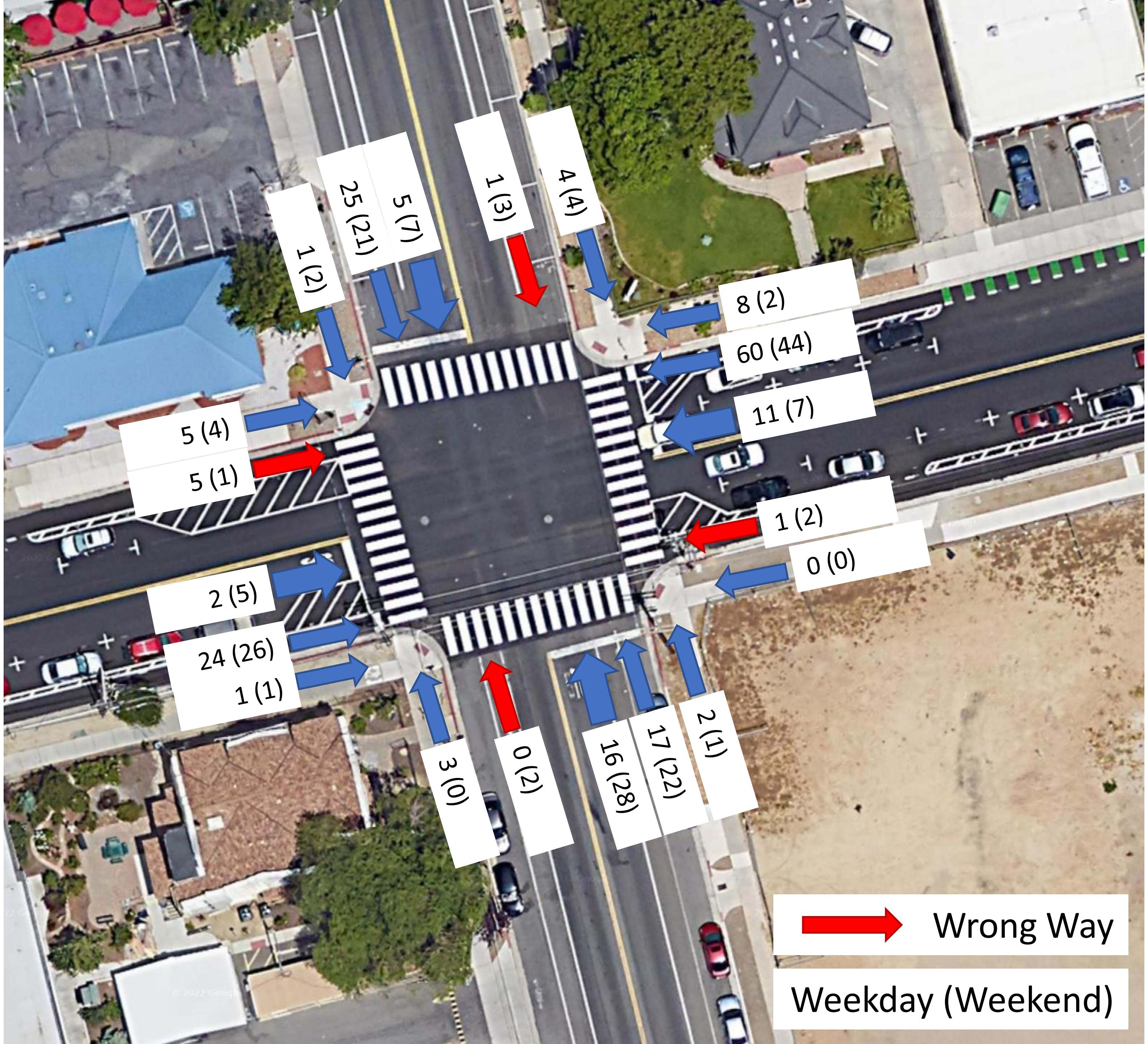
Scooters

Round 3

Bicycles



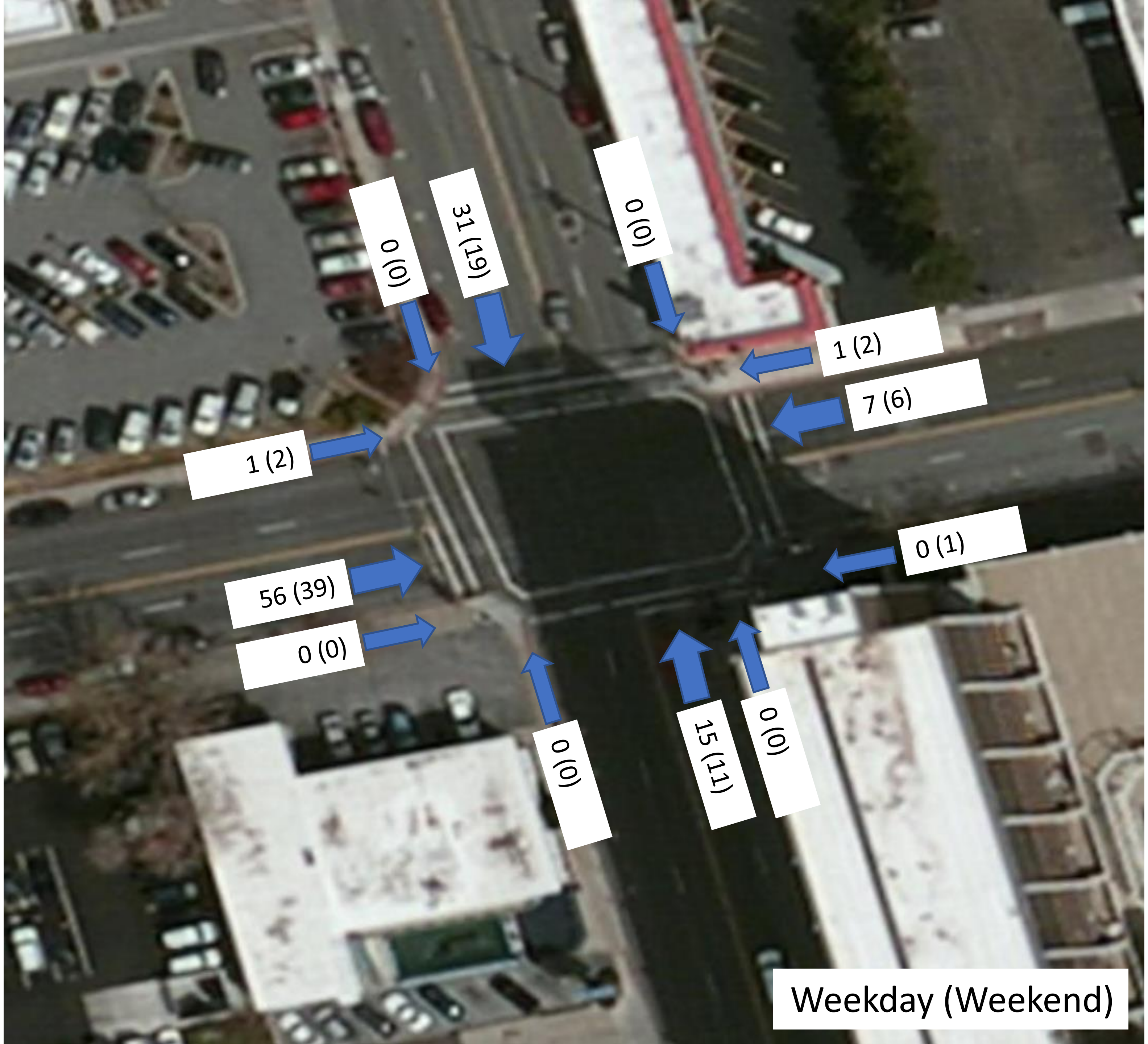
Round 3



Scooters

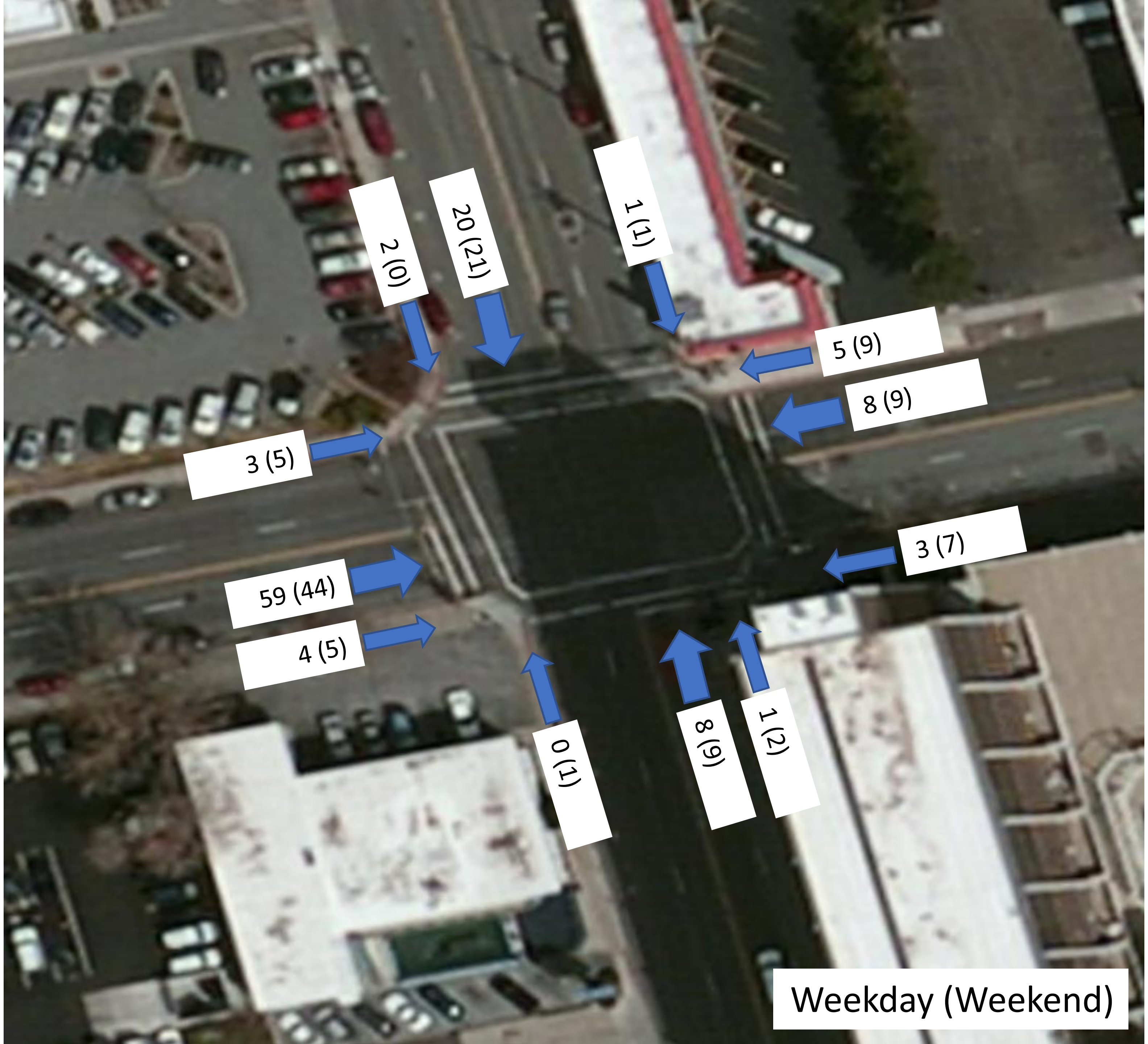
APPENDIX C: 5TH ST AND ARLINGTON AVE MICROMOBILITY

Round 1



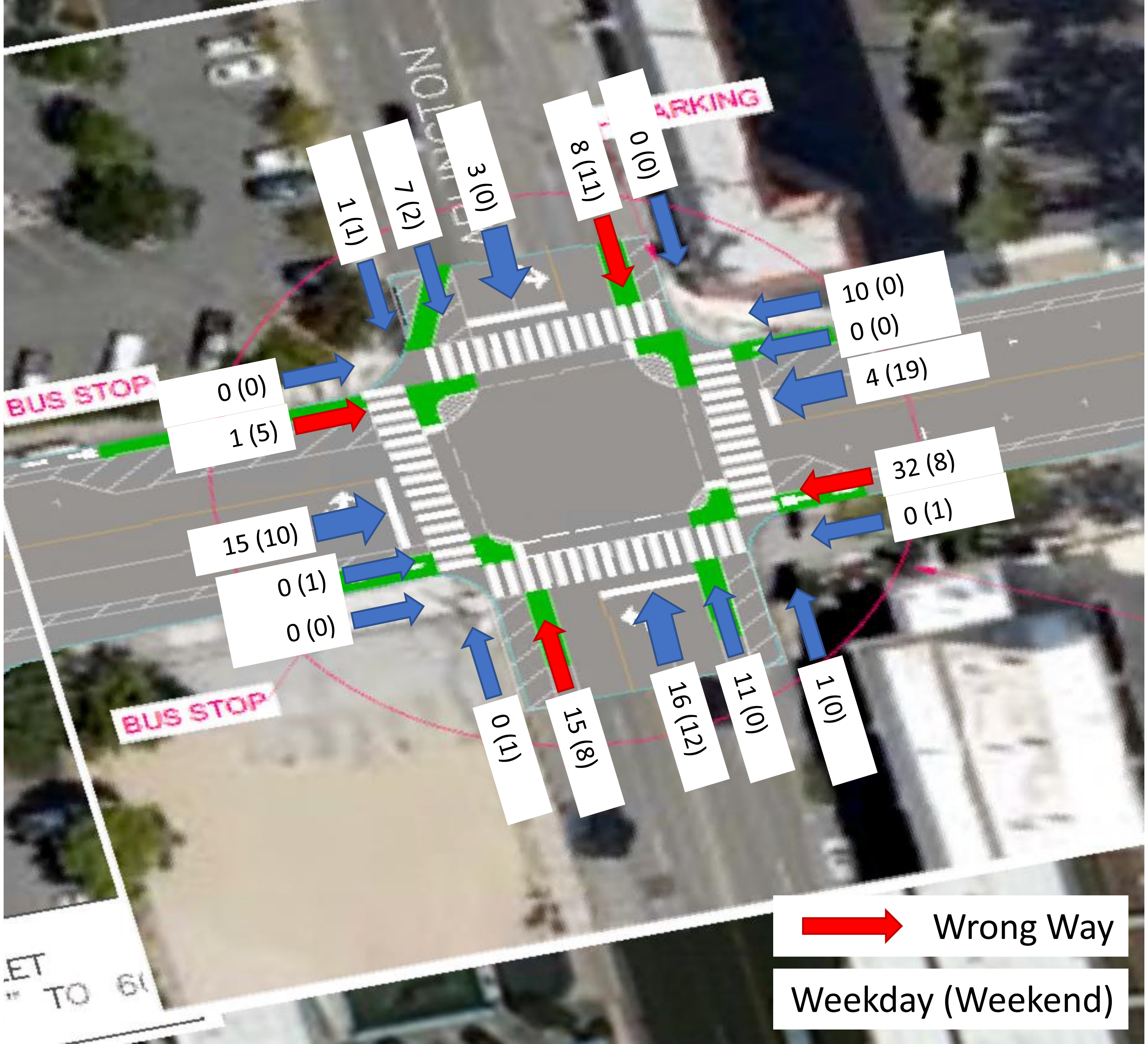
Bicycles

Round 1



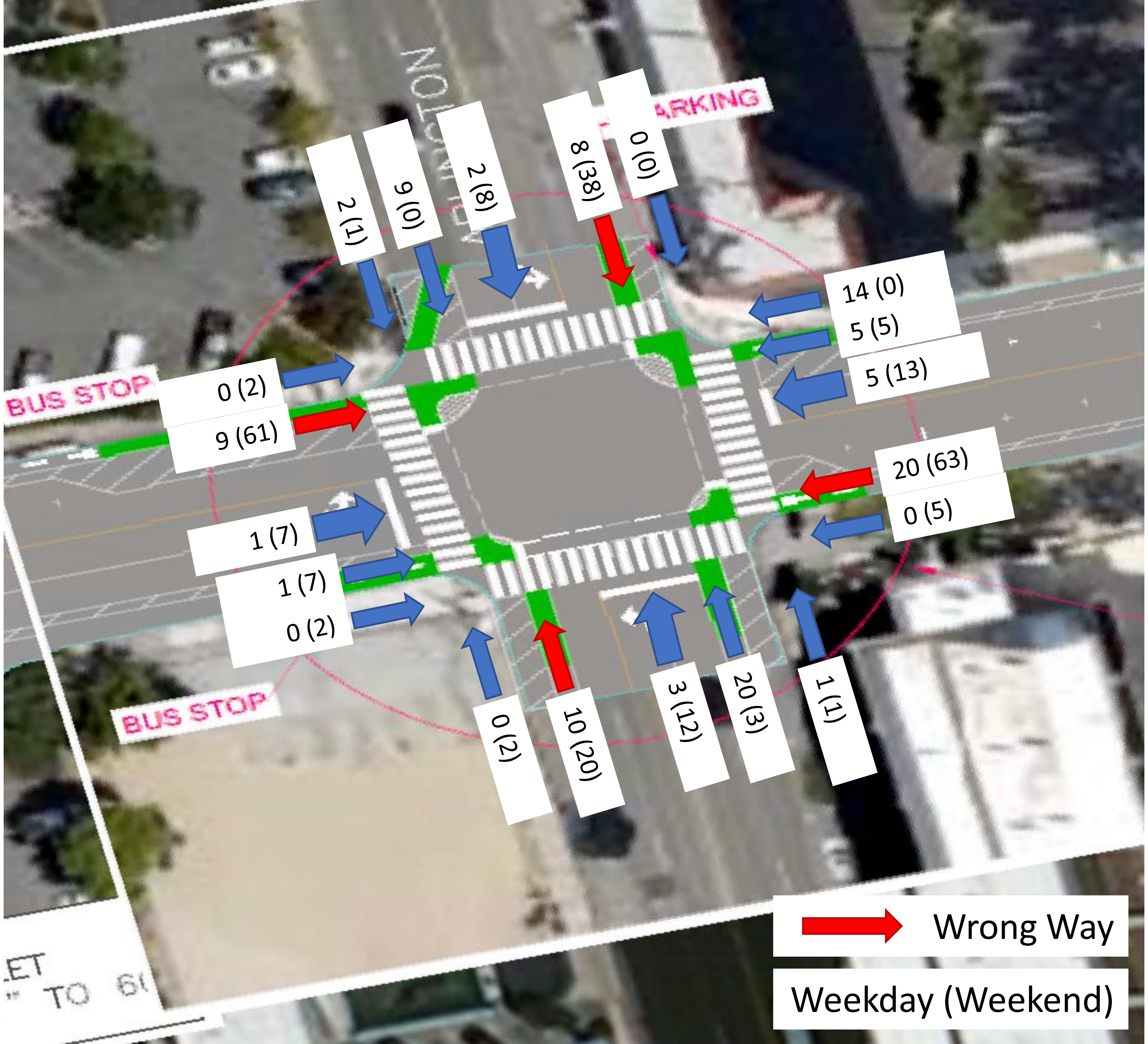
Scooters

Round 2



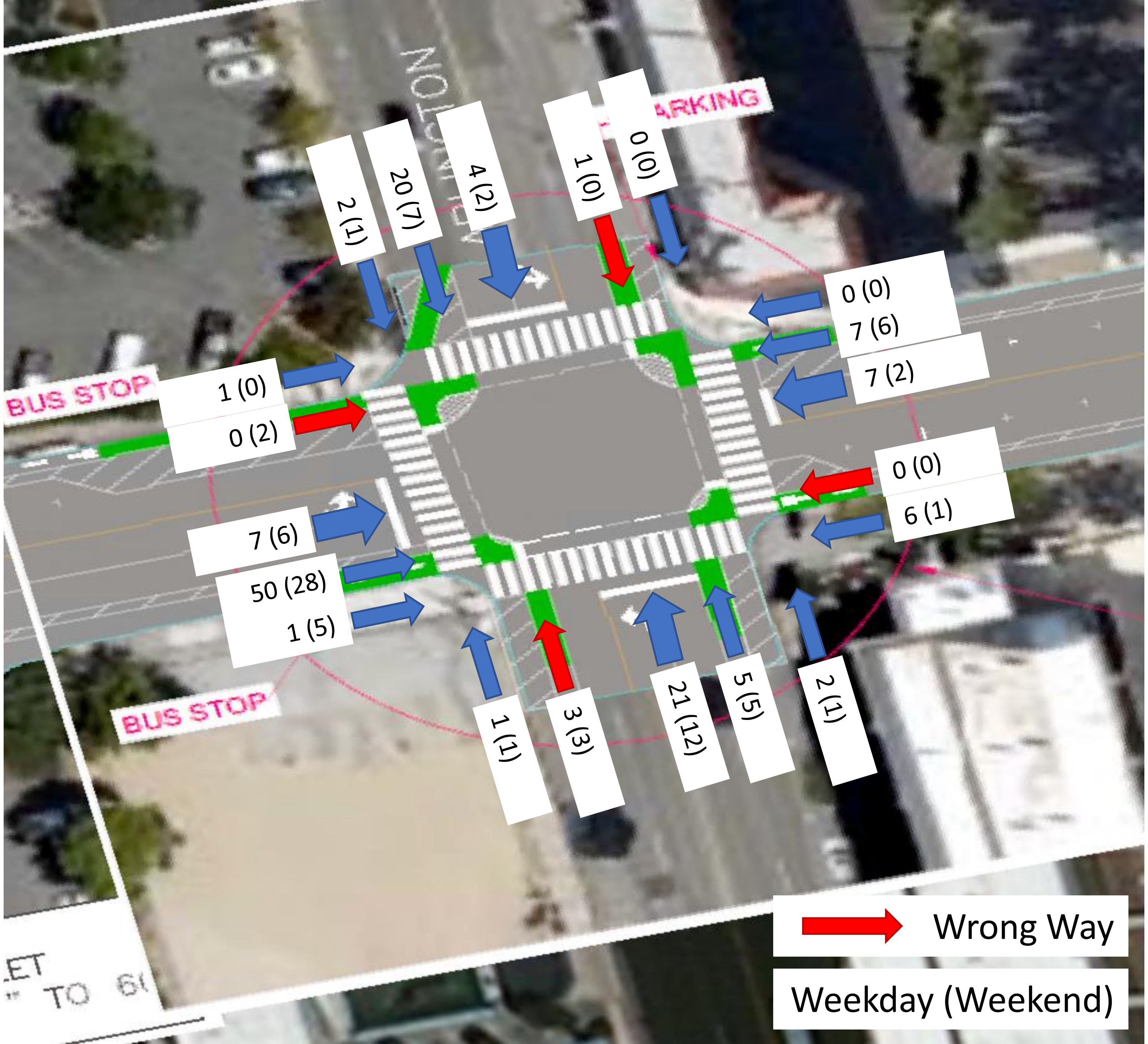
Bicycles

Round 2



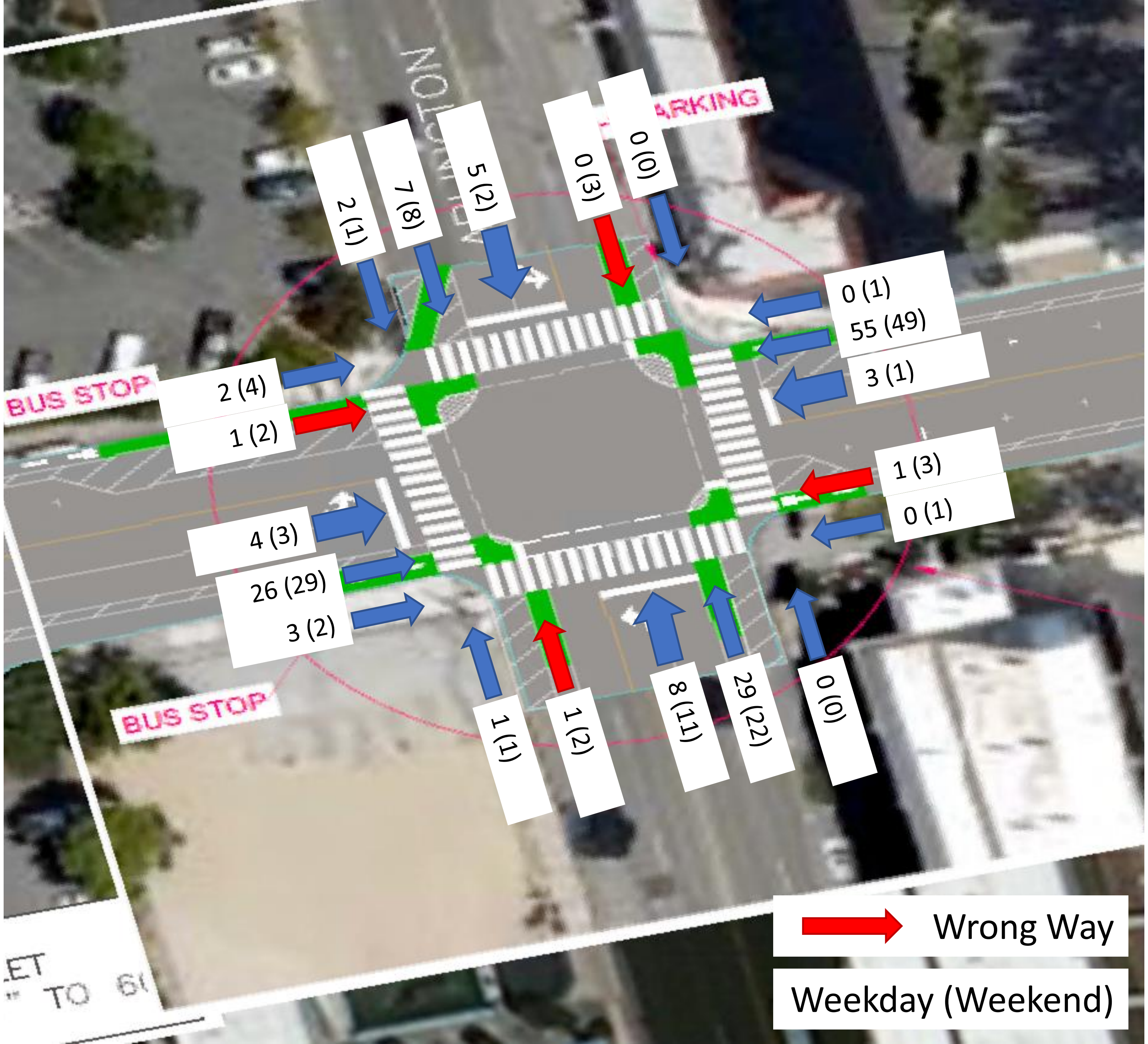
Scooters

Round 3



Bicycles

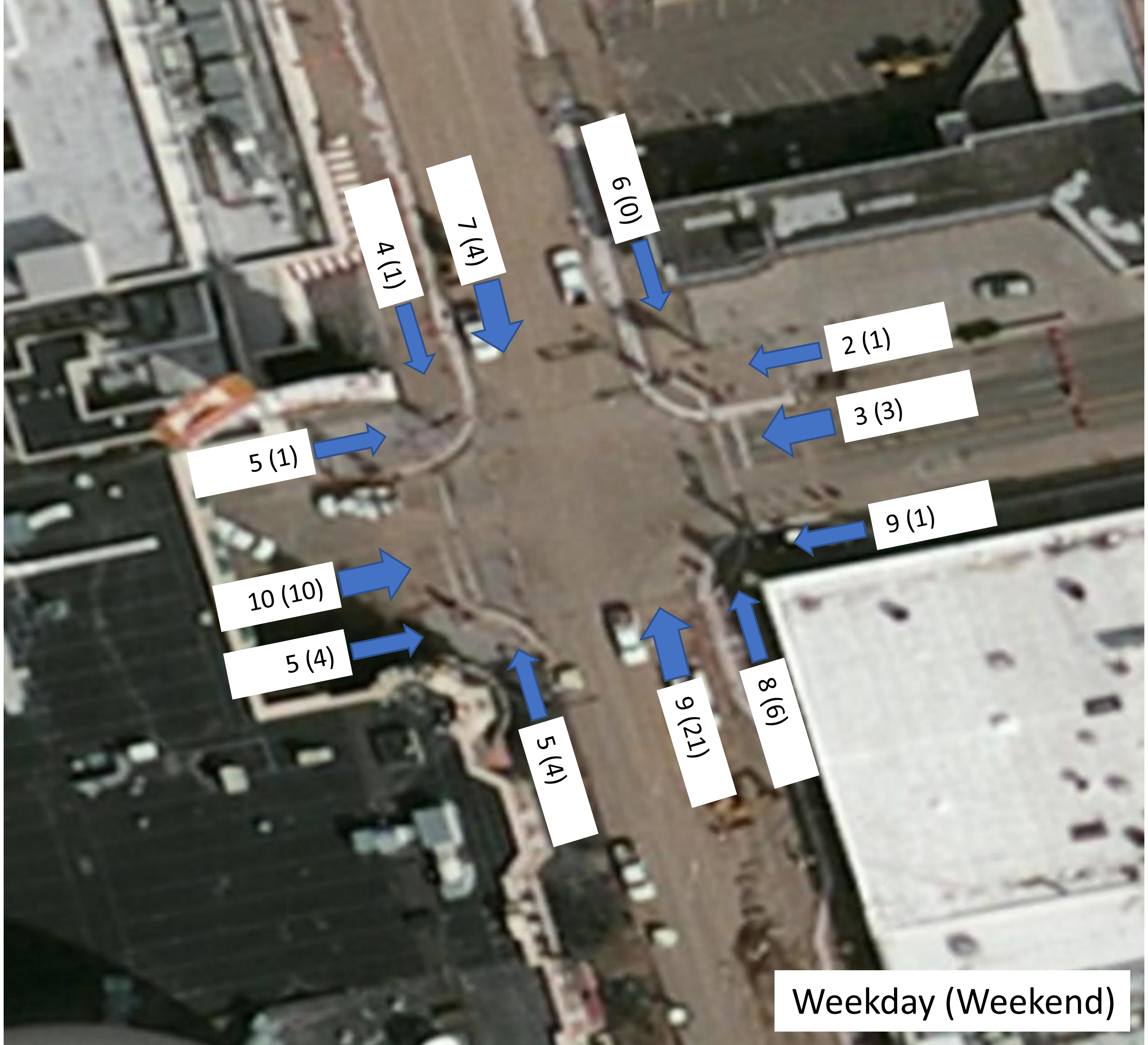
Round 3



Scooters

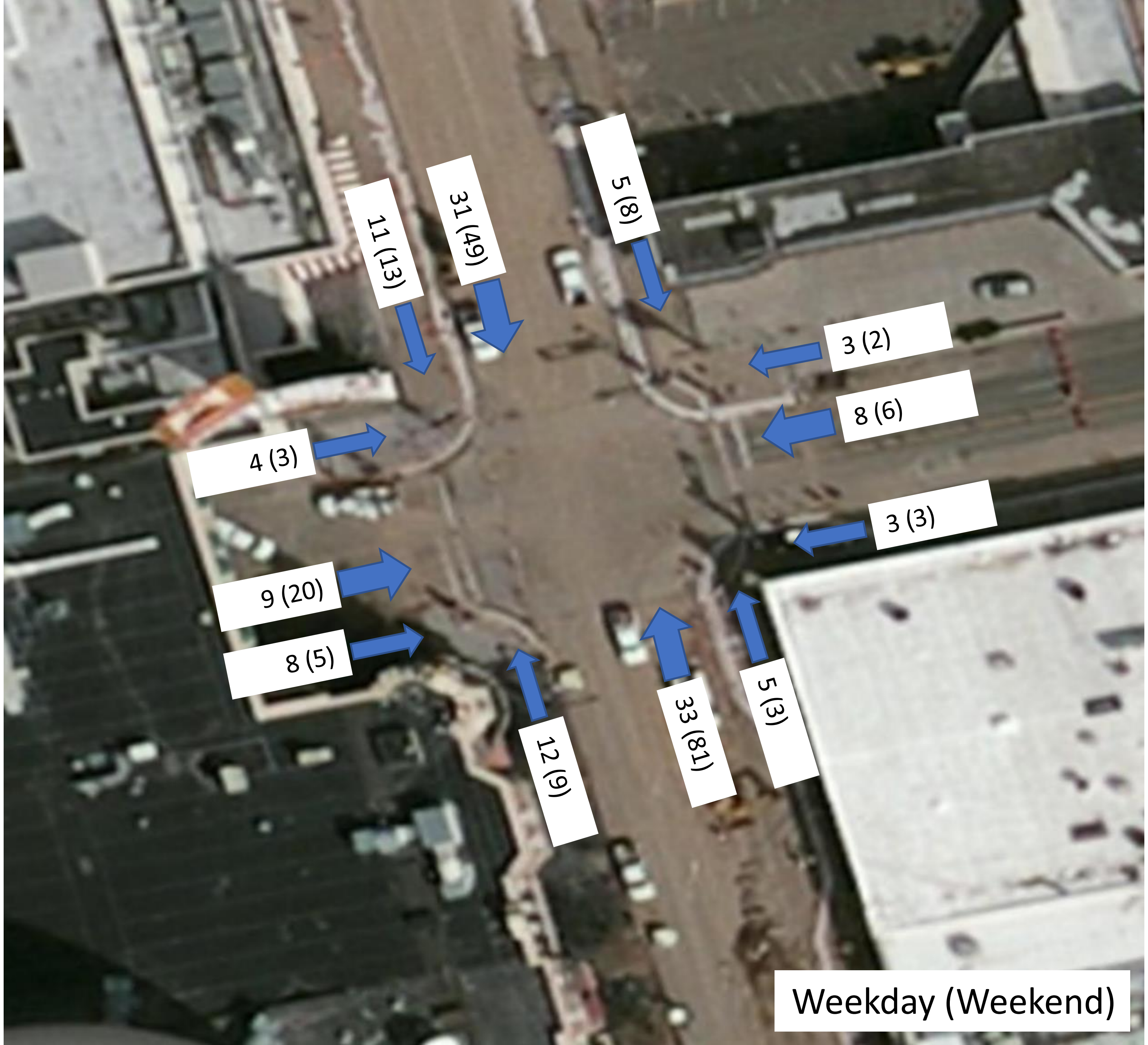
APPENDIX D: VIRGINIA ST AND 5TH ST MICROMOBILITY

Round 1



Bicycles

Round 1



Scooters

Round 2

Bicycles

Round 2

Scooters

Round 3

Bicycles

Round 3

Scooters

APPENDIX E: VIRGINIA ST AND 4TH ST MICROMOBILITY

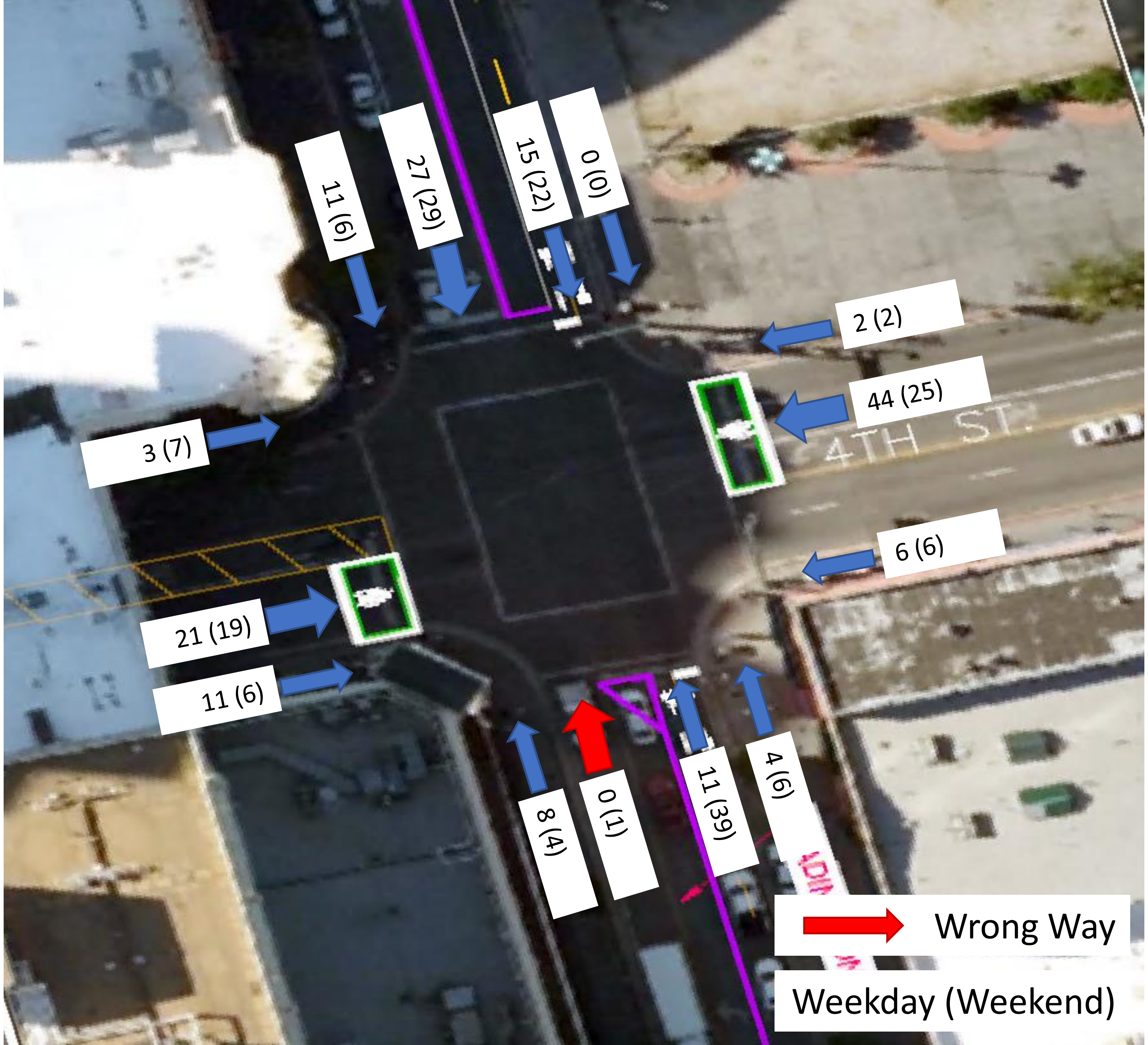
Round 1

Bicycles

Round 1

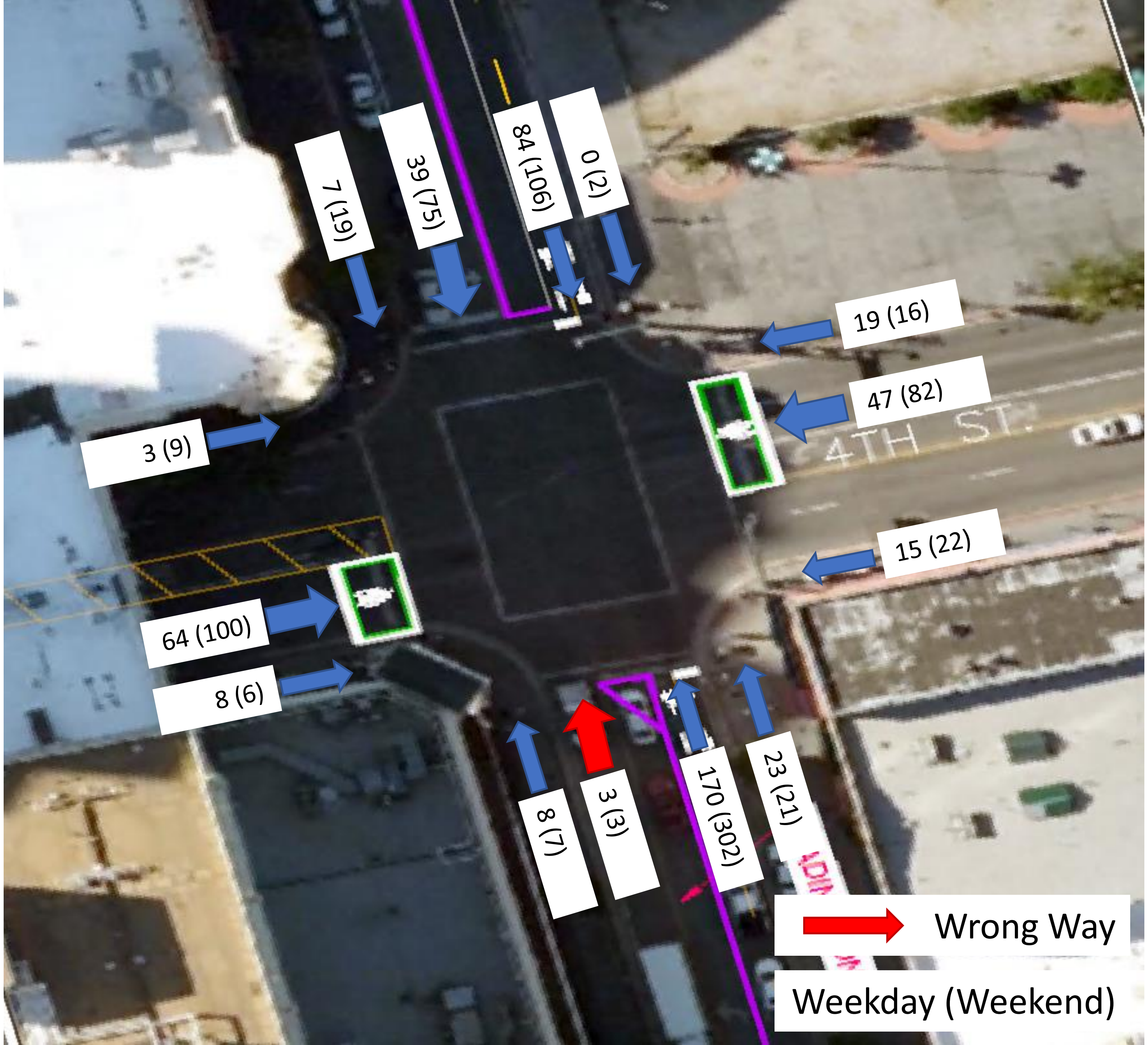
Scooters

Round 2



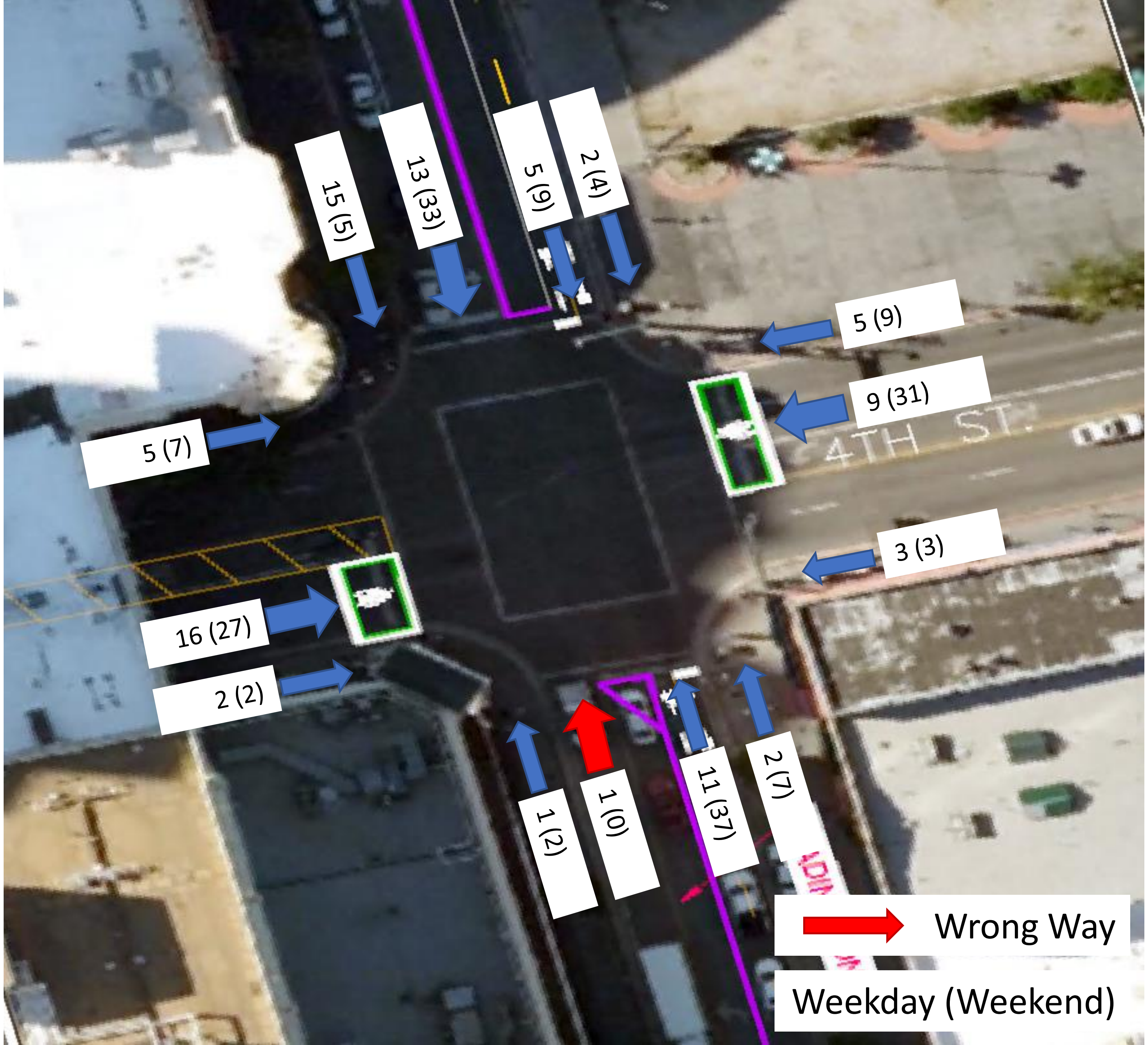
Bicycles

Round 2



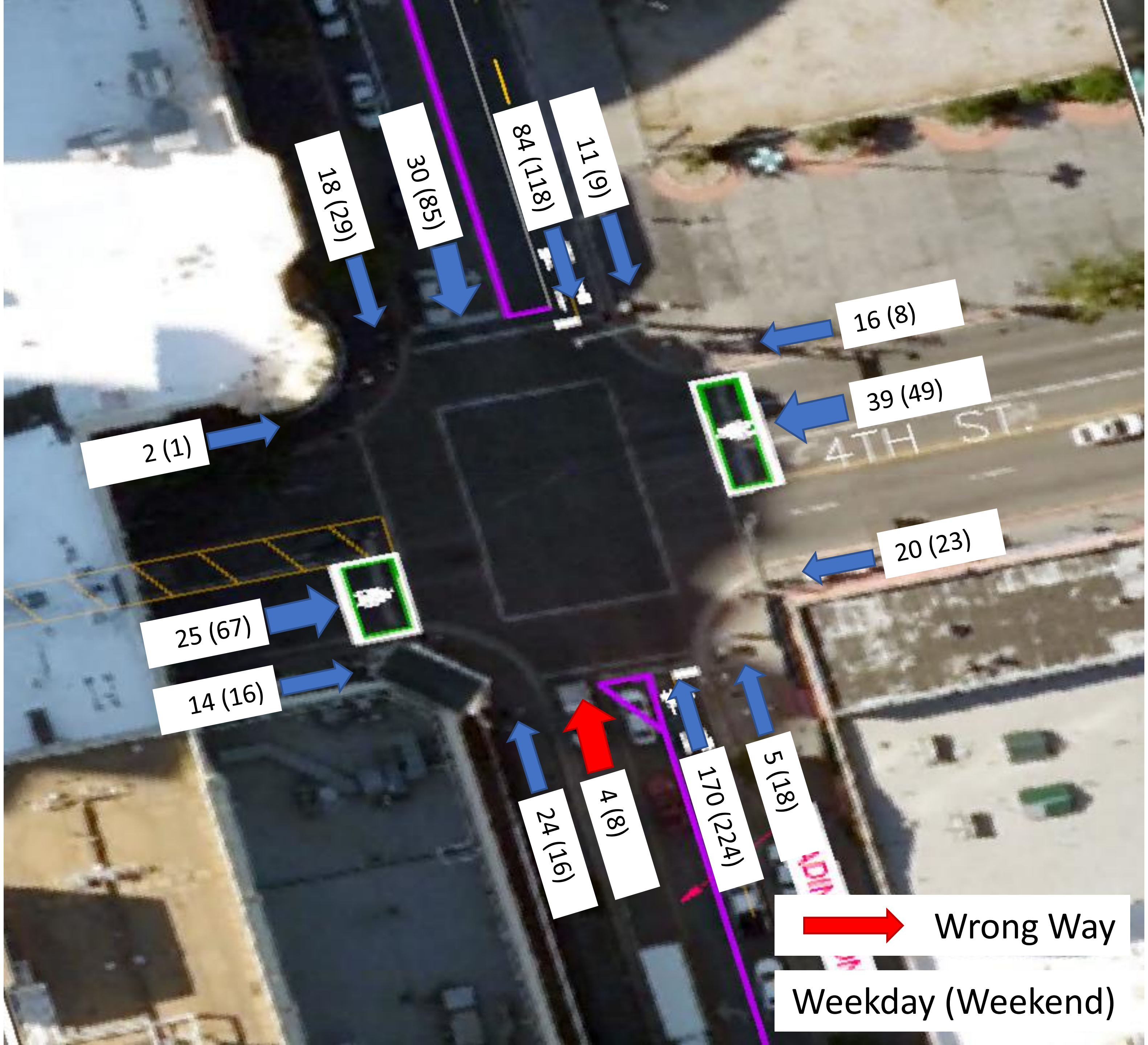
Scooters

Round 3



Bicycles

Round 3

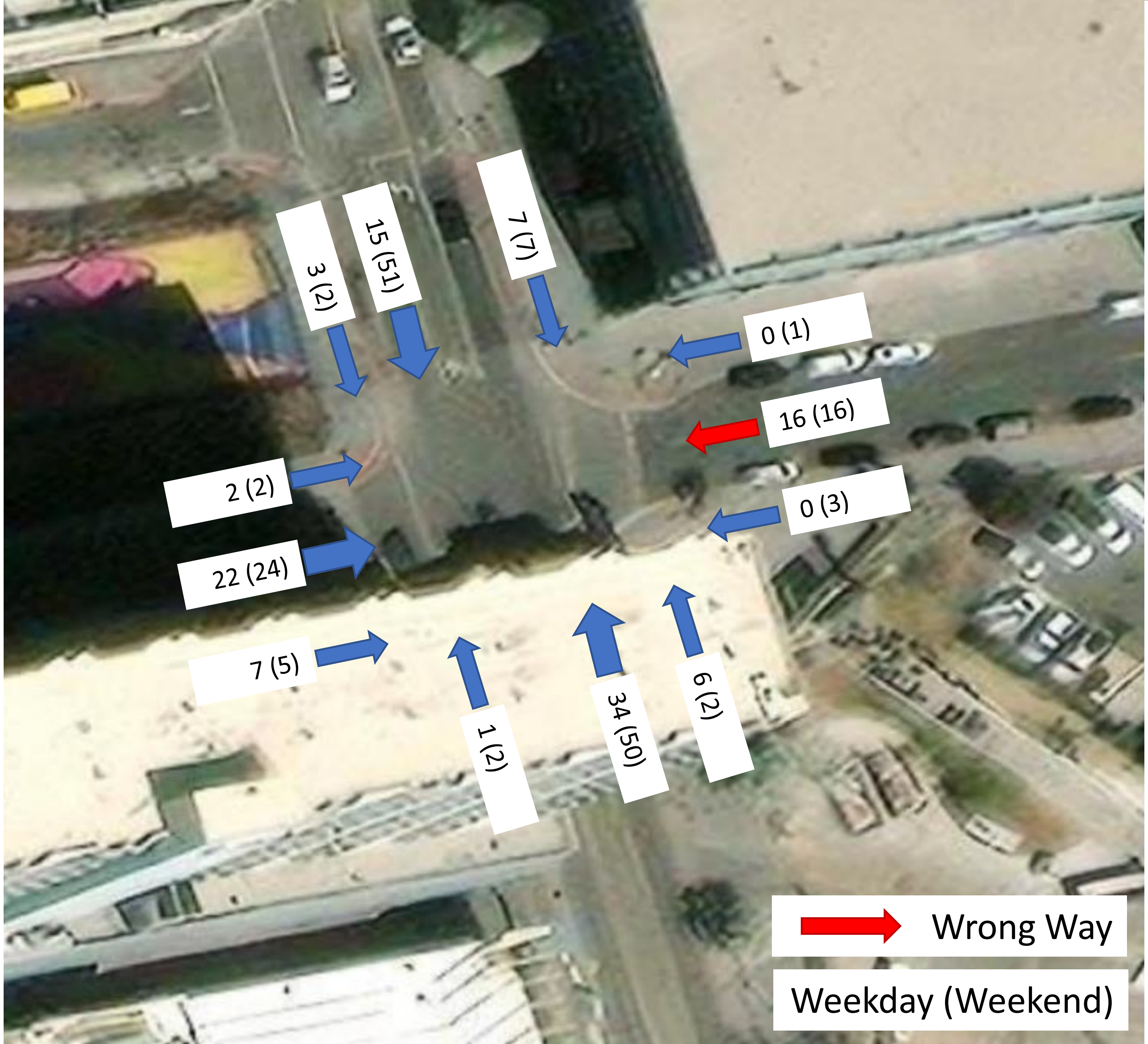


Scooters

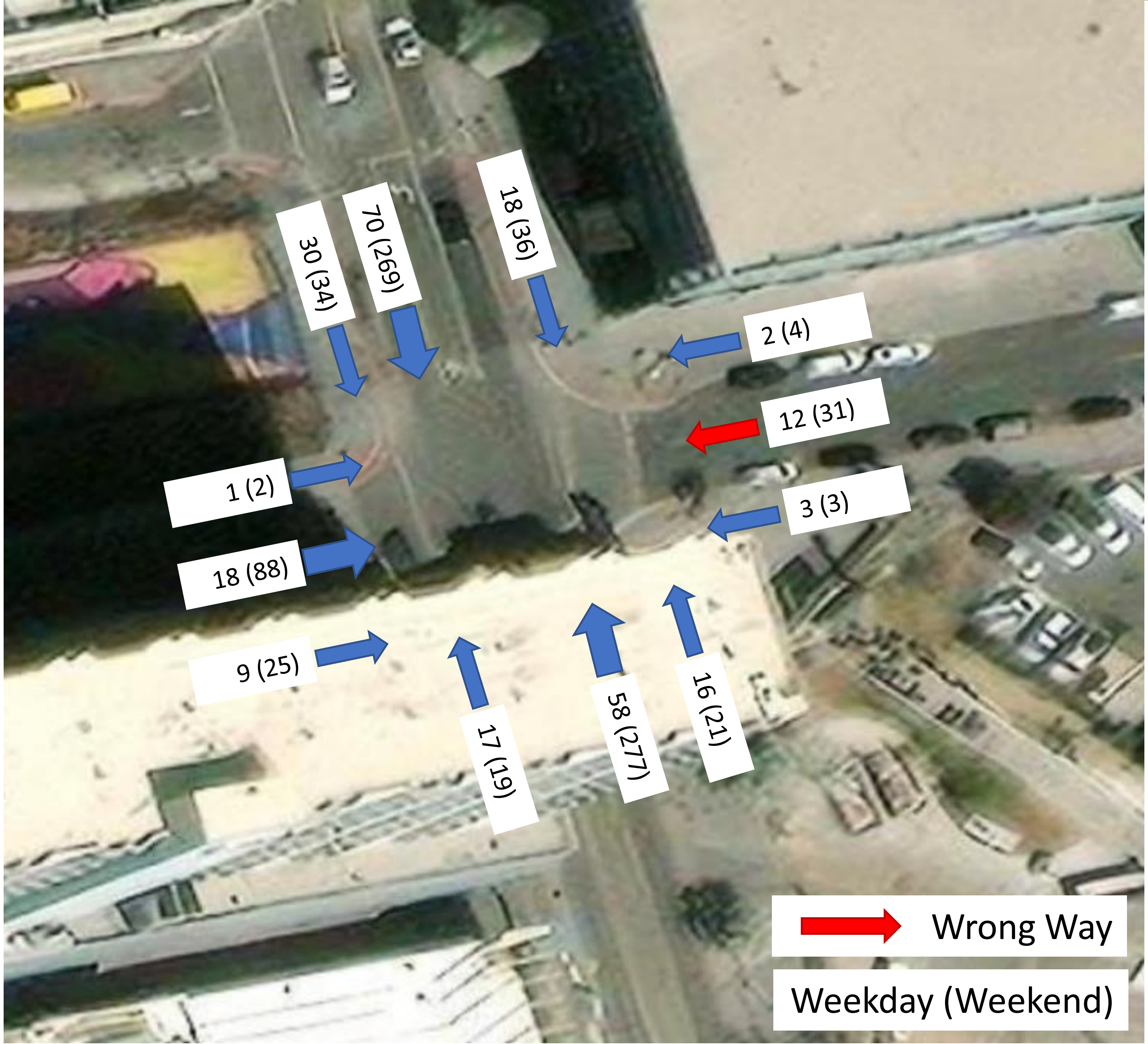
APPENDIX F: VIRGINIA ST AND COMMERCIAL ROW MICROMOBILITY

Round 1

Bicycles

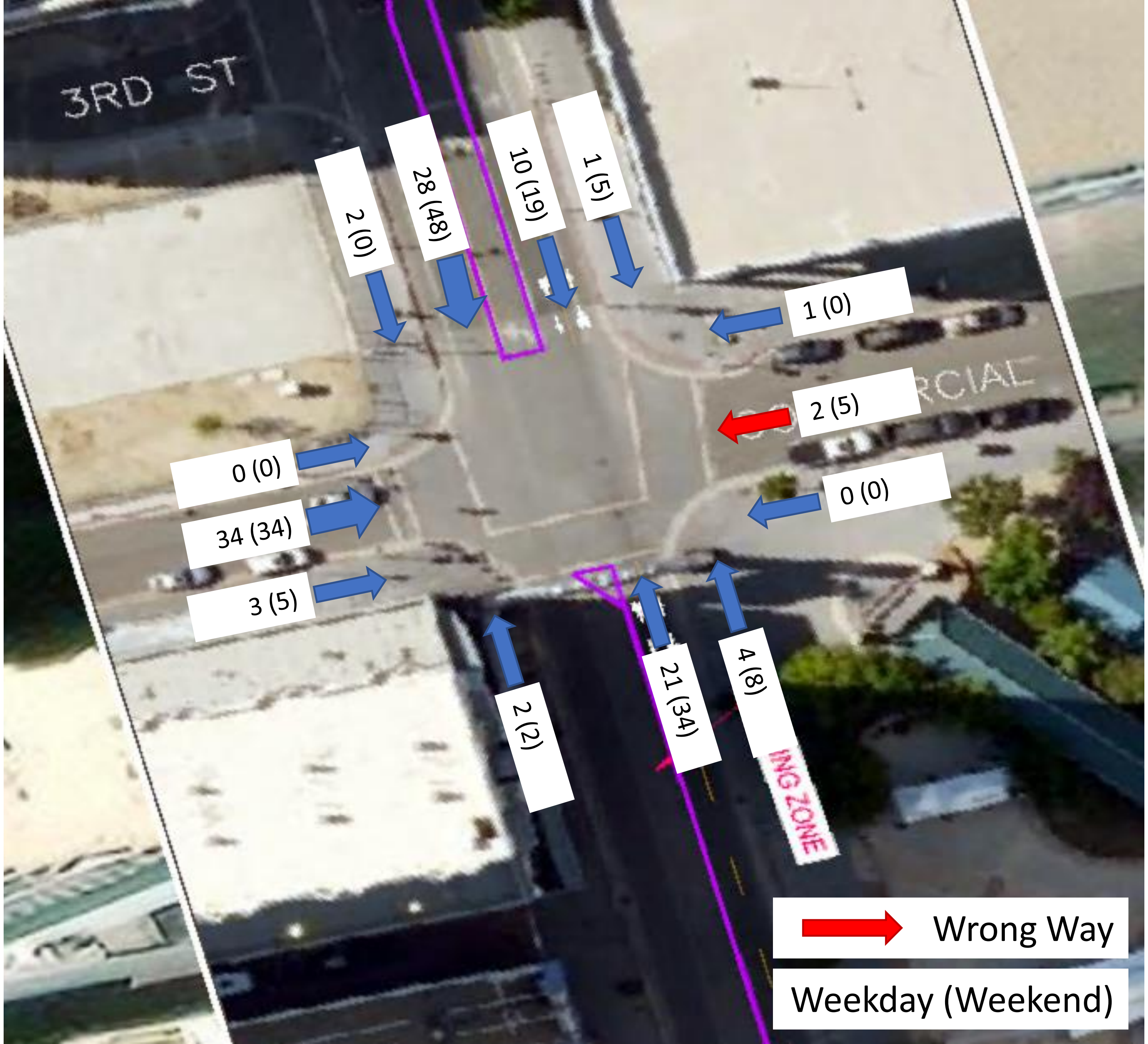


Round 1



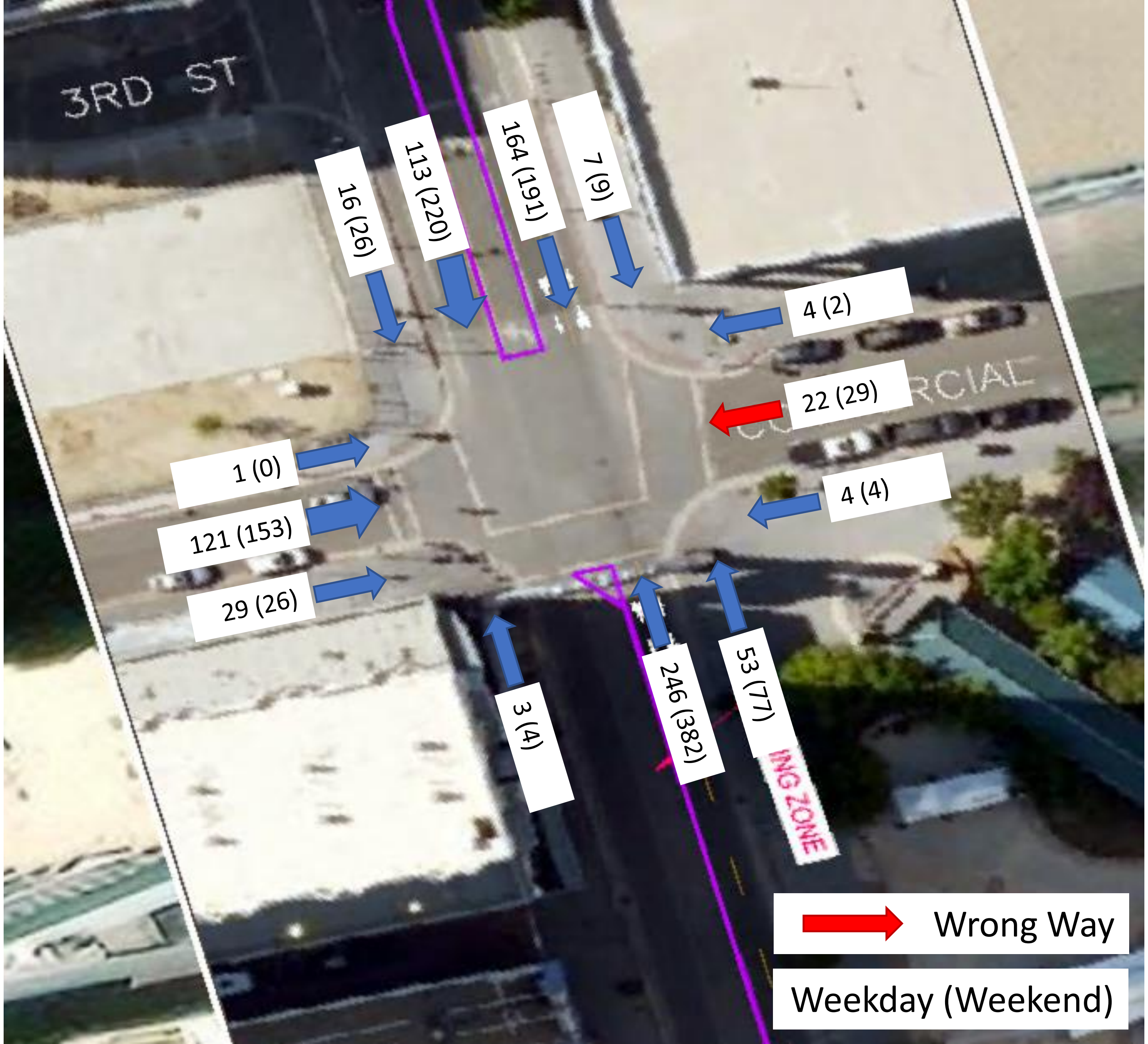
Scooters

Round 2



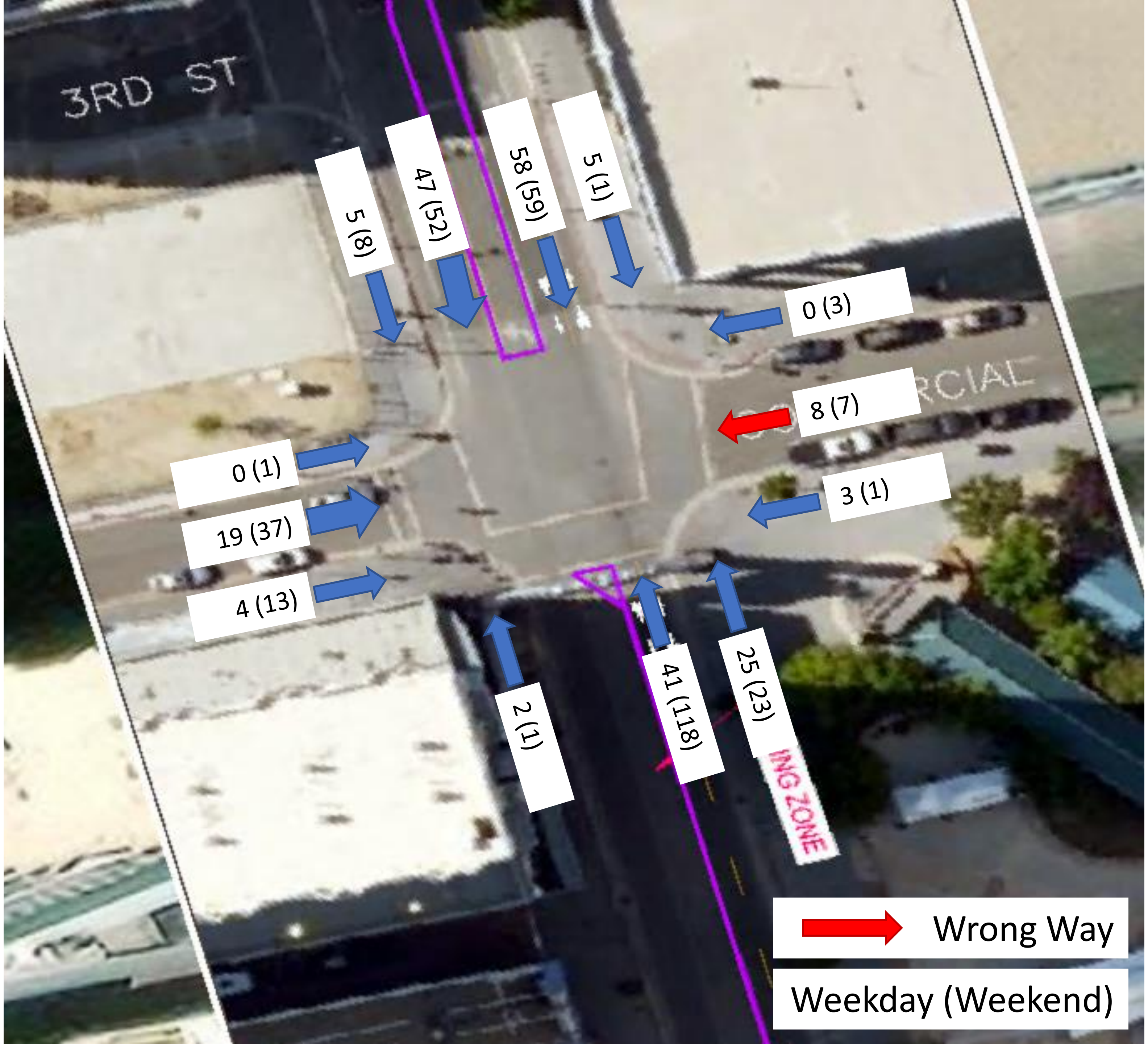
Bicycles

Round 2



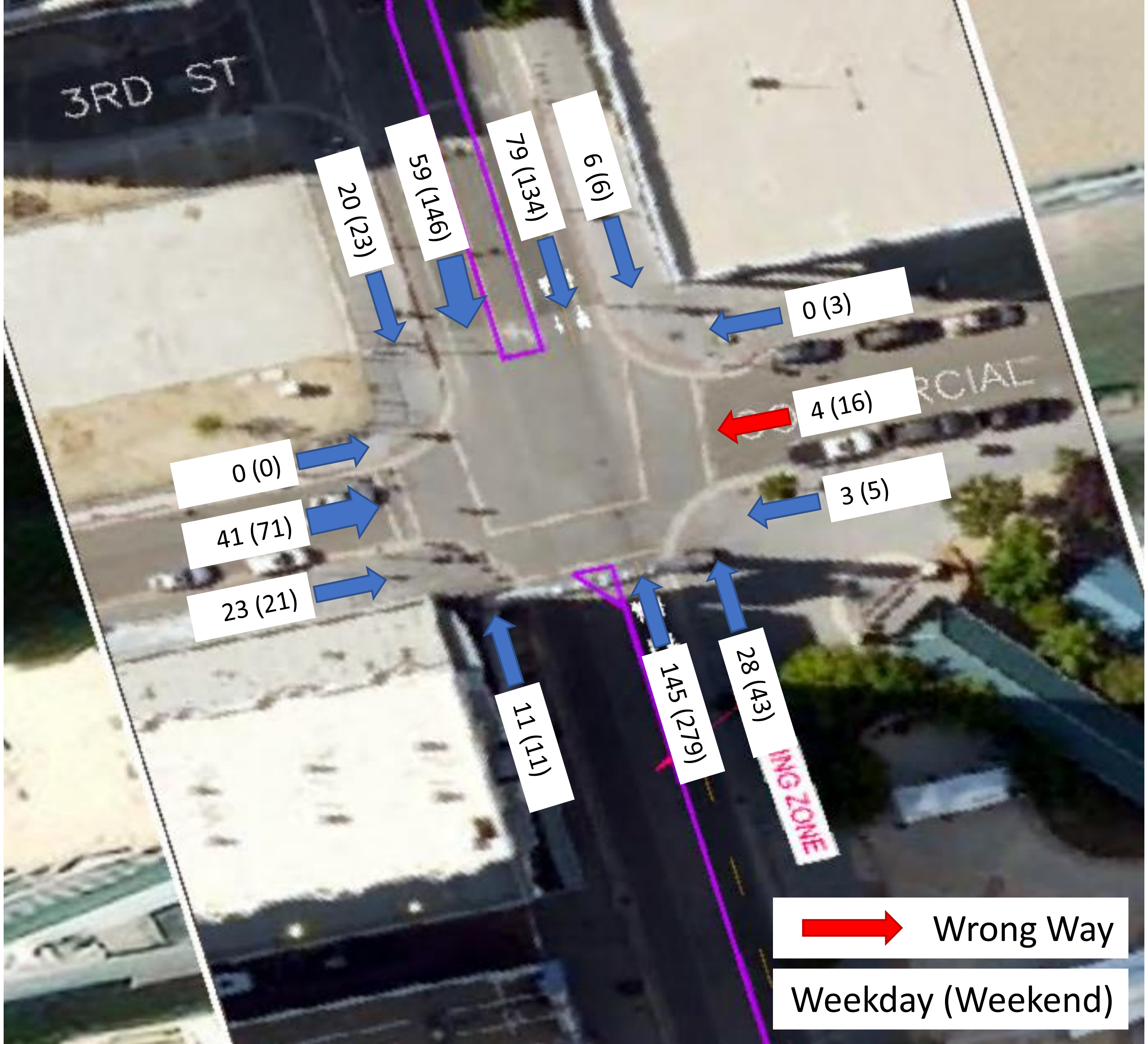
Scooters

Round 3



Bicycles

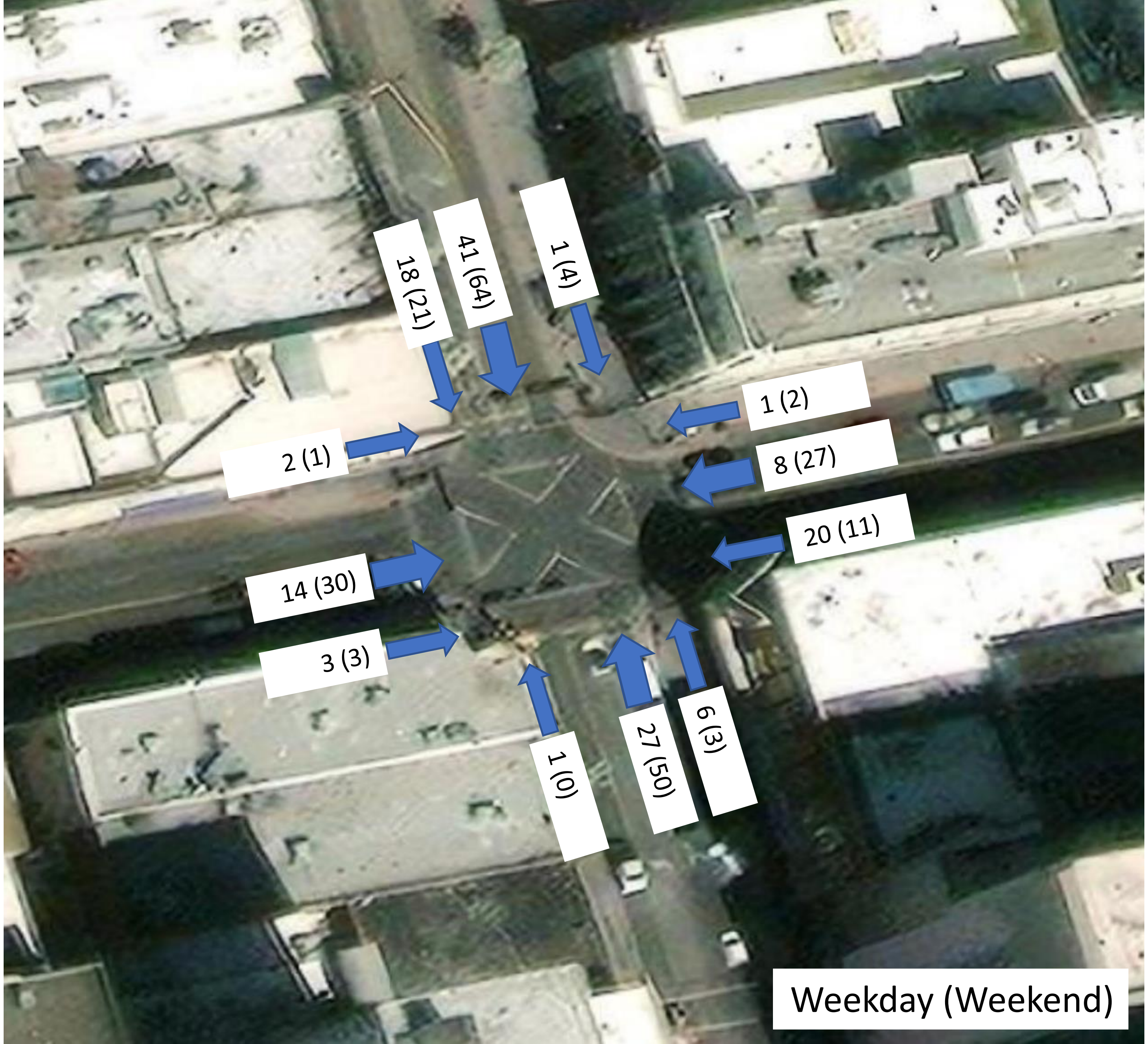
Round 3



Scooters

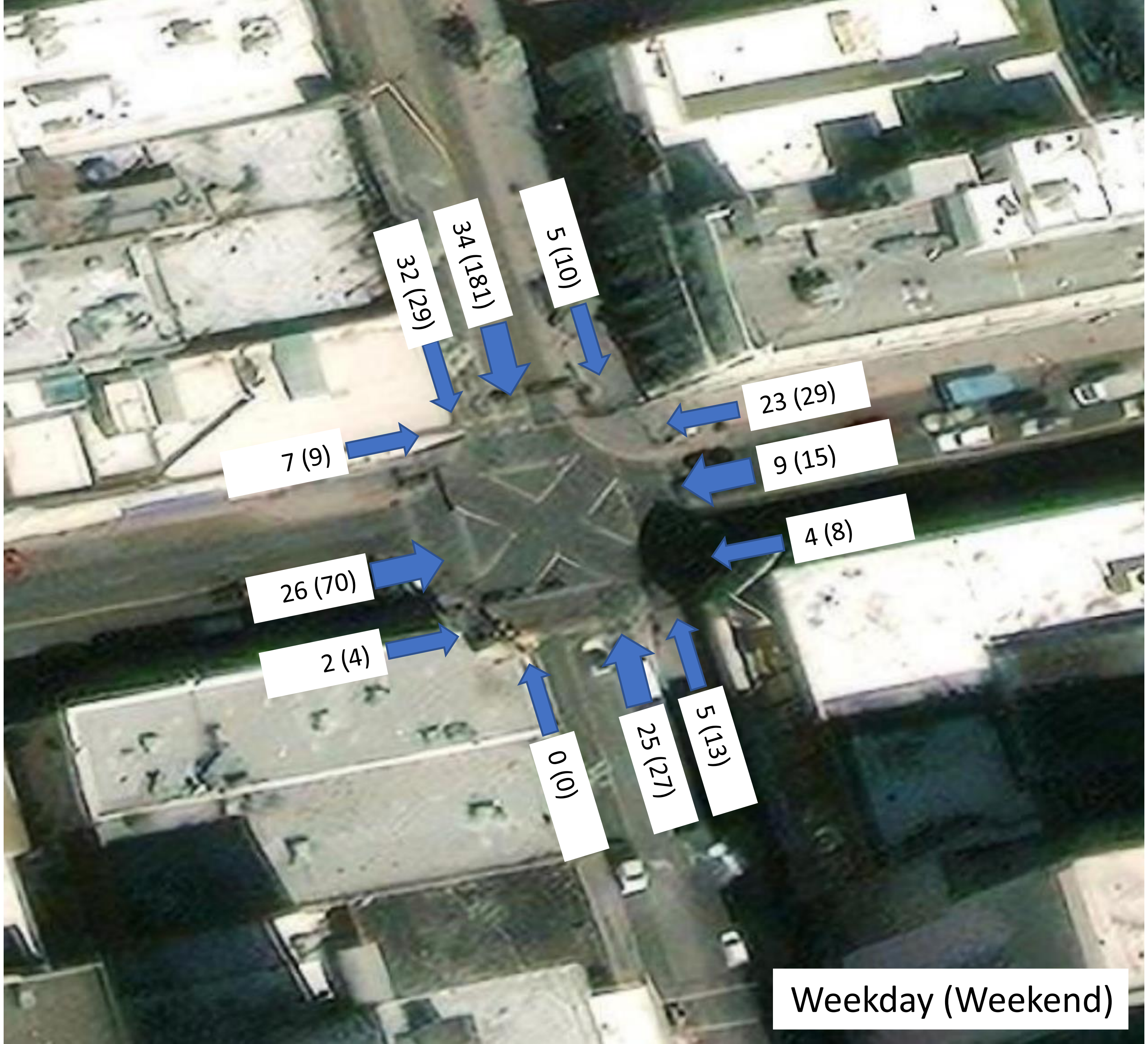
APPENDIX G: VIRGINIA ST AND 2ND ST MICROMOBILITY

Round 1



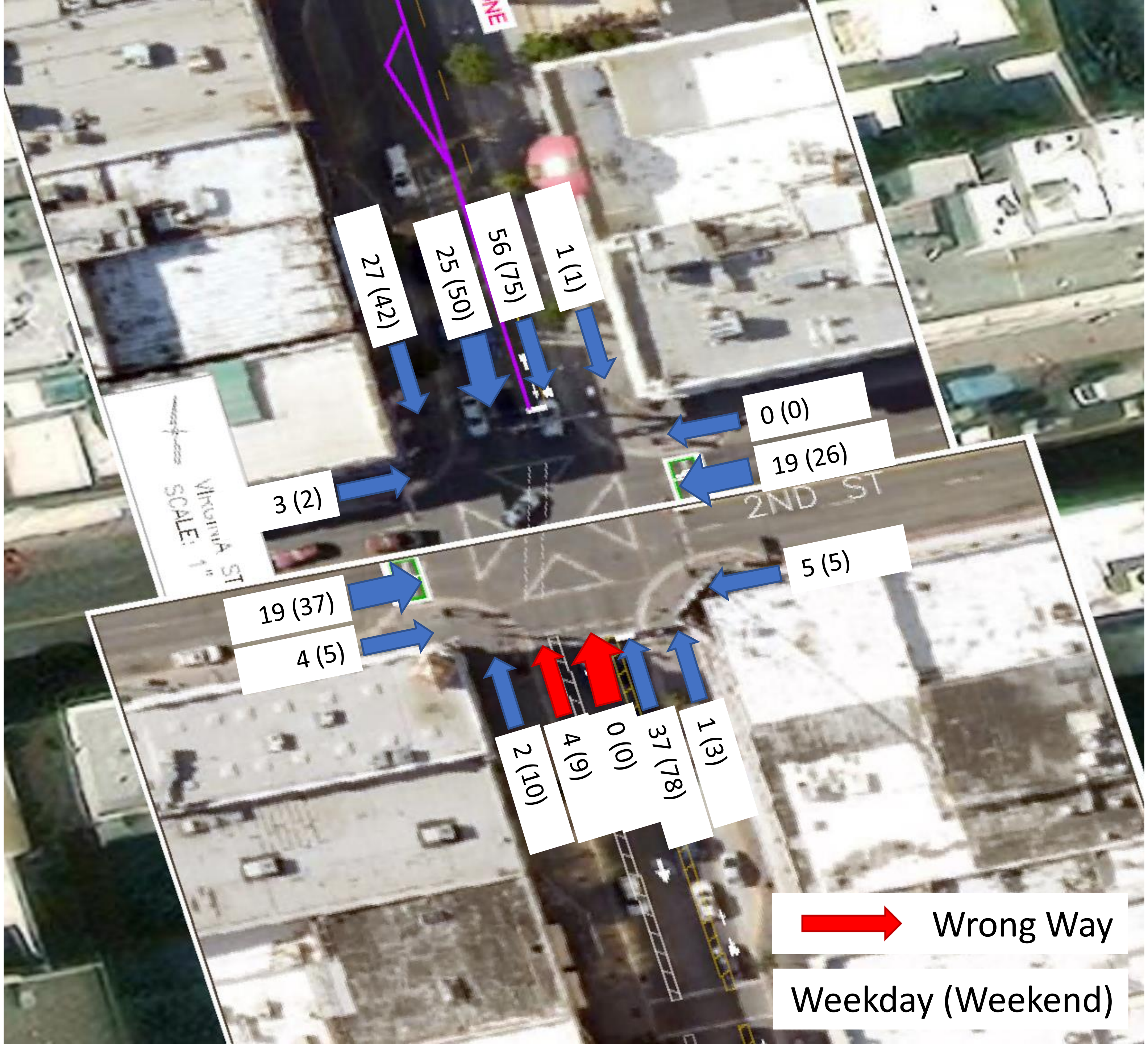
Bicycles

Round 1



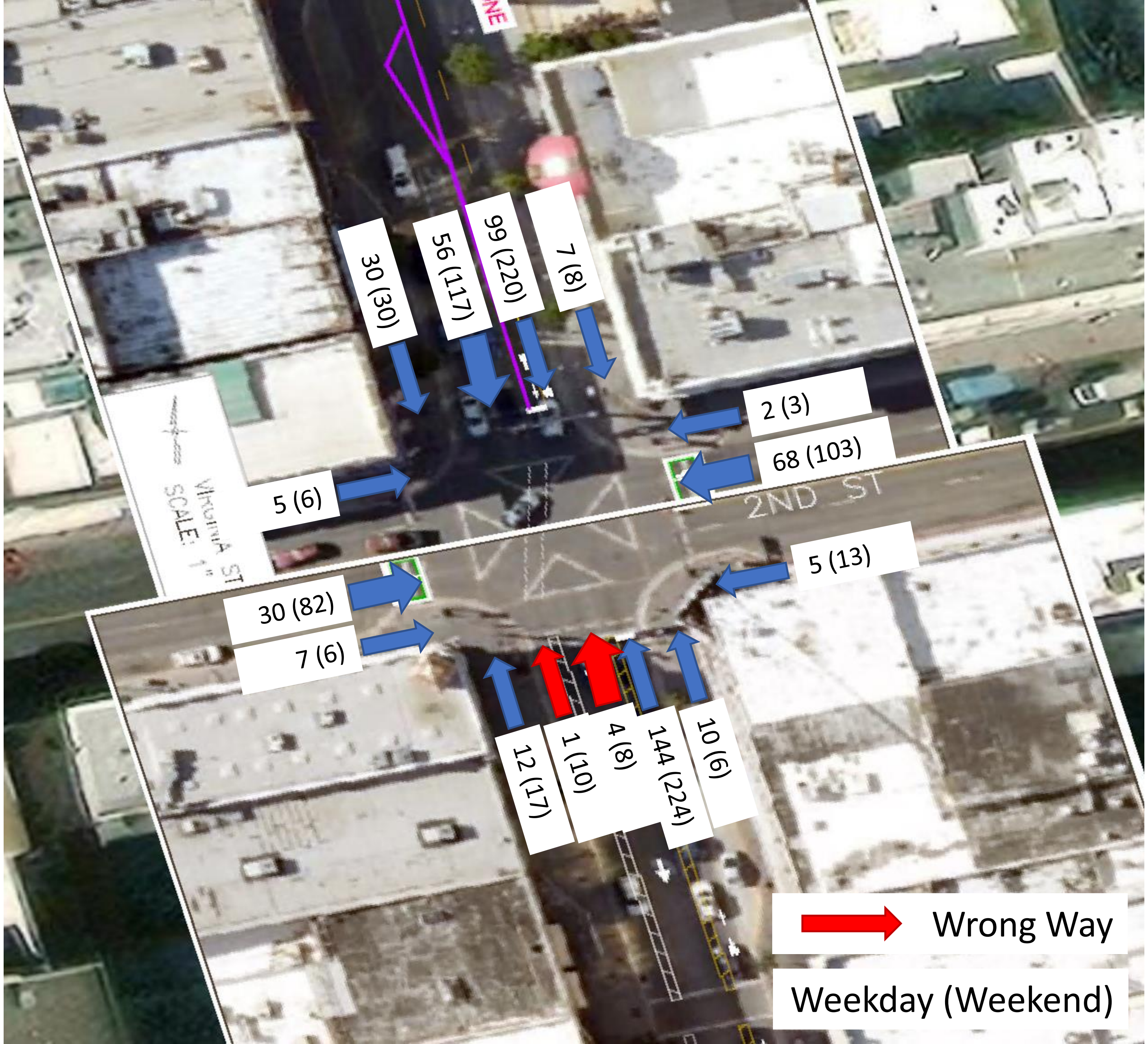
Scooters

Round 2



Bicycles

Round 2



Scooters

Round 3

Bicycles

Round 3

Scooters

APPENDIX H: VIRGINIA ST AND TRUCKEE RIVER WALK MICROMOBILITY

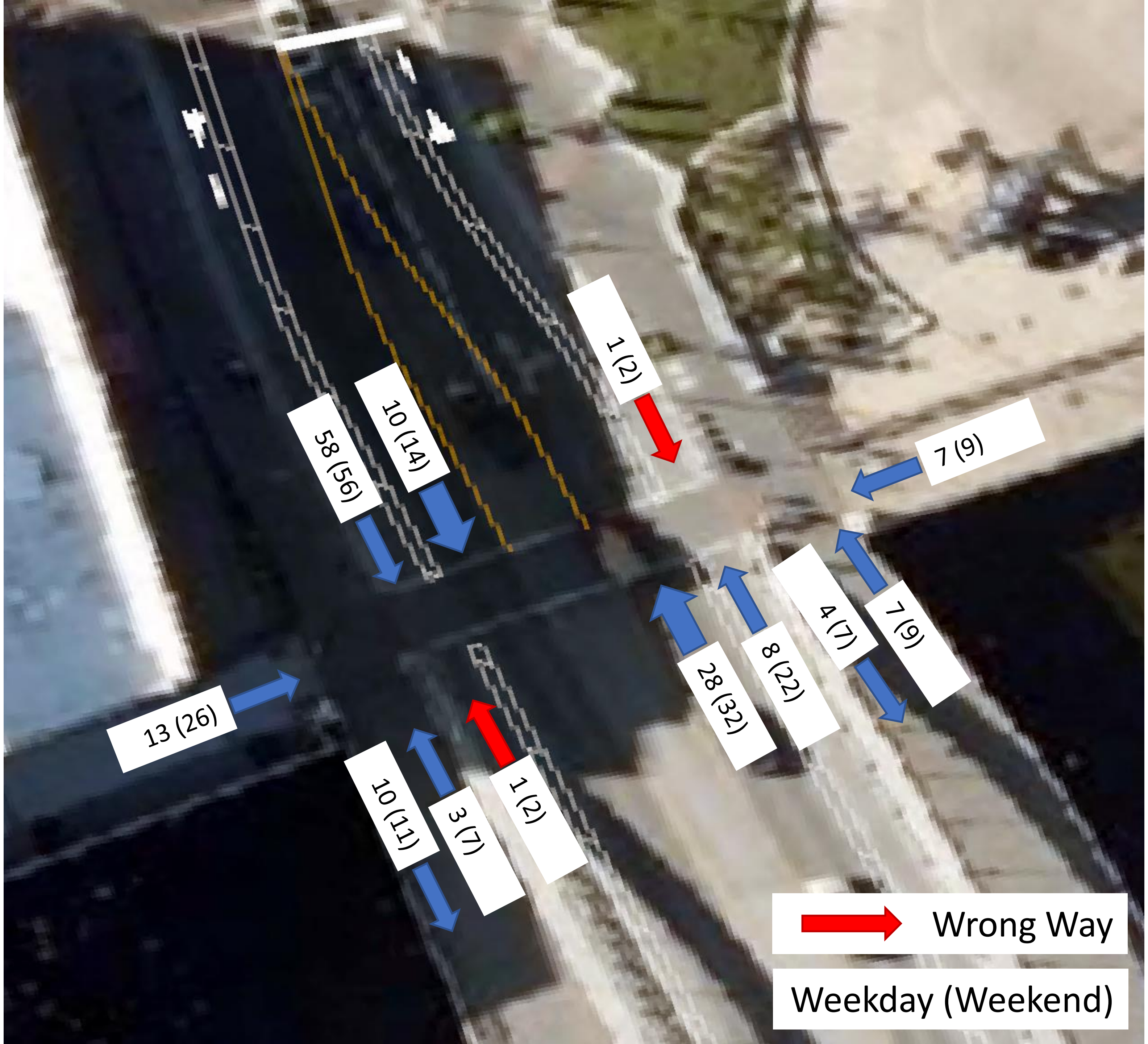
Round 1

Bicycles

Round 1

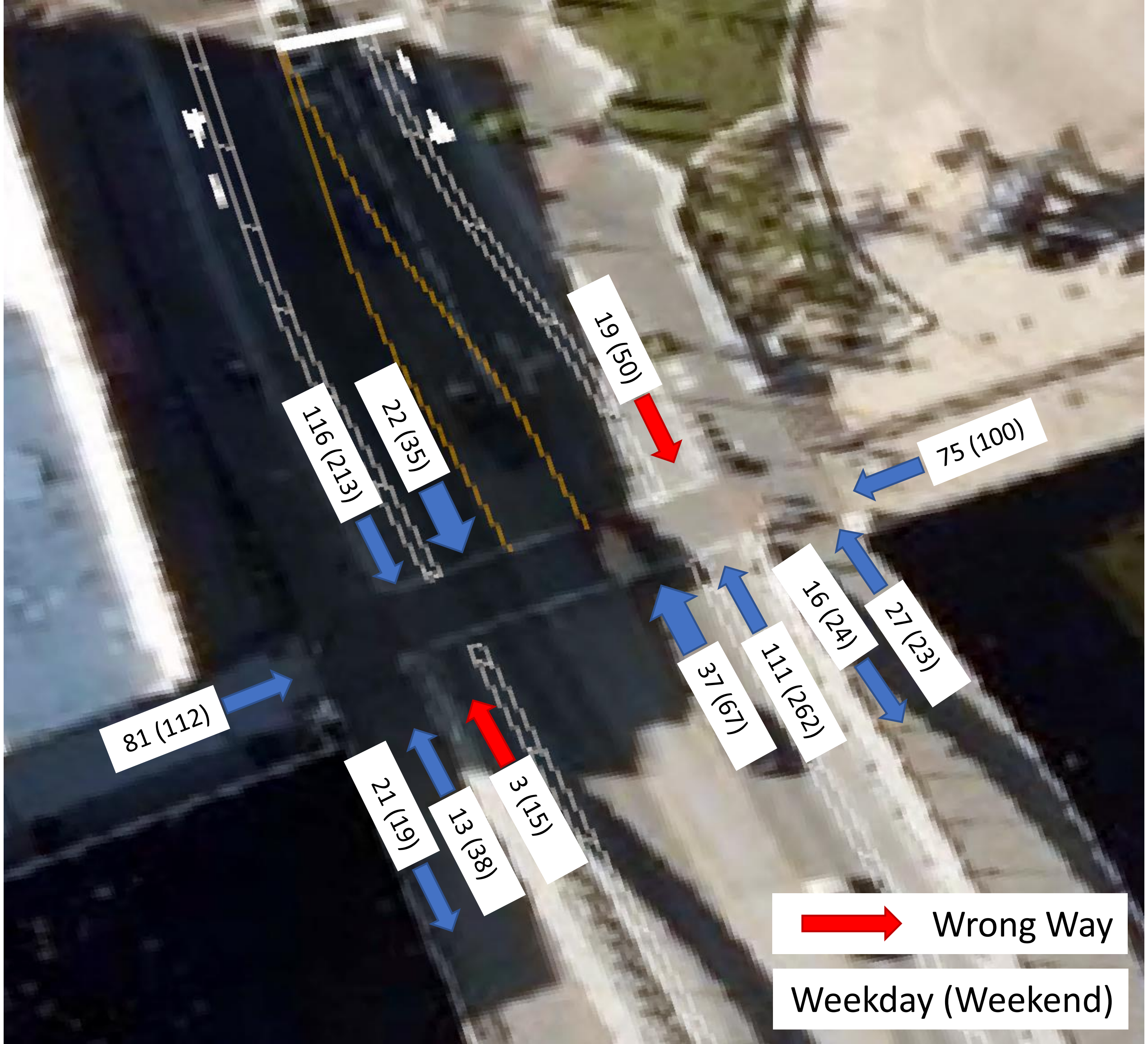
Scooters

Round 2



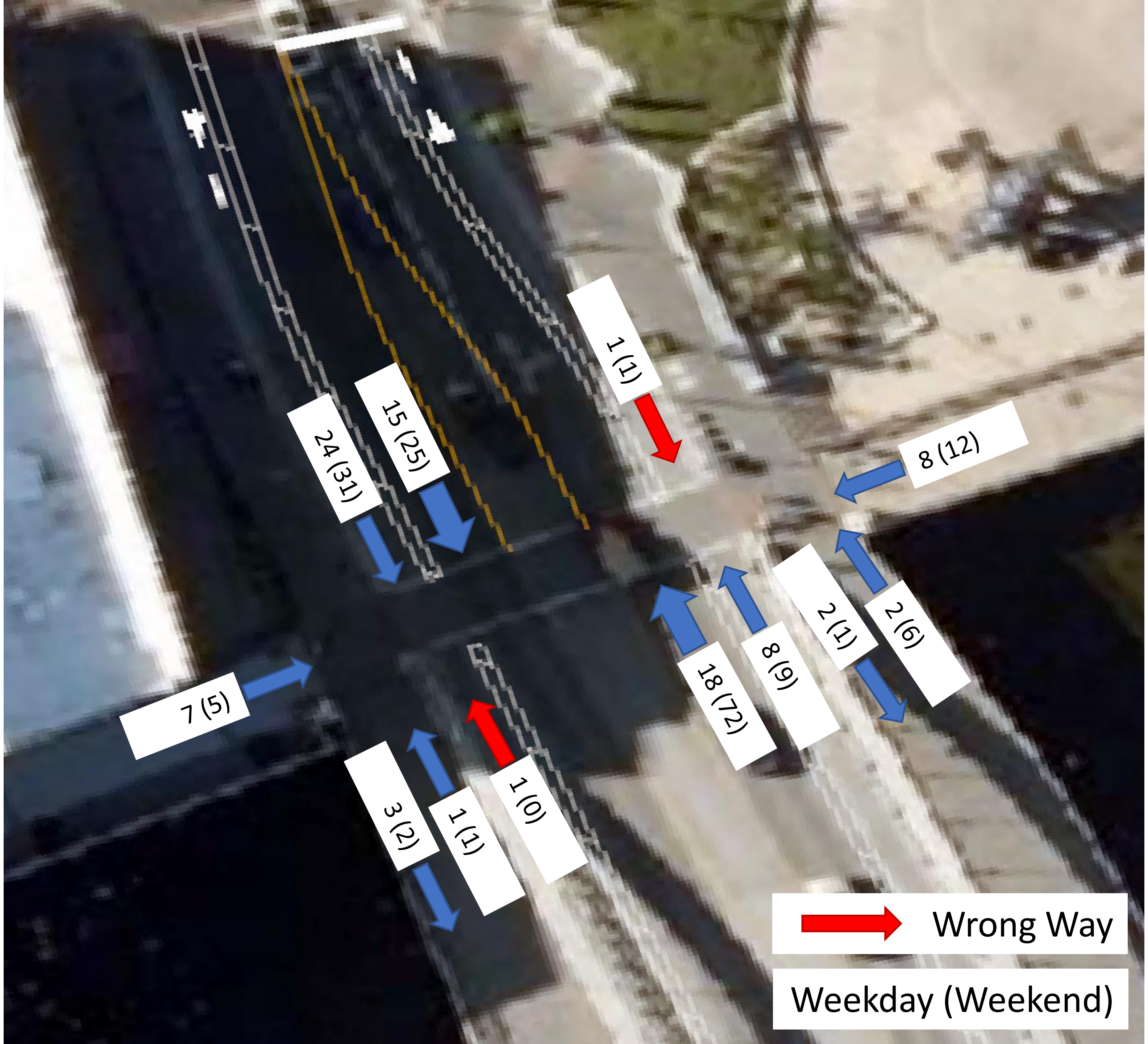
Bicycles

Round 2



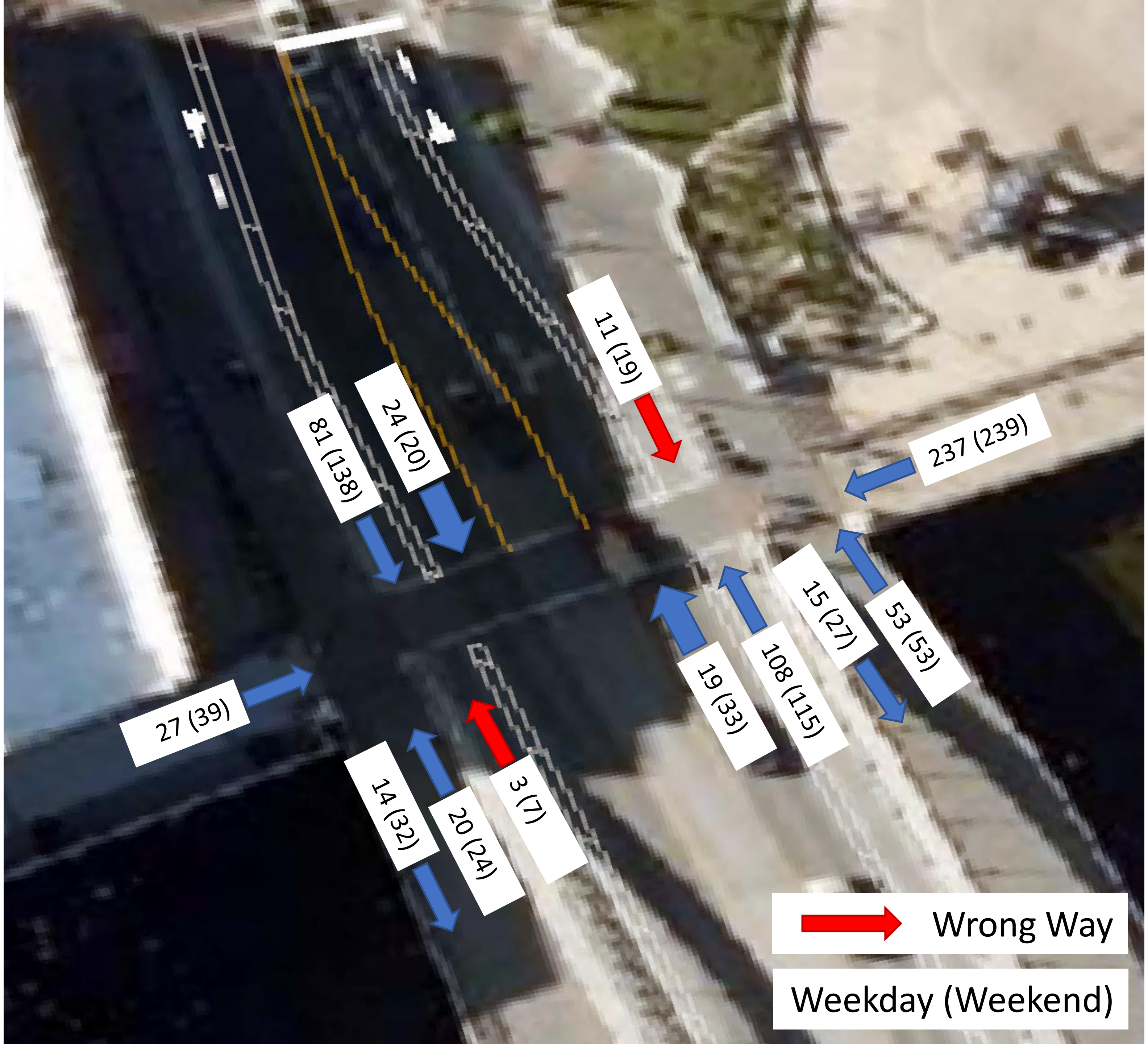
Scooters

Round 3



Bicycles

Round 3

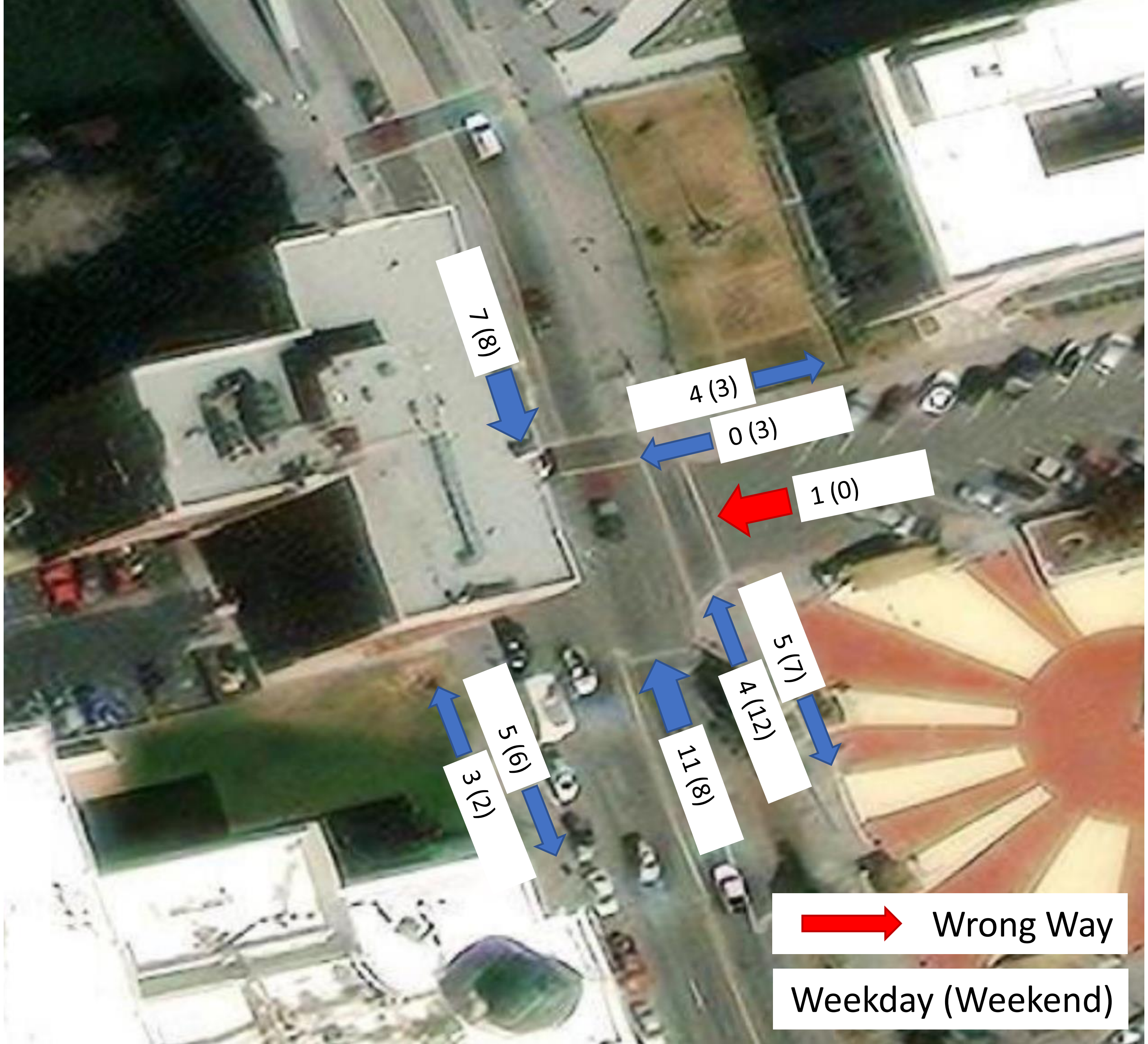


Scooters

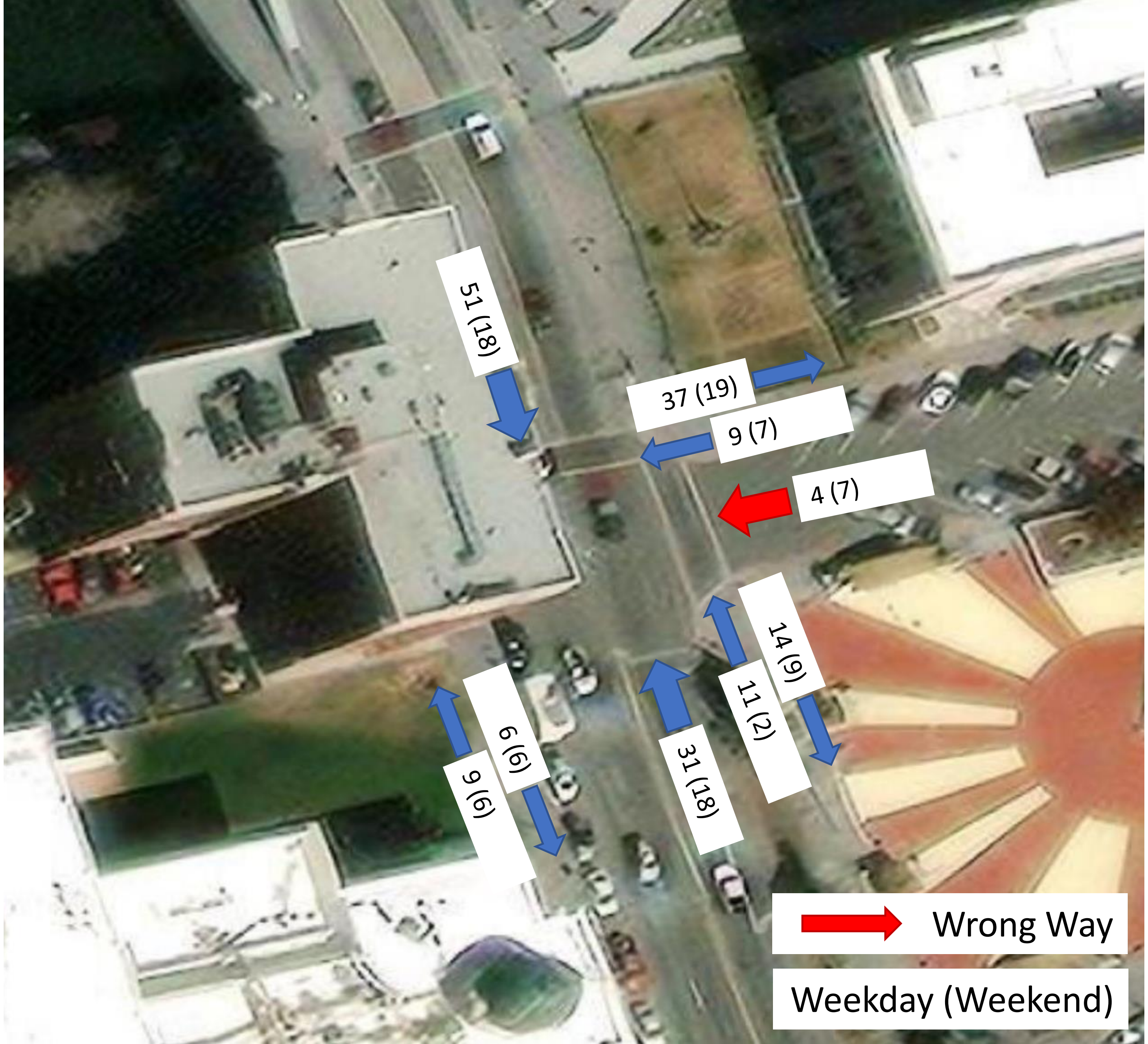
APPENDIX I: VIRGINIA ST AND MILL ST MICROMOBILITY

Round 1

Bicycles



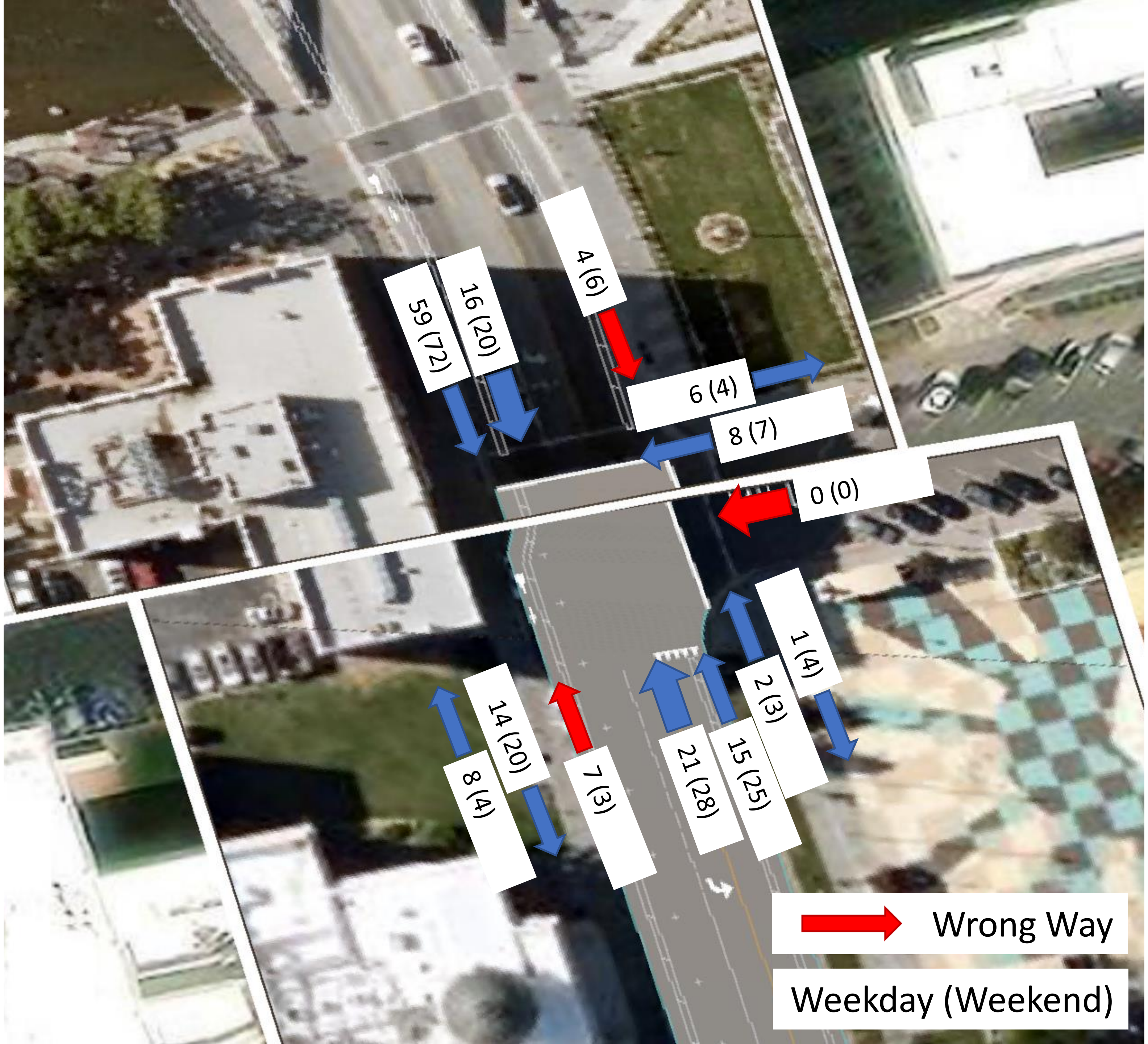
Round 1



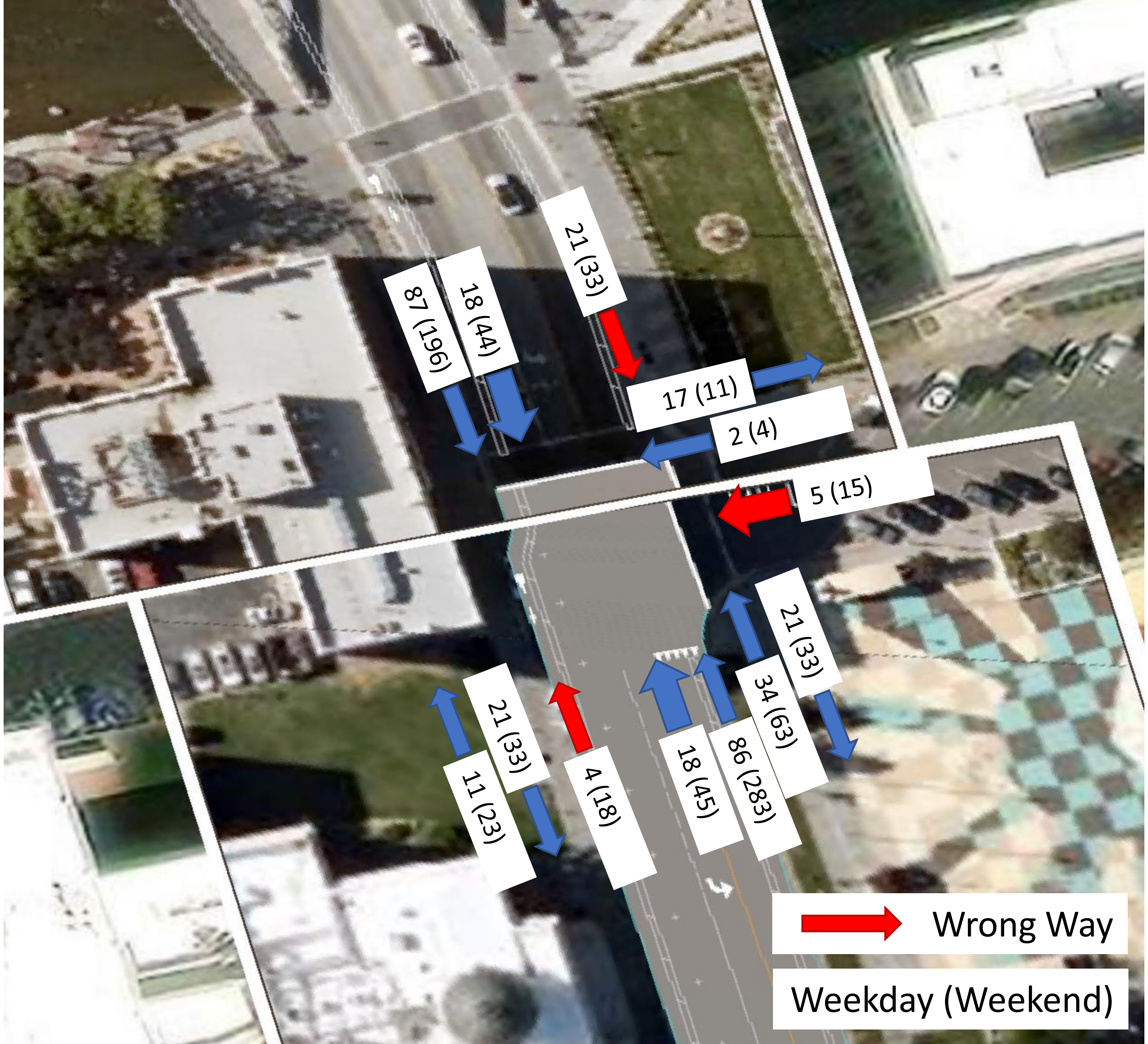
Scooters

Round 2

Bicycles



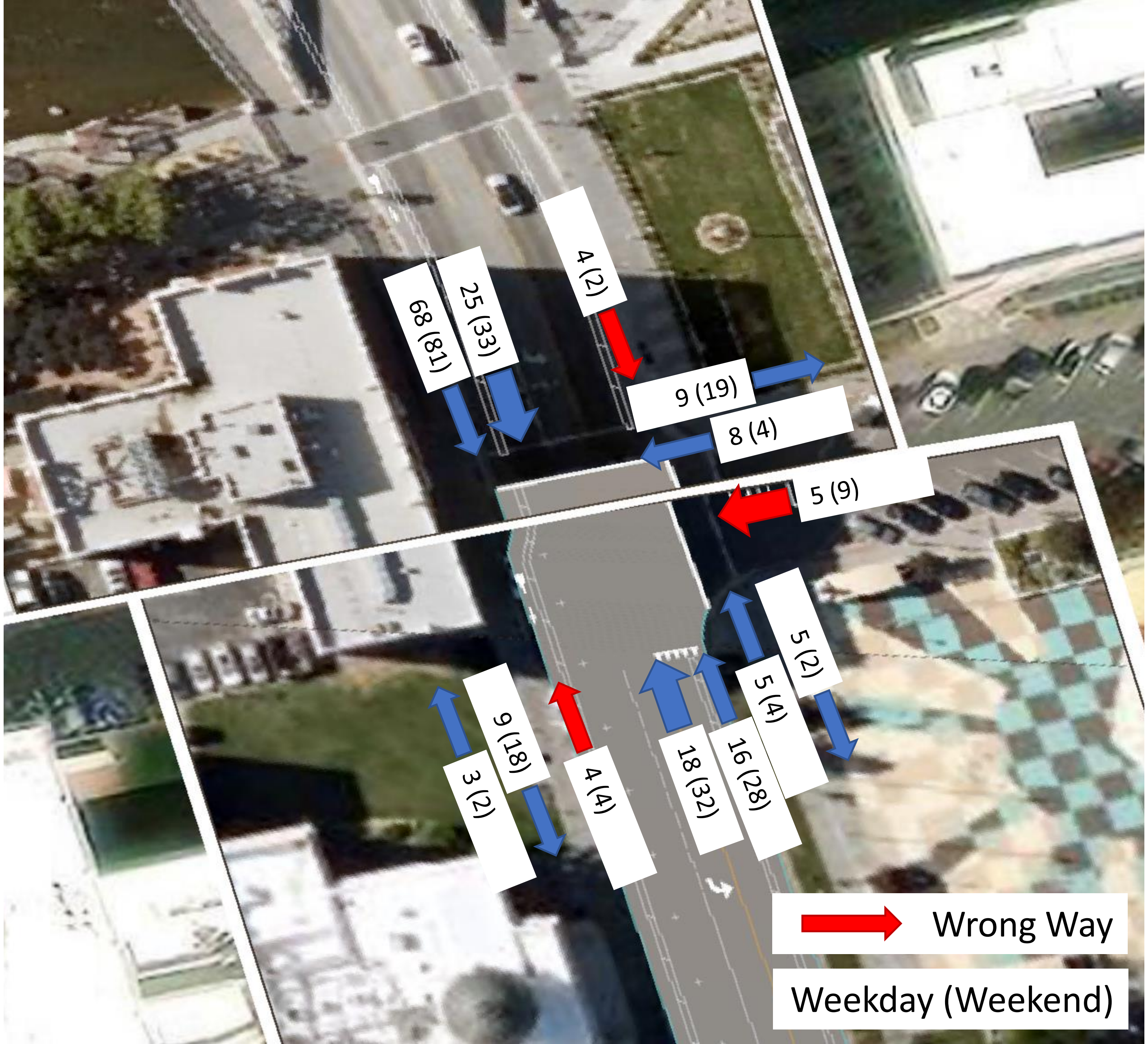
Round 2



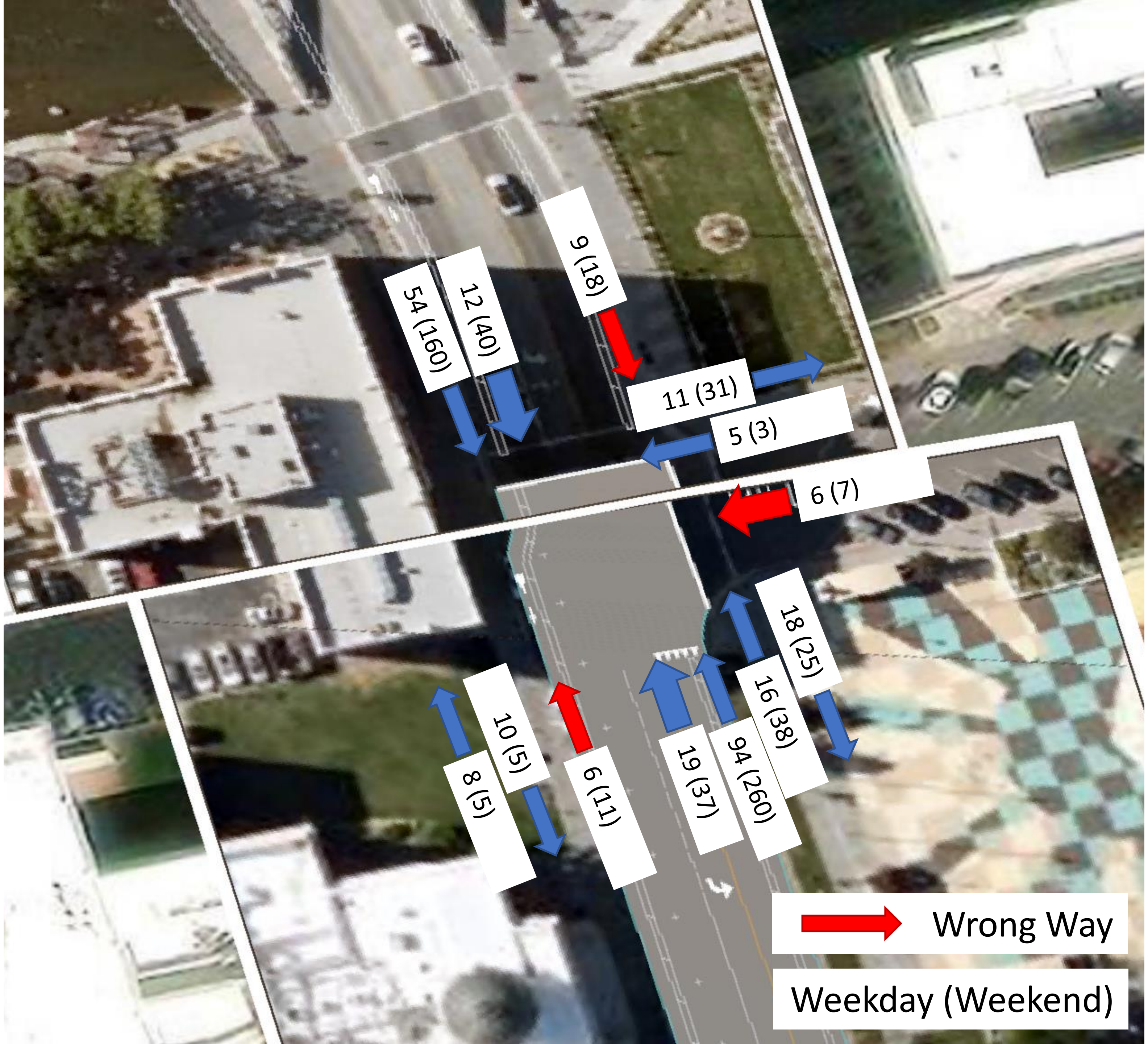
Scooters

Round 3

Bicycles



Round 3



Scooters