REGIONAL TRANSPORTATION COMMISSION
Metropolitan Planning • Public Transportation & Operations • Engineering & Construction
Metropolitan Planning Organization of Washoe County, Nevada

March 20, 2023

Kerrie Koski, P.E.
Director of Public Works / City Engineer
City of Reno
1 E. First Street
Reno, NV 89501

SUBJECT: RTC Virginia Street Bus RAPID Transit (BRT) Extension Project
Midtown Reno Post-Construction Evaluation Study

Dear Ms. Koski,

The Regional Transportation Commission of Washoe County (RTC) completed the Virginia Street Bus RAPID Transit Project (Project) in Fall 2020 to increase transit connectivity, enhance pedestrian safety, and improve access to the Virginia Street corridor. Following the completion of the Project, the RTC, in coordination with the City of Reno, performed a circulation study to address vehicle circulation and compliance concerns of the constructed improvements in Midtown Reno.

The enclosed reports, entitled Midtown Virginia Street BRT – Post Condition Traffic Study (Study) and Virginia Street/Center Street Technical Memorandum (Memo), analyzed several significant roadway changes to the Midtown segment of South Virginia Street between Plumb Lane and Liberty Street including the Center Street roundabout. Using roadside LiDAR and connected-vehicle data, the University of Nevada, Reno (UNR) evaluated the behaviors of road users, crash events, vehicle volumes, parking, and vehicular accessibility.

In summary, the Study concludes that the installed roadway infrastructure has improved safety while minimally impacting circulation and mobility. The majority of vehicles are traveling at the speed limit or lower. The raised medians, specifically, have reduced the number of severe angle conflicts and potential crashes. Although the center median limits left-turn movements, the Study supports that the roundabout and channelized left-turn pockets help mitigate the effects and support vehicle throughput. Parking appears to be adequately serving businesses. Lastly, the extended sidewalks invite greater multimodal activity in the now ADA accessible corridor especially around the business-dense areas.

While the Project was designed appropriately given the project constraints and standard practice guidelines, the Study identifies opportunities to improve safety and operations. The RTC recommends the following actions for consideration:

> <u>Recommendation #1:</u> With a high number of DUI and potential DUI related crashes in this area it is recommended that additional DUI and speed enforcement occur within this corridor.

Recommendation #2: Speed feedback signs along Virginia Street prior to entry into the roundabout will help inform drivers of their speed along with the showing the recommended speed of 15 miles per hour.

Recommendation #3: The installation of pedestrian bollard protection at the southwest corner of the Center Street roundabout to help protect the adjacent building and potential pedestrians in the area. Concrete bollards placed approximately 5-10’ north of the existing building will be a final layer of protection for the building and vulnerable users from errant vehicles. Additional pedestrian protection will be considered at all the intersection corners.

Recommendation #4: The installation of a pedestrian crossing at or near the intersection of Virginia Street and Cheney Street to address pedestrian movement across Virginia Street.

Recommendation #5: The consideration of rectangular rapid flashing beacons (RRFB) at unsignalized crosswalks where appropriate.

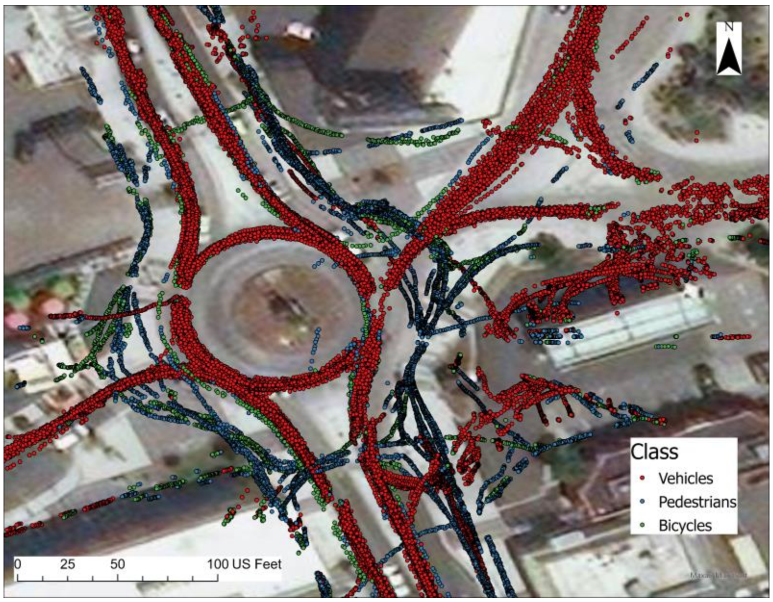
The above recommendations would support additional layers of driver notification and pedestrian protection to address the concerns from the City and adjacent property owners. We look forward to future collaborations with the City for Virginia Street at Midtown.

Sincerely,

Dale Keller, P.E.
RTC Director of Engineering

Enclosure:

- Midtown Virginia Street BRT – Post Condition Traffic Study
- Virginia Street / Center Street Technical Memorandum



Midtown Virginia St. BRT Post Study Analysis

For

Regional Transportation Commission (RTC), Washoe

Performed By:

Trevor Whitley and **Hao Xu, Ph.D., P.E.**

Center for Advanced Transportation Education and Research

University of Nevada, Reno

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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 conduct a post-construction evaluation study on the Virginia St Bus Rapid Transport (BRT) project in Midtown, Reno, Nevada. Roadside LiDAR data was collected at 18 intersections across 1.2 miles along South Virginia St in the Midtown neighborhood in Reno, NV. This data provides multi-modal traffic counts, speeds, conflicts, and is used to identify behaviors of road users such as non-compliance events. Wejo data was also used which is connected vehicle data that has a 4-5 percent penetration rate of all vehicles in Washoe County, NV. UNR used one week of this data to assess vehicle miles traveled and accessibility within the study area. Other data sets used in this study include the Nevada Department of Transportation's (NDOT) historical crash data from 2013 to 2017, as well as their Traffic Records Information Access (TRINA).

The study area is a commercial area with high multi-modal volumes such as vehicles, pedestrians, and bicyclists. Upon construction, complete street elements were added to the roadway such as raised medians, reduced lanes, greater crosswalk frequency, curb extensions, a roundabout, shared lane markings and improvements made related to the bus rapid transit Virginia Line. The purpose of this study is to evaluate the effects on travel behavior post-construction. The results of the following sections are summarized below:

Crash Analysis – From 2013 to 2017 there were 329 crashes along Midtown Virginia. There was one fatal crash, 147 injury crashes, and 181 property damage only crashes. 20 crashes were pedestrian-related and only 9 were bicycle-related. Plumb was a major hot spot for crashes but also has the highest traffic volumes. Vassar, Center, and Liberty were also hot spots

Virginia Through Volumes – Through volumes range from roughly 10,000 to 12,000 daily vehicles in both directions from Stewart St to Mt Rose and increases to 20,000 just south of Plumb Ln. Liberty has the lowest though volumes at approximately 6,000 vehicles

Vehicle Miles Traveled – From Wejo data, it is estimated that 45 percent of vehicles are traveling less than a quarter mile along the 1.2-mile Midtown Virginia St corridor. An additional 20 percent of vehicles traveled between a quarter and a half mile. Approximately 15 percent of vehicle traveled nearly the full length of the study area including five percent that traveled further than that. Those traveling further were from U-turns in the corridor or from vehicles traveling along the study area more than once in a single trip.

Accessibility – LiDAR data and Wejo data were used to measure the ingress and egress between Midtown Virginia St and the side streets. For ingress, the side streets Liberty, California, Regency, and Plumb were the most significant access points to Midtown Virginia. For egress, Plumb Ln was utilized by far the most, with Liberty and Wells also being utilized heavily.

Bicycle and Pedestrian Volumes – The bicycle and pedestrian volumes section is outlined in three ways, those traveling along Virginia St on the sidewalk and side street crosswalks, those crossing Virginia St, and bicycles traveling on the roadway. In general, overall pedestrian activity was higher in the northern most region at Moran, St. Lawrence, and Cheney. These are also areas in which there is a greater density of businesses and street parking along Virginia St and on the side streets rather than at parking lots. There are also a large number of Virginia St crossing events in areas where there are no crosswalks, such as Moran and Cheney. Bicycles follow a similar trend as pedestrians when traveling on the pedestrian right-of-way; however, the volumes are generally steadier throughout the corridor with a hot spot at St. Lawrence. For bicycles on the roadway, there are hot spots at Cheney, Mt Rose, and Wells.

Pedestrian Level of Service (LOS) – The pedestrian LOS is determined using methods from the Highway Capacity Manual 7th edition for two-way stop-controlled (TWSC) and signalized intersection crossing events on Virginia St. For the TWSC intersections, St. Lawrence and Taylor have LOS of C and the rest are LOS of F. This is because of the existence of a median refuge islands at those intersections. However, delay is also calculated which does not derive the LOS result. In looking at the delay, there does not appear to be a great difference between LOS C and LOS F. For signalized intersections, each crosswalk has an LOS of C or greater, with most being LOS B.

Vehicle Speeds – The through vehicle speeds were extracted along Virginia St to obtain a general speed profile for both passenger vehicles and vehicles over 38 feet such as buses. Overall, a majority of vehicles are traveling at the speed limit or lower. Larger vehicles such as buses are traveling at similar speeds as the rest of traffic except in areas in the southern most sites. The Center St roundabout slows traffic up to 15 MPH at the approaches.

Transit – Transit Ridership data was acquired from RTC Washoe for Route 1 and Route 100. The acquired data consists of the average offs, ons, and loads during the data collection period 12/8/2021 to 2/8/2022 for each stop throughout the day. For route 1 in the northbound direction, users tend to get off at Thoma St the most where there are greater density of businesses and pedestrian activity. In the southbound direction, users get off at Liberty St and Wells Ave. As for the ons, users tend to utilize the stops at Thoma, La Rue, and Taylor which is where there more businesses and pedestrian activity. The Virginia Line (Route 100) show more offs at Liberty St and at the southern bus stop near the roundabout. On the other hand, the ons occur more frequently at Liberty St and Walts in the southbound direction and at Center St near the roundabout in the northbound direction.

Parking – Parking data is generated for each street parking space detected by the sensor for each site. A total of 97 parking spaces were detected along Midtown Virginia. Such data includes the entering and exit of each vehicle in each parking space greater than 5 minutes duration. The map shows that there is a greater frequency of vehicles parking around Thoma St at durations less than one hour, which corresponds to where there is a higher density of businesses. Around La Rue, there are vehicles occupying spaces for longer than two hours. Martin St has one space that has an average parking duration up two days. Parking spaces in the southern half have less vehicle parking frequencies.

Conflicts – From the LiDAR data, conflicts between road users are extracted and used as a surrogate safety measure. Each conflict must have a time difference of under 2 seconds and at least one road user must be traveling faster than 15 miles per hour (MPH). For Vehicle-to vehicle conflicts, only those with a conflict angle of 90 degrees are greater were considered. For vehicle-to-vehicle conflicts, Regency showed as being a major hot spot, but upon further inspection, most of the conflicts had a time difference between 1.5 and 2 seconds. Overall, there are no significant safety concerns between vehicles based on this data because of a combination of low speeds and higher time differences. For vehicle-to-pedestrian interactions, Moran was triggered as a hot spot which is concerning given there is no crosswalk. However, upon further inspection of this data it appears that a majority of pedestrians cross more aggressively after a vehicle passes. This appears to happen more often at intersection without a crosswalk, such as Cheney.

Behavior Analysis and Compliance – Using the LiDAR trajectory data, more detailed information can be gleaned to understand more intricate patterns in the data. First off, there are a larger number of U-turns that occur in the north end which are not allowed because of the raised medians. Also, a majority of U-turns occur at the roundabout, which suggests the need for vehicles to utilize the roundabout to access areas along Midtown Virginia. Stewart St has between 17 and 21 percent of side street volumes making an illegal left turn around the raised medians. Wrong way driving events are also common on Mary St at the west leg of the roundabout and on the St. Lawrence left turn pocket. California saw many illegal eastbound through and southbound lefts to access the businesses on the east side of the intersection.

Overall, the raised medians do reduce the number of more severe angle conflicts and potential crashes. Additionally, they slow vehicles down more than in the southern half. While the restricted limits access limits left turns in the northern study area, the roundabout and existence of other left turn pockets mitigates the effect. The roundabout also reduces traffic speed and eliminates more severe angle conflict points between vehicles. The roundabout's impact to pedestrians appears minimal because these lower speeds. Parking appears to be adequately serving businesses, with minimal non-compliance issues of vehicles parking for longer than is allows. The extended sidewalks invite greater multimodal activity especially around the business-dense areas around St. Lawrence. The restrictions placed on vehicle turning movements in turn improves mobility and safety for other road users, particularly pedestrians. In conclusion, the infrastructure improvements appear to improve safety while minimally impacting the circulation and mobility.

1 Introduction

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 conduct a post-construction study evaluation study on the Virginia St Bus Rapid Transport (BRT) project in Midtown, Reno, Nevada.

1.1 Project Background

The Virginia St BRT Extension Project is a transit-oriented development along the Virginia St corridor located in Reno, NV and led by the RTC Washoe. The Virginia BRT evaluation study area spans 1.2 miles along the Virginia St corridor between the cross streets Liberty St to the north, and Plumb Ln to the South. The study area is located in the Midtown neighborhood, which is a commercial area of Reno that has high multi-modal traffic volumes such as vehicles, bicycles, and pedestrians. The study area has recently undergone reconstruction, with complete street elements added. These elements include the following:

- Two lanes per direction to one
- Extended sidewalks
- More crosswalks with curb extensions
- Shared lane markings (sharrows) for bicyclists
- Restricting access through continuous raised medians
- A roundabout
- New streetlighting
- Transit stop shelters
- A BRT line

Street parking was maintained through the corridor with a 2-hour limit 8:00 am to 8:00 pm Monday through Saturday.

1.2 Project Objectives

The objective of this study is to evaluate the effectiveness of the newly constructed complete street from the perspective of mobility, safety, and circulation. The study objectives include

1) Traffic mobility performance, including volumes, delays, and level of service (LOS) of multimodal traffic.
2) Traffic safety performance, including historical crash data, speeds, and conflict analysis.
3) Transit BRT performance, including BRT travel time, ridership, and station/stop access.
4) Business access including traffic circulation, parking, transit, and walking routes for business access.
5) Identification of roadway elements positively or negatively impacting mobility, safety, and business access for recommendations to future projects.

1.3 PROJECT DATA

The data used for this study is outlined. UNR used the following data to complete the evaluation

- Geometric design of S Virginia St. in the study zone – RTC
- Pre-construction corridor study report - RTC
- Transit routes, stations, and stops – RTC
- Business along S Virginia ST. in the study zone – Google Maps and Zillow
- AADT data (before the construction) – NDOT TRINA
- Historical crash data (before the construction) – NDOT Web Crash Data App
- Sample trajectory data – Wejo
- Transit ridership - RTC
- LiDAR data for all traffic trajectories – UNR

1.3.1 Roadside LiDAR Trajectory Data

UNR used their roadside data collection platforms to collect data at each intersection in the 1.2-mile stretch. Each data collection site is shown in Figure 1. Each data collection effort covers four intersections and 4-5 days of continuous data is collection. Data collection started December 10^{th}, 2021 and ended on February 8^{th}, 2022, as shown in Table 1. Each site has at least one full weekday and one full weekend day. Each sensor can detect a radius of 300 feet.

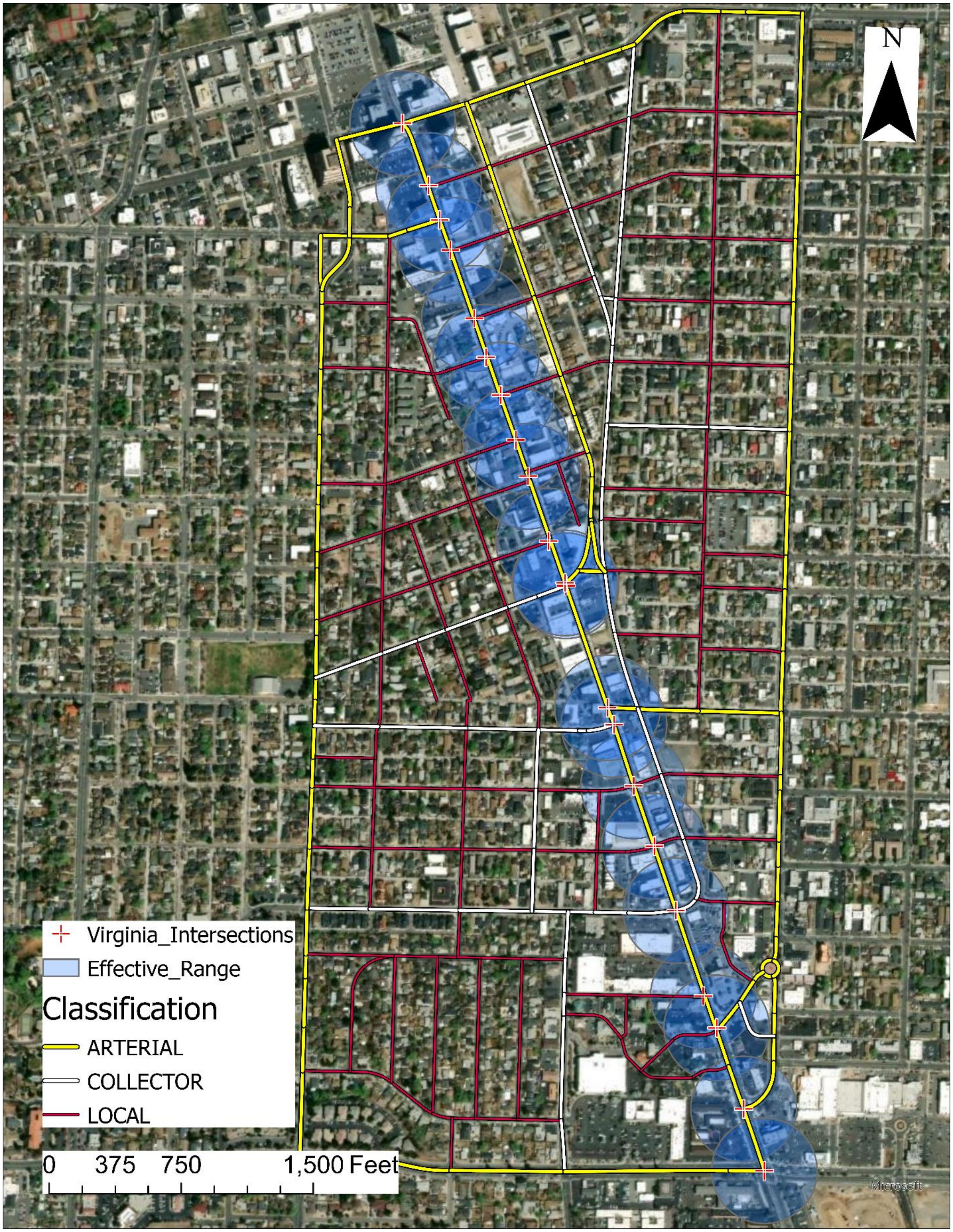


Figure 1 Study area and intersections

Table 1 LiDAR sensor installation locations and duration

Site	Start Day	End Day
Virginia St/Liberty St	Friday, December 10, 2021	Tuesday, December 14, 2021
Virginia St/Stewart St	Friday, December 10, 2021	Wednesday, December 15, 2021
Virginia St/California Ave	Wednesday, December 8, 2021	Tuesday, December 14, 2021
Virginia St/Moran St	Thursday, December 9, 2021	Thursday, December 16, 2021
Virginia St/Thoma St	Saturday, December 18, 2021	Wednesday, December 22, 2021
Virginia St/Saint Lawrence Ave	Saturday, December 18, 2021	Wednesday, December 22, 2021
Virginia St/Cheney St	Saturday, December 18, 2021	Wednesday, December 22, 2021
Virginia St/W Taylor St	Saturday, December 18, 2021	Wednesday, December 22, 2021
Virginia St/La Rue Ave	Wednesday, January 19, 2022	Tuesday, January 25, 2022
Virginia St/Martin St	Thursday, January 20, 2022	Tuesday, January 25, 2022
Virginia St/Center St	Wednesday, January 19, 2022	Tuesday, January 25, 2022
Virginia St/Vassar St	Wednesday, January 26, 2022	Tuesday, February 1, 2022
Virginia St/Arroyo St	Wednesday, January 26, 2022	Tuesday, February 1, 2022
Virginia St/Pueblo St	Wednesday, January 26, 2022	Sunday, January 30, 2022
Virginia St/Mount Rose St	Wednesday, January 26, 2022	Tuesday, February 1, 2022
Virginia St/Regency Way	Wednesday, February 2, 2022	Monday, February 7, 2022
Virginia St/S Wells Ave	Wednesday, February 2, 2022	Monday, February 7, 2022
Virginia St/Plumb Ln	Wednesday, February 2, 2022	Tuesday, February 8, 2022

The LiDAR sensor generates 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 artificial intelligence (AI) software to filter out the background, classify the road user as a vehicle, bicycle, or pedestrian, 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. The trajectories shown on the map show the movements of each road users' movement every 0.1 seconds. For this project, the vehicles, bicycles, and pedestrians are classified.

The traffic data that can be gleaned from these trajectories include the following:

- Multi-modal traffic counts (turning movement and crosswalk)
- Multi-modal traffic speeds
- Conflicts and interactions between road users
- Traffic compliance
- Localized traffic patterns
- Parking utilization

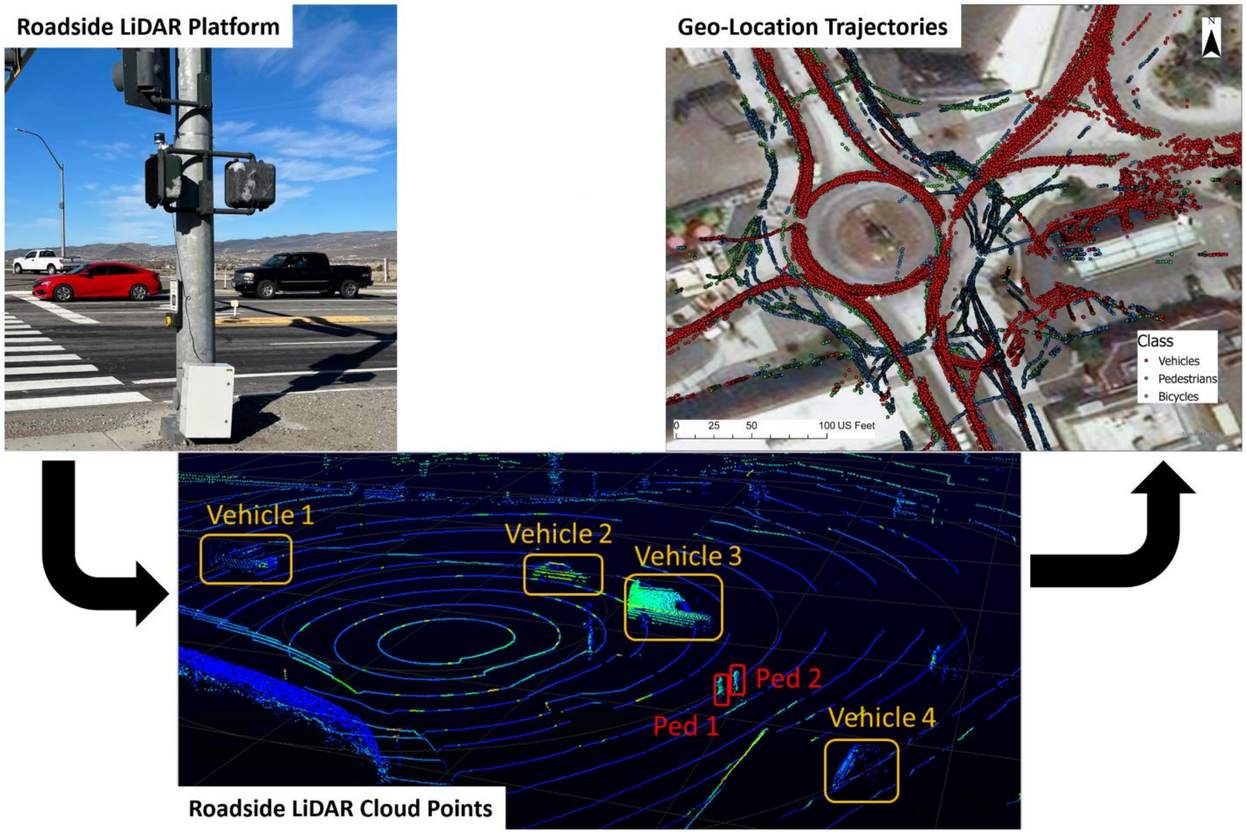


Figure 2 Stages of roadside LiDAR data processing

1.3.2 Wejo Data

Wejo data is connected vehicle data from the GPS units in vehicles, which is cleaned and provided by the company, Wejo. Much like the LiDAR trajectories, Wejo data can track the movements of vehicles through time and space, but at a lower frequency of every 3-seconds. Also, this data is only a sample of 4-5 percent of the actual vehicles on the roadway. A sample of Wejo data for the Washoe County area is shown in Figure 3.Wejo data is more macroscopic and therefore can provide a sample of vehicle origins and destinations to understand general travel patterns.

For this project, one week of Wejo data is used between March 1st and March 6th, 2021. The data is used to determine average miles traveled along Midtown Virginia St and accessibility to Midtown Virginia St.

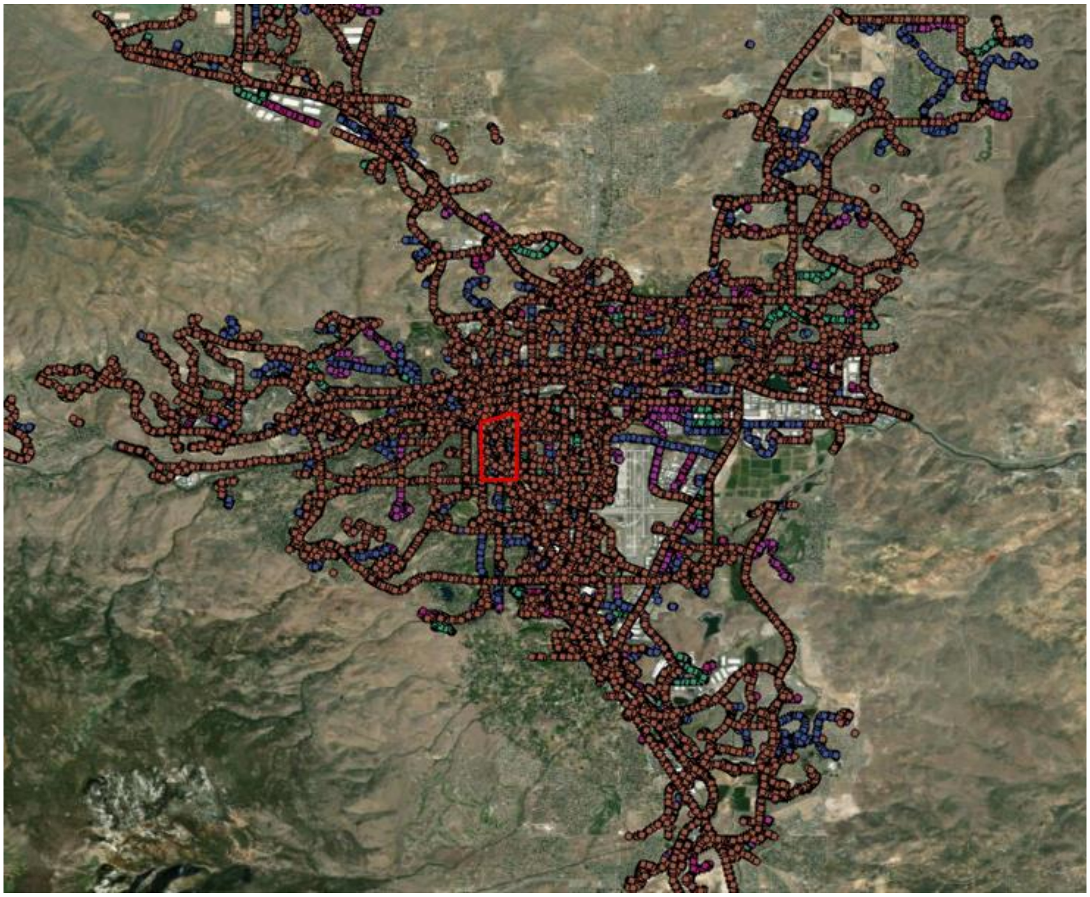


Figure 3 Sample of Wejo data in Washoe County, NV

2 Midtown Virginia St Corridor Information

The following section goes over the defining characteristics along the Midtown Virginia St corridor. This includes looking at each site where there was data collected and the corridor as a whole. These characteristics include the intersection control type, geometry, and where there is street parking, transit stops, and other unique characteristics.

Table 2 tabulates the intersection control type of each intersection along the study area. The top row is the northern-most site and the bottom row is the southern-most site. Many sites in the northern half are three-legged one-way stop controlled that connect to local roads. The only time for which vehicles' flow is interrupted is at signalized intersections, the Center St roundabout, and at crosswalks for crossing bicyclists and pedestrians. Otherwise, the flow is uninterrupted.

Table 2 Intersection control type

Site	Control Type	Restricted Movements
Virginia St/Liberty St	Signalized	None
Virginia St/Stewart St	One-Way Stop-Controlled	Westbound Left
Virginia St/California Ave	Signalized (3-Legged)	Westbound Left & Thru / Southbound Left / Eastbound Thru
Virginia St/Moran St	One-Way Stop-Controlled	Westbound & Southbound Left
Virginia St/Thoma St	One-Way Stop-Controlled	Southbound Left
Virginia St/Saint Lawrence Ave	One-Way Stop-Controlled	Eastbound Left & Thru / Southbound Left / Westbound
Virginia St/Cheney St	One-Way Stop-Controlled	Westbound Left
Virginia St/W Taylor St	One-Way Stop-Controlled	Eastbound Left
Virginia St/La Rue Ave	Two-Way Stop-Controlled	Westbound & Eastbound Left & Thru / Northbound & Southbound Left
Virginia St/Martin St	One-Way Stop-Controlled	Eastbound & Northbound Left
Virginia St/Center St	Roundabout	Southbound Right / Northbound Left / Westbound
Virginia St/Vassar St	Signalized	Eastbound
Virginia St/Arroyo St	Two-Way Stop-Controlled	None
Virginia St/Pueblo St	Two-Way Stop-Controlled	Eastbound
Virginia St/Mount Rose St	Signalized	None
Virginia St/Regency Way	Signalized	None
Virginia St/S Wells Ave	One-Way Stop-Controlled	Westbound & Southbound Lefts
Virginia St/Plumb Ln	Signalized	None

Figure 4 outlines the roadway classifications. Midtown Virginia St is classified as an arterial and there are seven arterial cross streets, four collector cross streets, and 14 local cross streets in the study corridor. The speed limit of the corridor is 25 miles per hour (MPH) from Liberty to Vassar and 30 MPH from Vassar to Plumb. Vassar is also where the raised medians end and turns into a standard median lane for left turns; therefore, access is less restricted. The raised medians return on the southbound approach of Plumb Ln along the Wells intersection. The raised medians in the northern half of the study area are used to restrict access in the left turn onto Virginia St from the side street and onto the side streets to Virginia St. The intersections at Stewart, St. Lawrence, Cheney, and Taylor do not allow for left turns onto Virginia, only right turns can be made, but Virginia St has a left-turn pocket to turn onto the side streets. The intersections at Moran, La Rue, and Martin also restrict access on the side street left turn, but there is also no left turn pocket on Virginia St to allow for left turns; therefore, it is just a continuous raised median. Thoma is a one-way in the westbound direction so there is no left turn pocket on Virginia St, but right and left turns are allowed from Thoma onto the Virginia.

At each of the one- to two-way stop-controlled intersections there is one Virginia St crosswalk except at Stewart, Moran, Cheney, and Wells. The signalized intersections have two Virginia St crosswalks except at Mt Rose\Holcomb where there is one. At Taylor Street, there is a skewed crosswalk. For bicyclists on the roadway, there are shared lane marking ("sharrows") along the corridor. From Mt Rose to Regency, there is a bus lane in both directions with sharrows. There is a total of 13 transit stops along Midtown Virginia St services with 3 transit stops along Center St that are also considered. Street parking was maintained through the corridor with a 2-hour limit 8:00 am to 8:00 pm Monday through Saturday. Figure 4 also maps the businesses along Midtown Virginia St. The density of businesses is greatest in the northern end at St. Lawrence; however, there is also a high density around the Center St roundabout. South of Center St, the density lowers as the number of parking lots and larger stores increases.

Figure 4 Roadway classification and adjacent businesses

3 Crash Analysis

According to the Nevada Department of Transportation's (NDOT) crash data from 2013 to 2017, a total of 329 crashes occurred along S Virginia St in the Midtown region. Of those 329 crashes, 189 occurred at an intersection and 277 occurred on Virginia St as opposed to the side streets. 25 crashes were as a result of impaired driving and 7 are speed-related. There are 20 crashes involving pedestrians and 9 involving bicyclists. There is one fatal crash, 147 injury crashes, and 181 property damage only crashes. The year-by year KABCO breakdown is shown in Table 3. "K" is a fatal injury, "A" is an incapacitating injury, "B" is a non-incapacitating injury, "C" is a possible or claimed injury, and "O" is a property damage only or no injury.

Table 3 Midtown Virginia St KABCO crash breakdown from 2013 to 2017

Year	Total	K	A	B	C	O
2013	66	0	3	8	15	40
2014	71	0	5	11	21	34
2015	60	0	2	8	11	39
2016	66	0	2	5	22	37
2017	66	1	1	11	22	31
Total	**329**	**1**	**13**	**43**	**91**	**181**

Figure 5 shows a heat map of all the 329 crashes along Midtown Virginia St. The Plumb St intersection shows significantly higher crash frequencies, but also has the higher traffic volumes. Other hot spots are shown on Vassar St and Center St/Mary St. However, since these crashes occurred, the number of through lanes has changed from two to one and raised medians were installed. Furthermore, The Center St/Mary St intersection was changed from a signalized intersection to a roundabout.

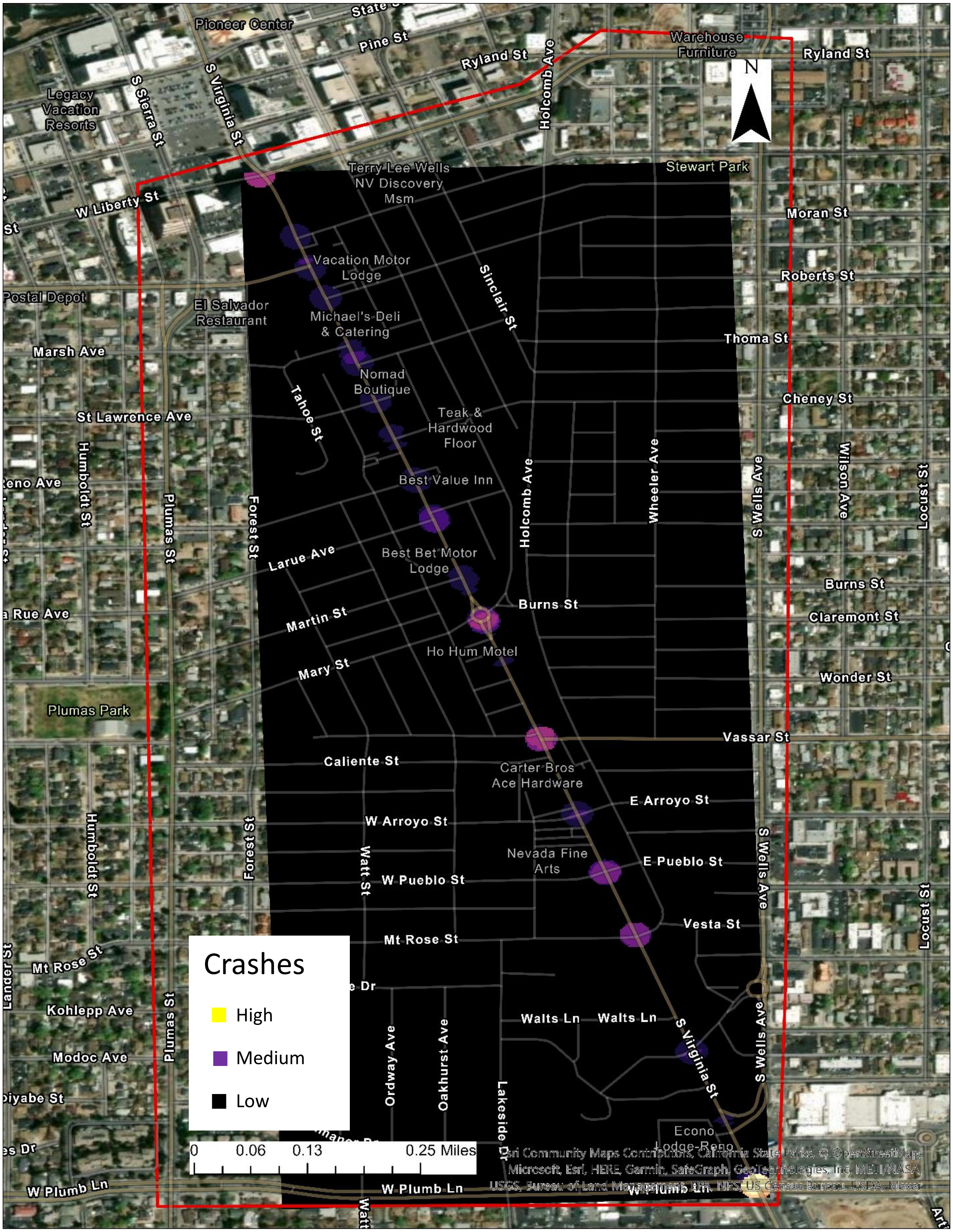


Figure 5 Midtown Virginia St 2013 to 2017 crash heat map

4 VEHICLES

4.1 VIRGINIA THROUGH VOLUMES

NDOT has three Annual Average Daily Traffic (AADT) counters along the study area on S Virginia St in their Traffic Records Information Access (TRINA). Table 4 illustrates the AADT at Stewart St, Vassar, and Wells Ave and the corresponding Daily volumes from the LiDAR trajectory data. The AADT in the northmost and southmost regions are similar, but there is a dip in ADDT by about 500 in the middle of the study corridor.

Table 4 TRINA AADT versus LiDAR daily volumes

Station	Route	Location	2021 AADT	LiDAR
310218	S Virginia St	100ft N of Stewart St	16,600	10,800
310189	S Virginia St	135ft N of Vassar St	11,500	9,600
311143	S Virginia St	510ft N of Plumb Ln	16,700	20,100

Using the traffic volumes generated by the roadside LiDAR data, more granular data on daily volumes can be extracted to see how through movement daily counts change throughout the corridor. Figure 6 shows 16 intersection sites where through movements were generated. There is large fluctuation in the northmost sites near Liberty, but shows more consistency from Thoma to Center. Then, there is a spike in through volumes at Wells. In comparing these results to the TRINA data set, the LiDAR output shows much less volume at Stewart and more volume at Wells near Plumb. The LiDAR volumes can breakdown the volumes by direction. Based on Figure 6, the direction volumes are similar for most sites except Liberty where northbound is higher and at Wells where southbound is higher. These volumes show that Liberty and Plumb are major access points to Midtown Virginia, as will be shown in a later section.

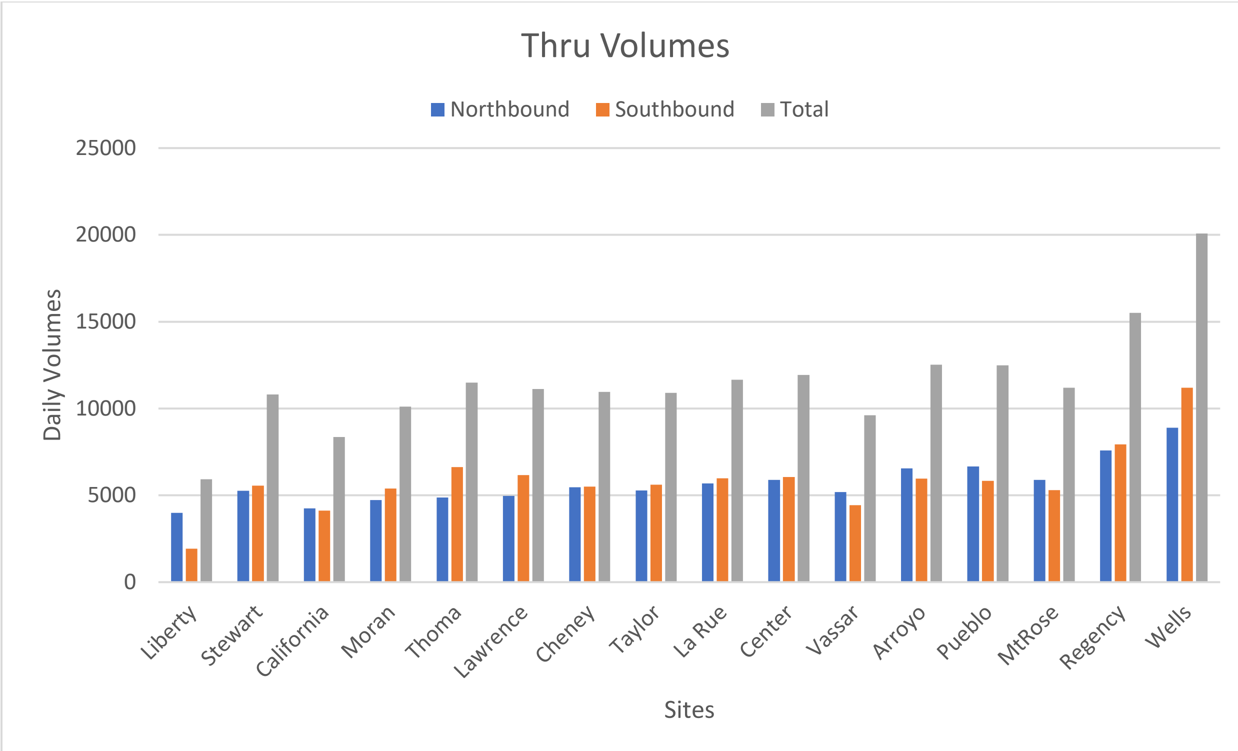


Figure 6 Site-by-site daily through volumes by direction and total

Figure 7 shows the daily volumes on a map with the distribution so of businesses along Virginia St. There is a greater density of businesses in the north half of the study area where there are more shops and restaurants. This are is also where there are more consistent volumes. However, there is higher volumes in the southern most half where there is less density of businesses indicating that more throughput volumes in this area.

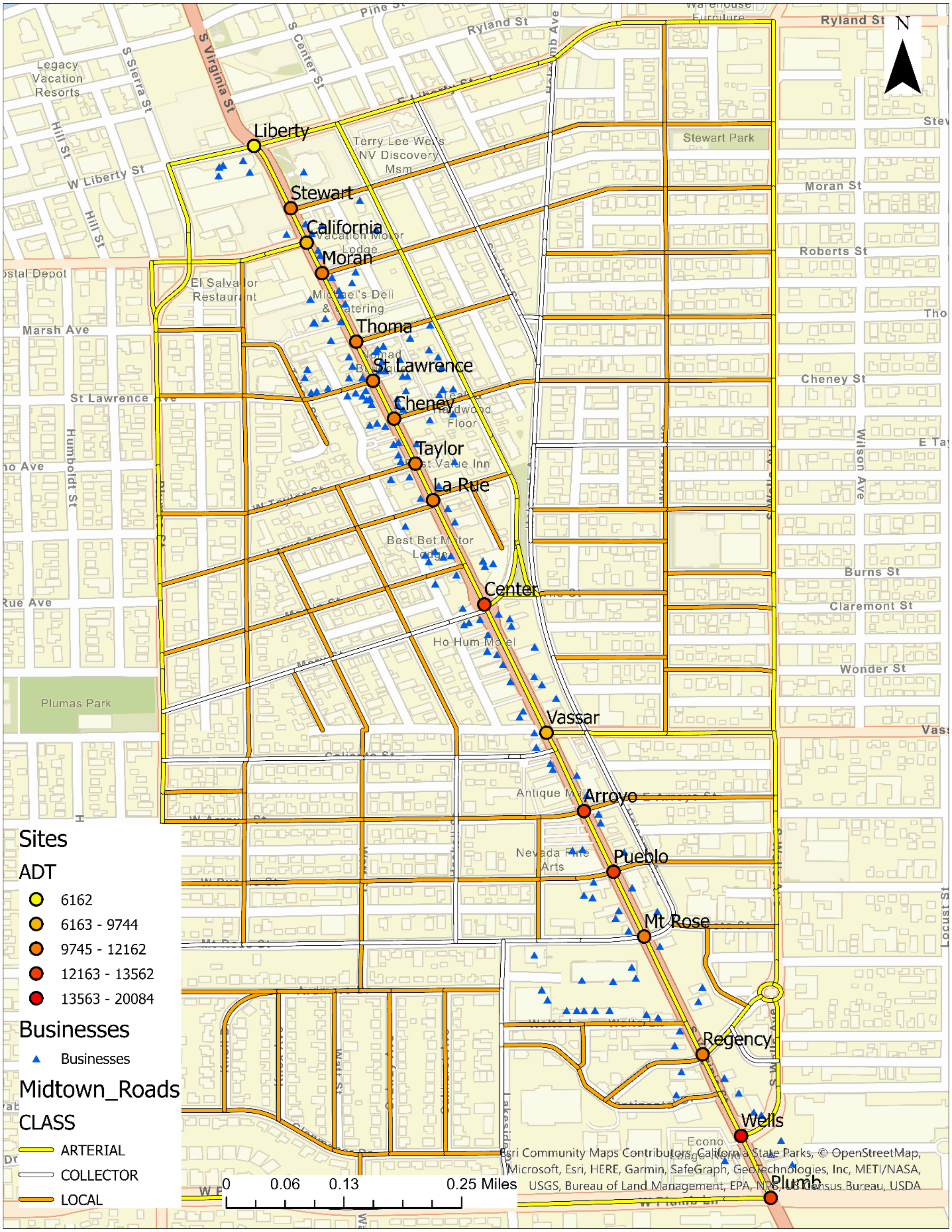


Figure 7 Daily through volumes

4.2 Vehicle Miles Traveled

Using Wejo data, the miles traveled through the approximately 1.2-mile Midtown Virginia can be determined. Based on approximately 1-week of Wejo data between March 1st and March 6th, 2021, there was a total of 3345 trips that traveled along Virginia St. Table 5 tabulates the breakdown of journey type. A majority of journeys are those that traveled through Midtown Virginia St which suggests the Virginia St is being used primarily for throughout; However, Figure 8 shows that an approximately 65% of all journeys are less than 0.5 miles. Therefore, many journeys along Midtown Virginia are for smaller segments rather than the full 1.2-mile length. Those journeys that traveled greater than the length of the study area is because of either U-turn being made, or that the journey traveled along Midtown Virginia two or more times in the same trip.

Table 5 Journey Type Breakdown

Journey Type	Count
Destination	303
Origin	334
Origin-Destination	24
Through	2685
Total	**3346**

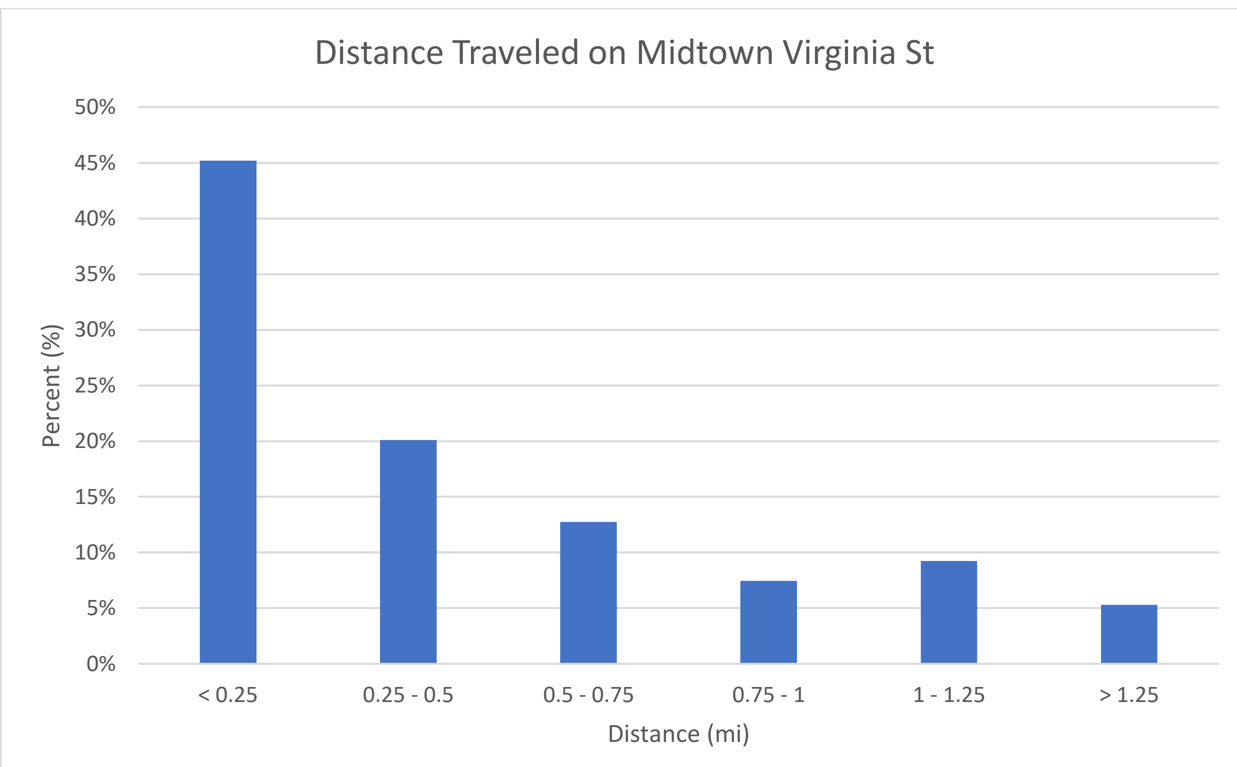


Figure 8 Distance Traveled on Midtown Virginia

Figure 9 breaks down the distribution of miles traveled along Midtown Virginia by journey type. The distribution between the 25th and 75th percentile is shown at the box, the horizontal line is the 50th percentile (median), and the "X" is the mean. The figure shows that there is overlap in the distance distributions between journey types and the similar means. This plot shows that the majority of journeys are traveling less than 0.75 miles regardless of the journey type. The journeys for which the study area is an origin shows generally lower distances traveled.

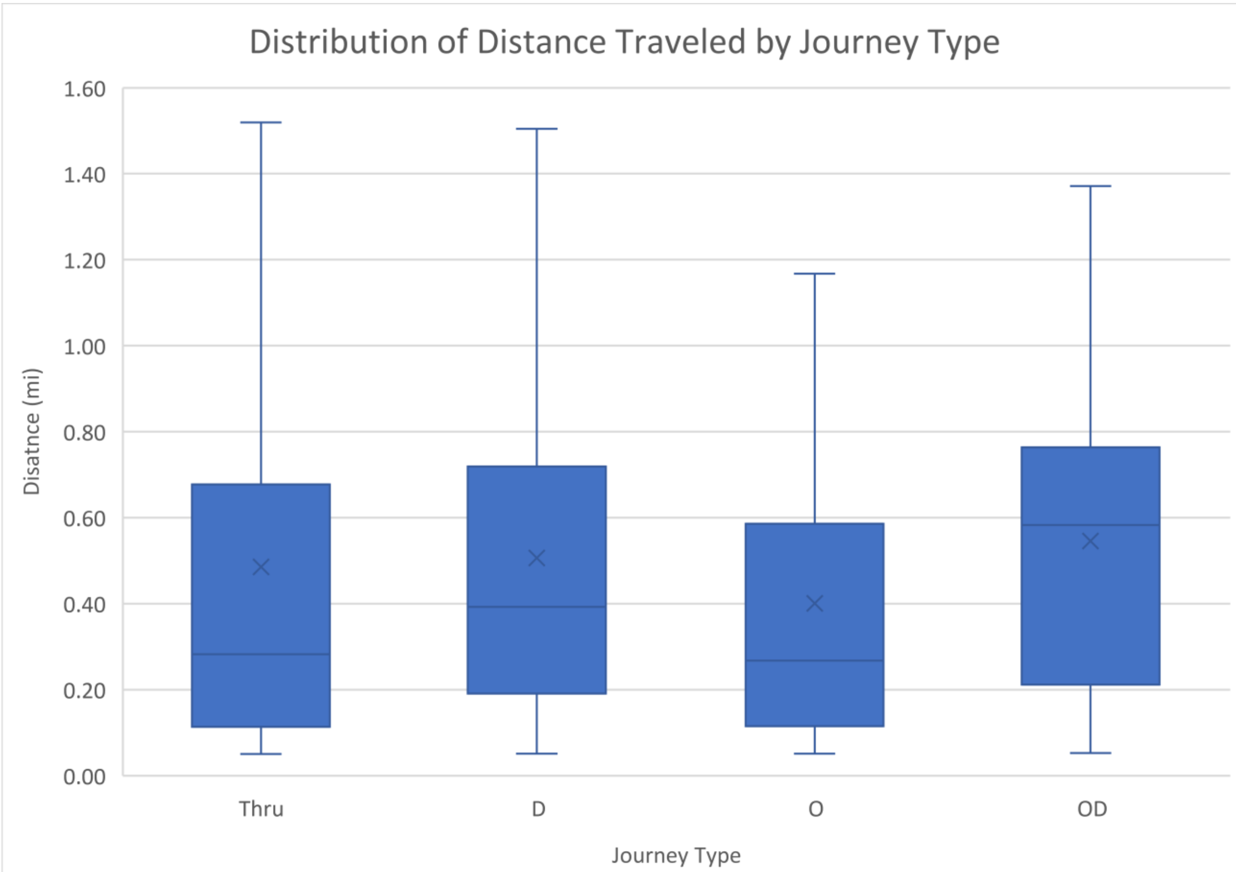


Figure 9 Journey distance distribution by journey type

4.3 Accessibility

Accessibility is an important indicator in determining which side streets are being utilized to enter and exit the Midtown Virginia corridor. For this section, both the Wejo and LiDAR trajectory data will be used.

Figure 10 illustrates which side streets are utilized most to access Midtown Virginia St which is determined based on if the vehicle turned onto Virginia St. Hot spots shown in the map include Liberty, California, Mt Rose, Regency, and Plumb. These hot spots are validated by the LiDAR trajectory data shown in Figure 11, where the daily volumes from the side streets for each intersection for both a weekday and weekend day is shown.

Figure 10 Wejo Virginia access from side street heat map

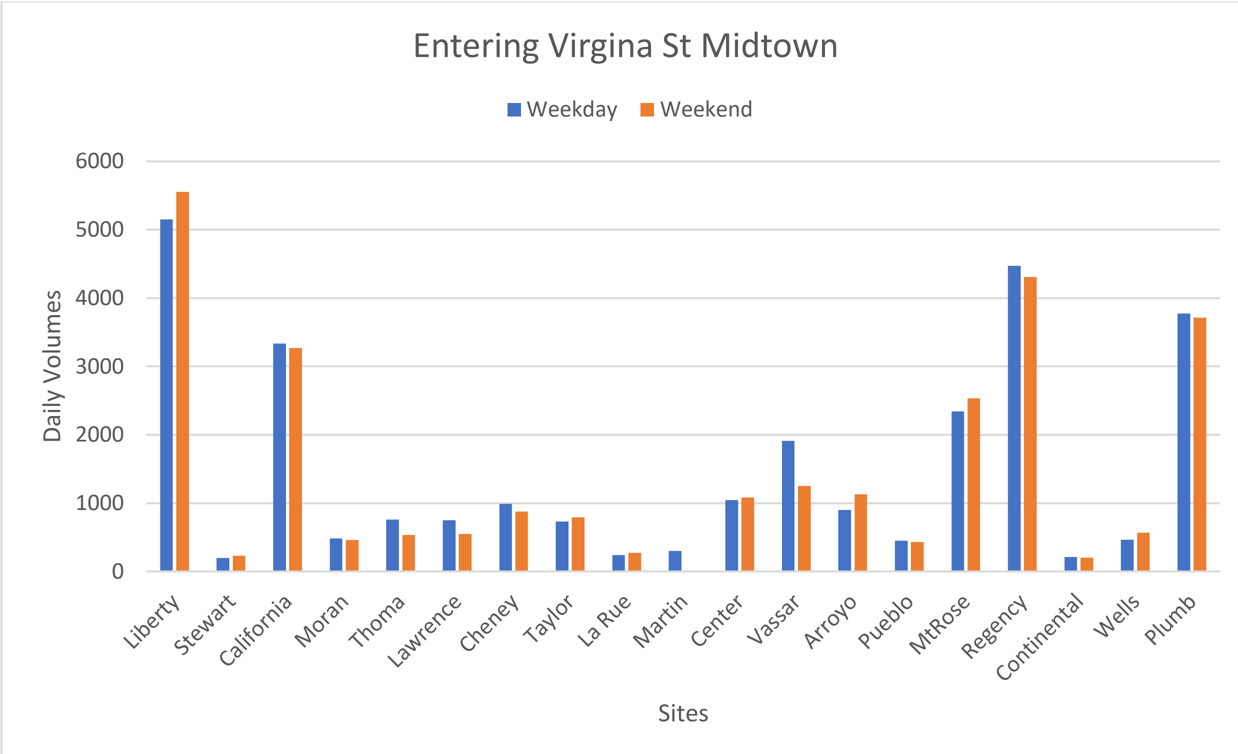


Figure 11 Daily side street access volumes for a weekday and weekend

Figure 12 illustrates which side streets are utilized most to exit Midtown Virginia St which is determined based on if the vehicle turned off of Virginia St. There is greater distribution of hot spots for which vehicles exit than enter from the side street. The major hot spots appear at Liberty, California, Wells and Plumb. These hot spots are validated by the LiDAR trajectory data shown in Figure 13, where the daily volumes from the side streets for each intersection for both a weekday and weekend day is shown.

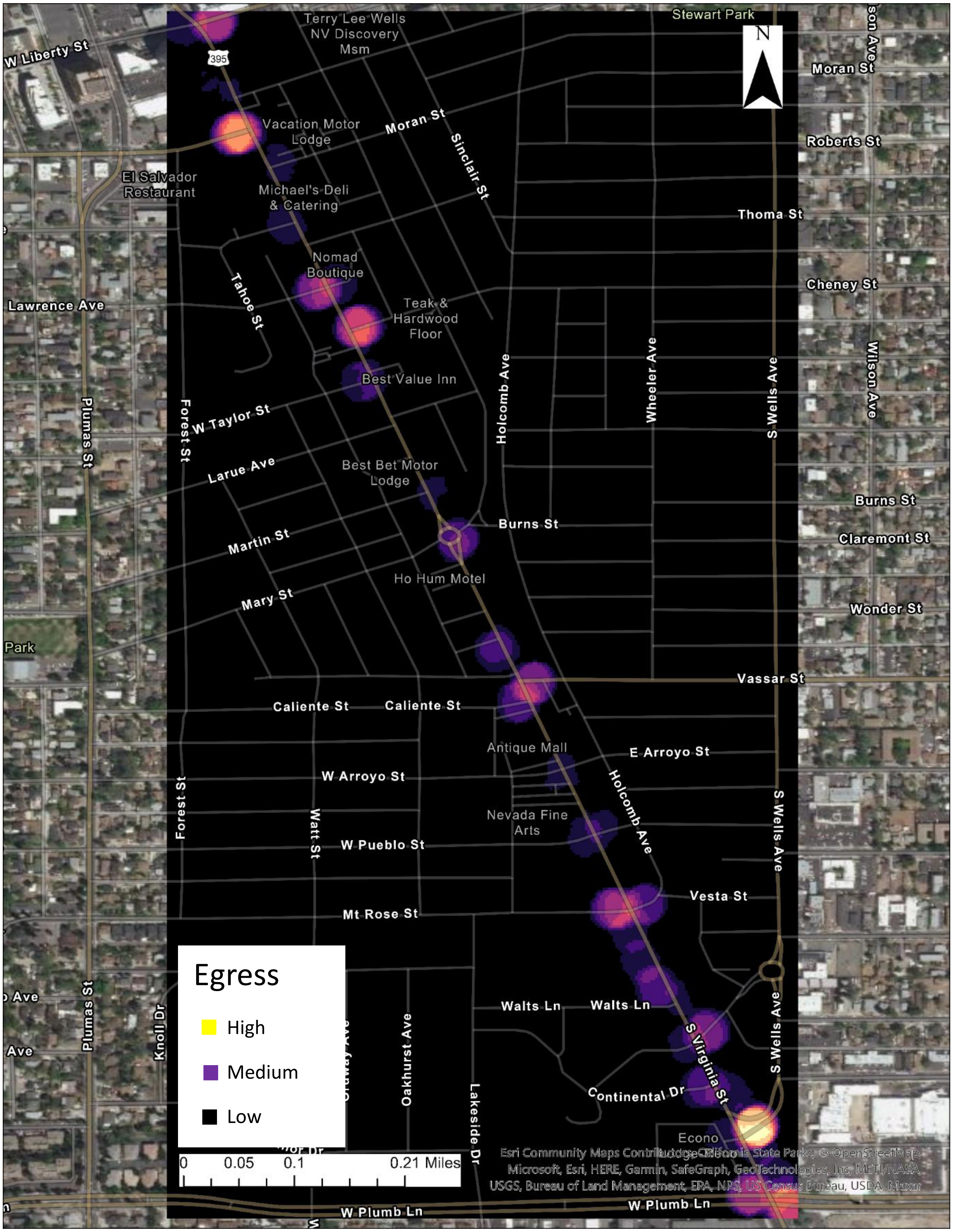


Figure 12 Wejo Virginia exits from side street heat map

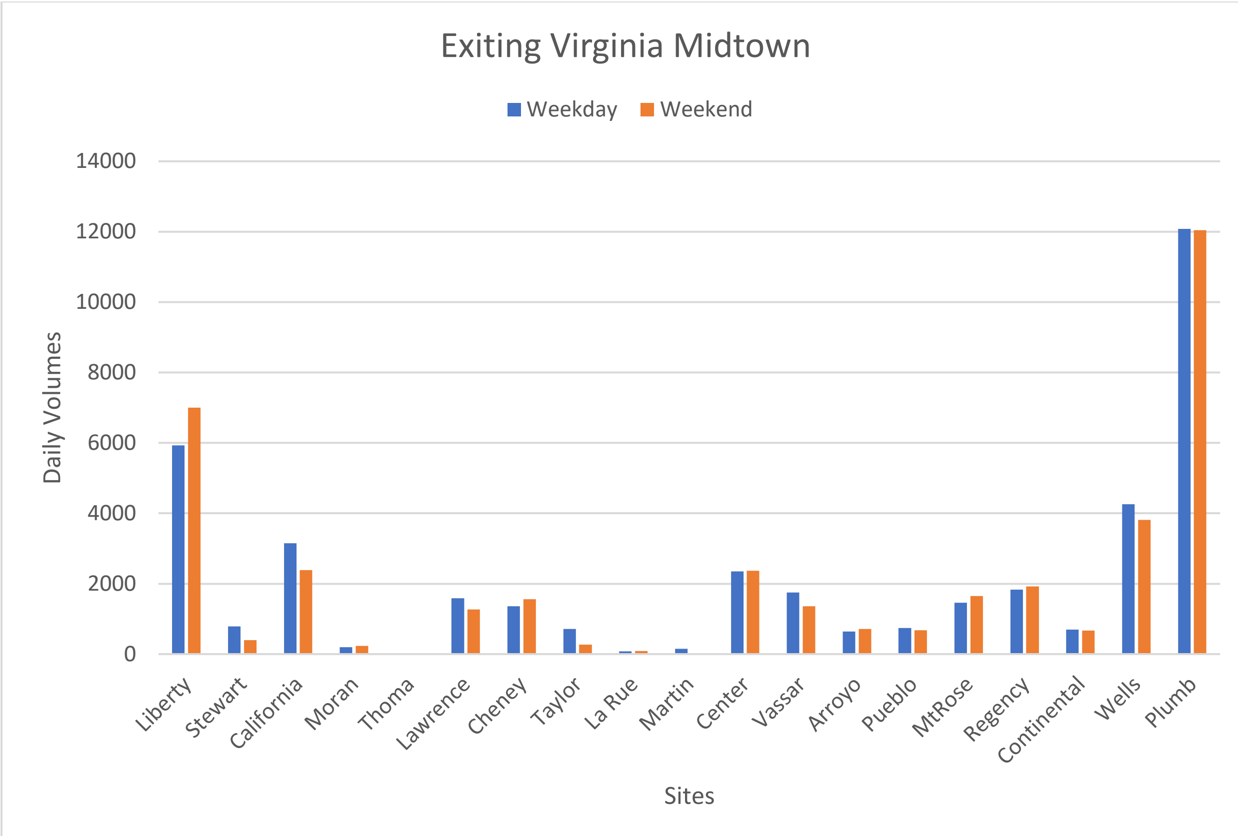


Figure 13 Daily side street exit volumes

Overall, entering into the study area occurs primarily in more localized areas along Virginia St, whereas, exiting vehicles use the minor intersection side streets more frequently. Furthermore, access from the side street occurs less frequently at the minor intersection in the northern end where there is a greater density of businesses.

4.4 Transit

Transit Ridership data was acquired from RTC Washoe for Route 1 and Route 100 which is the bus rapid transit Virginia Line. The acquired data consists of the average offs, ons, and loads during the data collection period 12/8/2021 to 2/8/2022 for each stop throughout the day. The offs refer to those that exit the bus and on refer to those that enter the bus. Therefore, off represent destinations and ons represent origins. In this study, the transit stops along Midtown Virginia St and the immediate vicinity are used and only the offs and ons are considered to understand the degree of transit utilization to and from Midtown Virginia St.

4.4.1 Route 1

Route 1 travels along the full length of Midtown Virginia St in both the northbound and southbound direction. Figure 14 and Figure 15 show the daily average offs and ons from 12/18/2021 to 2/8/2022, respectively. The Southbound stops will be located west of Virginia St and northbound stops will be located east of Virginia St. In the northbound direction, users tend to get off at Thoma St the most where there are greater density of businesses and pedestrian activity. In the southbound direction, users get off at the end points of the study area at Liberty St and Wells Ave. As for the ons, users tend to utilize the stops at Thoma, La Rue, and Taylor which is where there more businesses and pedestrian activity.

Figure 14 Daily average offs from 12/18/2021 to 2/8/2022 for Route 1

Figure 15 Daily average ons from 12/18/2021 to 2/8/2022 for Route 1

4.4.2 Virginia Line

The Virginia Line (Route 100) travels along the full length of Midtown Virginia St in both the northbound and southbound direction. Figure 16 and Figure 17 show the daily average offs and ons from 12/18/2021 to 2/8/2022, respectively. The Southbound stops will be located west of Virginia St and northbound stops will be located east of Virginia St. The number of stops appear to be less than in Route 1 and therefore there are no stops in areas with the highest density of businesses. The offs show on Center Street at Liberty St and at the southern bus stop near the roundabout. On the other hand, the ons occur more frequently at Liberty St and Walts in the southbound direction and at Center St near the roundabout in the northbound direction. Overall, the Center St, Walts, and Wells stops are utilized the most.

Figure 16 Daily average offs from 12/18/2021 to 2/8/2022 for Virginia Line (Route 100)

Figure 17 Daily average ons from 12/18/2021 to 2/8/2022 for Virginia Line (Route 100)

4.5 PARKING

Parking data is generated for each street parking space detected by the sensor for each site. A total of 97 parking spaces were detected along Midtown Virginia. Such data includes the entering and exit of each vehicle in each parking space greater than 5 minutes duration. Figure 18 displays a map of the average daily number of vehicles at each parking space detected along Midtown Virginia. The map shows that there is a greater frequency of vehicles parking around Thoma St where there are many shops and restaurants. Parking spaces in the southern half have less vehicle parking frequencies. Figure 19 displays the average parking duration in minutes along Midtown Virginia. In general, a lower value indicates greater turnover of parking and a larger value indicates vehicles parked all day or over a day. There are five breaks in the symbology as follows:

- Between five minutes and one hour
- Between one and two hours
- Between two and twelve hours
- Between twelve hours and one day
- Between one and two days

In general, the parking spaced along Thoma and St. Lawrence are occupied for less than one hour at a time. Around La Rue, there are vehicles occupying spaces for longer than two hours. Martin St has one space that has an average parking duration up two days.

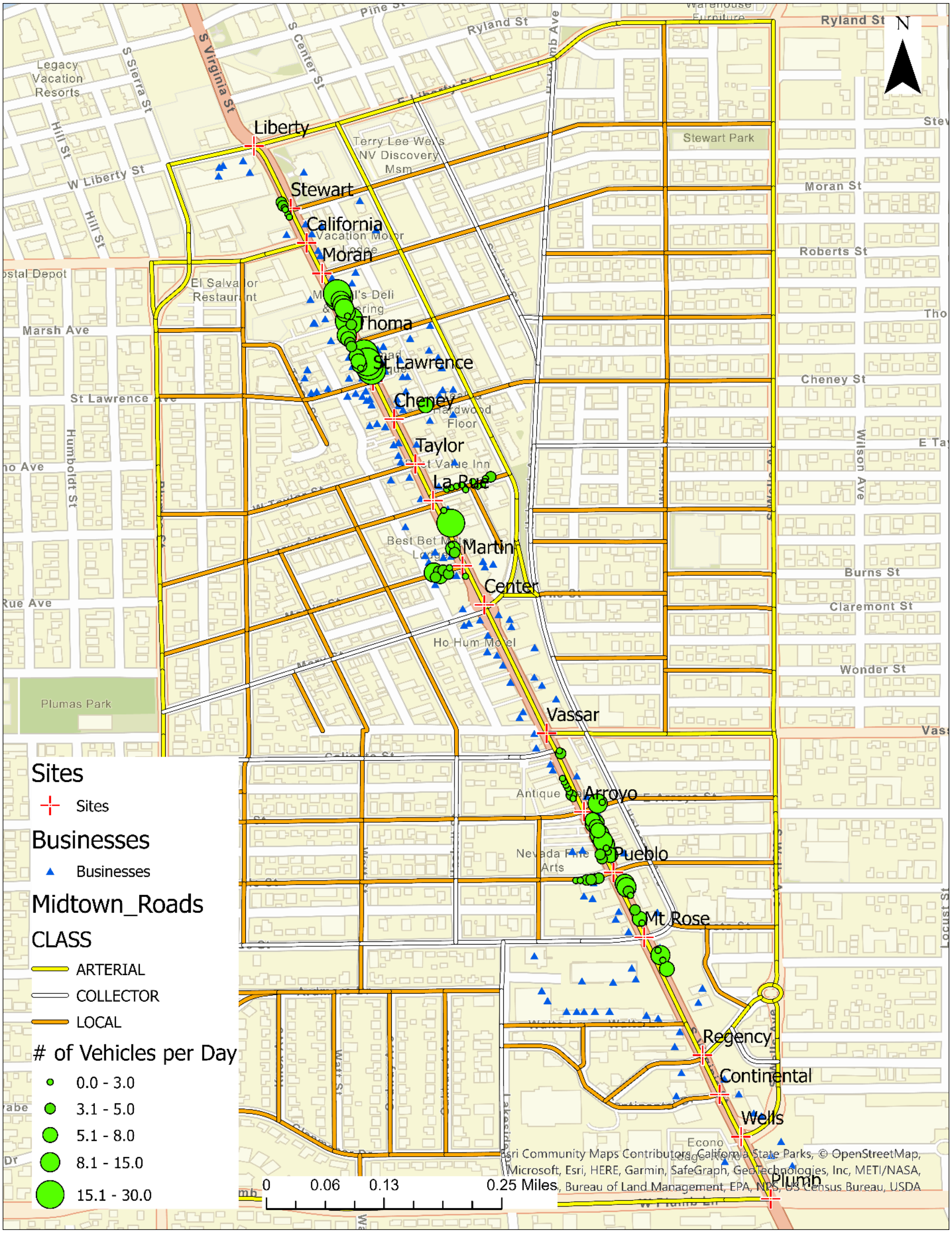


Figure 18 Average daily vehicles parked along Midtown Virginia

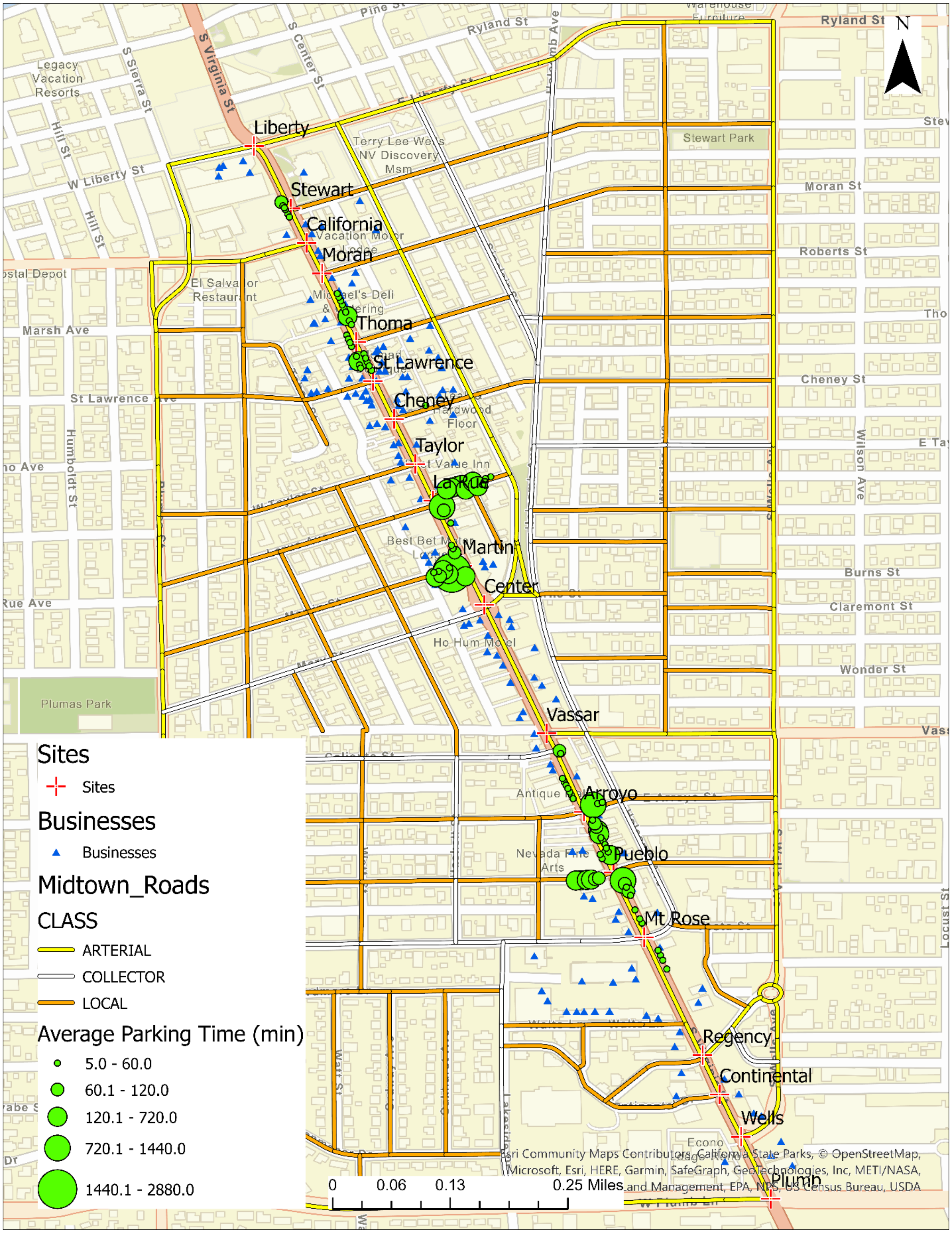


Figure 19 Average parking duration in minutes along Midtown Virginia

4.6 VEHICLE SPEEDS

Vehicle speeds refer to each vehicle's speed along Virginia St through the 18 data collection sites in both directions. In this section, only through movements are considered. Both directions are shown for both a weekday and weekend. Figure 20 and Figure 21 show the distribution of speeds via box and whicker plots along Virginia St in the northbound direction during a weekday and weekend, respectively. Similarly, Figure 22 and Figure 23 shows the same information in the southbound direction. The blue boxes (first column) indicate vehicles that are of length 38 feet or less, whereas orange boxes (second column) show vehicles 38 feet or greater. This breakdown is meant to isolate the buses to analyze the speeds they are traveling relative to the rest of traffic. The box portion of the plot is a distribution between the 25th and 75th percentile, the horizontal line is the 50th percentile (median), and the "X" is the mean. The lines connect the means at the "X". The whiskers at the extreme ends refer to the outlier speeds. Signalized intersections will have a wider distribution of speeds from stopped all the way to free flow, whereas uncontrolled intersection will have more tighter distributions since it is largely uninterrupted except in cases of pedestrian crossing events or during congested periods.

The common trend in each plot is that the south end speeds are steady and a majority are traveling slower than the 25 MPH speed limit. The speeds remain in the northern half despite the speed limit changing to 30 MPH. The Center St intersection provides traffic calming at the mid-point of the study area with speeds dropping up to 10 MPH at the approaches. Liberty St also shows significantly lower speeds. Buses tend to go similar speeds at the rest of traffic, but decrease in speed in the southern end where there are two lanes with one being a bus lane. Regency appears to be where the buses travel at consistently lower speeds than the rest of traffic. There is no clear distinction between weekday versus weekend speeds. Furthermore, northbound and southbound speeds follow similar trend except for St. Lawrence, where there is a dip in speeds in the southbound direction that does not appear in the northbound direction. The northbound direction appears to have greater speed distributions in the southern end at Mt Rose, Regency, and Wells. This region has two lanes in each direction which could contribute to variation.

Overall, a majority of vehicles are traveling at the speed limit or lower. Larger vehicles such as buses are traveling at similar speeds as the rest of traffic except in areas in the southern most sites. Center St see traffic slowing up to 15 MPH at the approach of the roundabout.

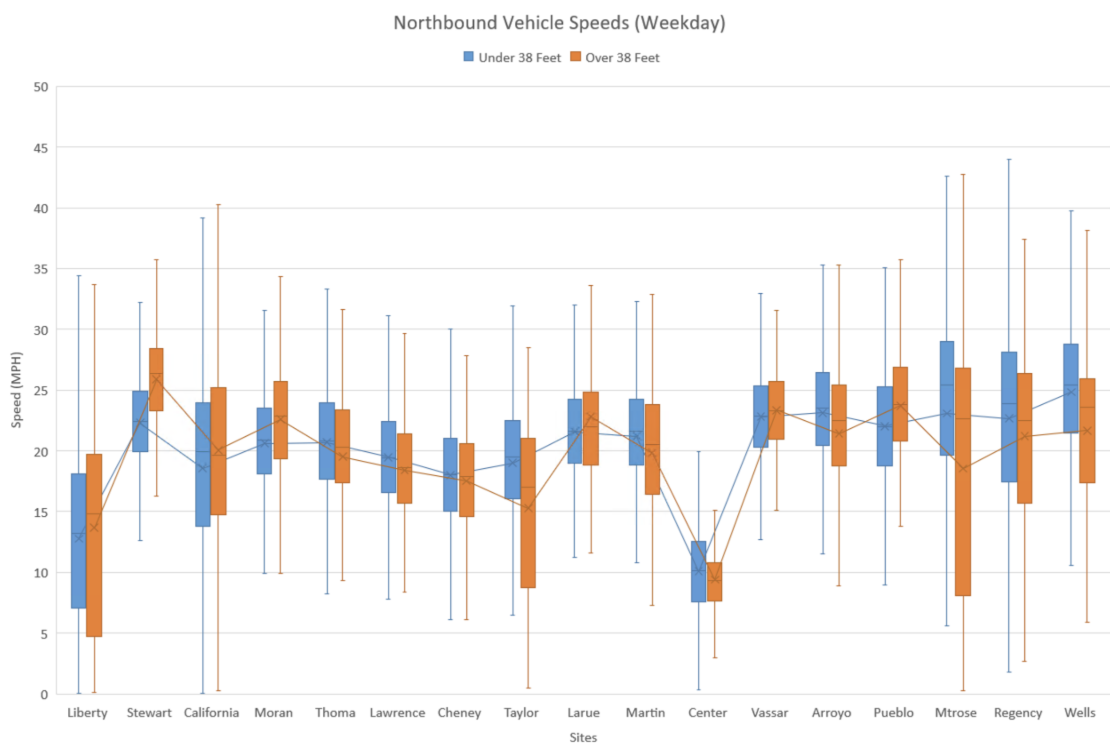


Figure 20 Distribution of northbound vehicle speeds through Virginia St on a weekday

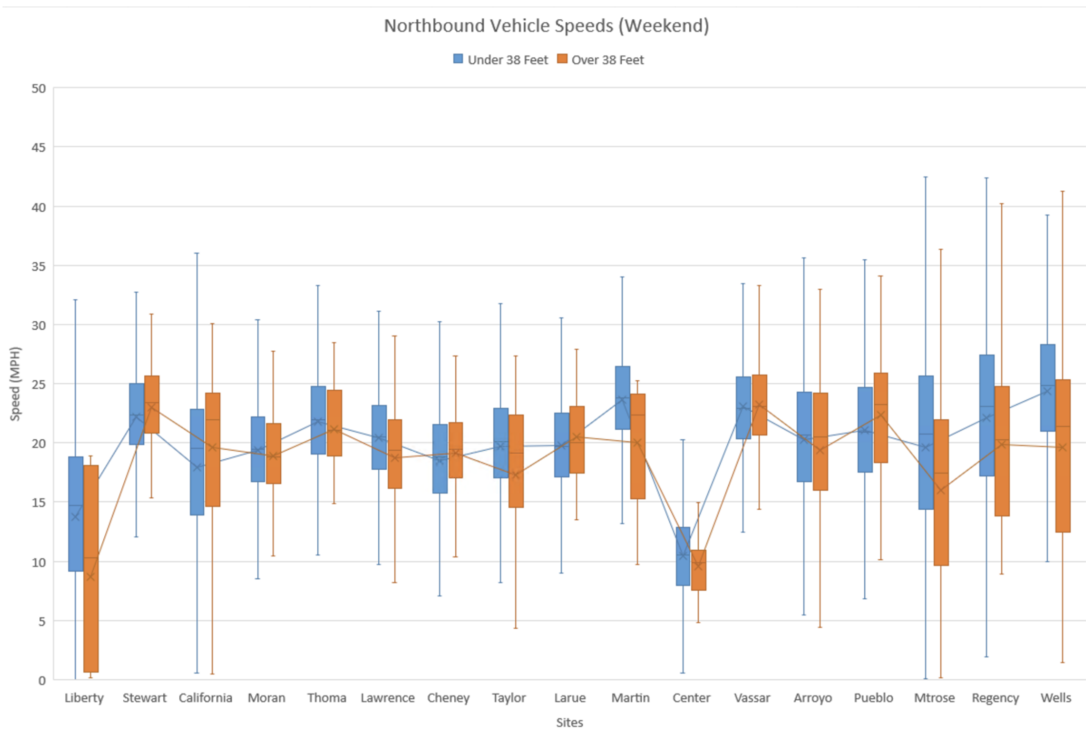


Figure 21 Distribution of northbound vehicle speeds through Virginia St on a weekend

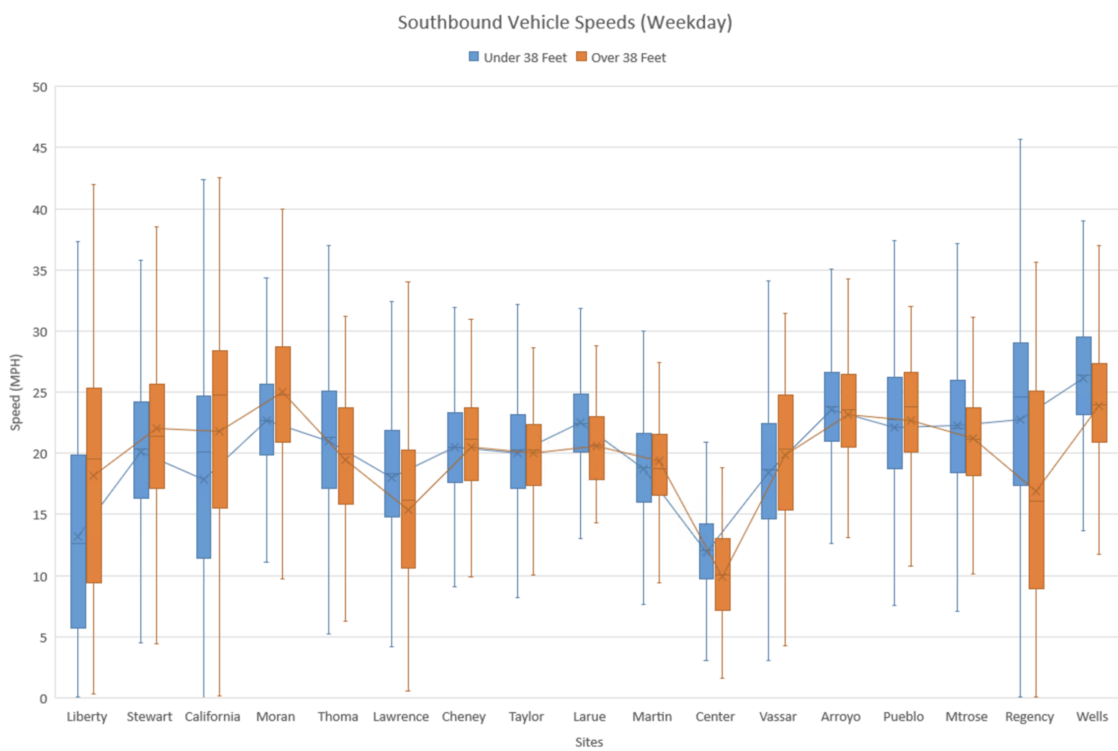


Figure 22 Distribution of southbound vehicle speeds through Virginia St on a weekday

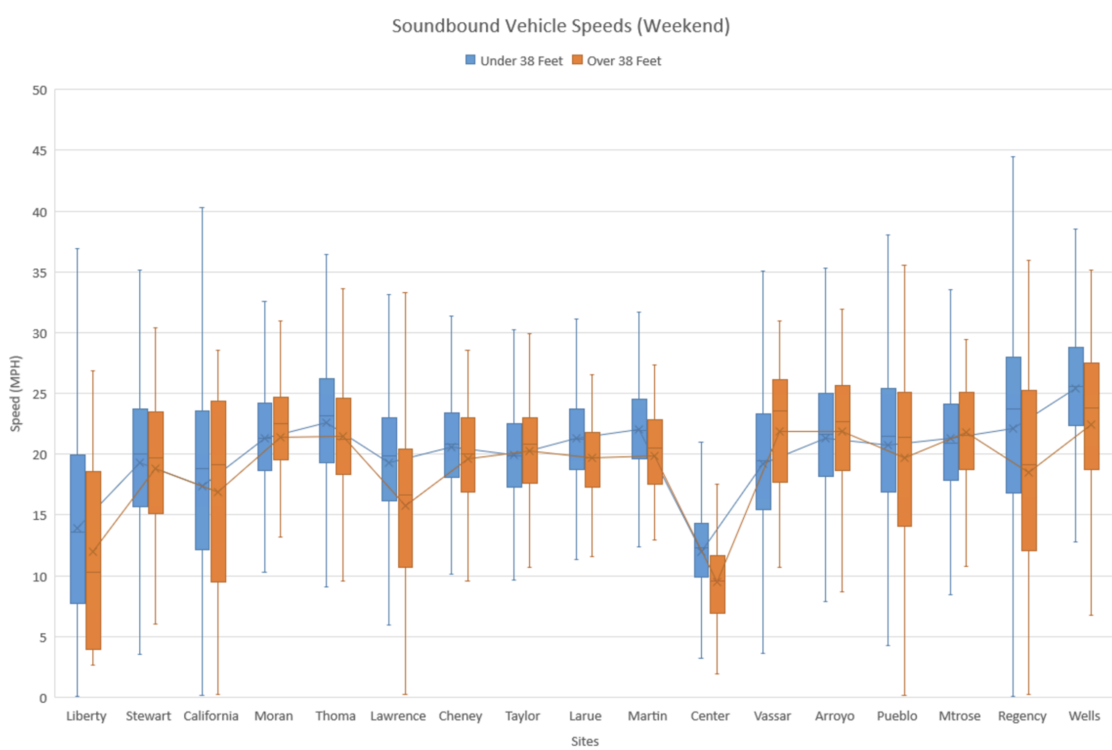


Figure 23 Distribution of southbound vehicle speeds through Virginia St on a weekend

5 PEDESTRIANS AND BICYCLES

The Midtown Virginia St area is a commercial area with high multi-modal volumes, such as bicycles and pedestrians. As such, this section will focus on network-wide bicycle and pedestrian volumes on the sidewalks and crossing the main street, as well as bicycles on the roadway.

5.1 PEDESTRIAN AND BICYCLE VOLUMES

The pedestrian and bicycle volumes refer to the total volumes of pedestrians and bicycles traveling alongside Virginia St on the sidewalks or side street crosswalks, both on the east and west side. Figure 24 shows the daily pedestrian volumes along Virginia St for a typical weekday and weekend day. Figure 25 shows the pedestrian volumes mapped with the businesses. There are greater pedestrian volumes in the northern half of the study area where there is a greater density of businesses. Furthermore, Lawrence and Cheney, which have the greatest business access, has the highest two pedestrian volumes on Virginia St. From Liberty to Moran, there is greater pedestrian volumes on the weekend than the weekday; However, the reverse is true for Thoma, Lawrence, Cheney, and Taylor. Pedestrian volumes level out from Center to Plumb from 200-300 daily volumes.

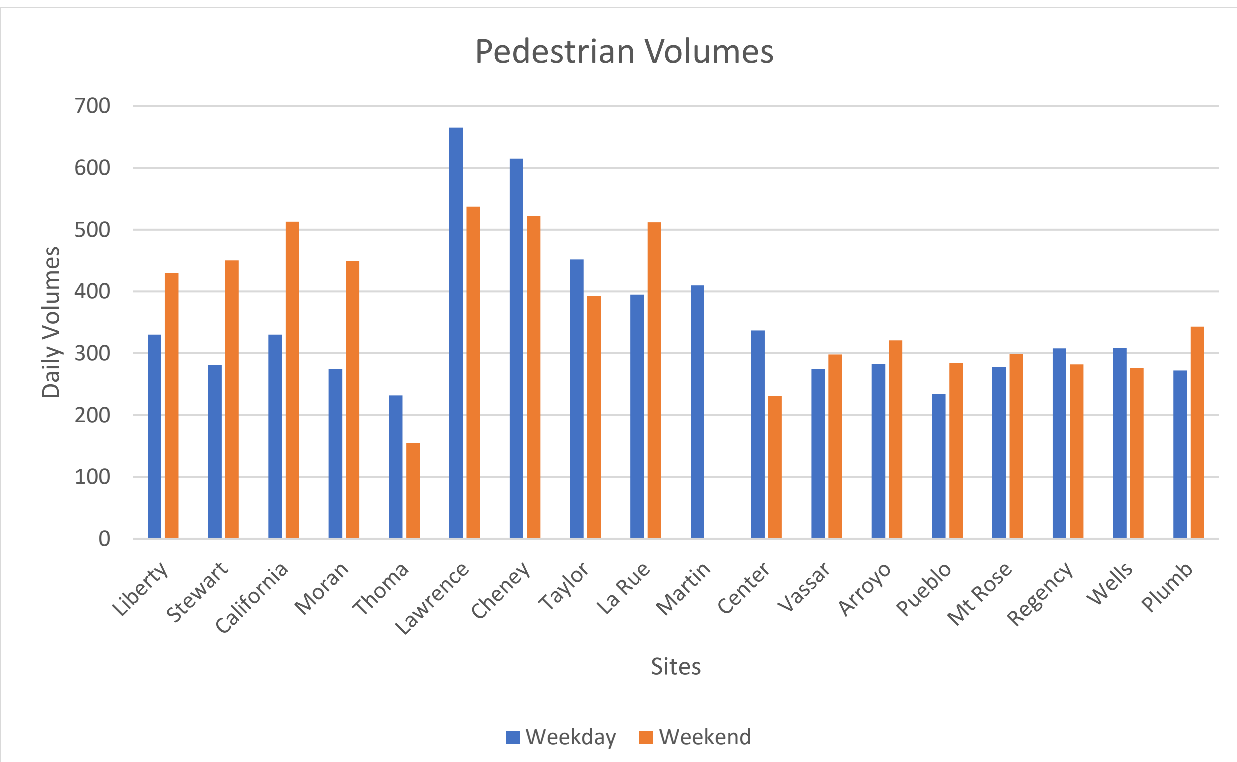


Figure 24 Daily pedestrian volumes along Virginia St for weekday and weekend

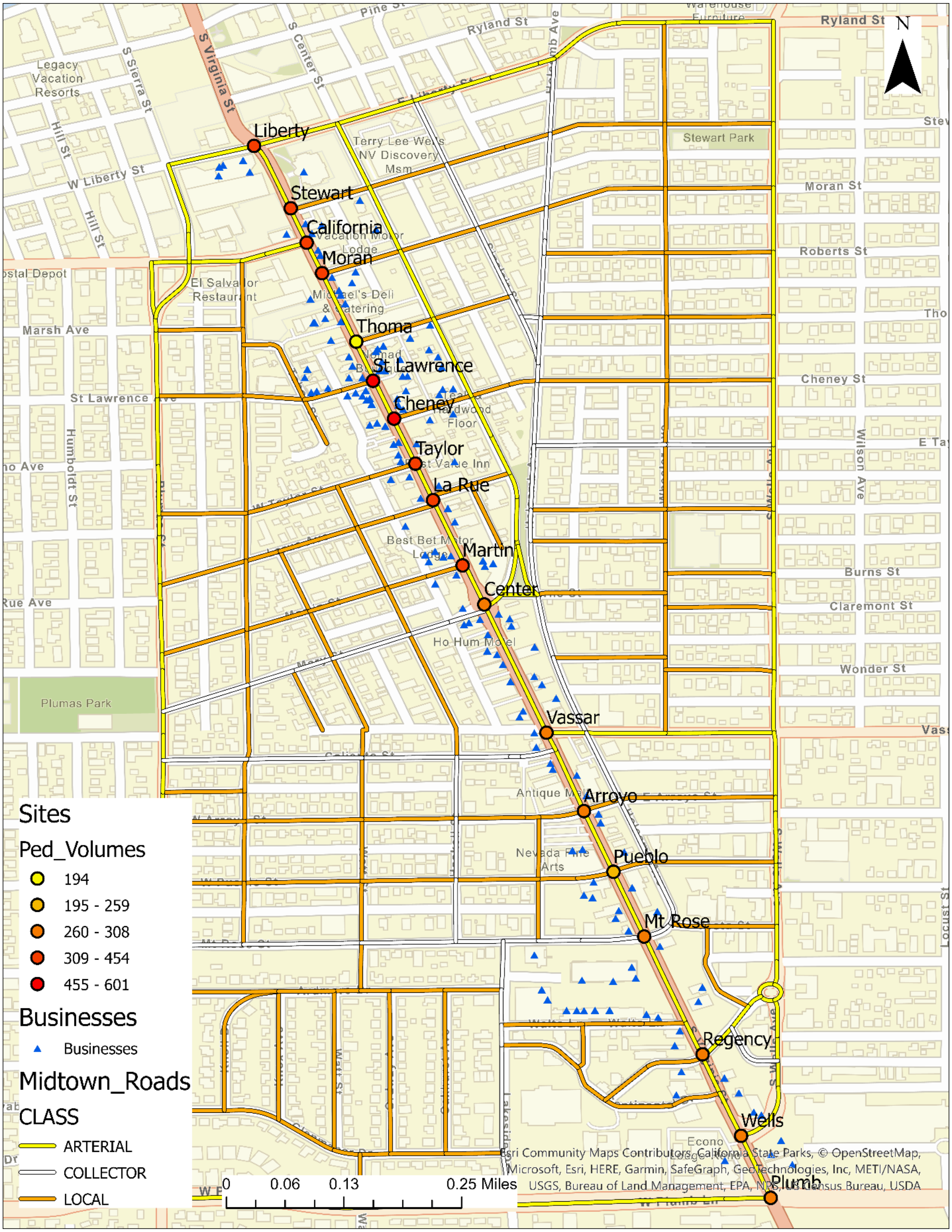


Figure 25 Mapped daily pedestrian volumes along Virginia St

Similar to the pedestrians, bicycle volumes traveling on the sidewalks and crosswalks can be analyzed. Figure 26 shows the daily bicycle volumes along Virginia St for a typical weekday and weekend day. Figure 27 shows the bicycle volumes mapped with the businesses. The daily volumes are relatively steady throughout the corridor with an increase at St. Lawrence which is where there is the greatest density of businesses. In the southern end of the corridor there are higher bicycle volumes on the weekend day versus the weekday; However, Center Street has double the bicycle volumes on the weekday.

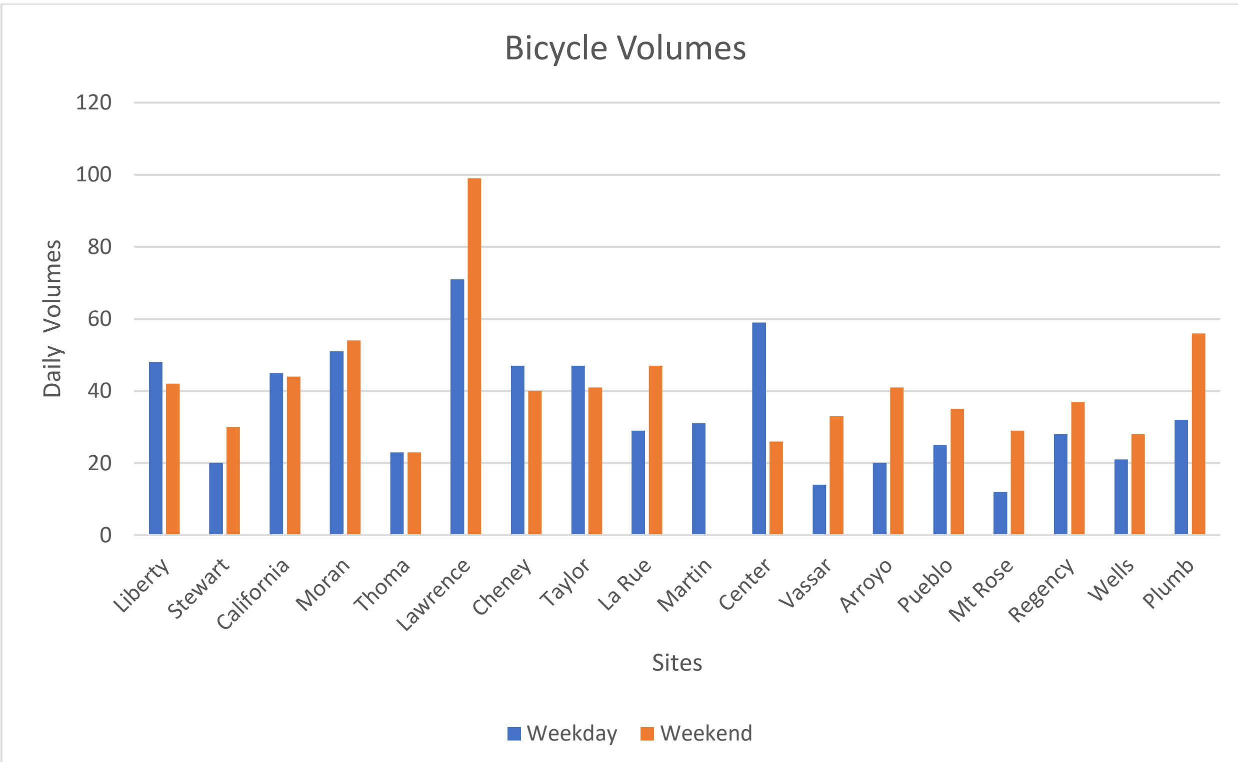


Figure 26 Daily Bicycle volumes along Virginia St for weekday and weekend

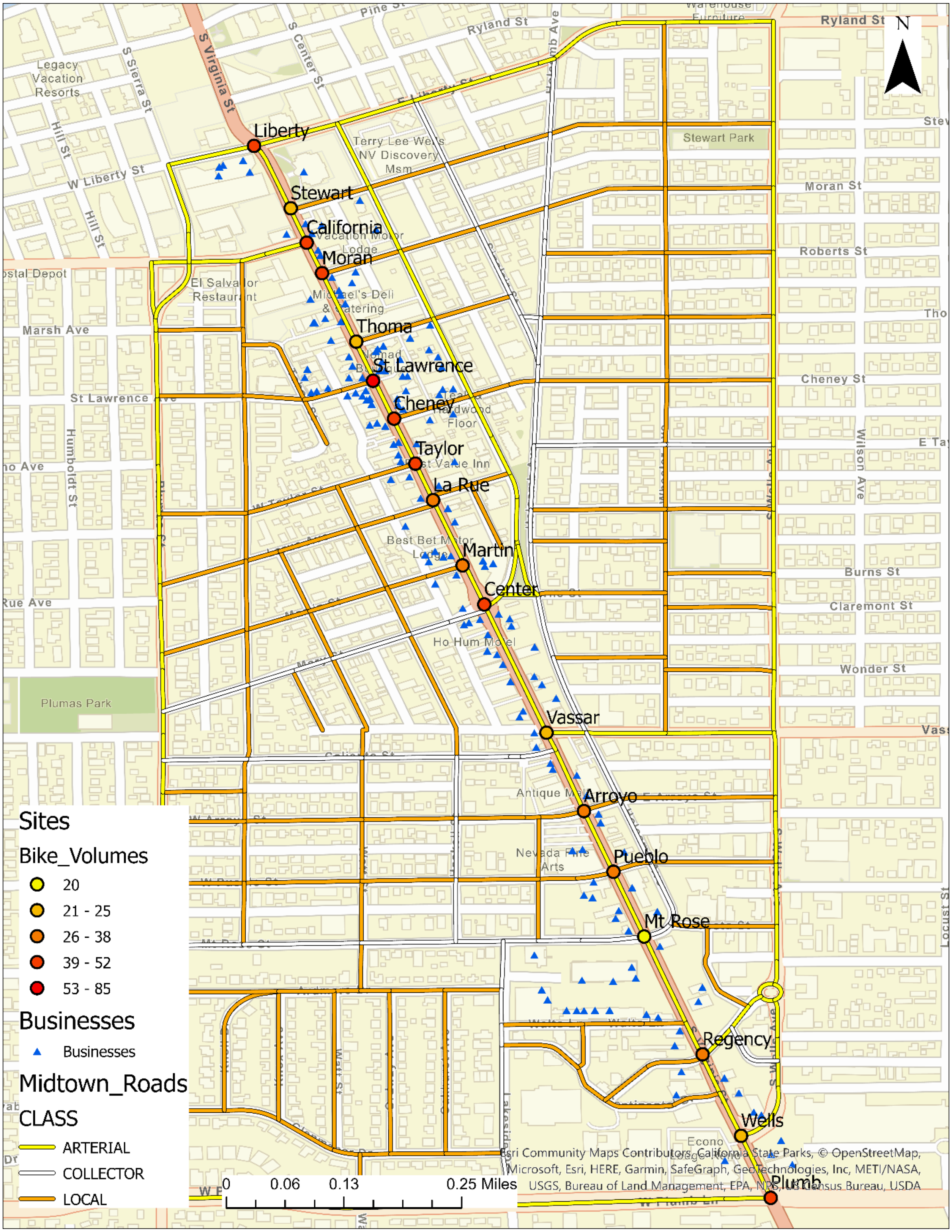


Figure 27 Mapped daily bicycle volumes along Virginia St

5.2 Pedestrian and Bicycle Crossing

The pedestrian and bicycle crossing volumes refers to the pedestrians and bicyclists that cross Virginia St. For pedestrian crossing volumes, sites without crosswalks were included to analyze the crossing volumes outside of crosswalks. These sites include Stewart, Moran, Cheney, and Wells. Figure 28 shows the daily pedestrian crossing volumes along Virginia St for a typical weekday and weekend day. Figure 29 shows the pedestrian crossing volumes mapped with the businesses. The sites with the highest pedestrian volumes include Liberty, Moran, Lawrence, Cheney, Center, and Plumb. The high crossing volumes at Lawrence and Cheney match the trend in the overall pedestrian volumes in the previous section and this is location where there is the highest density of businesses. There are also higher numbers of pedestrian crossings at the roundabout at Center, particularly on the weekend. The end points of the study area at Liberty and Plumb have high pedestrian crossing volumes, particularly during the weekday. Areas without crosswalks still showed high pedestrian crossing volumes, particularly at Moran and Cheney. At Wells, there may not be as many pedestrian crossings, but there are four lanes and a center median for which pedestrians need to cross.

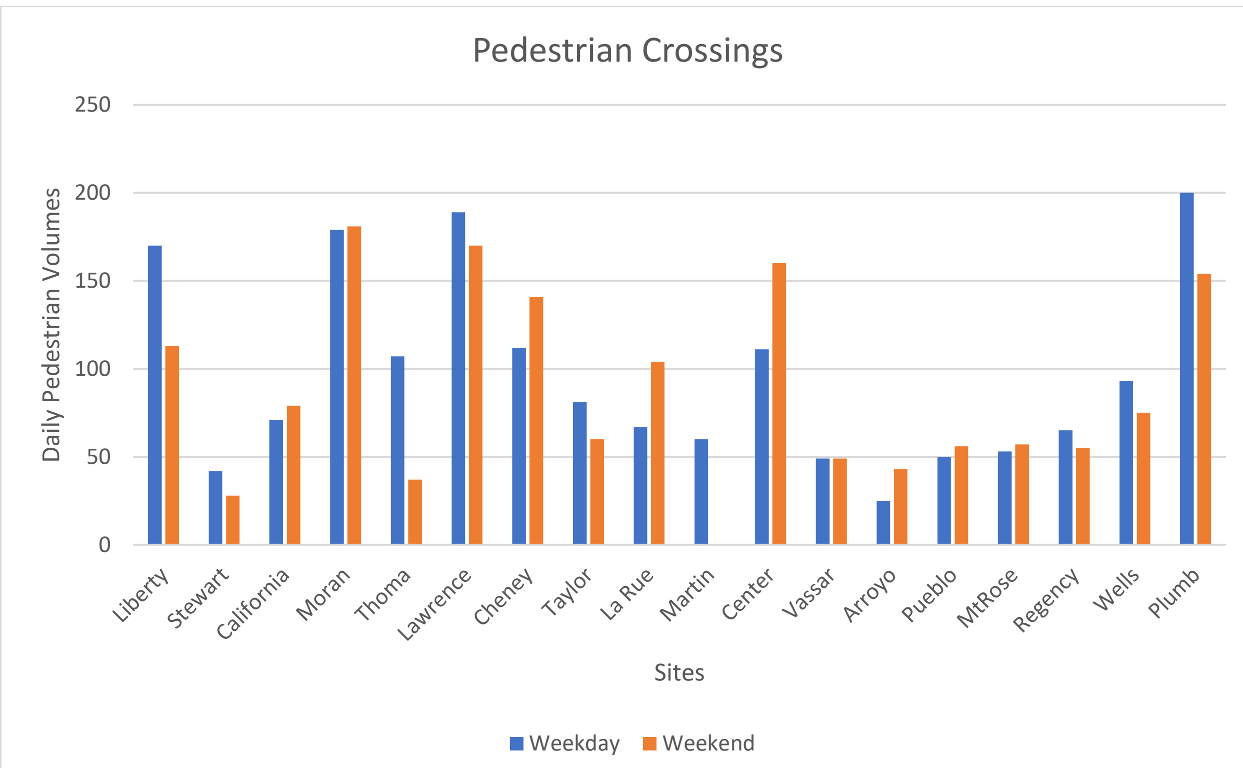


Figure 28 Daily pedestrian crossings along Virginia St for weekday and weekend

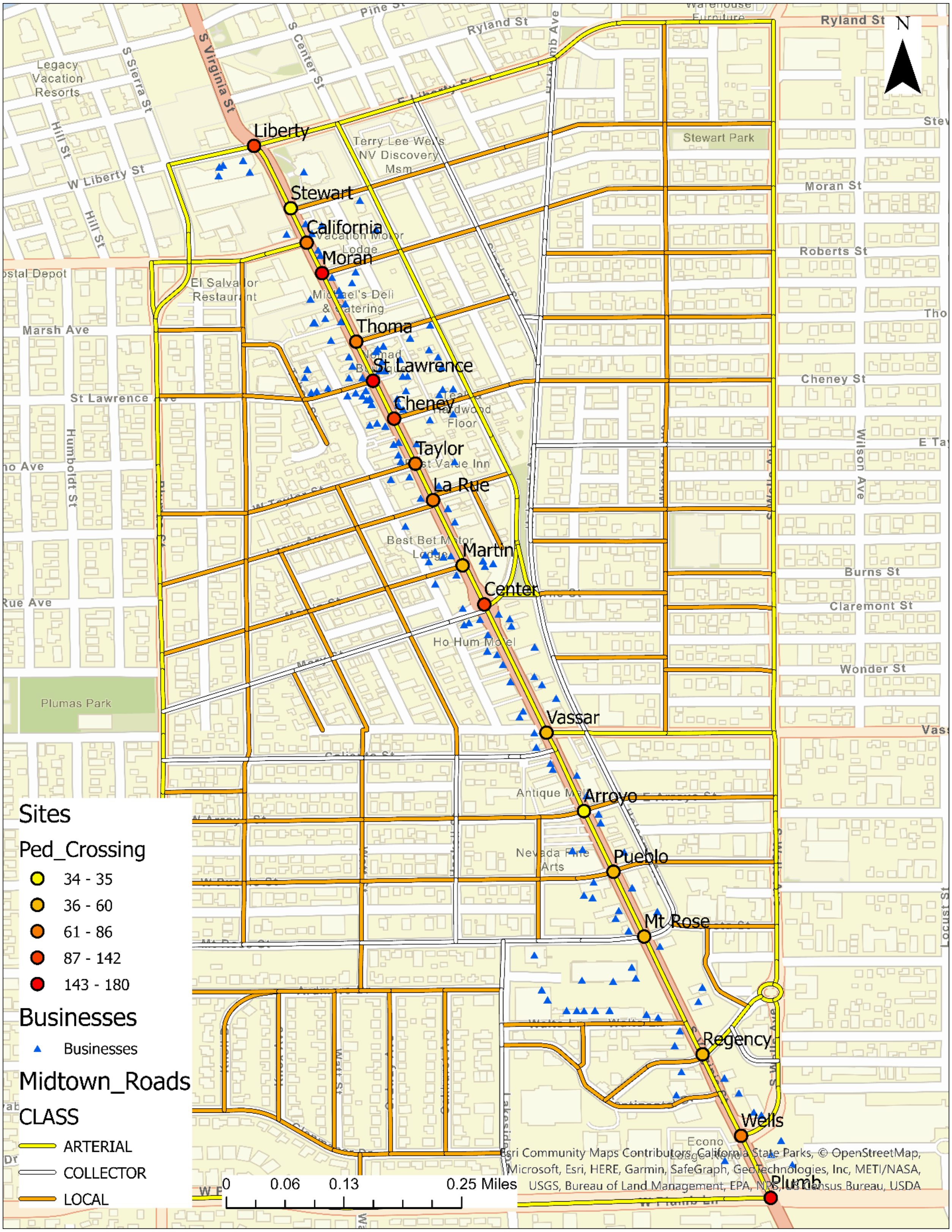


Figure 29 Mapped daily pedestrian crossings along Virginia St

Figure 30 shows the daily pedestrian crossing volumes along Virginia St for a typical weekday and weekend day. Figure 31 shows the pedestrian crossing volumes mapped with the businesses. Figure 30 shows that there is more bicycle crossing events on the weekend except at California Thoma, and Plumb. The hot spots occur at California, St. Lawrence, Center, Vassar, and Plumb. These trends largely match the pedestrian crossing volumes for where there are crosswalks.

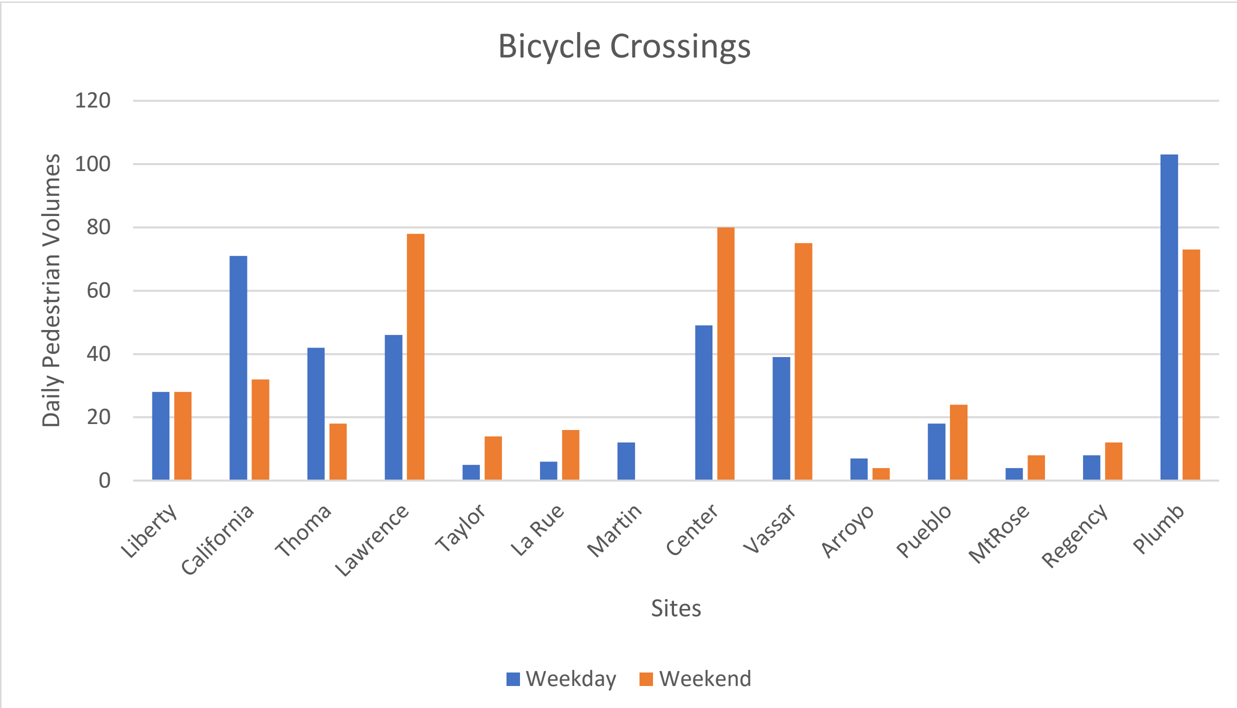


Figure 30 Daily bicycle crossings along Virginia St for weekday and weekend

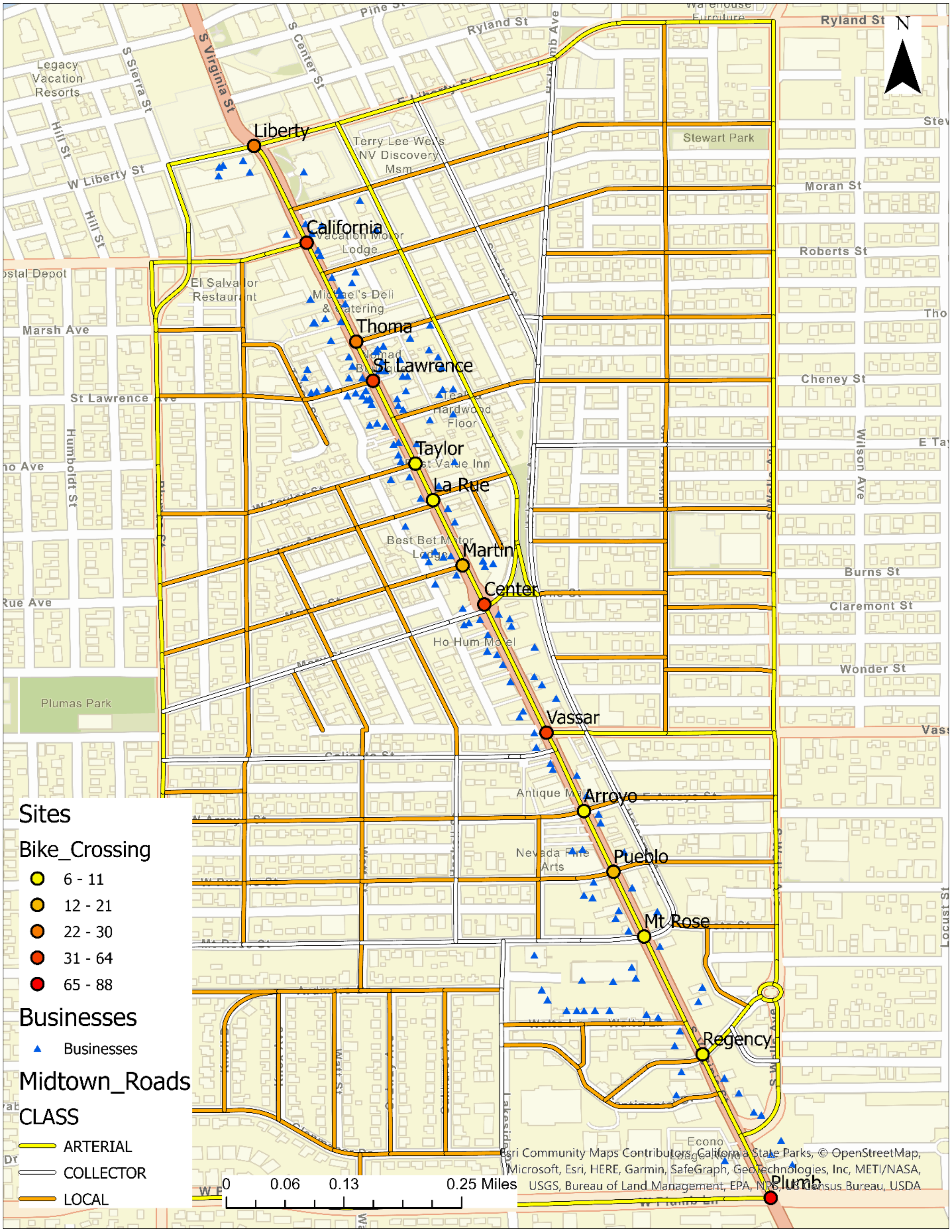


Figure 31 Mapped daily bicycle crossings along Virginia St

5.3 Bicycle On Roadway

The bicycles on the roadway refers to bicyclists traveling in the vehicle lanes. There are shared lane markings through the study area allowing for vehicles and bicyclists to share the road. Figure 32 shows the frequency of bicyclists on the roadway mapped with the businesses and roadway classifications. Hot spots appear at Cheney, Center, Mt Rose, and Wells. At Center St, there is interesting activity that occurs in which a group of bicyclists entered into the roundabout and circled the roundabout more than once. Between Regency and Mt Rose, the shared lane markings move to the outer bus lane. In this area, Regency has far less bicycle volumes than Mt Rose, indicating that more bicycles are Turing off of Virginia at somewhere in between the two sites.

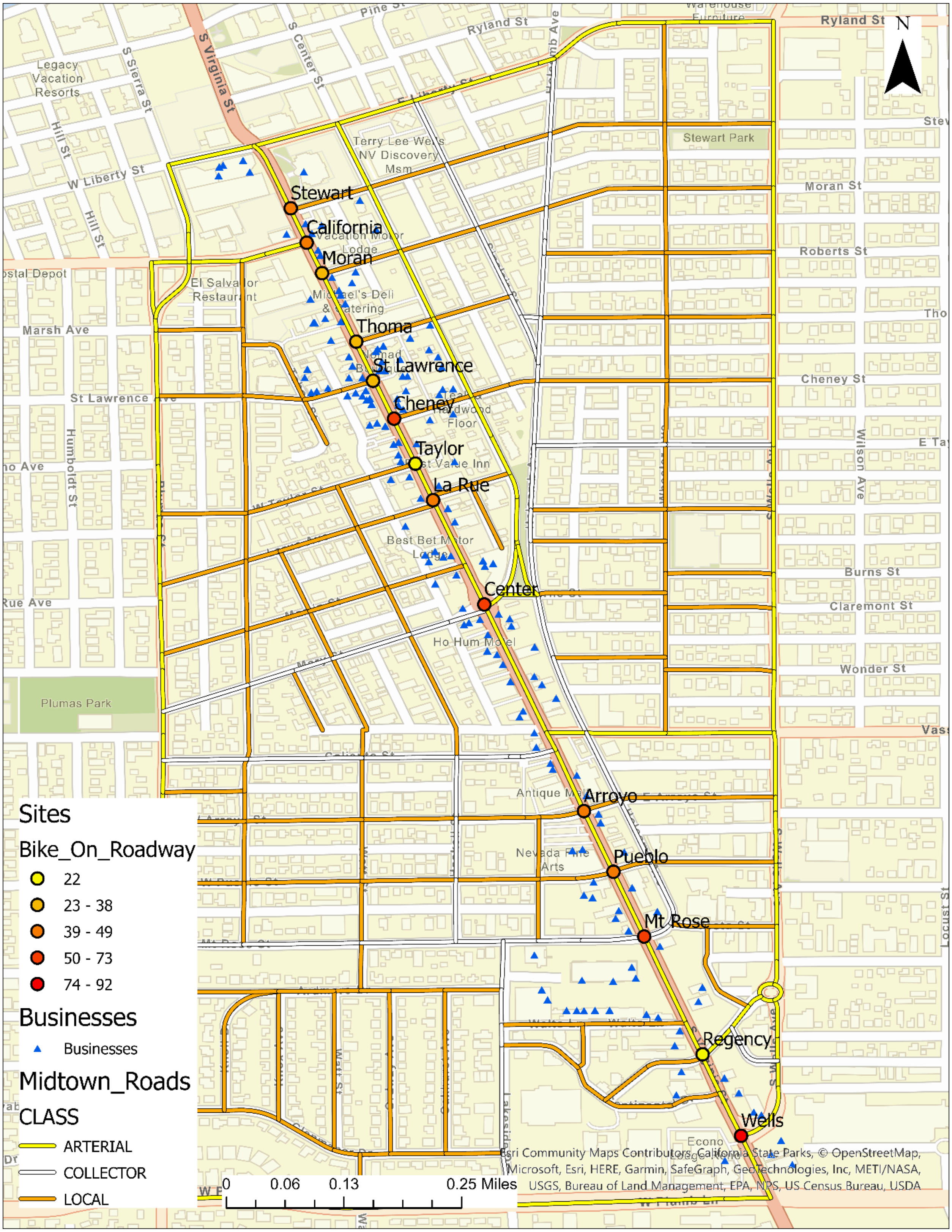


Figure 32 Mapped daily bicycle on the roadway along Virginia St

5.4 Pedestrian Level of Service

The Highway Capacity Manual (HCM) 7th edition is used to measure the pedestrian level of service (LOS) at each Virginia St crossing event. The methodologies differ between a two-way-stop-controlled (TWSC) intersection and a signalized intersection. Each will be discussed in this section.

5.4.1 Two-Way Stop Controlled Intersections

The HCM methodology for determining pedestrian LOS at a TWSC intersection is based on the following performance measures:

- Average pedestrian delay, and
- Perception-based LOS based on the probability of crossing without delay and the type(s) of treatment(s) provided at the crossing.

The average pedestrian delay is estimated by summing up the expected delay from crossings occurring when motorists yield, and the expected delay from crossings when pedestrians wait for an adequate gap. Those two terms can be calculated through the estimation of critical gap, which is the minimum time interval below which a pedestrian will not attempt to begin crossing the street, and the estimation of probability of a delayed crossing.

For pedestrian LOS, HCM provides a perception-based rating system considering the average proportions of pedestrians who would rate their crossing experience as "dissatisfied" or worse with their crossing experience, as shown in Table 6. HCM assume that the number of "satisfied" and "dissatisfied" ratings from pedestrians will be in proportion to the respective satisfaction probabilities when no delay occurs. So, the probability of "dissatisfied crossing" can be determined by estimating the probability of a delayed crossing. The variables that are used to determine the probability are as follows:

- Number of through lanes crossing on the major street
- Crosswalk length and width
- Presence of marks crosswalk, median refuge and RRFB
- AADT of major street
- Pedestrian flow rate
- Conflicting vehicle flow rate

Table 6 HCM pedestrian LOS breakdown

LOS	Condition	Comments
A	$P_D < 0.05$	Nearly all pedestrians would be satisfied
B	$0.05 \le P_D < 0.15$	At least 85% of pedestrians would be satisfied
C	$0.15 \le P_D < 0.25$	Fewer than one-quarter of pedestrians would be dissatisfied
D	$0.25 \le P_D < 0.33$	Fewer than one-third of pedestrians would be dissatisfied
E	$0.33 \le P_D < 0.50$	Fewer than one-half of pedestrians would be dissatisfied
F	$P_D \ge 0.50$	The majority of pedestrians would be dissatisfied

Note: P_D = proportion of pedestrians giving a "dissatisfied" rating or worse.

Since this method only applies to the two-way stop-controlled (TWSC) intersection major street crossings, the TWSC intersections without major-street crosswalk are not included. The sites for which this applies is as follows:

- Virginia & Thoma
- Virginia & St. Lawrence
- Virginia & Arroyo
- Virginia & La Rue
- Virginia & Taylor
- Virginia & Pueblo
- Virginia & Martin

The results of this analysis are shown in Table 7. From the results, the LOS scores show F for all site TWSC intersections except St. Lawrence and Taylor, which has a score of C. The main reason for the C score is because of the existence of a median refuge; in looking at the average delay, there does not appear to be a significant difference between each site. Another important note is that the HCM is using equations calibrated by the authors through studies of their own, which may not accurately reflect the unique situation in the Midtown Virginia region. Firstly, since speeds are generally lower along this corridor, pedestrians tend to cross more aggressively than the HCM calibration may account for. Secondly, there are many areas along Virginia St in which pedestrians will cross that are outside of the crosswalk markings, which also reflects the relative aggressiveness in crossing behavior.

Table 7 Pedestrian LOS at each two-way stop-controlled intersection

Side Street	Average Delay (s)	Prop of dissatisfied rating (%)	LOS score
Thoma	8.66	51.82	F
St. Lawrence	6.00	17.21	C
Taylor	5.76	17.50	C
LaRue	11.46	55.29	F
Martin	9.52	54.11	F
Arroyo	10.65	55.39	F
Pueblo	9.24	54.15	F

5.4.2 Signalized Intersections

For signalized intersections, the pedestrian level of service is based on performance measures of pedestrian delay and pedestrian LOS score. Pedestrian delay represents the average time a pedestrian waits for a legal opportunity to cross an intersection leg. The LOS score is an indication of the typical pedestrian's perception of the overall crossing experience. For this method, there are some assumptions made as follows:

- For the flow rate associated with the left-turn movement that receives a green indication concurrently with the subject pedestrian crossing and turns across the subject crosswalk. To assume a worst situation, here assume that all left turn traffic is permitted left turn.

- For the estimation of RTOR (right turn on red) flow rate, which is the flow rate associated with the approach being crossed and that also turns across the subject crosswalk. Assume the right-turn vehicle comes randomly and make right turn follows normal distribution, so that the RTOR flow rate is the total right-turn traffic multiplied by other phase's time divided by the total cycle length.

Table 8 shows the breakdown of LOS score and corresponding LOS. The main factors that may weigh the LOS score are as follows:

- Number of traffic lanes crossed when traversing crosswalk
- Number of right turn channelizing islands along crosswalk
- Vehicle flow rate
- Right turn on red flow rate
- Permitted left turn flow rate
- Midsegment 85th percentile speed
- Signal control information

Table 8 HCM signalized intersection crossing LOS score

LOS	LOS Score
A	≤1.50
B	>1.50–2.50
C	>2.50–3.50
D	>3.50–4.50
E	>4.50–5.50
F	>5.50

Table 9 shows the results for all the signalized intersection crossings except for Vassar St because of complications in the signal timing information. Each crosswalk has an LOS of B except for those on Plumb Ln, which has LOS C. This indicates that the LOS of service for pedestrians is good at signalized intersections along Midtown Virginia St. Also, the delay is lower is the northern sites where there are more businesses and generally more pedestrian activity.

Table 9 Signalized intersection pedestrian LOS

Crosswalk	Average Delay	LOS	LOS

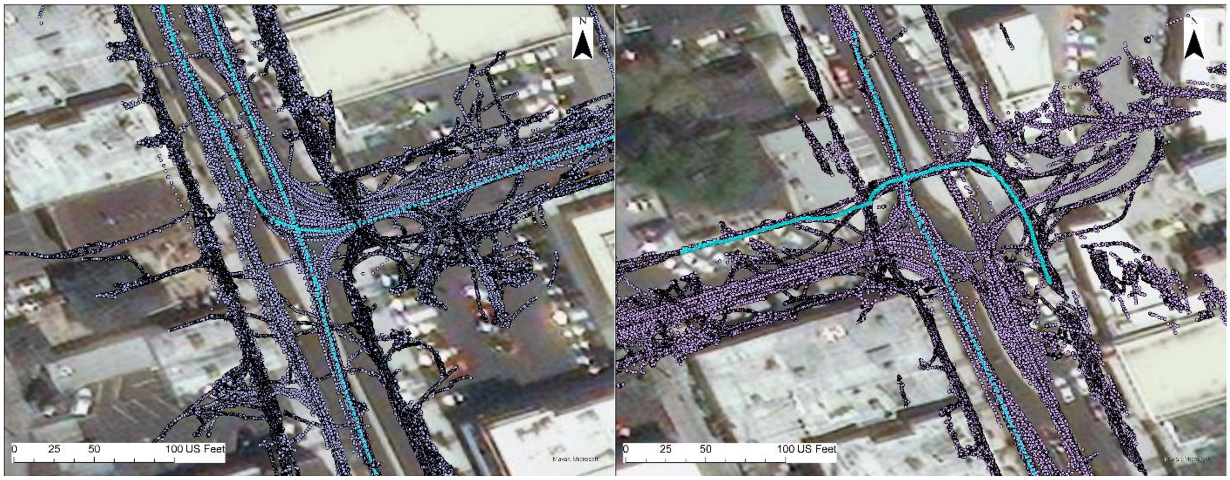
	(s)	Score	Grade
Liberty North	40	2.12	B
Liberty South	38	2.50	B
Liberty West	40	2.23	B
Liberty East	37	2.28	B
California North	24	2.25	B
California South	40	2.24	B
California West	40	2.36	B
Mt Rose South	57	2.49	B
Mt Rose West	57	2.02	B
Mt Rose East	57	1.91	B
Regency South	57	2.30	B
Regency West	55	1.82	B
Regency East	57	2.04	B
Plumb North	56	2.94	C
Plumb South	56	3.17	C
Plumb West	55	2.93	C
Plumb East	56	2.79	C

6 CONFLICTS AND INTERACTIONS

Through the trajectory data extracted from roadside LiDAR sensors, interactions and conflicts between road users can be extracted and used as surrogate safety measures. The methodology used in this report is extracting interactions for which two road users' trajectories cross each other within a certain time difference. In other words, if a vehicle makes a left turn in front of an oncoming through vehicle, what is the time difference in which the two vehicles occupied the same space. The same situation applies to other road users such as pedestrians. In the literature, two seconds or less is a common threshold to trigger concern. However, given that this is a low-speed intersection, speed is an important factor in determining if the interaction is truly dangerous. Two vehicles traveling at low speeds and crossing at a conflict point is less concerning than if one or both are traveling at fast speeds. The angle at with the two road users passes each other is another important factor in determining how severe an interaction is. At low speeds that are seen in Virginia St in Midtown, conflicts less than 90 degrees are not as critical as those closer to 180 degrees. The following criteria is used to extract conflicts for this study:

- Vehicle to vehicle:
  - Conflict angles of 90 degrees or greater: Left/thru and thru/thru conflicts
  - Time difference less than 2 seconds
  - Max speed is greater than or equal to 15 MPH
- Vehicle to pedestrian
  - Conflicts between crossing pedestrians and vehicles
  - Time difference less than 2 seconds
  - Max Speed greater than or equal to 15 MPH

Figure 33 shows an example of a vehicle to vehicle and vehicle to pedestrian conflicts. Note that not all sites have vehicle to vehicle conflicts with angles 90 degrees or greater because some geometries do not allow for it, such as the access controlled raised median sites and the roundabout. Also, vehicle to pedestrian conflicts can occur outside of crosswalks. A total of two days of data are used for each site, one weekday and one weekend.



(a) (b)

Figure 33 Example of (a) vehicle to vehicle conflict (b) vehicle to pedestrian conflict

Figure 34 shows a heat map of the vehicle-to-vehicle conflicts based on the outlined criteria. The most obvious hot spot appears at Regency which is a signalized intersection with permissive left turns in the northbound and southbound left directions. While the left turn volumes are not particularly high, the through movement volumes are high as outlined in Figure 6 and there are two lanes in each direction with one being a bus lane. However, a majority of conflicts occur at a time difference of 1.5 and greater, indicating less severe interactions. Other hot spot includes Arroyo, St. Lawrence, and Liberty. Overall, the main criteria in how many vehicle-to-vehicle conflicts occur at a site is proportionate to the amount of conflict points there are in which the one vehicle needs to yield or stop for oncoming traffic and find a gap to make their maneuver. St. Lawrence is the only hot spot where there is only one conflict point considered: southbound through and northbound left; however, if the threshold were changed to 1.5 seconds, St. Lawrence would not be a hot spot. Overall, there are no significant safety concerns for concerns between vehicles based on this data. With the combination of low speeds and higher time differences, the chances of severe crashes happening is reduced.

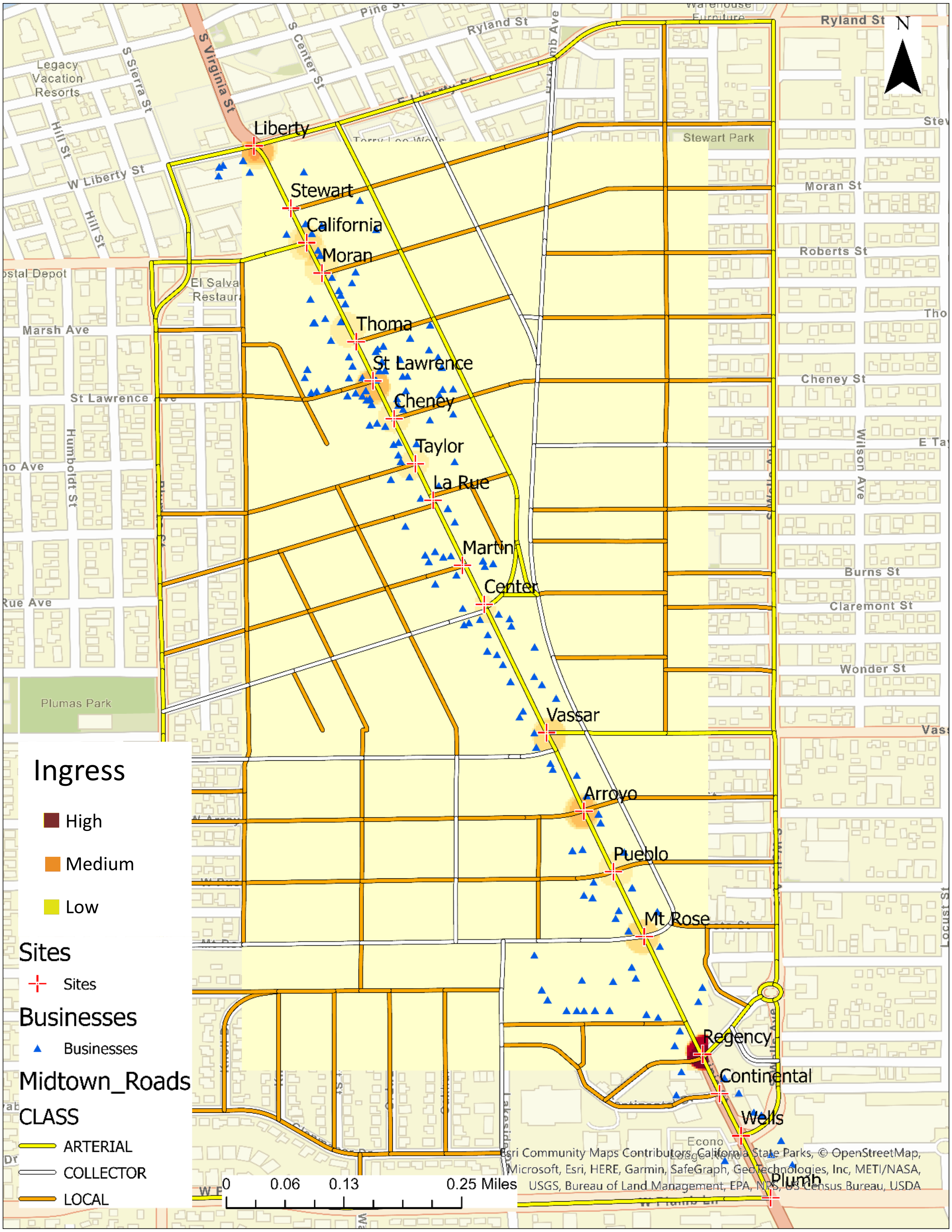


Figure 34 Vehicle-to-vehicle conflict heat map

Figure 35 shows a heat map of the vehicle to pedestrian conflicts based on the outlined criteria. The biggest hot spot is located at Moran St in which northbound and southbound vehicles conflict with crossing pedestrians. Recall that Moran Street does not have a crosswalks and relatively high pedestrian crossing volumes. St. Lawrence had comparable pedestrian crossing volumes but has a crosswalk but does not show up as a hot spot. Cheney is another site which had higher pedestrian volumes and no crosswalk and shows up as a hot spot in the map. Wells had lower volumes with no crosswalk and shows up as a minor hot spot. The Center St roundabout had more conflicts occurring on the east leg where there are only exiting vehicles. The literature shows that yield rates at the exits of roundabouts is lower, which may contribute to this hot spot. Lastly, Arroyo has relatively low pedestrian crossing volumes, but shows up as a minor hot spot. This suggests that this location has a higher rate of conflicts when normalized to pedestrian crossing volumes.

Another major criterion in determining how severe these conflicts are is by understanding the order of the conflict. In other words, which road user entered into the conflict zone first, the pedestrian or the vehicle. A pedestrian walking in front of a vehicle is more dangerous than a pedestrian crossing directly after a vehicle has passed. For each site, the majority of conflicts are pedestrians crossing directly after the vehicle has passed, which a less severe situation. That being said, in order for the conflict to be triggered, the pedestrian would have to be close to the passing vehicles, which, as speeds greater than 15 MPH, could be concerning.

Overall, most intersections have good pedestrian safety, however, areas where are no crosswalks and high pedestrian activity are of higher concern.

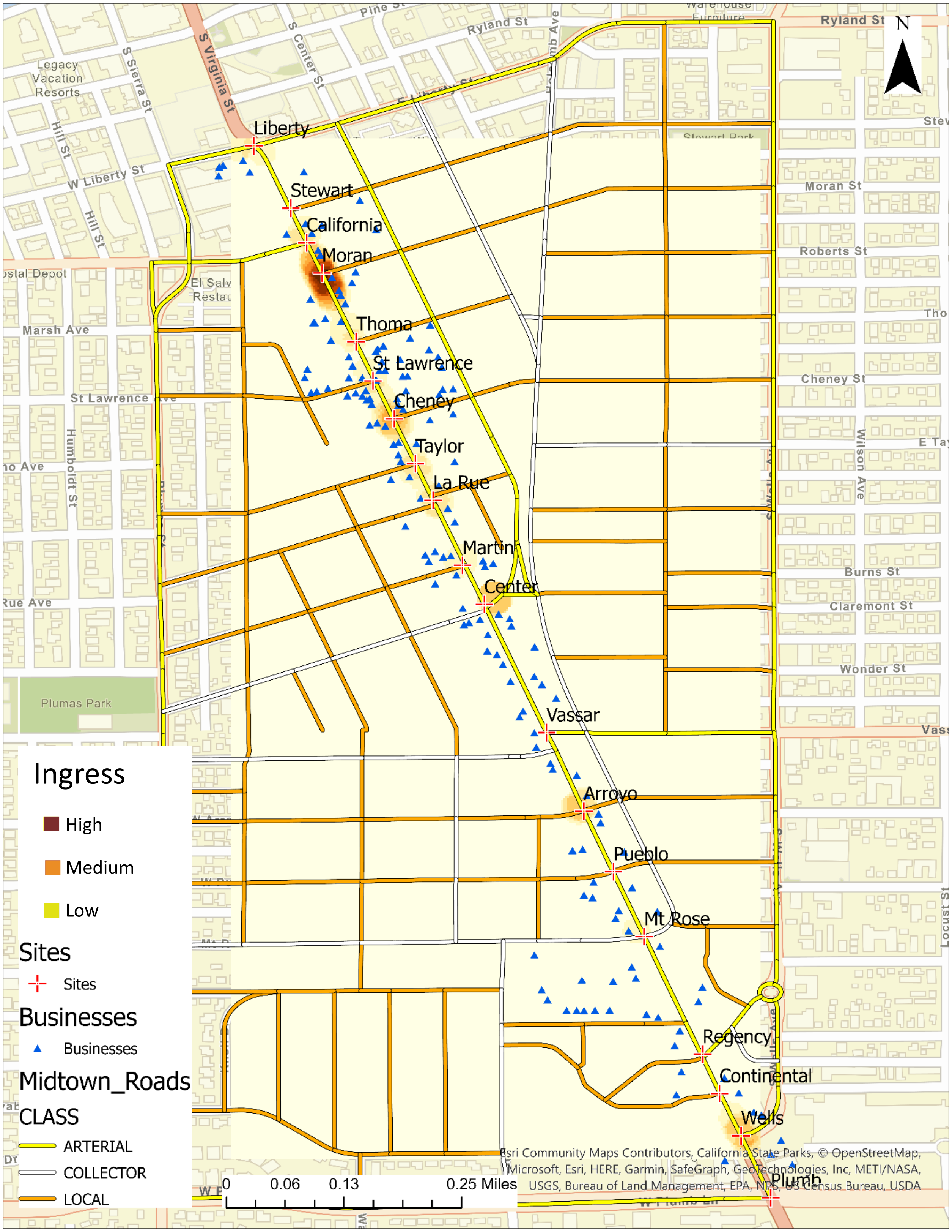


Figure 35 Vehicle-to-pedestrian conflict heat map

7 Behavior Analysis and Compliance

The LiDAR trajectory data tracks each road users' movement which allows for comprehensive behavior analysis to see if there are any non-compliance and other interesting patterns. Non-compliance includes illegal U-turns, left turns, and wrong-way driving. In the northern half there are raised medians that restrict side street left turns and therefore it is important to understand if drivers are following this. Furthermore, the medians also have large left turn pockets that cause issues for drivers in the opposite direction that use them to make an illegal left. Examples of these non-compliance events are shown in Figure 36. Figure 36 (a) shows an example of an illegal U-turn and Figure 36 (b) shows a wrong way on the left turn pocket and an illegal maneuver from the side street. Also shown in this section is all U-turns made at an intersection regardless of compliance which will demonstrate areas in which restricted access has the greatest effects.

(a) (b)

Figure 36 Non-compliance Examples

7.1 U-Turns

U-turns made along Virginia St will be outlined. Figure 37 and Figure 38 show daily U-turns made along Virginia St on a weekday and weekend day, respectively. Both figures show that most of the U-turns are made at the roundabout, which means the roundabout improves accessibility. However; There are still illegal U-turn events occurring along the north end of the corridor from Liberty to Taylor. There are far less U-turn events that occur south of Center. This shows that the limited accessibility from the raised medians causes more vehicles to make illegal U-turns.

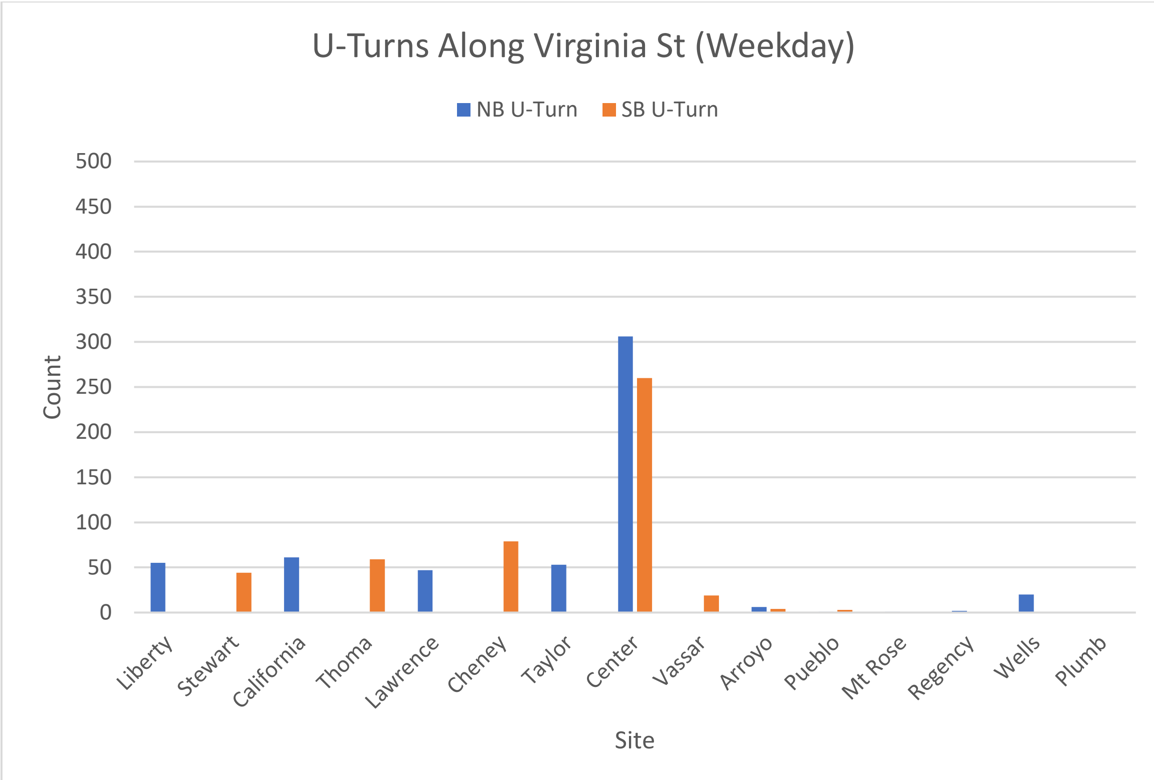


Figure 37 Daily weekday U-turns along Virginia St

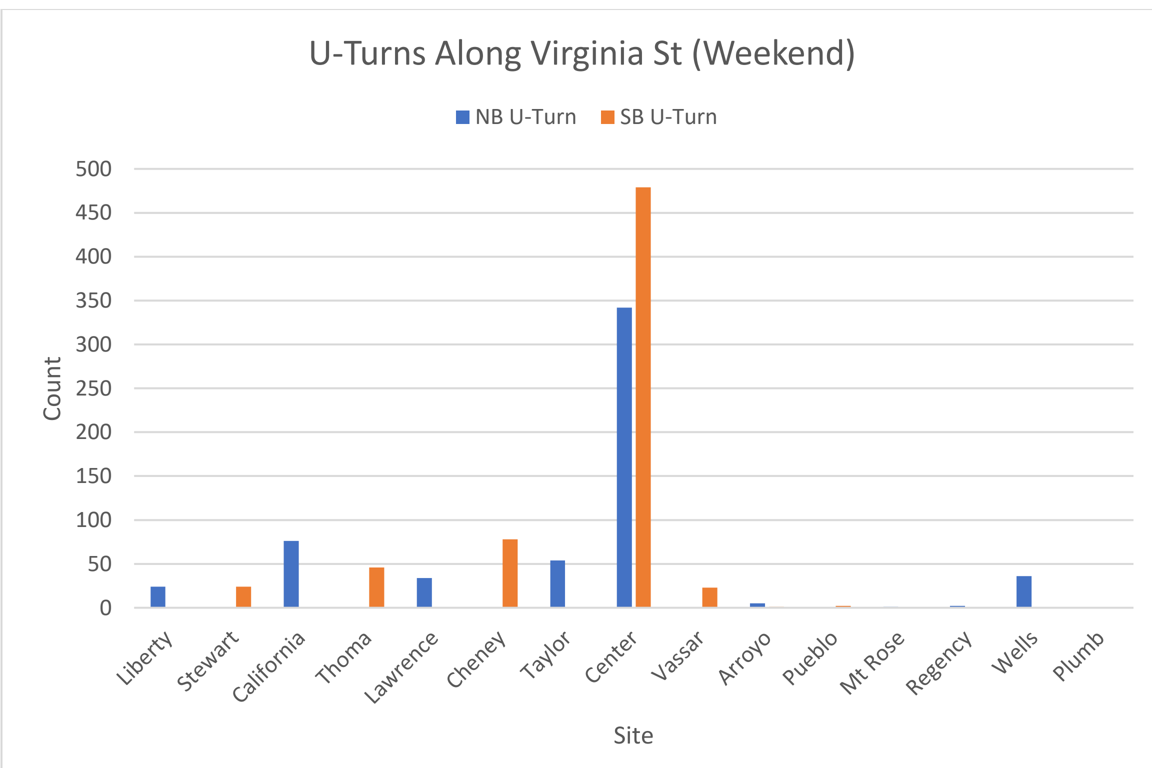


Figure 38 Daily weekend U-turns along Virginia St

7.2 Side Street Non-Compliance

Side street non-compliance refers to those vehicles that make illegal left turns where there are raised medians that are designed to restrict side street access. The side streets Stewart, St. Lawrence, Cheney, and Taylor are sites in which only right turns are permitted; however, Table 10 that there are vehicles making left turn maneuvers. Much like the illegal U-turns, these illegal left turns are cause by the restricted access from the raised medians. Where this is most evident is at Stewart St where 17 and 21 percent of side street volumes turn left for the weekday and weekend day, respectively. Instead of turning westbound right toward Liberty St, these drivers want to turn left toward the heart of midtown.

Table 10 Daily side street lefts and proportion to side street total daily volumes

Sites	Left		Total		Percent	
	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Stewart	33	47	198	228	17%	21%
St. Lawrence	18	19	748	546	2%	3%
Cheney	31	42	990	884	3%	5%
Taylor	21	29	748	546	3%	5%

7.3 Wrong way

Wrong way driving events are those in which vehicles travel in the opposite direction in a one-way street or pocket. There are six side streets that are one way and two scenarios of entering into a left turn pocket in the wrong direction. Table 11 shows the breakdown of each scenario. The Lawrence St row refers to the business access east of Virginia St, which is a one-way entering access only. The St. Lawrence and St. Lawrence left turn pockets are those situations in which vehicles are trying to exit and enter the business access, respectively. The Roundabout has two one-way legs, the east and west leg. The west leg is Mary St and is an access point to midtown Virginia, and east leg is Center St and is an exit. Mary St has many cases in which vehicles use Mary St as an exit. Based on observations, this done both intentionally to access businesses, or by accident because of confusion. Since this is a low volume street there is not much concerns; however, Figure 39 shows some higher exit speeds which could lead to a head-on conflicts or crashes.

Table 11 Wrong way driving events along Virginia St

Sites	Weekday Wrong Way	Weekend Wrong Way	Weekday Total	Weekend (Total)	Weekday (%)	Weekend (%)
Stewart Left Turn Pocket	11	3	552	244	2%	1%
Thoma	19	14	758	535	3%	3%
St. Lawrence	19	14	349	312	5%	4%
St. Lawrence Left Turn Pocket	25	34	661	574	4%	6%
Mary St	50	70	1045	1082	5%	6%
Center St	10	11	2353	2367	0%	0%
Caliente	3	4	148	141	2%	3%
Pueblo	9	14	423	339	2%	4%

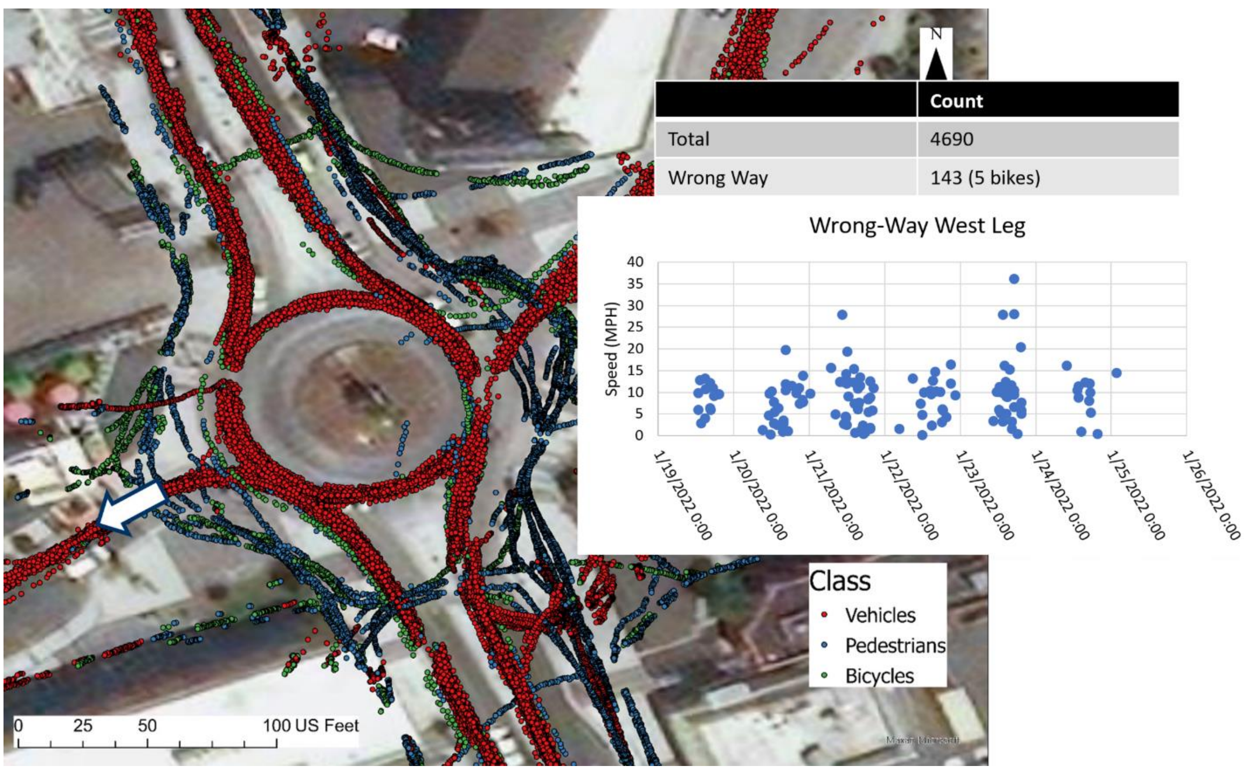


Figure 39 Mary St wrong way driving details

7.4 Other Non-Compliance

California Street has a driveway that meets the signalized intersection, but is meant to only turn right in and out of and yield for any traffic. It is not part of the signal timing sequence; however, there are cases in which vehicles try to exit and enter into the business access through illegal maneuvers such as eastbound through, southbound left, westbound through, and westbound left. Table 12 shows the breakdown of these maneuvers.

Table 12 California St non-compliance

California		
Direction	Weekday	Weekend
Eastbound Through	97	77
Southbound Left	42	44
Westbound Through	15	15
Westbound Left	4	10

8 CONCLUSIONS

The concluding remarks for the BRT Midtown Virginia Street LiDAR Study is outlined. Roadside LiDAR data was collected at 18 sites along the 1.2-mile Midtown Virginia St segment. Other datasets used include NDOT's historical crash and TRINA data; Google Maps, RTC Washoe's transit routes, stations, stops, and ridership data; and Wejo trajectory data. Wejo data is obtained from the company, Wejo, which provides cleaned vehicle trajectories from GPS units in vehicles on the roadway a 3-second frequency and a 4-5% penetration rate.

A majority of vehicles on Midtown Virginia St use it as an origin or destination rather than a throughput, as shown in the Wejo data. The daily through traffic is significantly higher in the southern region near Plumb Ln where two multilane arterials intersect. Ingress accessibility primarily comes from the arterials at Liberty, California, Regency, and Plumb. For egress the minor side streets are utilized slightly more, but Wells and Plumb are used the most. For bus route 1, the unloading events occur more at Liberty, Thoma, and Wells and the loading events occur at Thoma, La Rue, and Taylor. In general, this corresponds with the business densities. For bus route 100 (Virginia Line), more unloading events occur at Liberty St and on Center St near the roundabout; whereas, more loading events take place at Liberty St, Walts, and on Center St near the roundabout. Greater vehicle parking events occurred around Thoma at durations less than an hour which corresponds with business density. Parking spaces in the southern half have less vehicle parking frequencies. Vehicle speeds along Midtown Virginia are generally lower than the speed limits. There is no significant difference between larger vehicles such as buses and passenger vehicles. The roundabout at Center Street provides traffic calming by reducing speeds up to 15 MPH.

Bicycle and pedestrian activity on sidewalks and side street crosswalks are generally greater in areas with greater densities of businesses, such as Moran, St. Lawrence, and Cheney. Pedestrian crossing events also occurred in these areas, but Moran and Cheney do not have marked crosswalks. Bicycles on the roadway had steady volumes throughout, with greater volumes at Cheney, Mt Rose, and Wells. At one/two-way stop-controlled intersections, the pedestrian crosswalk LOS is F at each except for St. Lawrence and Taylor, which both have pedestrian refuge islands. However, the delays for these LOS F intersections are within reason. At signalized intersections, the pedestrian crossing LOS is C or greater, with most being B.

Vehicle-to-vehicle conflicts occurred the most at Regency, but most of these conflicts were less severe. The other sites did not show any major conflict data. Vehicle-to-pedestrian conflicts occurred more frequently in areas in which there is no crosswalk, particularly at Moran and to a lesser extent Cheney. Most of these occurred from more aggressive pedestrian crossing events. There are also more vehicle-to-pedestrian conflicts at the east leg of the roundabout where vehicles are exiting and need to yield for pedestrians.

As a result of restricted access in the northern half of the study area with raised medians, there are greater number of U-turn events and side street lefts. However, the higher number of U-turns occurring at the roundabout indicates that the presence of a roundabout reduces the impact of restricted access. Many wrong way driving events occurred at the west leg of the roundabout at Mary St. At the St. Lawrence left turn pocket, there were many you used it in the wrong direction to access the businesses to the east of St. Lawrence. California St saw many illegal eastbound through and southbound lefts to access the businesses on the east side of the intersection and to a lesser extent illegal westbound throughs and lefts.

The following bullets direct the conclusions based on the project objectives outlined in the Project Objectives section:

1) Traffic mobility performance, including volumes, delays, and level of service (LOS) of multimodal traffic.

The traffic mobility performance along Midtown Virginia serves multi-modal activity. Reduction in vehicle lane and restricted access for vehicle mobility is counteracted by the roundabout to improve circulation. As a result of lane reductions, sidewalks were widened to provide greater pedestrian mobility. Additionally, shorter crossing lengths with the help of curb extensions improve pedestrian mobility to cross Virginia St. Refuge islands greatly improve the LOS of pedestrian crossings. Pedestrian LOS at signalized intersections is also adequate. Overall, mobility for other road users in improved with minimal impact to vehicles.

2) Traffic safety performance, including historical crash data, speeds, and conflict analysis.

Traffic safety along the corridor is greatly improved from the new roadway elements. Narrow lanes, raised medians, and traffic calming particularly at the roundabout reduce the free flow speed greatly. The restricted access reduces the number of conflict points, particularly those with angles 90 degrees or greater. Based on conflict data, there is little concern for vehicle-to-vehicle traffic safety. Based on newer crash records, however, there are concerns for traffic safety at the roundabout, particularly for impaired drivers. Vehicle-to-pedestrian conflicts are higher in areas where there are no crosswalks, but is primarily a result of more aggressive crossing behavior. The lower vehicle speeds along Virginia mitigates the concern to vulnerable road users.

3) Transit BRT performance, including BRT travel time, ridership, and station/stop access.

Transit speeds generally match passenger vehicle speeds along the corridor. The improved transit stops provide greater service. Ons and offs at each transit stop shows higher number in more dense areas in the northern half of the study area.

4) Business access including traffic circulation, parking, transit, and walking routes for business access.

The roundabout provides access to businesses by allowing vehicles to make U-turns to navigate to and from their destination. The restricted access does encourage non-compliance issues of U-turns, side street lefts, and entering the left turn pockets in the wrong direction. Parking turnover is within the 2-hour limit in areas of greater business density and appears to be adequately serving businesses. Transit ons and offs are generally higher in the more business dense area. The higher crossing events and overall pedestrian volumes is greater in the business dense areas where there is also a greater frequency of crosswalks.

5) Identification of roadway elements positively or negatively impacting mobility, safety, and business access for recommendations to future projects.

Overall, the raised medians do reduce the number of more severe angle conflicts and potential crashes. Additionally, they slow vehicles down more than in the southern half. While the restricted limits access limits left turns in the northern study area, the roundabout and existence of other left turn pockets mitigates the effect. The roundabout also reduces traffic speed and eliminates more severe angle conflict points between vehicles. The roundabout's impact to pedestrians appears minimal because these lower speeds. Parking appears to be adequately serving businesses, with minimal non-compliance issues of vehicles parking for longer than is allows. The extended sidewalks invite greater multimodal activity especially around the business-dense areas around St. Lawrence. The restrictions placed on vehicles in turn improves mobility for other road users, particularly pedestrians. In conclusion, the infrastructure improvements appear to improve safety while minimally impacting the circulation and mobility.

Recommendations for future projects to improve safety and operations are as follows:

- Roundabout
    - Place a wrong-way sign on Mary St
    - Place dynamic or passive signs at the approaches of the roundabout on Virginia St to alert drivers of speed reduction (15 MPH recommended speed)
- Crosswalks
    - Consider adding crosswalks at Moran and/or Cheney
    - Note: refuge islands and rectangular rapid flashing beacons (RRFB) improve the LOS at unsignalized crosswalks
- Left turn pocket
    - Extend raised median to reduce wrong-way driving and U-turns, particularly at St. Lawrence
- California St:
    - Restrict or allow movement to and from parking lot

Virginia Street/Center Street

Technical Memorandum

December 23, 2022

To: Jeff Wilbrecht, PE, RTC Project Manager

From: Chad Anson, PE, CA Group

Background

The Virgina Street and Center Street roundabout was constructed as part of the Regional Transportation Commission's (RTC) Virginia Street BRT Extension project. The roundabout replaced an existing signalized intersection to aid in controlling vehicular speeds. Roundabouts are also a FHWA Proven Effective Safety Countermeasure on providing a safer intersection. Since opening of the roundabout, there has been concern raised by an adjacent property due to several accidents resulting in building damage. Discussions between the City of Reno, RTC, and CA Group have been conducted reviewing the concerns, evaluation of crash data, and overall roundabout design. This memo summarizes these evaluation and discussions.

Roundabout Design

The roundabout was designed in accordance with guidance from the NCHRP's Report 672 "*Roundabouts: An Informational Guide*". The roundabout utilized an inscribed diameter of 100'. This was the maximum diameter that could be provided given right-of-way constraints within the corridor and falls within the inscribed diameter recommendation range for single lane roundabout per Exhibit 6-9 of NCHRP Report 672. A fastest path analysis was also conducted on a vehicle's potential speed based on the roundabout geometry in the northbound and southbound directions. For both directions, the geometry produced a 15-16 mph fastest path through the roundabout. This would be 10 mph lower than the mainline posted speed of Virginia which is acceptable per NCHRP's recommendation of minimizing maximum speed differentials between movements to no more than approximately 10 to 15 mph (Section 6.7.1.3). NCHRP also recommends a 12 mph maximum difference between approach speed and entry speed which the Center Street roundabout design meets (Section 6.4.5). Curved roadway geometry and splitter islands have also been provided as much as possible given right-of-way constraints to aid in controlling entry speeds and encouraging drivers to slow down prior to entering the roundabout.

Crash Data

Crash data from March 2021 to present was provided by the City of Reno to see if any trends could be identified. The following is a summary of the crash data.

- 14 total crashes happened within the roundabout from 3/2021 to present
- 6 crashes resulted in a DUI citation
- 3 crashes were hit and run
- 1 crash was a medical event with driver losing consciousness
- 2 crashes resulted from large trailers clipping the roundabout median or parked cars
- 1 failure to yield
- 1 crash was from a car going over the median and striking another vehicle

Based on this data over 70% of crashes were a result of DUI, hit and run, or a medical event. It is common for hit and run crashes to have intoxication involved since drivers do not want to have law enforcement contact. Only 4 of the 14 crashes, or less than 29% were from coherent drivers and resulted in minimal property damage.

The concern has arisen from the DUI crashes resulting in vehicles traveling at higher speeds and losing control. This has resulted in vehicles striking the building in the southwest corner of the roundabout. The building is approximately 30′ from the curb line of the roundabout. Other minor damage caused includes damage to light poles, signs, and landscaping.

Conclusion

The roundabout is designed appropriately given the project constraints and standard practice guidelines. There is a concern though of the number of crashes resulting from impaired drivers. While standard engineering practice does not specifically consider impaired drivers, there is a concern of potential severe damage that could occur to adjacent buildings or pedestrians from impaired drivers or higher speed vehicles losing control within the roundabout Several additional layers of notification and protection could be added given this concern. The following is a list of recommendations to address the concerns from both agency and property owner perspective.

Recommendation #1 – It is important that behavioral change be addressed as part of the overall recommendations and to address the primary cause. With a high number of DUI and potential DUI related crashes in this area it is recommended that additional DUI and speed enforcement occur within this corridor. Enforcement including DUI checkpoints near the roundabout and overall police presence during the evening hours to create awareness of impaired driver enforcement. Law enforcement resources are limited; however, the crash data is indicating a need for enforcement and awareness within this corridor.

Recommendation #2 – Since law enforcement cannot stop every driver not adhering to driving laws including speeding and driving impaired additional measure should be taken to raise additional awareness. Speed feedback signs along Virgnia Street prior to entry into the roundabout will help inform drivers of their speed along with the showing the recommended speed of 15 miles per hour. These digital feedback signs can also help attract the driver's attention during the nighttime hours due to digitally lighted feedback speed. In addition, static speed advisory signs can be added in advance of the roundabout for driver's unfamiliar with roundabouts and the need to slow down prior to entry. Sign placement will be critical ensuring signs can be seen and not create too much signing in the corridor.

Recommendation #3 - A higher level of protection will help protect the building on the southwest corner and potential pedestrians in the area. Concrete bollards placed approximately 5-10' north of the existing building will be a final layer of protection for the building and vulnerable users from errant vehicles. These bollards would be outside the clear zone distance recommend by the AASHTO Road Design Guide criteria. These bollards should have a 5' spacing to provide an "escape area" for pedestrians between the bollards and roundabout should an errant vehicle enter this area. While concrete bollards will provide an abrupt stop of the errant vehicle, it is important to provide safety for innocent bystanders along the sidewalk and avoid potential damaging adjacent buildings' structural integrity. Pedestrian bollard protection adjacent to a roadway has been used in various locations across the country to protect pedestrians from errant vehicles. Clark County, Nevada has extensively utilized closely spaced bollards to protect pedestrians along Las Vegas Boulevard.

The three recommendations above are considered a layered approach to addressing vehicles unsuccessfully navigating the Center Street roundabout by starting with addressing driver behavior with Recommendation #1 to protecting innocent bystanders and property with Recommendation #3 when drivers still choose on their own to violate driving laws. Recommendations #1 and #2 need to be implemented in an effort to change driver behavior while Recommendation #3 is a final protective effort.

If you have any questions or concerns, please contact me at chad.anson@c-agroup.com or at 775-283-8394.

Sincerely,

Chad Anson, P.E.