COMPARATIVE ANALYSIS AND INTEGRATION OF REGION-WIDE TRAFFIC DATA

Final Report

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ACRONYMS, ABBREVIATIONS, AND TERMS

PAG	Pima Association of Governments
MPO	Metropolitan Planning Organization
UArizona	University of Arizona
STL	Smart Transportation Lab (at the University of Arizona)
COT	The City of Tucson
PCDOT	Pima County Department of Transportation
ADOT	Arizona Department of Transportation
ATMS	Advanced Traffic Management System
GPS	Global Positioning System
RTDN	(Tucson) Regional Traffic Data Network
UITS	University (of Arizona) Information Technology Services
TMC	Turning Movement Counts/Volumes
AADT	Annual Average Daily Traffic
TAZ	Traffic Analysis Zone
POCL	Percentage of Communication Losses
AED	Advance Event Detector
ASC	Advanced System Controllers
MLP	Multi-Layer Perceptron Neural Network
POI	Point of Interest
RMSE	Root Mean Square Error
MAE	Mean Absolute Error
MAPE	Mean Absolute Percent Error
TOD	Time of Day
STL-SQL	Smart Transportation Lab - Structured Query Language
HAWK	High-Intensity Activated CrossWalk
QA/QC	Quality assurance and quality control

EXECUTIVE SUMMARY

Transportation planning and modeling are important for the future enhancement of regional mobility, sustainability, and livability. All planning decisions are based on regional traffic modeling results. In order to control the accuracy of traffic modeling, regional traffic volume data is required to calibrate and validate the regional modeling efforts. Regional traffic volume data could be manually collected from sample locations every year. This traditional data collection method can only provide sample data from limited time periods, and the data collection process is time-consuming and costly. The greatest disadvantage of this traditional data collection method is labor costs.

Currently, member jurisdictions in the PAG region utilize a variety of traffic sensors at signalized intersections. Data collection with these smart sensors is cost-effective; however, these various collection methods and collection periods often result in inconsistent results from jurisdiction to jurisdiction and from intersection to intersection. To efficiently apply these traffic sensor data to PAG's traffic count program and transportation model, PAG initiated this project to develop a comparative analysis approach to integrate region-wide traffic data and improve the efficiency of regional traffic volume data collection.

In the PAG region, multiple types of smart sensors are currently installed and used: Autoscope® sensors by Econolite®, Iteris® sensors, inductive-loop detectors, Miovision® sensors, and Wavetronix sensors. The sensor inventory was created to summarize information of all available sensors used by the City of Tucson, the Town of Oro Valley, the Town of Marana, Pima County Department of Transportation, Arizona Department of Transportation, and the Town of Sahuarita. After this, a simple vendor interview was conducted by email or phone with video-based sensor vendors regarding the data collection method, traffic parameters collection, and data storage. Sample video-based volume data was collected from existing sensors for data quality evaluation using ground-truth data.

A limited number of signalized intersections have a data collection module configured for automatic volume data collection. Most signalized intersections in the PAG region cannot provide traffic volume data due to a lack of a traffic data collection module. Event-based data, which is an existing data source generated by the default traffic detection module, is explored and utilized to estimate volume data at these intersections without the data collection module. The proposed Multi-Layer Perceptron Neural Network (MLP) model was calibrated and evaluated using ground-truth volume data provided by PAG.

These estimated TMC data and video-based TMC data were further integrated for segment volume estimation, which is more cost-efficient than installing mid-block sensors. The proposed segment volume estimation method was evaluated using ground-truth segment volume provided by PAG. In addition to traffic volume data, the coverage and accuracy of some emerging crowdsourced data, such as the data provided by INRIX, HERE, and StreetLight Data, were explored and analyzed.

In order to ensure the quality of the estimated volume data, a QA/QC procedure was developed and acceptance criteria were decided based on literature review and sample data evaluation. Then, more ground-truth volume data was collected by PAG to further evaluate the estimated TMC and video-based volume. By using smart sensors and the well-calibrated estimation model, one year of regional TMC and segment volume data was collected and estimated.

The following conclusions can be drawn from this project:

- About 588 signalized intersections in the PAG region have smart sensors configured as of November 2020. Most of the existing traffic sensors are video-based sensors. Most sensors only have the traffic detection module configured for signal control, which can generate event-based data. A limited number of sensors have the traffic data collection module for traffic volume data collection.
- Traffic volume data collected by Autoscope sensors have higher accuracy than Miovision sensors, likely because an Autoscope sensor is installed for one approach rather than a whole intersection. The detectors close to the stop bar in Autoscope sensors provide more accurate volume data than the advance detectors.
- A multi-output MLP-based model with three layers was developed to estimate through, left-turn, and right turn volumes using selected variables. The evaluation results show that the average %RMSE of through, left-turn, and right-turn movement is around 30%, 45%, and 60%, respectively.
- By integrating estimated TMC and TMC collected by Miovision sensors, the segment volume was estimated using the proposed method. The evaluation results show that most locations have a MAPE below 20%, indicating the accuracy of the proposed method.
- INRIX data and HERE data are available on most major roads but do not cover most minor side streets. INRIX data and HERE data have the same accuracy with a MAPE of 26%. Both data sources overestimate actual traffic speed during most periods.
- The results of including INRIX speed data in the TMC estimation and segment volume estimation models show that INRIX speed does not significantly improve model performance.

Based on the conclusions above, we recommend the following to PAG regarding the use of multiple data sources and future work:

- Most of the newest generation of video-based sensors have been configured with a data collection module and provide the remote data collection option, i.e., an API, so the 24/7 traffic volume data is available and accessible. But more sample data are required to evaluate the video-based data because the data accuracy varies by location.

- The detectors in outdated video-based sensors that are near the stop bar yield higher accuracy. However, the data collected by outdated sensors have low accessibility, as it requires engineers to go out to the field to download it.
- The proposed MLP model was calibrated using volume from peak hours in this project. In the future, volume from off-peak hours could be collected for model calibration to increase the generalization of the proposed model. The video-based sensors are sensitive to vehicle headlights at night and cause a high error rate for the event-based data. Therefore, the proposed model is not recommended to estimate traffic volume at night.
- In this project, event-based data has shown its advantage of availability and large coverage. In addition to TMC data, other traffic performance measures at signalized intersections (such as delay and level-of-service) are important for regional Transportation Systems Management and Operations (TSMO). More studies are needed to further explore the potential use of event-based data to develop cost-effective regional TSMO-related performance measures.

CHAPTER 1: INTRODUCTION

Pima Association of Governments (PAG) is the designated Metropolitan Planning Organization (MPO) for the Eastern Pima County region, and as such is mandated to create, maintain and expand as necessary a regional transportation model. Collecting traffic volume data, including turning movement counts (TMC) at intersections and road segment volumes in the PAG region, is an essential data collection task for most traffic studies such as transportation planning and transportation model calibration.

Member jurisdictions in the PAG region utilize a variety of traffic sensors to collect traffic data. These various collection methods and collection periods often result in inconsistent results from jurisdiction to jurisdiction and from intersection to intersection. The goal of this project is to develop a comparative analysis approach to integrate region-wide traffic data and provide guidelines to manage and maintain regional traffic data to improve PAG's traffic count program and to calibrate and validate the ongoing regional modeling efforts.

1.1 BACKGROUND

Existing methods of traffic data collection in the PAG region are essentially limited to manual counts by recruiting volunteers or outsourcing the data collection task to companies with traffic data collection services. These methods may be not feasible for region-wide traffic volume data collection due to its labor costs. Therefore, the development of area-wide traffic data collection using smart sensors has been spurred by the potential to save time and cost.

PAG's member jurisdictions are currently operating and maintaining various traffic sensors. These traffic sensors are managed by six agencies, including the City of Tucson, the Pima County Department of Transportation (PCDOT), the Arizona Department of Transportation (ADOT), and the Towns of Oro Valley, Marana, and Sahuarita. The traffic data collected by these existing smart sensors can be a good source of region-wide traffic volume data. However, these various traffic data collection methods and collection periods often result in inconsistent results from jurisdiction to jurisdiction and from intersection to intersection. To efficiently apply these traffic sensor data to support PAG's traffic count program, these multiple data sources collected from various traffic sensors need to be first evaluated and integrated.

The traffic sensors currently installed in the PAG region include inductive-loop detectors, video-based sensors, and radar-based traffic sensors. Among these sensors, video-based sensors are the majority in the PAG region. Most of these existing sensors are installed at signalized intersections in the Tucson Metropolitan Area and under the control of the MaxView© system. The MaxView© system is a type of Advanced Traffic Management System (ATMS) by Intelight Inc. These existing traffic sensors in MaxView© have been correctly configured with the traffic detection module which is used for traffic detection and signal timing management but without a traffic volume data collection module. However, these traffic detection and signal timing events from MaxView© are available and called traffic signal controller event-based data (hereafter called “event-based data”). Event-based data are high-resolution, consisting of a series of events with timestamps, and are used to estimate traffic volume in this project because of its accessibility and informativeness. Some signalized intersections in the PAG region have Econolite Autoscope® sensors, Miovision sensors, or Iteris sensors with the traffic data collection module configured and can directly collect traffic volume data. Additionally, several advanced crowdsourced traffic data sources, such as INRIX, HERE, and StreetLight Data, are available in the PAG region.

This project will investigate and develop approaches to integrate the available regional traffic data within the PAG region to understand the data availability and quality. The integrated traffic data and developed methodology guidelines will be efficiently applied to transportation planning and modeling and other regional traffic studies.

1.2 PROJECT OUTLINE

The goal of this project is to develop a comparative analysis approach to integrate region-wide traffic data and provide guidelines to manage and maintain regional traffic data to improve PAG’s traffic count program and to calibrate and validate ongoing regional modeling efforts. This project was conducted as ten tasks in two phases as shown in **Figure 1-1**. Phase 1 focused on multiple-source sample data evaluation and development of integration methodology and acceptance criteria based on the evaluation results. Phase 2 aimed to apply the integration methodology to the PAG region and obtain regional traffic volume data for one year.

The final report is organized based on the project outline. Each task in Phase 1 is a separate chapter in the final report. Regional application of traffic data integration in Phase 2 is summarized in Chapters 8 and 9.

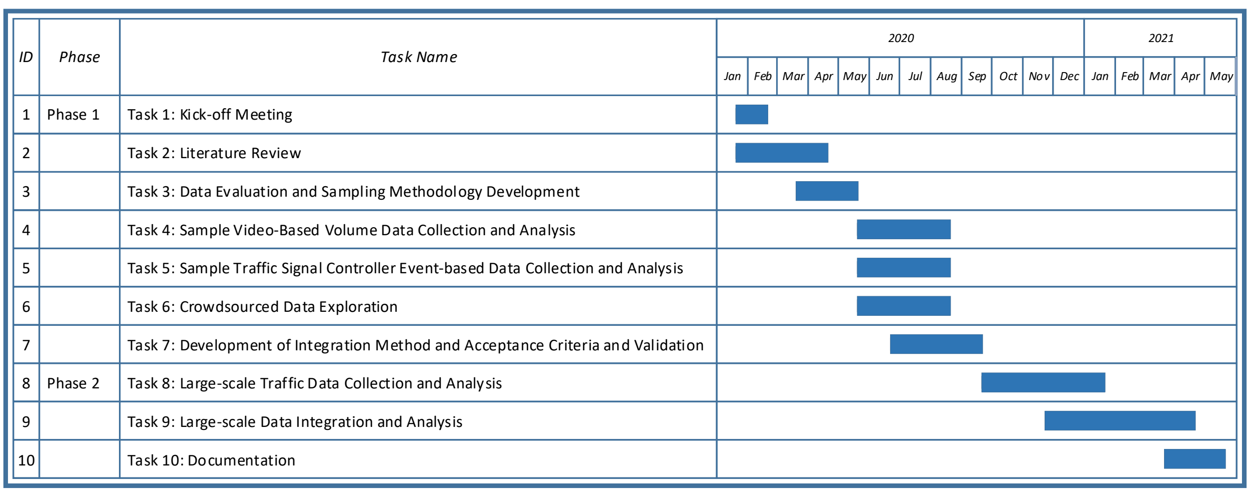


Figure 1-1 Project tasks

CHAPTER 2: LITERATURE REVIEW

This section summarizes the previous studies regarding recent applications of data sources that are used in this project and also summarizes traffic volume estimation methods by integrating these multi-source traffic data. The various data sources that are available in the PAG region include event-based data and crowdsourced data.

2.1 VARIOUS DATA SOURCE APPLICATIONS

2.1.1 Event-based data

Traffic signal controller event-based data is a high-resolution data source because it consists of a log of discrete events such as changes in detector and signal phase states in real-time. In the past decade, event-based data has been widely used in several areas, such as for traffic performance measures (An et al., 2018; Liu et al., 2009; Wu et al., 2010), signal control optimization (Day & Bullock, 2011; Hu & Liu, 2013), and traffic volume estimation (Li & Wu, 2021; Li et al., 2019). (Wu & Liu, 2014) conducted an overview of current research on the application of event-based data and practices in traffic modeling and control and demonstrated the value of event-based data. Additionally, event-based data collection is more cost-effective than other data collection methods because it can be directly collected from existing controller cabinets without any changes to infrastructure. Thus, event-based data is an important data source in this project.

2.1.2 Crowdsourced data

The use of GPS devices and apps running on mobile phones generates an increasing amount of unofficial or crowdsourced georeferenced data that has gained significant attention in the field of transportation. Crowdsourced data has the advantage of broader coverage and lower cost compared with official traffic data from smart sensors. Many private data vendors have collected and sold these crowdsourced data, such as INRIX, HERE, and Street Light.

Many U.S. state departments of transportation collaborate with universities and commercial data vendors to study innovative mobility performance measures using these data sources. Texas A&M University developed the Twin Cities Metropolitan area mobility performance measures using INRIX data (Turner & Qu, 2013). The operational performance of Indiana's state highway system was assessed by Purdue University using a variety of metrics based on real-time speeds from INRIX (Day et al., 2014). In addition, crowdsourced data can be widely used to evaluate the performance of adaptive traffic control systems such as the In|Sync adaptive signal control systems (Hu et al., 2016) and SURTRAC system (Khattak et al., 2019). Crowdsourced data can also provide disaggregated speed data to improve freeway segment crash prediction models (Dutta & Fontaine, 2019) and predict secondary incident occurrences (Park & Haghani, 2016). This crowdsourced data could be used to further estimate other traffic performances. For example, (Fan et al., 2019) utilized INRIX GPS trajectory data and HERE road network data to estimate the vehicle miles traveled in Maryland. (Sekuła et al., 2018) focused on estimating hourly traffic in the Maryland highway network using probe data from INRIX, but few research articles focus on using crowdsourced data to estimate arterial traffic volume in urban areas.

Crowdsourced data has been widely used in transportation studies because it can directly provide speed, travel time, and other performances across the whole network without the need for deploying any costly local sensors. However, some studies show that INRIX speed data have speed bias (Kim & Coifman, 2014) and latency (Adu-Gyamfi et al., 2017; Sharma et al., 2017). The INRIX speed data quality varied across different cities and different types of roads due to differences in the sample numbers of probe vehicles as well as affected by a different version of the estimation methods. Therefore, crowdsourced data quality needs to be considered and evaluated before it is applied to solve real-world traffic problems.

2.2 TRAFFIC VOLUME ESTIMATION

2.2.1 Turning Movement Counts Estimation

The traditional method to collect turning movement counts (TMC) is manually counting at sample study intersections. However, the manual count method is time-consuming, making it infeasible for region-wide TMC collection 24/7. In the last decade, intelligent transportation technologies have become popular for data collection. These sensors are currently costly to be installed on a large scale and require cost and labor to maintain the system. Due to the above limitations, some locations have not been equipped with intelligent sensors for TMC data collection. Therefore, some studies have explored existing data sources for TMC estimation.

Recently, GPS devices have become available and popular, and real-time vehicle locations from navigation and ride-hailing software can be collected in a region. However, only a limited amount of vehicle location information is available for real-time collection. Some studies applied probability theory or shock-wave theory to estimate TMC using a limited number of vehicles' GPS information at signalized intersections. (Zheng & Liu, 2017) modeled vehicle arrival as a time-dependent Poisson process during a signal cycle. Based on the information of signal time and locations of vehicles with onboard GPS devices, the average arrival rate during one period was then estimated using the expectation-maximization algorithm. The estimated average arrival rate is deemed as the TMC at an intersection. In their further study (Zhao et al., 2019), historical stopping positions of vehicles with GPS devices are used to estimate the penetration rate of vehicles with GPS devices during a cycle using probability theory. The estimated penetration rate can be used to project the traffic volume for a movement at a signalized intersection. It is worth noting that this proposed method cannot be used to estimate traffic volume for the right-turn movement and shared lanes. The existing GPS data-based methods for TMC estimation require both enough historical trajectory counts and trajectory details. Because some signalized intersections have few or even zero vehicles with onboard GPS devices, it is difficult to estimate TMC at intersections without enough GPS information.

Another existing large-scale data source is signal controller event-based data. Signal controller event-based data is collected from signal controllers and default sensors for signal control. Event-based data is available from most existing signal controllers, and has been used for volume estimation. Vehicle arrival is modeled as a stochastic process using the detection events. Based on the relationship between signal status and detection duration, a dynamic Hidden Markov Model was proposed to estimate cycle-based traffic volume, as shown by a study in (Li et al., 2019). However, this proposed method can only be used to estimate through movement volumes on major roads configured with advance detectors.

2.2.2 Mid-block Volume Estimation

In addition to collecting TMC data, collection arterial segment volume on mid-block is important for transportation operations and urban applications. Road segments in most cities are not equipped with sensors for data collection due to the high cost. One conventional method to estimate mid-block volume is to use the input-output method by relying on the volume from upstream and downstream intersection sensors. One of the major limitations when using the input-output method is that the upstream or downstream intersection may not have sensors installed, as mentioned in the above section.

Similar to TMC estimation with GPS data, some studies also used GPS data to estimate segment volume. (Zhan et al., 2017) merged the machine learning method and traditional fundamental diagrams (FD) of traffic flow theory to estimate large-scale volume using a large amount of GPS data, point of interest data, weather, and road network information. This FD-based approach relies on the relationship between traffic volume, density, and speed to perform the estimation and requires a large amount of data to calibrate. Therefore, the FD-based method is suitable for highways and major arterials but may tend to perform poorly on minor roads or small streets due to the limited GPS sample on minor roads. Another study conducted by (Sekuła et al., 2018) focused on estimating hourly traffic volumes using probe data. This study examined applications of an artificial neural network (ANN) method to estimate hourly segment volume in the Maryland highway network. In addition to probe vehicle data (e.g., vehicle probe speed and vehicle probe volumes), the infrastructure data, weather data, and temporal data are also used to construct the ANN model. Other studies have applied other data sources to estimate the road segment volume, for example (Caceres et al., 2012) proposal of several straightforward models to estimate volume using the number of phone calls.

Most existing volume estimation studies utilized GPS data from navigation software or taxi vehicles, but these GPS data are not currently available in the PAG region. Therefore, our project tends to use other available traffic volume data. Hundreds of signalized intersections are equipped with controllers for signal timing control in the PAG region, and the event-based data generated by these signal controllers can be used as an alternative data source to estimate volume, which (Li et al., 2019) proved to be feasible. Since multiple variables affect the volume at different intersections, machine learning methods are applied for large-scale volume estimation in the PAG region.

Aside from the signal controller event-based data, StreetLight Data can be another large-scale data source that provides long-term traffic volume data. Similar to the use of phone call records to estimate road segment volume in the study (Caceres et al., 2012), simple models (e.g., linear model and Cobb–Douglas model) can be calibrated from the relationship between actual volume and StreetLight Data volume for either TMC or mid-block estimation when event-based data is missing or unavailable.

CHAPTER 3: DATA EVALUATION AND SAMPLING METHODOLOGY DEVELOPMENT

PAG member jurisdictions operate and maintain various sensors and traffic data from those sensors. This chapter explains the availability of traffic volume data from the various jurisdictions. Additionally, the sampling methodology is developed based on the availability of the sensor data and ground-truth data, and provides sample locations and sample sizes for further traffic sensor data evaluation.

3.1 DATA AVAILABILITY

Six PAG member jurisdictions, including the City of Tucson, Pima County DOT(PCDOT), Arizona DOT(ADOT), and the Towns of Oro Valley, Marana, and Sahuarita, are currently operating and maintaining various traffic sensors. These traffic sensors are placed at signalized intersections for traffic signal control and performance measure. Sensor ownership and types as of 2020 are summarized in **Figure 3-1** and **Table 3-1**.

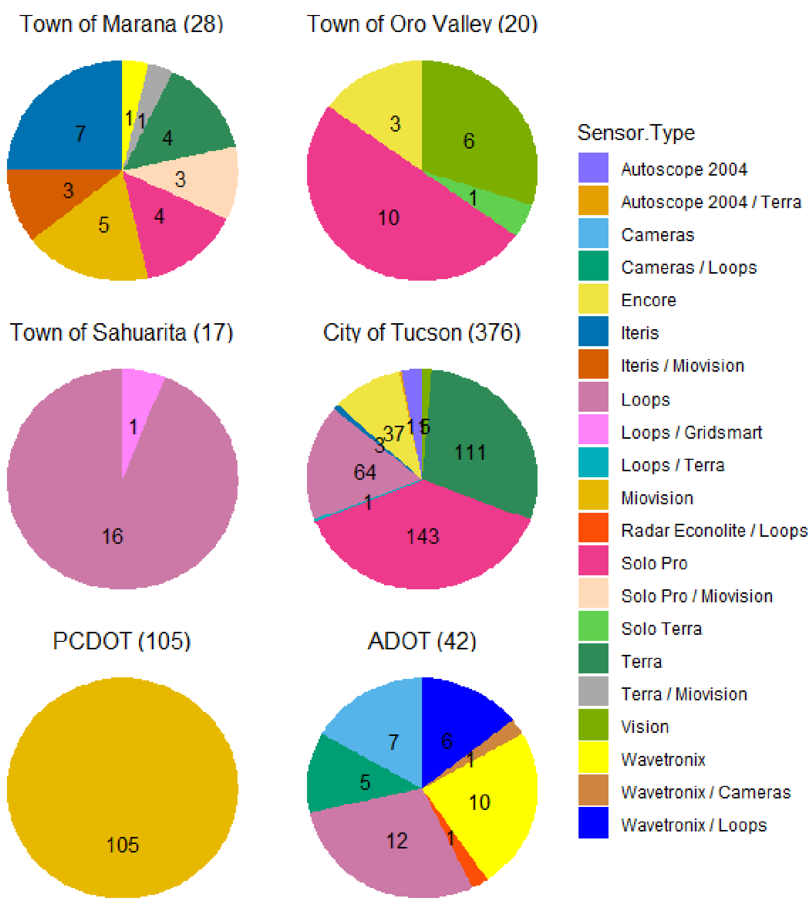


Figure 3-1 Sensor overview by jurisdiction

Table 3-1 Summary of Number of Intersections by Sensor Type and Jurisdiction

Sensor (Agency)		COT	Oro Valley	Marana	PCDOT	ADOT	Sahuarita
Solo Pro		**143**	**10**	**4**			
Terra		**111**	**1**	**4**			
Encore		**37**	**3**				
Autoscope 2004		**11**					
Vision		**5**	**6**				
Iteris		**3**		**7**			
Miovision				**5**	**105**		
Loops		**64**				**12**	**16**
Iteris	**Miovision**			**3**			
Solo Pro	**Miovision**			**3**			
Terra	**Miovision**			**1**			
Autoscope 2004	**Terra**	**1**					
Loops	**Terra**	**1**					
Loops	**Gridsmart**						**1**
Cameras						**7**	
Cameras	**Loops**					**5**	
Radar Econolite	**Loops**					**1**	
Wavetronix				**1**		**10**	
Wavetronix	**Cameras**					**1**	
Wavetronix	**Loops**					**6**	
Sum		**376**	**20**	**28**	**105**	**42**	**17**
Note: Video-based sensors in yellow; Loops in blue; Radar sensors in green.							

Because these traffic sensors at signalized intersections are mainly used for traffic signal control, they are equipped with the traffic detection module but not the traffic volume collection module, especially in the case of old sensors. That means the traffic signal controller event-based data can be obtained in the PAG region, but traffic count data is unavailable for most intersections.

As of August 2020, 100 of 122 signalized intersections equipped with Miovision sensors are online and can currently collect traffic data including TMC data. The real-time traffic data collected by Miovision sensors are collected and saved to the cloud, and this data (including TMC data) can be directly archived through either the web interface or the API. The video sensors lacking the collection module to collect TMC data can provide event-based data without traffic volume data. The traffic controller event-based data contains a series of events with timestamps, including signal timing events and vehicle detection events, which are highly correlated with turning movement counts. Therefore, traffic controller event-based data can be used to estimate turning movement counts instead of installing new sensors. These available event-based data would be a cost-effective and time-saving scheme for estimating regional-level turning movement counts. **Figure 3-2** shows that most of the signalized intersections in the PAG region have been included in the MaxView© system, an Advanced Traffic Management System (ATMS) software package. This ATMS currently shows approximately 670 sites including 550 signalized intersections and 120 High-intensity Activated crosswalk signals (HAWK) as of May 2020. The availability of the data in the database server is highly and dynamically dependent on the communication over the Tucson Regional Traffic Data Network (RTDN).

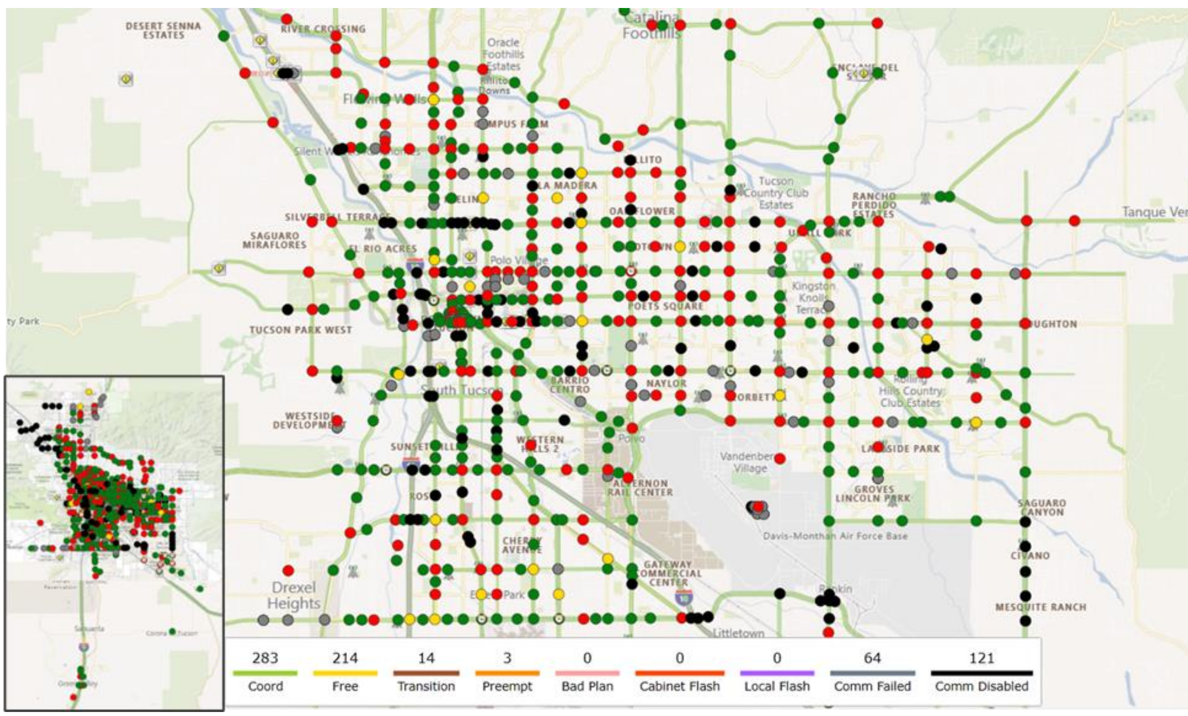


Figure 3-2 Locations of signal controllers in MaxView© system

3.2 SAMPLING METHODOLOGY

To evaluate the feasibility and accuracy of traffic volume data from traffic sensors, sample locations are determined by the developed sampling method and are suggested to PAG to collect more ground-truth TMC data. A sampling method is proposed in this section that considers sample locations with varying socioeconomic characteristics, land uses, AADT, and intersection layouts.

First, all locations where PAG has collected TMC data are matched to all locations that can collect event-based data. Then, k-means clustering is used to cluster all matched locations into different groups. Finally, sample locations are selected from each group for method validation.

3.2.1 Intersection Matching

Since the TMC estimation method requires traffic controller event-based data, these intersections with event-based data need to be filtered and cleaned according to predefined criteria before matching them with locations having ground-truth data collected by PAG. **Figure 3-3** presents the process of selecting intersection candidates.

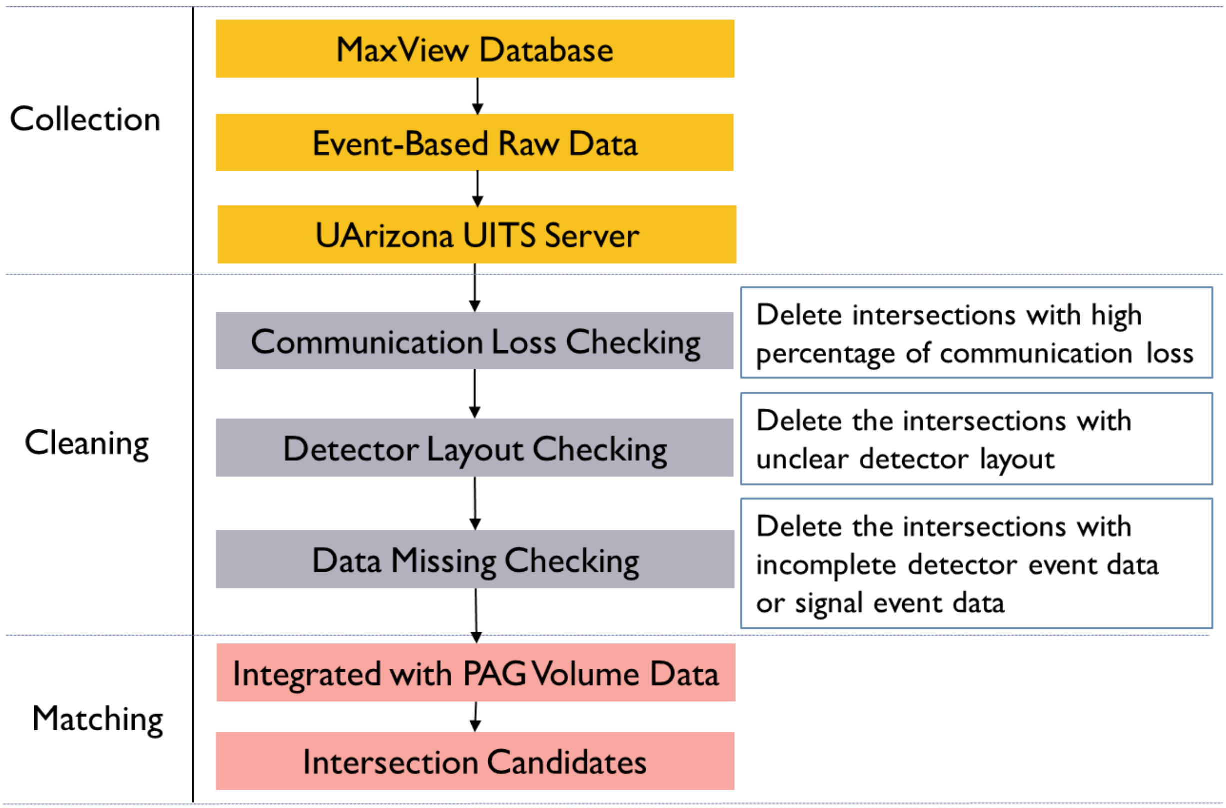


Figure 3-3 Framework of the intersection selection process

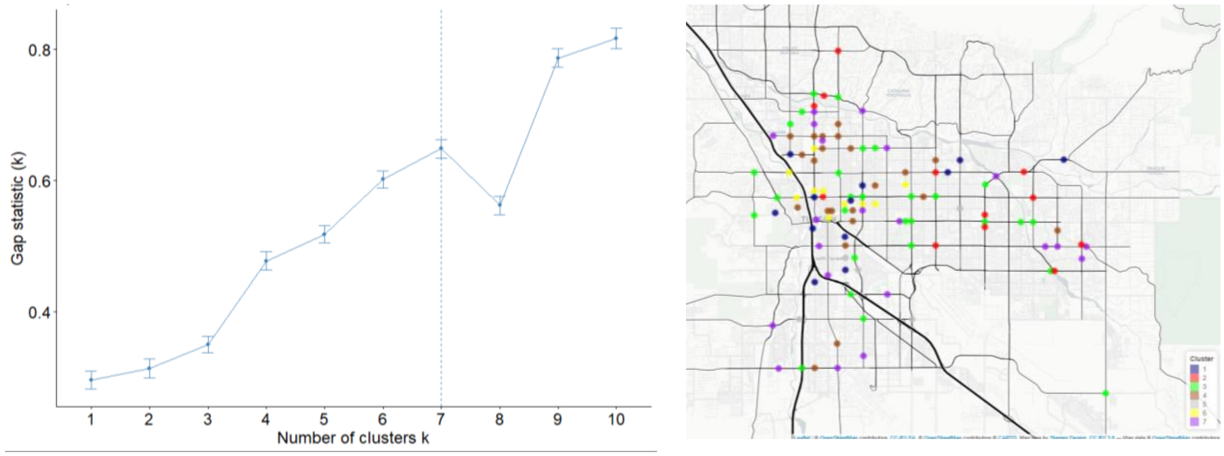
The communication between signal controllers and the server is sometimes unreliable, causing a loss of event-based data logging in the database server. These intersections with unreliable communication quality are first removed in the data cleaning process. Sensors at some intersections may not be configured according to the standard layout; these intersections having an unclear sensor layout are also removed. After the cleaning process, all remaining intersections are used to match with locations having ground-truth data based on spatial and temporal dimensions to select the final intersection candidates.

3.2.2 K-means Clustering

Stratified sampling is one of the most famous methods for sampling from a large population. The critical step in stratified sampling is to divide the total population into smaller sub-groups, also known as strata. In this study, K-means clustering is used to cluster all intersection candidates into different clusters according to a series of variables:

- Mean_Pop: the mean of the populations of the TAZs surrounding an intersection, with data provided by PAG's TAZ dataset
- Mean_Incom: the mean of the mean incomes of the TAZs surrounding an intersection, with data provided by PAG's TAZ dataset
- Mean_Emp: the mean of the numbers of employees in the TAZs surrounding an intersection, with data provided by PAG's TAZ dataset
- AADT_Mi: the AADT on the minor street, with data provided by PAG
- AADT_Ma: the AADT on the major street, with data provided by PAG
- Num_of_Direc: the number of directions at an intersection, with data manually collected from Google Maps
- Lanes_Ma: the number of lanes on the major street
- Lanes_Mi: the number of lanes on the minor street
- Shared_Left_Ma: a binary dummy variable that indicates if the major street has a shared left-turn lane
- Shared_Right_Ma: a binary dummy variable that indicates if the major street has a shared right-turn lane
- Shared_Left_Mi: a binary dummy variable that indicates if the minor street has a shared left-turn lane
- Shared_Right_Mi: a binary dummy variable that indicates if the minor street has a shared right-turn lane

These twelve variables are used to represent the intersection's characteristics regarding socioeconomics, traffic volume, and intersection layout. In the K-means method, a gap statistic is first used to determine the optimal number of clusters. The result of this method suggested that all intersections can be clustered into seven groups. **Figure 3-4(a)** shows the process to determine the optimal number of clusters, and **Figure 3-4(b)** shows the results of clustering.



(a) (b)

Figure 3-4 (a) Determining the optimal number of clusters; (b) Clustering results

Figure 3-5 is the radar plot used to visually profile each cluster. The radar plots also show the relative importance of each variable in each cluster. For example, the variables **Num_of_Direc** and **Shared_Right_Mi** are most important for Cluster 1.

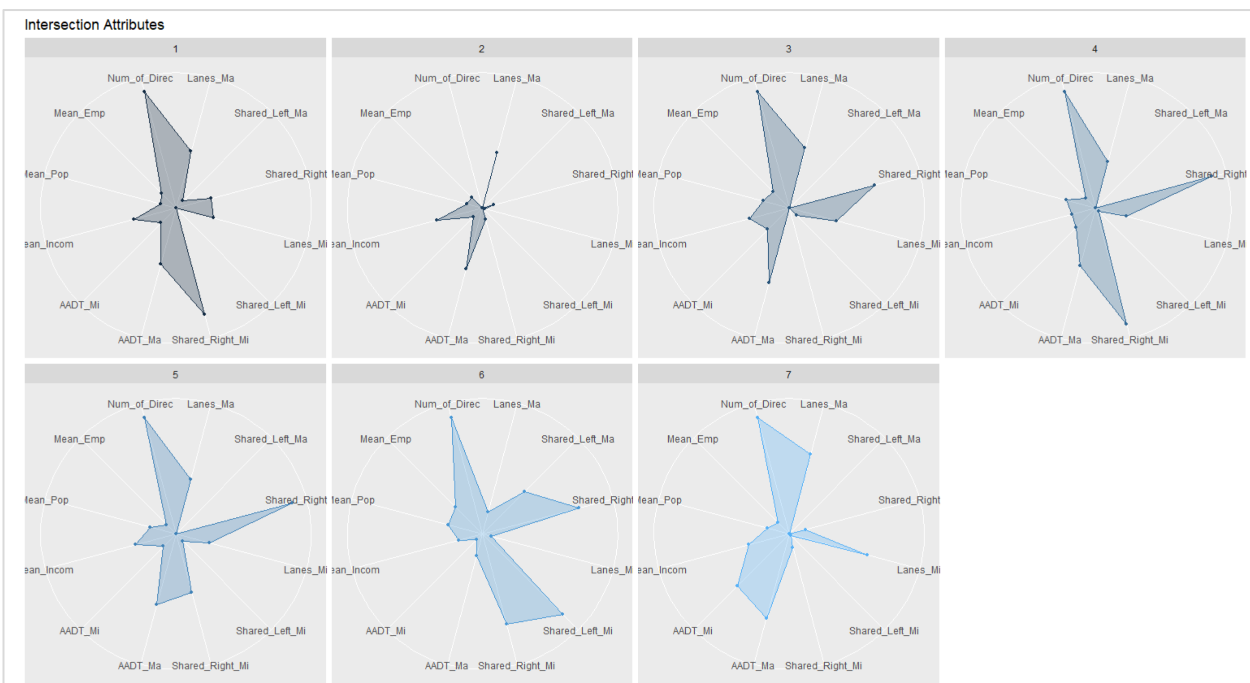


Figure 3-5 Radar chart of variable distribution by cluster

3.2.3 Sample Locations

84 signalized intersections with available event-based data and ground-truth TMC data were used to calibrate the proposed TMC estimation model. 50 sample intersections from seven clusters were recommended to validate the TMC estimation model. Since different clusters have different numbers of intersections, the number of intersections selected from a given cluster was based on the proportion of all intersections in that cluster. The final sample locations, shown in **Table 3-2**, were decided in coordination with PAG.

Table 3-2 Recommended Sample Locations

ID	IntID	Road1	Road2	Latitude	Longitude
1	108	LA CHOLLA BL	ORANGE GROVE RD	32.32315	-111.012
2	146	LA CHOLLA BL	RIVER RD	32.3052	-111.012
3	214	1ST AV	ROGER RD	32.27935	-110.961
4	224	ALVERNON WY	RIVER RD	32.27584	-110.91
5	229	CRAYCROFT RD	RIVER RD	32.27344	-110.875
6	248	CAMPBELL AV	PRINCE RD	32.27221	-110.944
7	277	1ST AV	FORT LOWELL RD	32.26481	-110.961
8	287	CAMP LOWELL DR	SWAN RD	32.26535	-110.892
9	355	COUNTRY CLUB RD	GRANT RD	32.25038	-110.927
10	358	ALVERNON WY	GRANT RD	32.25062	-110.91
11	399	ELM ST	TUCSON BL	32.24274	-110.935
12	405	PIMA ST	SWAN RD	32.24341	-110.893
13	437	MAIN AV	SPEEDWAY BL	32.23585	-110.978
14	442	PARK AV	SPEEDWAY BL	32.23602	-110.957
15	484	4TH AV	UNIVERSITY BL	32.23166	-110.966
16	486	PARK AV	UNIVERSITY BL	32.23169	-110.957
17	498	GRANADA AV	SAINT MARYS RD	32.22761	-110.978
18	501	6TH AV	6TH ST	32.22771	-110.969
19	582	BROADWAY BL	RANDOLPH WY	32.22158	-110.918
20	584	ALVERNON WY	BROADWAY BL	32.22157	-110.91
21	612	BROADWAY BL	HOUGHTON RD	32.22084	-110.773
22	669	COLUMBUS BL	22ND ST	32.20699	-110.901
23	681	PRUDENCE RD	22ND ST	32.20647	-110.832
24	694	HOUGHTON RD	22ND ST	32.20634	-110.773
25	719	SWAN RD	29TH ST	32.19974	-110.892
26	754	GOLF LINKS RD	KOLB RD	32.19195	-110.841
27	763	GOLF LINKS RD	HARRISON RD	32.19178	-110.79
28	794	AJO HY	LA CHOLLA BL	32.17791	-111.012
29	802	AJO WY	6TH AV	32.17783	-110.968

30	804	AJO WY	PARK AV	32.17787	-110.956
31	807	AJO WY	KINO CONNECT	32.1779	-110.941
32	814	ESCALANTE RD	KOLB RD	32.17739	-110.841
33	835	IRVINGTON RD	MIDVALE PARK RD	32.16034	-111.001
34	843	IRVINGTON RD	NOGALES HY/6TH AV	32.16325	-110.968
35	844	IRVINGTON RD	PARK AV	32.16335	-110.956
36	846	BENSON/TUCSON	IRVINGTON RD	32.16323	-110.935
37	861	HARRISON RD	IRVINGTON RD	32.16285	-110.79
38	869	NEBRASKA ST	12TH AV	32.15594	-110.978
39	894	ALVERNON WY	BENSON HY	32.1468	-110.909
40	913	MIDVALE PARK RD	VALENCIA RD	32.13382	-110.999
41	914	CALLE SANTA CRUZ	VALENCIA RD	32.13383	-110.991
42	923	CAMPBELL AV	VALENCIA RD	32.13413	-110.943
43	924	TUCSON BL	VALENCIA RD	32.13413	-110.935
44	970	OLD VAIL RD	VALENCIA RD	32.11911	-110.813
45	971	NEXUS RD	VALENCIA RD	32.11905	-110.797
46	973	NEXUS RD	RITA RD	32.11494	-110.797
47	974	OLD VAIL RD	RITA RD	32.10091	-110.801
48	976	HOUGHTON RD	OLD VAIL RD	32.08813	-110.773
49	4131	KOLB RD	SABINO CANYON RD	32.24005	-110.842
50	4491	SPEEDWAY BL	COUNTRY CLUB RD	32.236	-110.927

CHAPTER 4: SAMPLE VIDEO-BASED VOLUME DATA COLLECTION AND ANALYSIS

In the PAG region, 485 intersections are equipped with video-based sensors provided by one of the three companies Econolite Inc., Miovision Technologies Inc., and Iteris Inc. As of 2020, only a few intersections have been configured with the traffic volume data collection module that automatically collects volume data: 24% of intersections with the Miovision sensors, 6% of intersections with Enconolite Autoscope® sensors, and 2% of intersection with the Iteris sensors The sample video-based volume data were collected from different jurisdictions and analyzed with ground-truth data to verify data quality.

4.1 VIDEO-BASED DATA COLLECTION

The existing video-based sensors used in the PAG region were manufactured by Econolite Inc., Miovision Technologies Inc., and Iteris Inc. The Econolite traffic sensors are Autoscope® series products, including *Autoscope 2004*, *Solo Pro*, *Encore*, *Solo Terra*, etc. These manufacturers release specific traffic sensors irregularly. **Figure 4-1** shows a timeline of when these products were released.

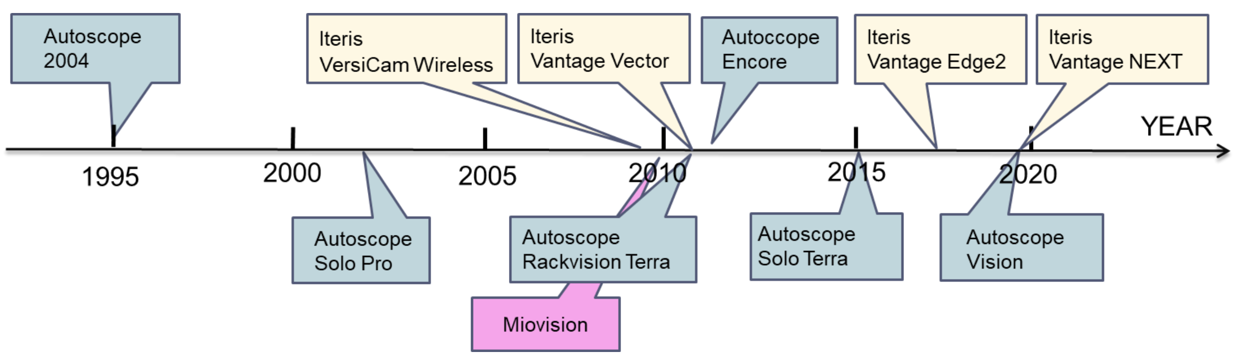


Figure 4-1 Video-based sensor products timeline

The UArizona team simply interviewed these sensor vendors by either phone or email regarding the video-based sensor technology, including traffic parameters, collection method, and data storage capability. All results from the interviews with these three brands are summarized in **Table 4-1**.

Econolite did not supply detailed information on some of the older sensors in its Autoscope® series, including the *Autoscope® 2004, Solo Pro, Encore*, and *Terra*. Based on their performance history, these outdated sensors can store approximately 1 to 2 years of data depending on the collection interval, the parameter categories, and the number of configured sensors. *Vision*, one of the newest Autoscope® sensors, can store 8 to 10 years of data, which can be collected through certain software and API. Four Iteris products have software that can be used for data collection. Econolite Autoscope® sensors and Iteris® sensors differ from Miovision sensors, which store data to the cloud indefinitely, and this data can be downloaded via the API or the online interface.

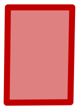
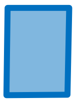
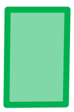
Table 4-1 Comparison of Video-Based Sensor Technology

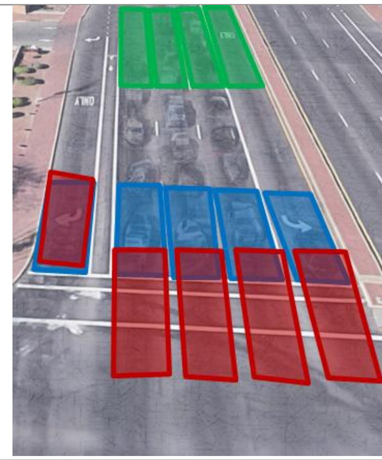
<table>
<tr><th>Manufacturer</th><th>System (sensors)</th><th>Technology</th><th>Traffic Parameters</th><th>Collection Method</th><th>Data Storage Capability</th></tr>
<tr><td rowspan="5">Econolite Inc.</td><td>Autoscope 2004</td><td rowspan="5">Video Image Processor</td><td rowspan="5">Volume, Speed, Occupancy, Classification, Bicycle Count …</td><td>NA (outdated)</td><td>NA (outdated)</td></tr>
<tr><td>Autoscope Solo Pro</td><td>NA (outdated)</td><td>NA (outdated)</td></tr>
<tr><td>Autoscope Encore</td><td>NA (outdated)</td><td>NA (outdated)</td></tr>
<tr><td>Autoscope Terra</td><td>NA (outdated)</td><td>NA (outdated)</td></tr>
<tr><td>Autoscope Vision</td><td>Software API</td><td>8 -10 years</td></tr>
<tr><td rowspan="4">Iteris Inc</td><td>Vantage Vector</td><td rowspan="4">Video Image Processor</td><td rowspan="4">Volume, Occupancy, Classification, Average vehicle speed …</td><td rowspan="4">Software</td><td rowspan="4">Dependent on storage capacity</td></tr>
<tr><td>VersiCam Wireless</td></tr>
<tr><td>Vantage Edge2</td></tr>
<tr><td>Vantage Next</td></tr>
<tr><td>Miovision Technology Inc.</td><td>Miovision TrafficLink</td><td>Video Image Processor</td><td>Traffic count data, Occupancy, Point to point travel time, Pedestrian delay …</td><td>API and Online Interface</td><td>Stored in cloud Indefinitely</td></tr>
</table>

4.1.1 Econolite Autoscope® Sensors

Each Econolite Autoscope® sensor can monitor multiple lanes of traffic with multiple detection zones. For example, an Autoscope® sensor at an intersection could have a camera configured with three types of virtual loop detectors. Each detector is configured to focus on the collection of different traffic parameters including volume, classification, occupancy, and speed. The "volume count and stop bar" detector is a virtual loop detector that is configured at the stop bar mainly to collect traffic volume data. The presence detector is configured near the stop bar mainly to collect occupancy data. The advance detector is configured 100 to 200 feet upstream from the stop bar mainly to collect occupancy and speed data. **Table 4-1** summarizes the detector configuration layout in Econolite Autoscope® sensors used in Tucson.

Table 4-1 Detector Layout in Econolite Autoscope® Products in Tucson

Detector Symbol	**Detector Type**	**Parameters Collection**	**Purpose**
	Volume Count @ Stop Bar	Volume*** Classification* Occupancy	Traffic Count
	Presence Detector	Occupancy** Volume* Speed	Congestion Detection
	Advance Detector	Occupancy** Volume* Speed**	Congestion Detection



Asterisk (*) shows the importance of the parameter

Since 2017, the UArizona team has worked with the City of Tucson to configure Econolite Autoscope® sensors to collect traffic data at specific intersections. As of 2020, 27 signalized intersections on Speedway Boulevard, Campbell Avenue, and Kolb Road have been configured with the data collection module to collect lane-by-lane traffic parameters as well as turning movement counts, as shown in **Figure 4-2**. To obtain traffic volume data at these intersections, traffic engineers must collect it in the field from the intersection signal cabinets.

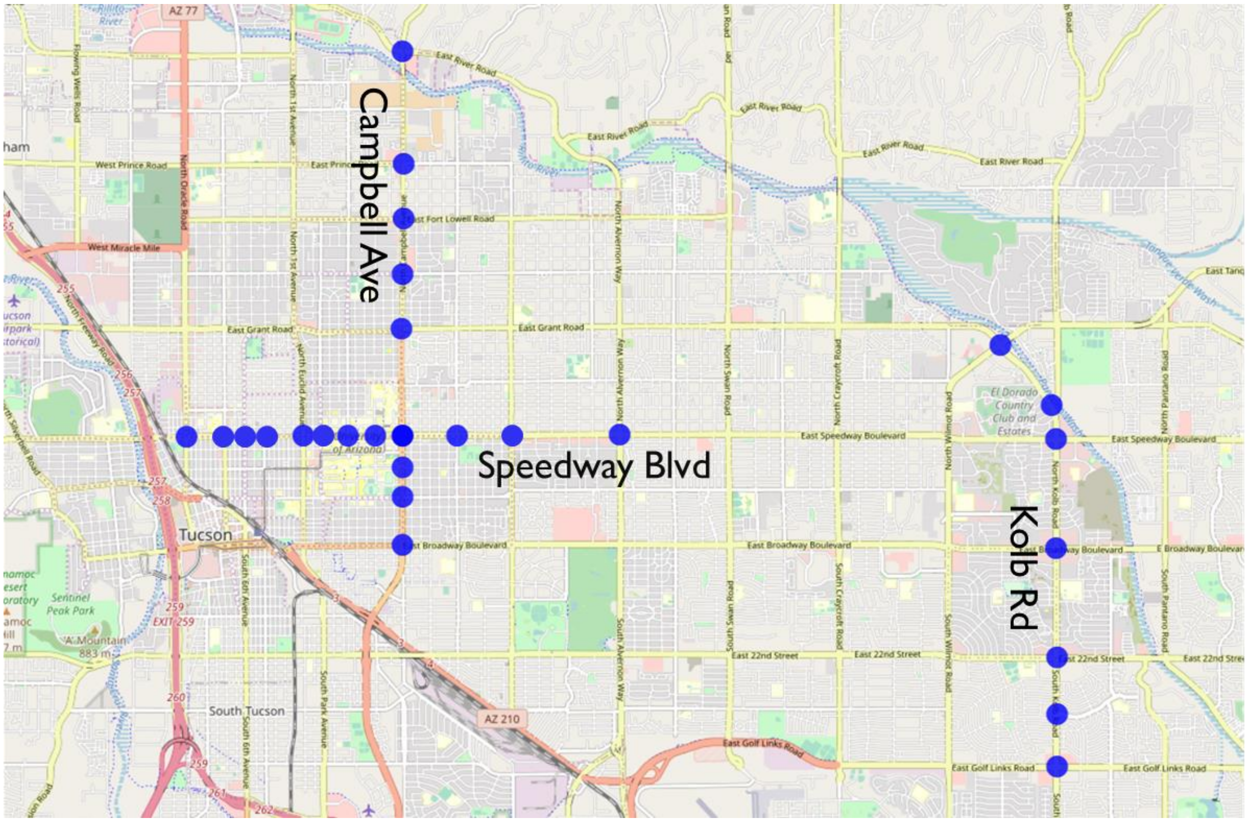


Figure 4-2 Map of available Autoscope® sensor data locations

4.1.2 Miovision Sensors

Miovision sensors can provide several traffic parameters, including turning movement count data in one-minute intervals. 122 intersections in the PAG region have been configured with Miovision sensors as of August 2020. Among these, 110 are managed by the Pima County Department of Transportation (PCDOT), and 12 are located in and managed by the Town of Marana. The UArizona team has worked with PCDOT to develop a "Miovision API Tool[1]" web interface, which can be used to download historical traffic parameters, including turning movement count data, directly from the cloud. Computer code that uses the API keys (provided by PCDOT and the Town of Marana) can also be written to collect data via the Miovision API.

Most intersections use a single Miovision camera, but there are 4 large intersections where two cameras are used to accurately collect traffic data. **Table 4-3** summarizes the number of Miovision cameras used at individual intersections. Four large intersections in Pima County with two cameras are La Cholla Boulevard / Ruthrauff Road, La Cholla Boulevard / River Road,

[1] http://pcdot.ua-star.org/

Alvernon Way / Brandi Fenton Driveway / River Road, and La Cholla Boulevard / Orange Grove Road. In the Town of Marana, the intersections at Cortaro Road / Arizona Pavilions, Cortaro Road / Silverbell Road, and Thornydale Road / Orange Grove Road are equipped with two cameras.

Table 4-2 Summary of the Number of Miovision Cameras at Individual Intersection

Number of Cameras	**Number of Intersections**	
	PCDOT	**Town of Marana**
No Smartlink	9	0
1	98	9
2	4	3
SUM	111*	12

*: one sensor is the test sensor

4.1.3 Iteris® Sensors

13 intersections in the PAG region are equipped with Iteris® sensors; 10 intersections are located in the Town of Marana and 3 in the City of Tucson.

Iteris® sensors can provide traffic parameters regarding vehicles and pedestrians including volume, occupancy, average speed, and the amount of green time in real-time, as shown in **Table 4-3**. **Figure 4-3** shows the sample raw Iteris® data. The bin data structure is formatted as "xxx, yyyy-mm-dd hh:mm:ss, V, X, X, X, X, X, I, Video Status, Label" and varies by different data types.

```
File   Edit   Format   View   Help
510, 2020-05-01 00:00:00, 0,0,0,0,0,0,0, Video OK,C4 LT
511, 2020-05-01 00:00:00, 0,0,0,0,0,0,0, Video OK,C4 T
512, 2020-05-01 00:00:00, 0,0,0,0,0,0,0, Video OK,C4 RT
607, 2020-05-01 00:00:00, 0,0,0,0.0,0.0,0.0,0, Video OK,C4 PD
608, 2020-05-01 00:00:00, 0,0,0,0.0,0.0,0.0,0, Video OK,C4 PD
731, 2020-05-01 00:00:00, 0,0,0,0,0,0,0, Video OK,C4 R1
738, 2020-05-01 00:00:00, 0,0,0,0,0,0,0, Video OK,C4 L1
739, 2020-05-01 00:00:00, 0,0,0,0,0,0,0, Video OK,C4 L2
501, 2020-05-01 00:15:00, 9,0,2,0,0,0,0, Video OK,C1 LT
502, 2020-05-01 00:15:00, 0,0,0,0,0,0,0, Video OK,C1 T
```

Figure 4-3 Example of Iteris® sensors raw data

Table 4-3 Summary of Iteris® Bin Data Structure

Type	XXX (Zone number)	T	V	X	X	X	X	X	I	Video Status	Label
Vehicle and Bike Zones	701-740	T	V	-	-	-	-	-	I	Ok or No Video	
Automatic Direction Counts	501-512			-	O*	-	-	-		OK or No Video, Video GLR, Video LC	
PedTrax (Pedestrian data)	-			-		S	MaxSpd	MinSpd		Ok or No Video	
CSO and Vector Trip Line	651-654			S	O	Csm	Cmd	Clg		Ok or No Video	

- **Zone number**: denotes which movement occurs and on which camera
- **T**: timestamp with format of "yyyy-mm-dd hh:mm:ss"
- **V**: volume (count) for the bin interval
- **S**: average vehicle (or pedestrian) speed for the bin interval
- **MaxSpd**: speed of the fastest pedestrian for the bin interval
- **MinSpd**: speed of slowest pedestrian for the bin interval
- **O***: occupancy, note: only for zone number with each sensor (501, 504, 507, 510). All other zones not used, always zero
- **O**: occupancy
- **Csm**: volume (count) for small vehicle classification
- **Cmd**: volume (count) for medium vehicle classification
- **Clg**: volume (count) for large vehicle classification
- **I**: green time in seconds for the bin interval. This is always zero for Vector Trip Lines
- **Label**: automatic or user-configured

4.2 VIDEO-BASED VOLUME DATA ANALYSIS

4.2.1 Econolite Autoscope® Volume Data

Data from two types of Econolite Autoscope® sensors, *Autoscope Terra* and *Autoscope Solo Pro*, were collected and evaluated based on data availability.

- *Autoscope Terra*

The Speedway Boulevard / Stone Avenue intersection was chosen as the study location to compare the volume data collected by *Autoscope Terra* sensors with ground-truth TMC data provided by PAG. Due to a lack of ground-truth data with which to evaluate the *Autoscope Terra* data quality, only the TMC data during peak periods were compared. Since the time periods of collecting *Autoscope Terra* volume and ground-truth data did not match, these two data sources were collected from different dates for evaluation. We chose three days of PAG data (10/19/2016, 10/13/2016, 9/18/2019) and slightly more than 2 months of Terra data (02/01/2018 to 04/12/2018) to compare. As shown in **Figure 4-4**, a similar trend is observed, indicating the TMC data collected by Terra sensors can capture the traffic volume trend. The accuracy of the *Autoscope Terra* volume data still needs further evaluation by using more ground-truth data.

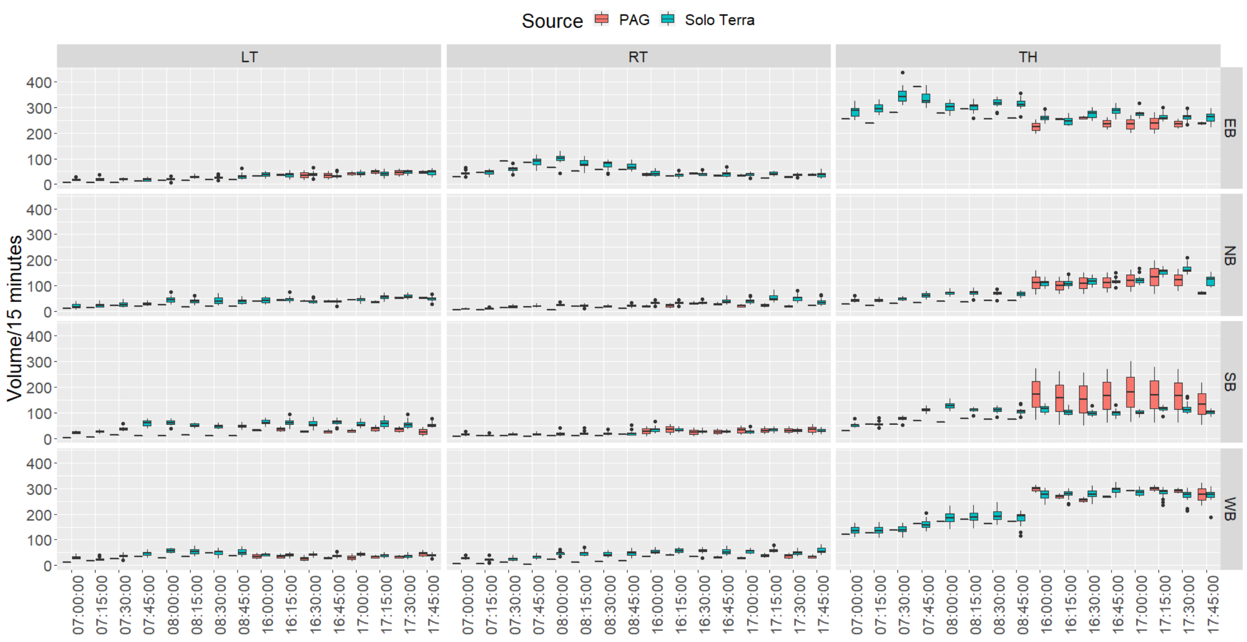
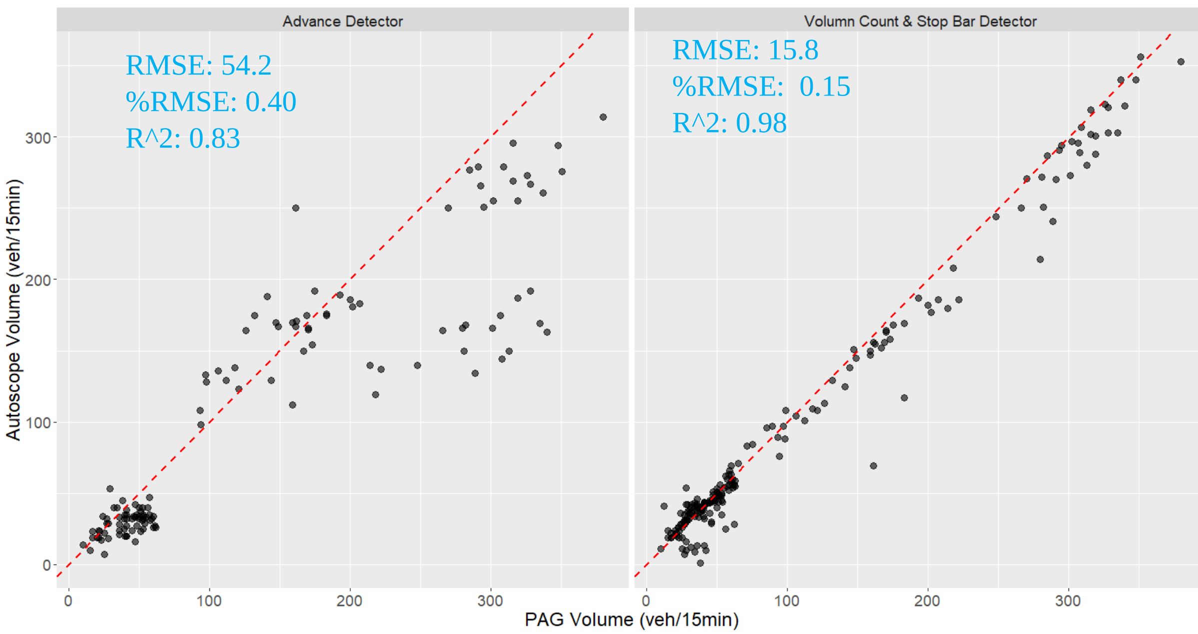


Figure 4-4 Comparison of Terra data with ground-truth data

- *Autoscope Solo Pro*

The Speedway Boulevard / Euclid Avenue intersection was chosen as the study location to compare *Autoscope Solo Pro* volume data with PAG ground-truth TMC data. The data used in this comparison were collected by the advance detectors and the “volume count and stop bar” detectors during peak periods on 10/31/2017. **Figure 4-5** shows that the turning movement count data collected by the “volume count and stop bar” detectors (located at the stop bar and mainly used to collect traffic volume) is more accurate than the TMC data collected by the advance detectors. Also, the accuracy of the data for each of the three movements collected by the “volume count and stop bar” detectors is specifically evaluated. **Figure 4-6** shows that the *Autoscope Solo Pro* volume for all three movements are close overall to PAG’s ground-truth data; the metrics of %RMSE and R^2 show that the through and left-turn volumes are more accurate than the right turn volume.



(a) Advance detector (b) Volume count & Stop Bar detector

Figure 4-5 Comparison between TMC collected by *Autoscope Solo Pro* and PAG ground-truth data

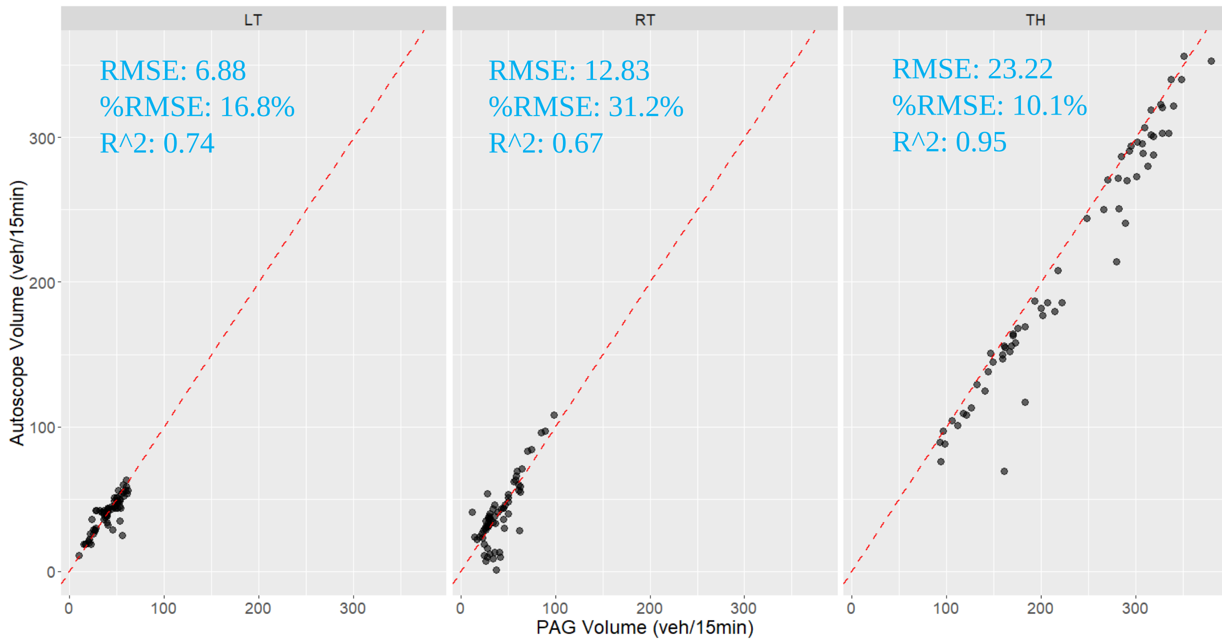


Figure 4-6 Comparison of *Autoscope Solo Pro* ("volume count & stop bar" detector) volume data with ground-truth volume data by movement

4.2.2 Miovision Volume Data

Four intersections were chosen as the study locations to compare Miovision volume data with PAG ground-truth TMC data. These study intersections and dates are: (1) Ina Road / La Canada Drive (9/19/2019); (2) Ina Road / La Cholla Boulevard (9/19/2019); (3) La Cholla Boulevard / River Road (9/26/2019); (4) La Cholla Boulevard / Ruthrauff Road (9/25/2019). Due to the availability of ground-truth data, the data were compared only for the AM and PM peak periods. **Figure 4-7** shows that volume for the left-turn movement is more accurate than the right turn and through movements. The Miovision volume for the through movement significantly underestimates the ground-truth data. We found that the underestimation is mainly isolated at La Cholla Boulevard / River Road, and possibly caused by a video sensing error at the far end of the large intersection, which is difficult for video cameras to capture.

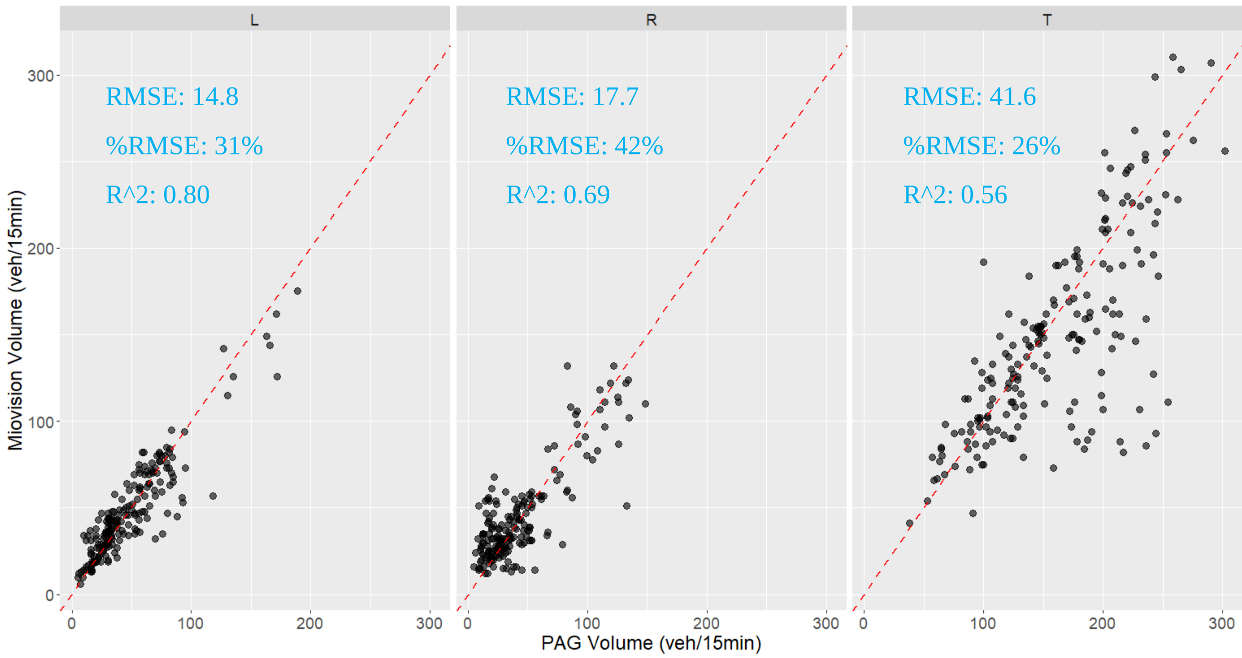


Figure 4-7 Comparison of Miovision volume data and ground-truth data

4.2.3 Iteris® Volume Data

The Town of Marana provided the sample Iteris data collected by a sample sensor. The traffic volume trend in May 2020 is illustrated in **Figure 4-8** and shows a similar volume trend as other intersections in the PAG region. The preliminary results suggest that the Iteris data can be used as long-term traffic count data.

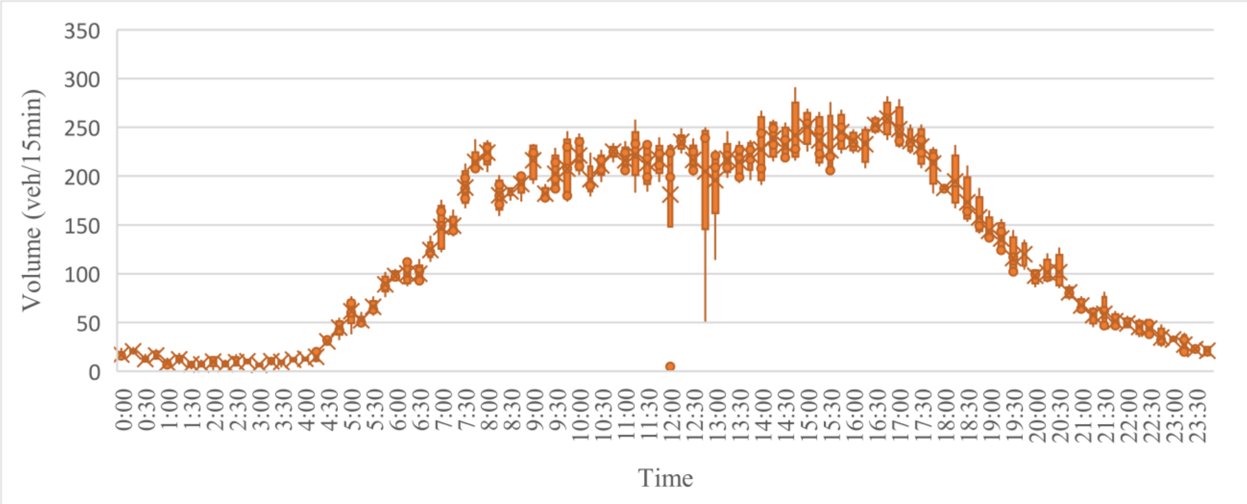


Figure 4-8 Hourly trend of Iteris® through movement volume at an example intersection

CHAPTER 5: SAMPLE TRAFFIC SIGNAL CONTROLLER EVENT-BASED DATA COLLECTION AND ANALYSIS

This chapter introduces traffic signal controller event-based data concepts and data collection methods and also explores ways of obtaining region-wide TMC data using existing event-based data. This discussion provides a brief background for readers less familiar with event-based data.

5.1 TRAFFIC CONTROLLER EVENT-BASED DATA COLLECTION

5.1.1 Data Collection Method

Advanced traffic management systems (ATMS) serve as a platform for monitoring traffic and managing all traffic signals and sensors to improve traffic operation and safety. The City of Tucson deployed a MaxView© ATMS system for traffic signal control and optimization, with a majority of ASC/2 and ASC/3 model traffic controllers. **Figure 5-1** shows a conceptual view of the event-based data collection and data archiving procedure. Real-time event-based data is typically recorded by traffic signal controllers from video-based detectors, and pedestrian pushbutton sensors transmit data to traffic signal controllers at signalized intersections. The signal controller is the primary component, as it determines the various signal indications. Then, data from all the controllers are archived into the MaxView database server. To back up the event-based data, the Smart Transportation Lab (STL) at the University of Arizona (UArizona) started to archive the data from the MaxView database server into a UArizona UITS Server in 2017.

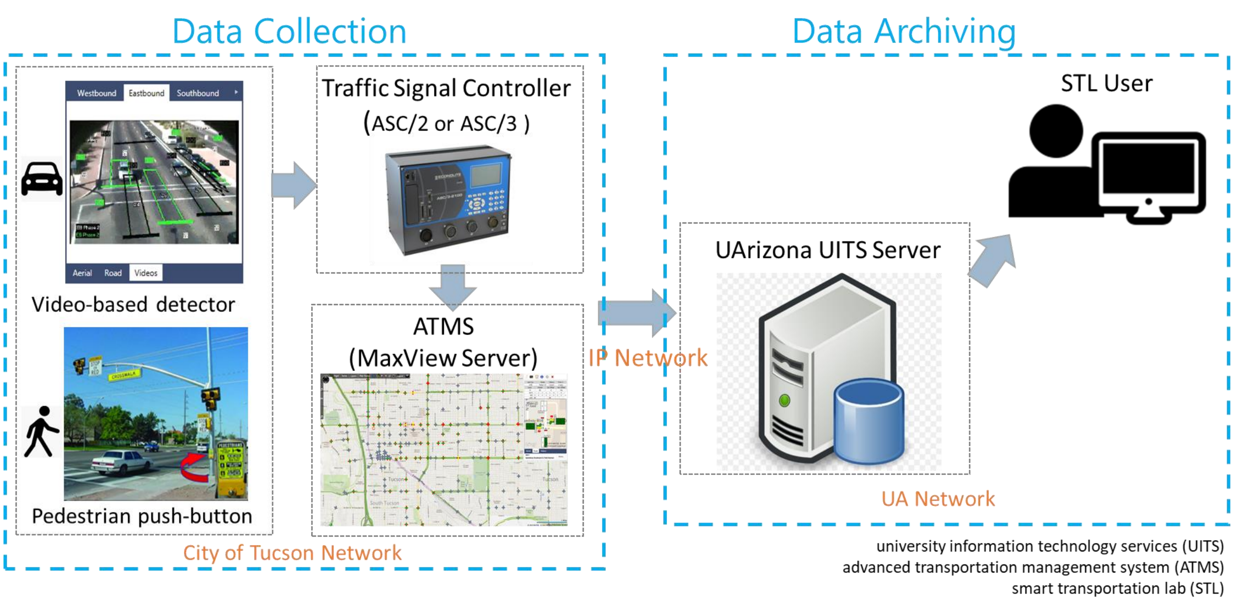


Figure 5-1 Event-based data collecting and archiving process

After the event-based data from traffic signal controllers have been logged, the data is transported to the management center for archival and generation of performance measures. Because of this, the state of communication over the Tucson Regional Traffic Data Network (RTDN) plays an important role in obtaining complete event-based data sets. A good state of communication can provide accurate logs of controller activity and vehicle behavior.

Approximately 600 controllers in the region comprise the MaxView system, but due to communication issues, not all have complete event-based data. The daily percentage of communication losses (POCL) for all controllers from October 2017 to September 2020 are summarized as shown in **Figure 5-2**. When the POCL was less than 12.5%, the majority of events could be sent to the database server. When the POCL was larger than 12.5%, more events are missing because they could not be sent to the database server. When the POCL was 100%, all of the events are missing. A high POCL for a controller can result in a biased TMC estimation. Before May 2020, only approximately 60% of the controllers in the MaxView system had a low POCL and reliable communication. Since May 2020, more controllers have been reconfigured, and the number of controllers with reliable communication as of September 2020 has risen to 90%.

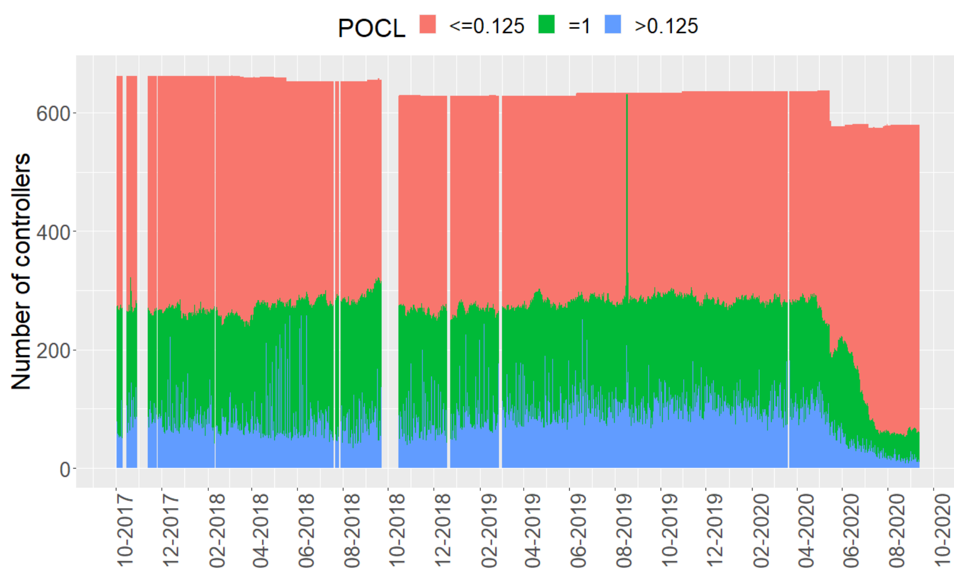


Figure 5-2 Daily percentage of communication losses

5.1.2 Event-based Data Description

Traffic controller event-based data consists of a series of events (detector actuation events, signal change events, pedestrian-related events, controller communication events, etc.) generated in real-time. **Table 5-1** summarizes the event categories.

Table 5-1 Event Summary by Category

Event Categories	Event Example
Phase Events*	Phase On; Phase Begin Green; Phase Check; Phase Begin Red
Pedestrian Phase Events	Pedestrian Begin Walk; Pedestrian Begin Clearance…
Flashing Yellow Arrow Events (FYA)	FYA Begin Permissive; FYA End Permissive
Phase/Ped Call Events	Ped Detector Off/On/Failed
Overlap Events	Overlap Begin Green/Yellow
Detection Events*	Detector On/Off/Failed
Preemption Events	Preempt Advance Warning Input; Preempt Input On/Off
Transit Signal Priority Events (TSP)	TSP Check In/Out; TSP Delay Begin/End
Cabinet/System Events	Unit Flash Status Change; Unit Alarm 1 Change
Communication Events*	Time Drift; Percent Comm Loss; Total Comm Attempts
Ramp Meter Events	Act. Action Rest in Green; Act. Action Fixed Rate
Coordinate events	Actual Cycle Length; Actual Cycle Offset

*: used in traffic volume estimation research

Data from signal change events, detector actuation events, and communication loss events are mainly used in this project. **Figure 5-3 (a)** shows sample data of these three types of events. The detector actuation event data logs the time stamp of each time that the detector switches on or off due to vehicles triggering or leaving it. The **DeviceId** column contains the signal controller IDs, referred to in this study as an intersection location. The **EventId** column contains values that represent the specific event. For example, **EventId** = 81 represents the event "detector off", and **EventId** = 82 represents the event "detector on". The **Parameter** column contains the detector numbers associated with the turning movement. As shown in **Figure 5-3 (b)**, an even number is typically associated with a detector for a through movement, while an odd number is typically associated with a detector for a left-turn movement as defined in *Signal Timing Manual* (Urbanik et al., 2015). Signal change event data records each signal phase change, such as "phase on" (**EventId** = 0), "phase green beginning" (**EventId** = 7), and "phase green termination" (**EventId** = 1). The **Parameter** column contains the signal phase sequence number. Communication event data indicates the controller communication-related events, such as failed communication attempts (**EventId** = 501), the average response time (**EventId** = 503), and the percentage of communication loss (**EventId** = 502). When a controller loses communication, the ATMS server has difficulty collecting event-based data from the signal controller (An et al., 2017). Thus, communication events are important for data quality control before using event-based data.

Detector actuation events

TimeStamp	DeviceId	EventId	Parameter
2019-11-04 00:00:08.900	218	81	8
2019-11-04 00:00:08.900	222	82	2
2019-11-04 00:00:09.000	430	82	2
2019-11-04 00:00:09.000	666	82	6
2019-11-04 00:00:09.000	40	81	2
2019-11-04 00:00:09.000	685	81	6
2019-11-04 00:00:09.000	703	82	1
2019-11-04 00:00:09.100	444	82	2
2019-11-04 00:00:09.100	698	81	2

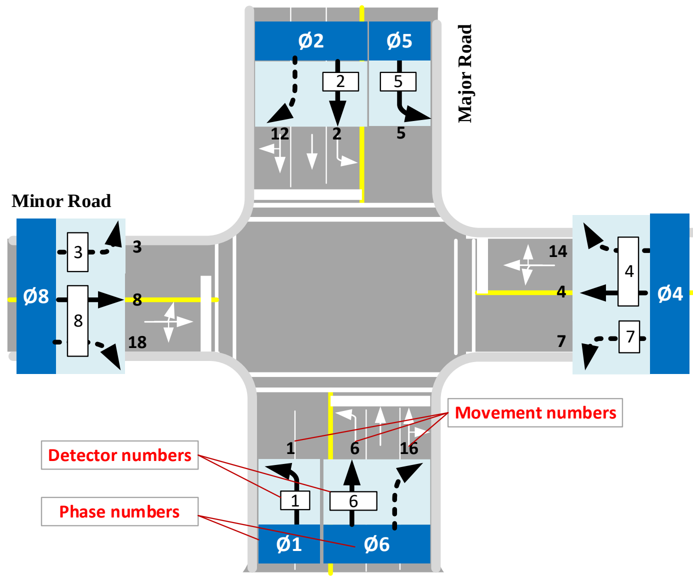
Signal change events

TimeStamp	DeviceId	EventId	Parameter
2017-10-20 04:55:40.963	7	11	4
2017-10-20 04:55:40.963	7	12	4
2017-10-20 04:55:40.963	7	11	8
2017-10-20 04:55:40.963	7	12	8
2017-10-20 04:55:40.963	7	0	2
2017-10-20 04:55:40.963	7	1	2
2017-10-20 04:55:40.963	7	21	2
2017-10-20 04:55:57.173	7	22	2
2017-10-20 04:56:10.273	7	3	2

Communication loss events

TimeStamp	DeviceId	EventId	Parameter
2019-10-21 00:10:25.987	3	500	19
2019-10-21 00:10:25.987	3	501	15
2019-10-21 00:10:25.987	3	502	78
2019-10-21 00:15:23.860	3	400	-30
2019-10-21 00:15:26.033	3	500	21
2019-10-21 00:15:26.033	3	501	15
2019-10-21 00:15:26.033	3	502	71
2019-10-21 00:15:26.033	3	503	11093

(a) Sample data



(b) Detector & Signal parameter layout

Figure 5-3 (a) Examples of three types of event-based datasets; (b) Signal phase and detector layout

5.1.3 Comparison to Video-Based Traffic Data

For video-based sensors configured at a signalized intersection, either a traffic data collection module, a traffic detection module, or both can be integrated. The traffic detection module is used for signal control or management by generating event-based data, while the traffic data collection module is mainly used for the collection of parameters, such as traffic volume, speed, and density. Traffic data sourced from the data collection module of video-based sensors is called video-based traffic data in this report.

The data collection process and the data provided by these two modules are different. **Figure 5-4** demonstrates the comparison between the event-based data collection process (blue lines) and the aggregated video-based traffic data collection (red lines). For instance, an advance event detector covering multiple lanes can detect the vehicle arrival and departure used for signal control. These actuation events, consisting of a detector on and a detector off, are transferred to the controller in the cabinet by video-based sensors. In addition to actuation events, the events of signal phasing change, button-pushing, pedestrian actuation, and other events are transferred to and archived in the controller. Then, the controller transfers these events to a database server in real-time. The process of collecting aggregated traffic data differs from the event-based data collection process in its use of “virtual loops” in video-based sensors through embedded algorithms. A data storage device, such as a memory card, is commonly used in a cabinet in connection with the sensor for storing the aggregated traffic data. Depending on the sensor type and brand, the aggregated traffic data could be stored in the cloud or the local memory card that can be accessed by users.

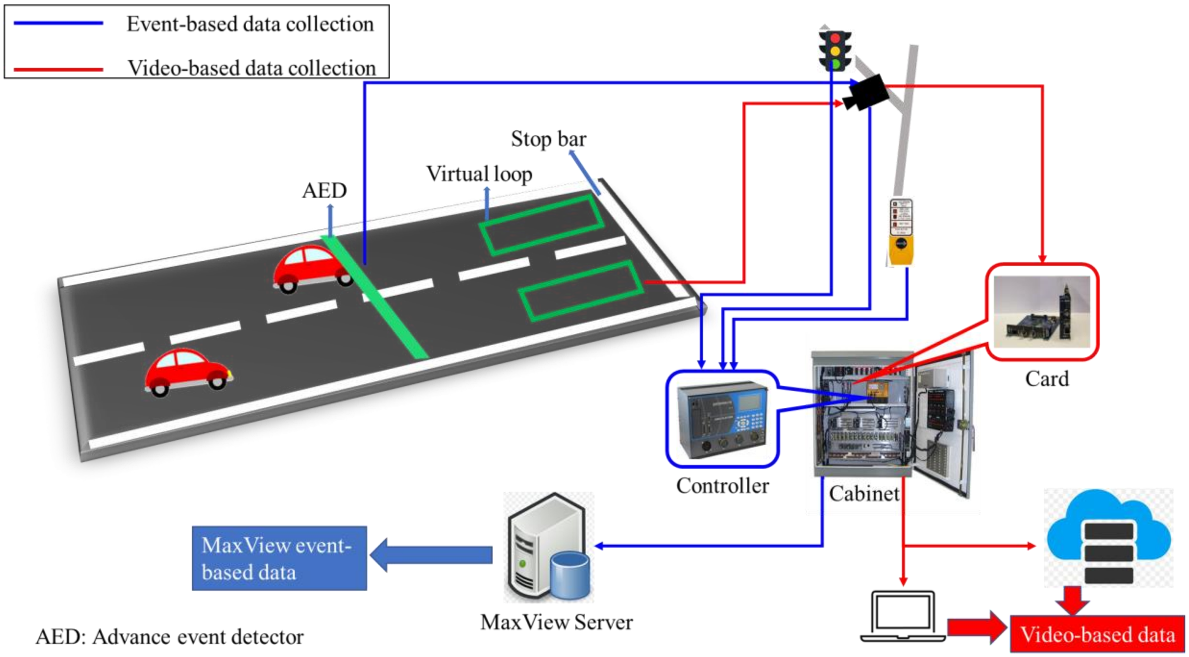


Figure 5-4 Processes of event-based data and video-based data collection in MaxView system

In addition, video-based traffic data are commonly aggregated to a defined time interval, such as 5 minutes or 15 minutes. By aggregating data into a fixed time interval as breakpoints, traffic state changes within these time intervals are lost. Because event-based data is generated in real-time, it is much more informative than video-based traffic data.

The major differences between traffic controller event-based data and video-based traffic data are summarized below:

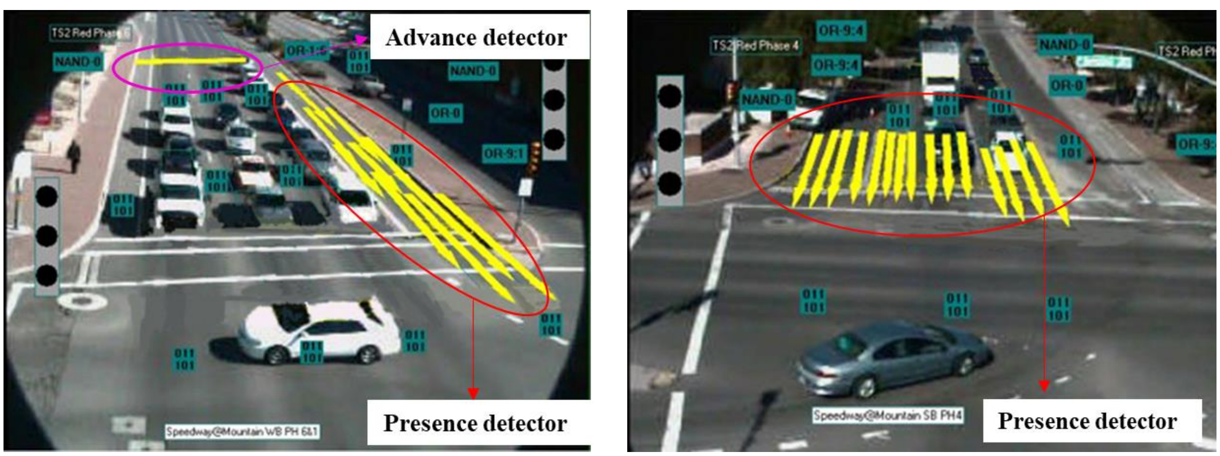
- The process and transition of event-based data and video-based traffic data in the same MaxView system are different.
- Video-based traffic data is aggregated to a defined interval and can provide traffic parameters such as volume, speed, or occupancy directly within the time interval.
- However, event-based traffic data is real-time and more informative. Event-based data usually records the time when a vehicle arrives or departs, and the time when a signal (such as a red, green, or yellow light) and a signal phase change.
- The video-based traffic data collected by the collection module is stored in the cabinet if no communication exists with the MaxView. However, the event-based data collected by the detection module is lost if no communication with the MaxView exists. Currently, some ATMS in the market are able to resend event-based data once communication is back.

5.2 EVENT-BASED DATA ANALYSIS

Even though the traffic data collection module can provide volume and other traffic parameters directly, configuring this module requires additional efforts, costs, and devices in comparison to a traffic detection module with the default configuration. Therefore, most existing video-based sensors in the MaxView system still only have a traffic detection module without a traffic data collection module. This section explores how to estimate turning movement counts (TMC) at signalized intersections using event-based data considering its wide coverage and availability in Tucson, avoiding purchasing and installing new sensors.

5.2.1 TMC Estimation Model Development[2]

Although event-based data have been used to estimate traffic volume in previous studies, estimating TMC in the PAG region is still challenging because of the various scenarios with complex uncertainties caused by two major issues: single-channel detectors covering multiple lanes and different detector configurations on different approaches. As shown in **Figure 5-5**, the major road is configured with an advance detector on through lanes and right-turn lanes, while the minor road is configured with only a presence detector. The same time duration recorded by advance detectors and presence detectors could refer to different traffic counts due to the different lengths of these two types of detectors. Advance detectors are used to detect moving vehicles, and so the time duration is most likely to be the vehicle passing time, reflecting the vehicle speed. The presence detectors are typically used to detect stopped vehicles, and so the time duration is most likely to be the vehicle stopping time.



a. WB (Major road) b. SB (Minor road)

[2]Peipei Xu, Xiaofeng Li, Hyunsoo Noh, and Yao-Jan Wu, (2021). *Estimating Network-Level Turning Movement Counts using Traffic Controller Event-Based Data*. Presented at the 100th Annual Meeting of the Transportation Research Board.

Figure 5-5 Detection system configuration at Speedway Blvd & Mountain Ave in Tucson, Arizona

To capture the non-linear and uncertain relationship between the performances extracted from event-based data and TMC, the Multi-Layer Perceptron (MLP) Neural Network model is introduced. The MLP model is a class of fully connected feedforward artificial neural networks that can capture underlying relationships of the problem examined without the need for a priori assumptions (Zhang et al., 1998). The MLP model developed and used in this study includes four layers: the input layer, two hidden layers, and the output layer; its structure is illustrated in **Figure 5-6**. Each node in a layer connects to every node in the following layer, making a fully connected network. The leftmost layer is the input layer, which consists of a set of nodes representing the input variables.

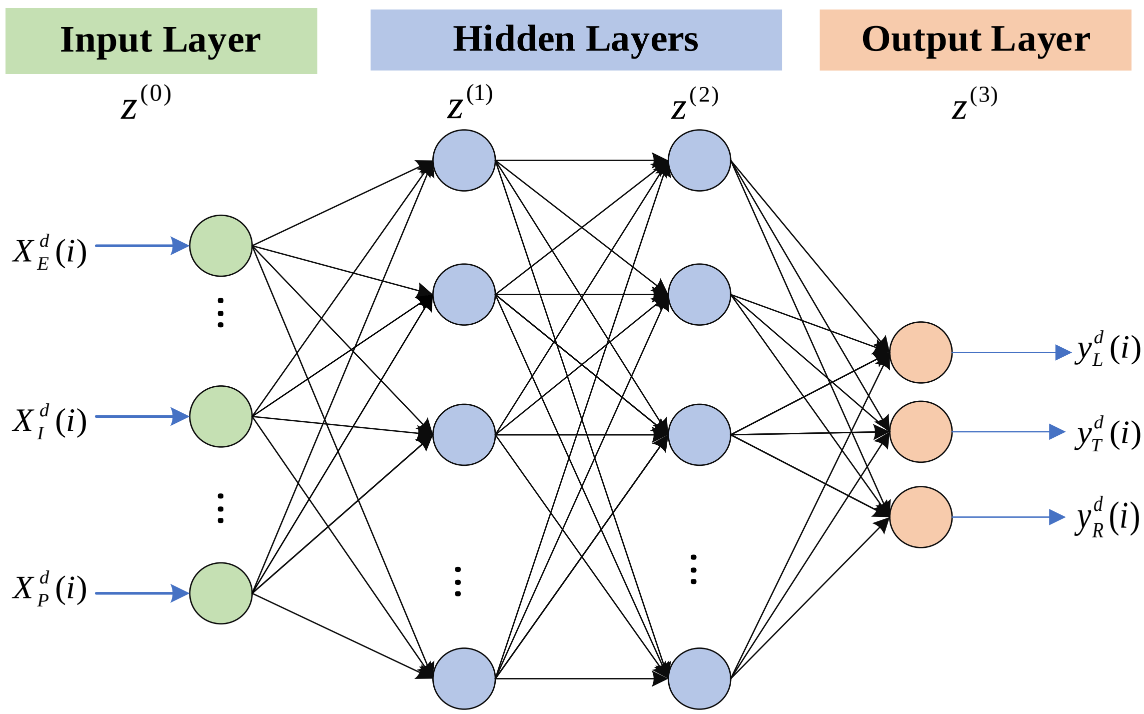


Figure 5-6 Topology of the MLP model for TMC estimation

The input layer vectors consist of event-based features, intersection infrastructure features, and point-of-interest (POI) features, as summarized in **Table 5-2**.

Table 5-2 Summary of Input Variables of MLP Model

Input Layer	Feature Name	Definition
Event-based features	Occupancy.x	Detector occupancy time during a 15-min interval
	DetOffCount.x	Detector trigger counts during a 15-min interval
	GreTime.x	Green time duration during a 15-min interval

	Cycle.x	Number of phase cycles during a 15-min interval
	Mean_Gap.x	Average time gap between every pair of corresponding detections during a 15-min interval
	Median_Gap.x	Median time gap between every pair of corresponding detections during a 15-min interval
	SD_Gap.x	Standard deviation of the time gaps between every pair of corresponding detections during a 15-min interval
	Occupancy.y	Detector occupancy time during a 15-min interval
	DetOffCount.y	Detector trigger counts during a 15-min interval
	GreTime.y	Green time duration during a 15-min interval
	Cycle.y	Number of phase cycles during a 15-min interval
	Mean_Gap.y	Average time gap between every pair of corresponding detections during a 15-min interval
	Median_Gap.y	Median time gap between every pair of corresponding detections during a 15-min interval
	SD_Gap.y	Standard deviation of time gaps between every pair of corresponding detections during a 15-min interval
	GreTimePermi	Permissive green time duration during a 15-min interval
Intersection infrastructure features	RoadType	Whether an approach is a major or minor road
	Lanes_SLT	Number of shared left-turn lanes
	Lanes_LT	Number of exclusive left-turn lanes
	Lanes _TH	Number of through lanes
	Lanes _RT	Number of exclusive right-turn lanes
	Lanes _SRT	Number of shared right turn lanes
POI features	POI_Emp	Number of employees of all POI within 400 meters of the intersection
	POI_n	POI category counts within 400 meters of the intersection

*.x variables are associated with through movements, where the detector parameter is an even number.
*.y variables are associated with left-turn movements, where the detector parameter is an odd number.

Event-based features include detector occupancy time, detector-triggered count, green time duration, and type of left-turn phase. Intersection infrastructure features consist of the type of road (major road or minor road), number of left-turn lanes, number of shared left-turn lanes, number of through lanes, number of right-turn lanes, and number of shared right-turn lanes. POI features include counts of all POI categories within a 400-meter buffer of the intersection and the number of employees for all POI categories within a 400-meter buffer of the intersection. The output layer consists of left-turn movement volume, through movement volume, and right-turn movement volume for one approach.

5.2.2 Model Evaluation Using Ground-Truth Data

The MLP model was calibrated and tested with ground-truth data collected from 84 intersections after overlapping the historical event-based data and ground-truth data. **Figure 5-7** shows the study intersections and corresponding POIs. The root mean square error (RMSE), the percent root mean square error (%RMSE), and the correlation coefficient R-squared are used to quantify the accuracy of the TMC estimation model. As shown in **Figure 5-8**, RMSEs for the through movement is higher than that of the left-turn and right-turn movements because the average traffic volume of the through movement is relatively higher than the other two movements at an intersection. The TMC estimation model showed excellent performance on the through movement with the highest R-squared and the lowest %RMSE values of the three movements. The left turn movement volume estimation slightly outperformed the right turn movement, it is likely because some advance detectors and presence detectors configured at intersections are not extended to right turn lanes. A lack of right turn event-based information is a probable cause of the lower R-squared value of the right turn volume estimation.

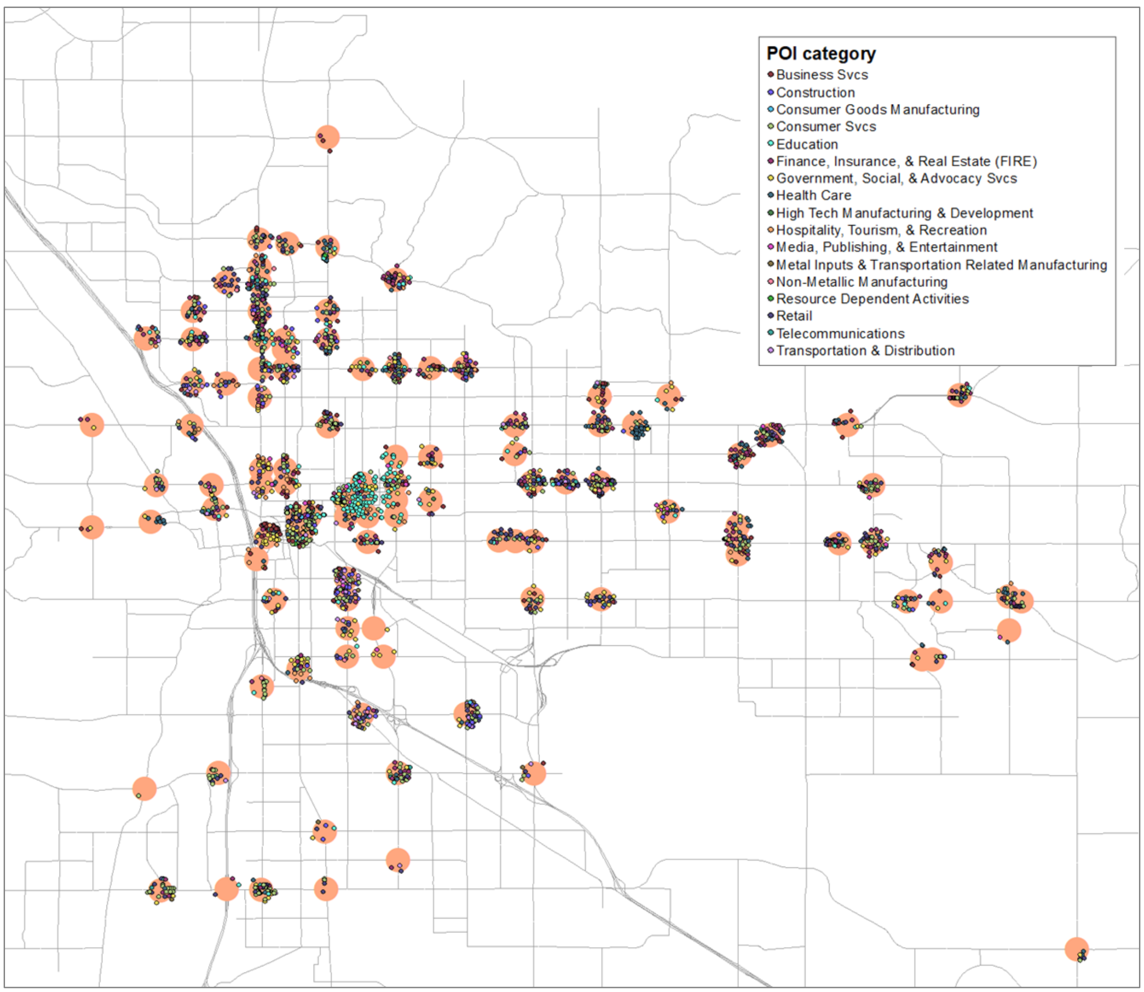
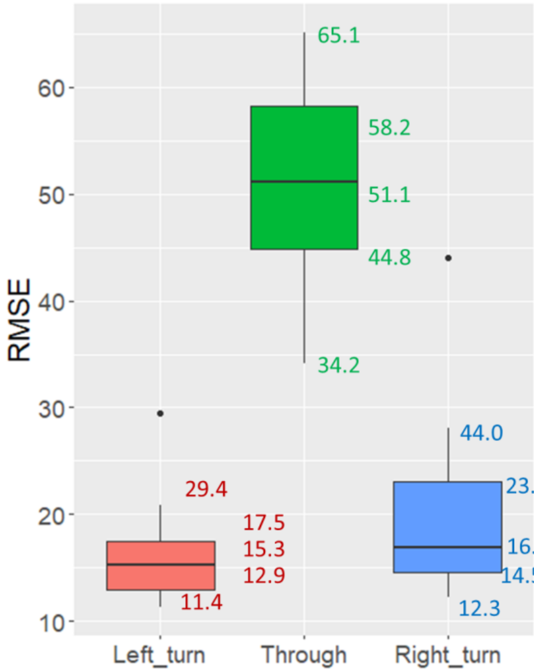
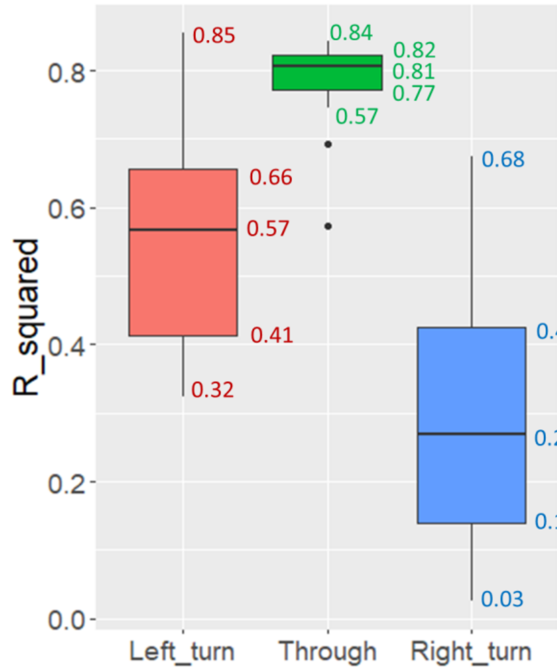


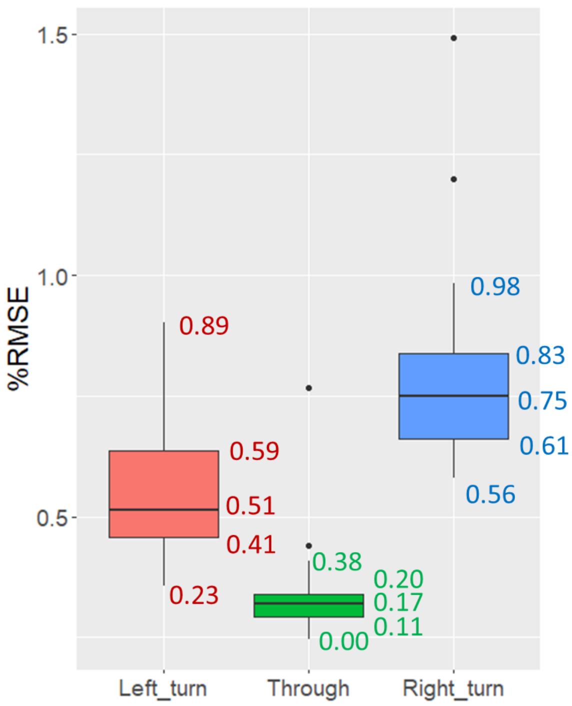
Figure 5-7 Study intersections



(a) RMSE



(b) R-Squared



(c) % RMSE

Figure 5-8 MLP-based TMC estimation model performance evaluation

CHAPTER 6: CROWDSOURCED DATA EXPLORATION

The rapid increase of location-based services has been generating a massive amount of GPS-based data. With its benefits of low cost and wide coverage, crowdsourced data has become a potentially significant data source in transportation-related research. Several types of crowdsourced data are available in the PAG region including INRIX, HERE, and StreetLight Data. This chapter explores the characteristics of crowdsourced data in terms of coverage, reliability, and accuracy.

6.1 INRIX DATA EXPLORATION

6.1.1 INRIX Data Collection

INRIX (INRIX, 2005), a company that was founded in 2005, can provide traffic-related data and insight into how people move around the world. INRIX uses a proprietary system to aggregate traffic information from millions of GPS-enabled vehicles and mobile devices, road sensors, and other sources. **Figure 6-1** shows an example of sample INRIX data reported in minute intervals. The main attributes are listed and defined below:

- **Code**: segment ID. These segment IDs may be updated.
- **Type**: the type of INRIX segment. INRIX provides either INRIX eXtreme Definition (XD) segments or Traffic Message Channel segments. XD segments cover more miles of road than TMC segments, generally with greater granularity. The data collected from INRIX XD segments are utilized in this project.
- **Speed**: the current mean estimated speed in miles per hour for the segment.
- **Average**: the historical mean speed in miles per hour for the segment for that hour of the day and day of the week.
- **Reference**: the 85th percentile speed of all observed speeds on the segment for all periods, which reliably approximates the free-flow speed for the segment.
- **Score**: the relative amount of data used from each of the data sources. The score has three possible values of 10, 20, and 30;
    - 30 – high confidence. The INRIX data is reported exclusively based on real-time data for that specific segment.
    - 20 – medium confidence. The INRIX data is reported based on real-time data across multiple segments and/or based on a combination of expected and real-time data.
    - 10 – low confidence. The INRIX data is exclusively generated from historical data or road reference data.
- **Confidence Value**: an additional degree of detail for real-time data that is only applied to data with a **Score** of 30. The **Confidence Value** indicates the “probability” that the current probe reading represents the actual conditions on the segment based on recent and historic trends (0 = low probability, 100 = high probability). A value of -1 designates that INRIX needs more data before a **Confidence Value** can be determined.

- **Speed Bucket**: a value of 0, 1, 2, or 3 that depends on the ratio of the **Speed** to the **Reference** speed. The **Speed Bucket** determines which color is displayed on the segment and indicates the congestion level on the segment.
- **Segment Closed**: the value of **TRUE** if the segment is closed and **FALSE** otherwise.

	timestamp	code	type	speed	average	reference	score	confidenceValue	travelTimeMinutes	speedBucket	segment_closed
1	2019-02-06 18:06:26.000	122233944	XDS	39	33	36	30	100	0.763	3	FALSE
2	2019-02-06 18:06:26.000	1226271262	XDS	50	65	65	30	0	0.944	2	FALSE
3	2019-02-06 18:06:26.000	1226251068	XDS	50	52	53	30	100	0.661	3	FALSE
4	2019-02-06 18:06:26.000	1226251029	XDS	50	52	53	30	100	0.661	3	FALSE
5	2019-02-06 18:06:26.000	384894357	XDS	50	55	55	30	100	0.661	2	FALSE
6	2019-02-06 18:06:26.000	1226232612	XDS	50	62	63	30	100	0.661	2	FALSE
7	2019-02-06 18:06:26.000	1226271108	XDS	64	65	64	30	0	0.601	3	FALSE
8	2019-02-06 18:06:26.000	1226271067	XDS	65	66	65	30	0	0.326	3	FALSE
9	2019-02-06 18:06:26.000	1226268861	XDS	50	65	66	30	100	0.551	2	FALSE
10	2019-02-06 18:06:26.000	1226268828	XDS	50	65	66	30	64	1.089	2	FALSE
11	2019-02-06 18:06:26.000	1226271296	XDS	50	66	66	30	0	0.508	2	FALSE
12	2019-02-06 18:06:26.000	1226265589	XDS	31	30	32	20		0.771	3	FALSE

Figure 6-1 Sample INRIX data

The UArizona Smart Transportation Lab archives INRIX data collected from the entire state of Arizona, which includes 44,210 segments that cover most freeways and arterials and, specifically, around 4,882 segments in the eastern Pima County region, as shown in **Figure 6-2**.

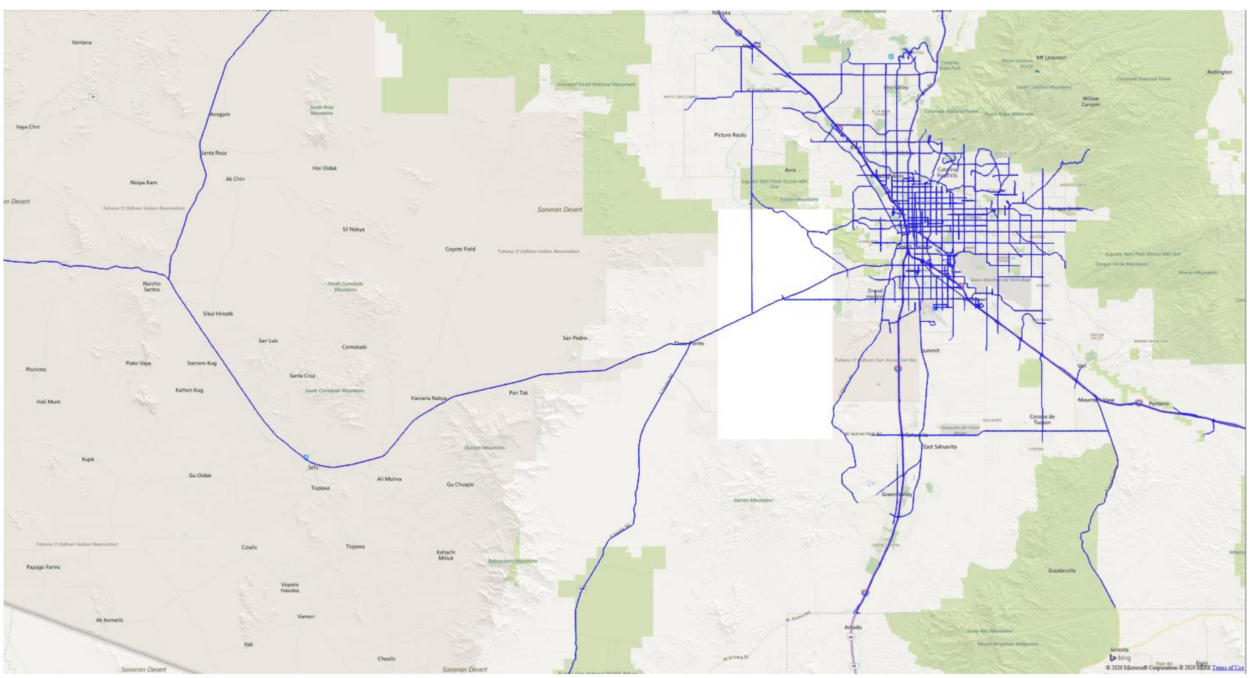


Figure 6-2 INRIX speed segment locations in the PAG region during January 2019

6.1.2 Speed Data Evaluation

The reliability of INRIX data is illustrated temporally in the PAG region in **Figure 6-3**, which shows the percentage of segments with the different values of **Score** (hereafter referred to as "score" or "scores") in the PAG region by the hour of the day. During nighttime (10 PM - 4 AM), the INRIX data for most segments are reported with a score of 10, indicating that the reported data only uses historical data due to a limited number of sample vehicles on the segments. During daytime (7 AM - 6 PM) on weekdays, the data for most segments are reported based on real-time data with the highest score because there are enough vehicles on the segments to provide sufficient samples. During the remaining periods, the INRIX data is reported based on real-time and historical data for most segments because some segments lack enough vehicles to provide sufficient samples during some hours. The results of the analysis indicate that the INRIX data during the daytime on weekdays can provide reliable data for traffic managers and decision-makers. During the nighttime and on weekends, sensor-based data could possibly be used in conjunction with INRIX data to provide reliable data.

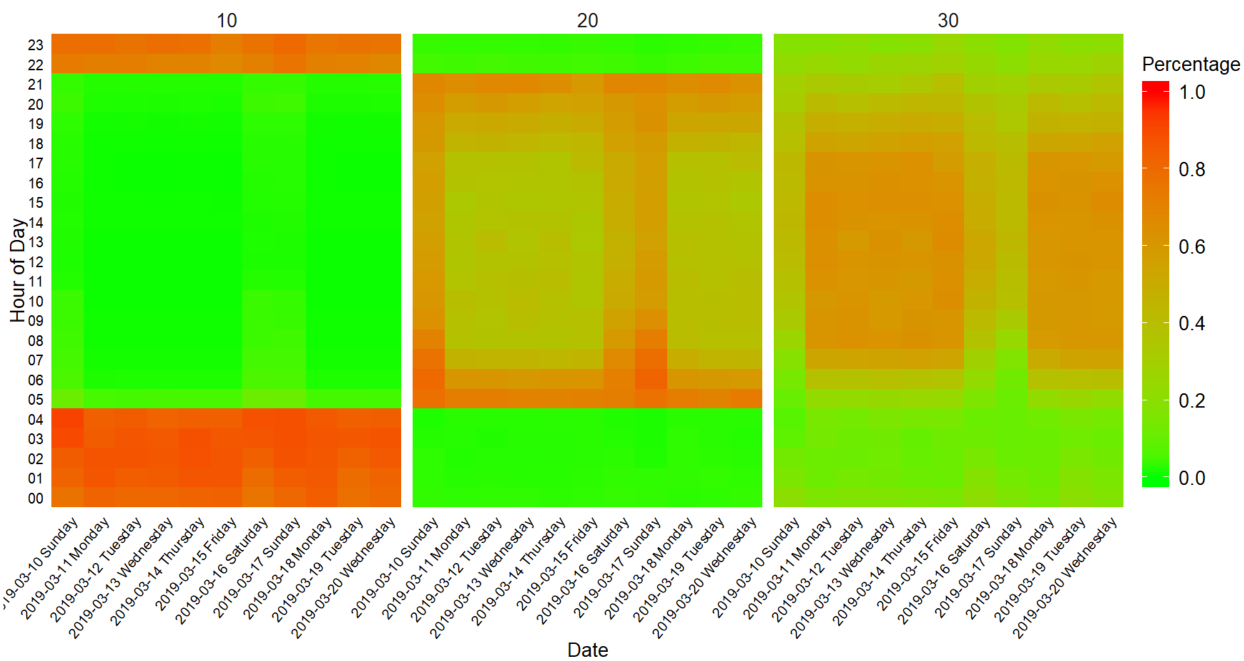


Figure 6-3 Reliability of INRIX data by hour of the day

As mentioned above, the score is one of the most important indicators of the INRIX data quality (Ahsani et al., 2019; Kim & Coifman, 2014). Scores of 10, 20, and 30 indicate low-quality data, medium-quality data, and high-quality data, respectively. The more data with a score of 30, the more accurate these INRIX data are. Speedway Boulevard in Tucson was chosen as the study corridor to illustrate the confidence score changes from August 2018. **Figure 6-4** shows the daily percentage of INRIX data with different scores along Speedway Boulevard from August 2018 to August 2020. Before March 2019, the INRIX data in most periods were reported with a score of

20. After that, approximately 75% of data for Speedway Boulevard was reported with a score of 30, indicating that the INRIX data quality had improved. During March - June 2020, the percent of data reported with a score of 30 decreased slightly because the Stay-at-Home order caused less vehicle use.

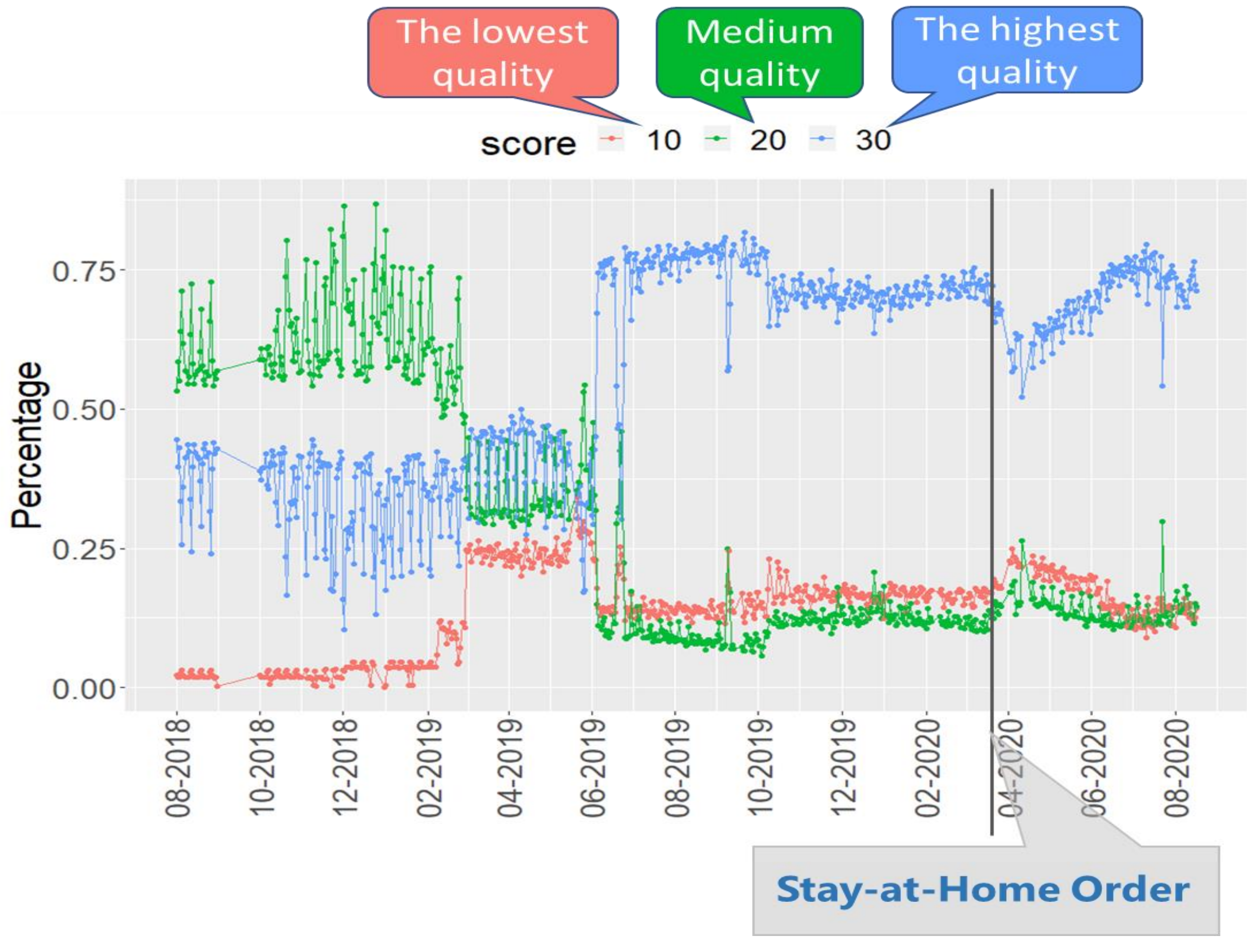


Figure 6-4 Percentage of INRIX data reported with different scores on Speedway Blvd

To verify the accuracy of INRIX speed data, ground-truth GPS data were collected with probe vehicles on Speedway Boulevard and Golf Links Road as described in **Table 6-1**.

Table 6-1 GPS Data Collection Description

Corridor	From	To	Date and Period	Number of Vehicles
Speedway Blvd	Euclid Ave	Kolb Rd	06/19/2019 • 7 – 9 AM • Noon – 2 PM • 4 – 6 PM	Three vehicles

Golf Links Rd	Swan Rd	Houghton Rd	10/27/2020 - 10/29/2020 • 7 – 9 AM • Noon – 2 PM • 4 – 6 PM	Six vehicles

The statistical measures of mean absolute percent error (MAPE) and root mean square error (RMSE) were used to validate the INRIX average speed data during 15-minute intervals. **Figure 6-5** compares INRIX speed data against ground-truth data on Speedway Boulevard with a MAPE of 8.7%. **Figure 6-6** compares INRIX speed data against ground-truth data on Golf Links Road with a MAPE of 15.1% and RMSE of 5.4 mph. The MAPE of the INRIX speed data for Speedway Boulevard is lower than that for Golf Links Road, likely because a higher percentage of data reported for Speedway Boulevard has a score of 30. The results also show that INRIX tends to overestimate the real speed during most periods.

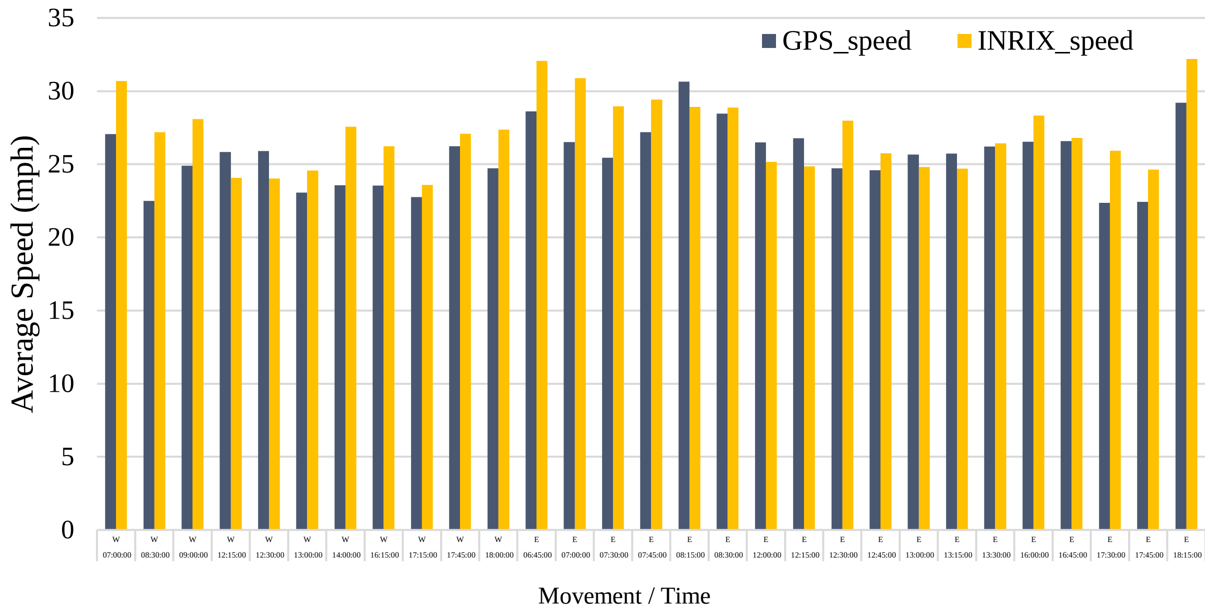
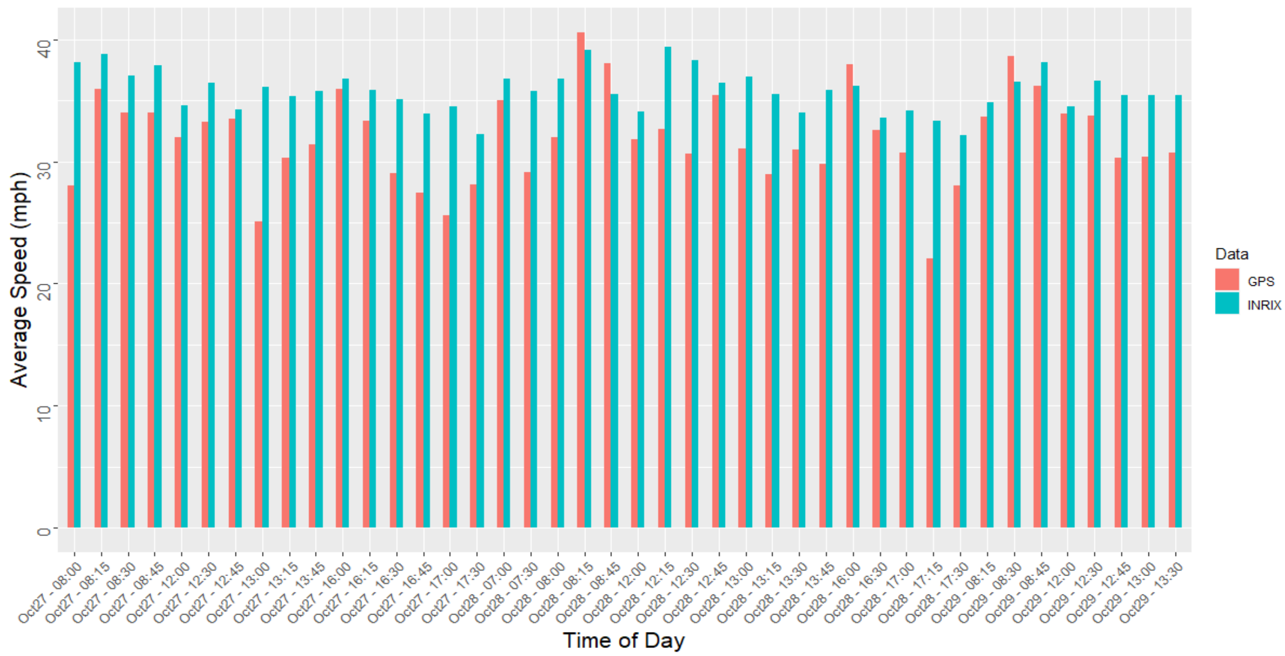
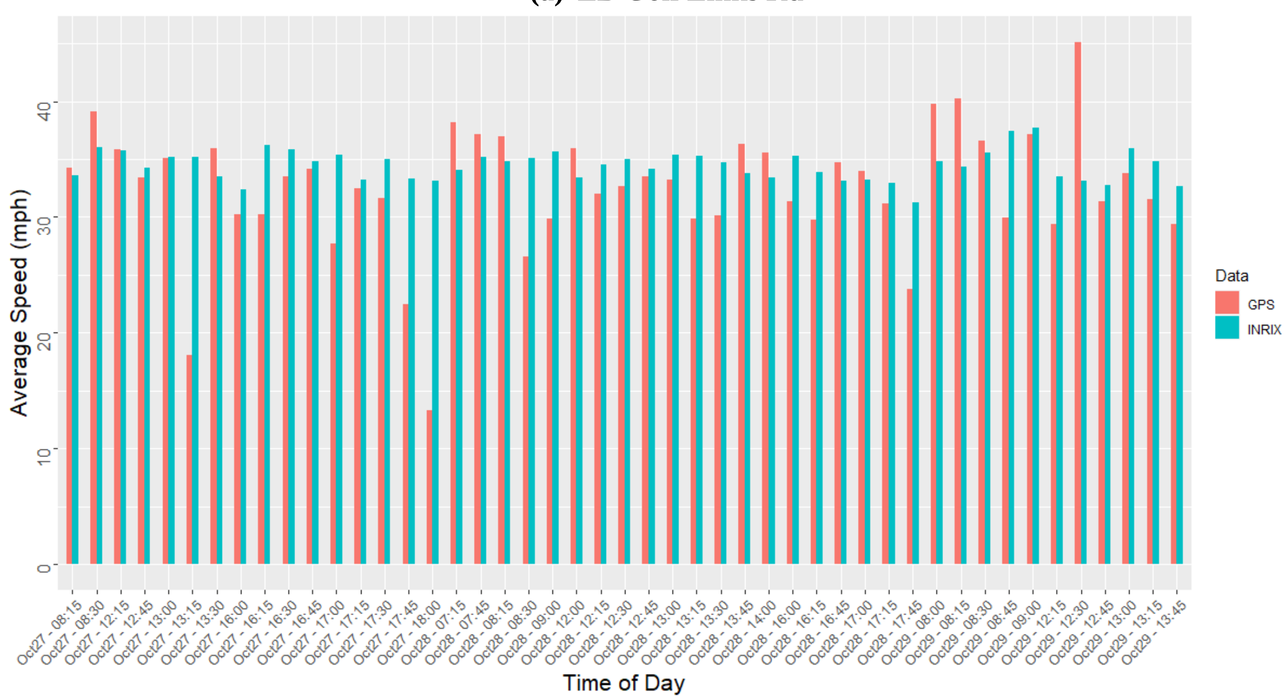


Figure 6-5 Comparison of INRIX speed data with GPS data on Speedway Boulevard



(a) EB Golf Links Rd



(b) WB Golf Links Rd

Figure 6-6 Comparison of INRIX speed data with GPS data on Golf Links Rd

6.2 HERE DATA EXPLORATION

6.2.1 HERE Data Collection

HERE speed data integrates multiple data sources, including roadway sensors, operation centers, and navigation devices, to provide real-time speed data similar to INRIX data. HERE offers a free API (https://developer.here.com/) for the public to archive speed data with limited query times. Using the HERE API, the UArizona Smart Transportation Lab developed a program to archive real-time HERE speed data as shown in **Figure 6-7**. Based on the input area (“Location TopLeft” and “Location BottomRight” on the right side figure of Figure 6-7), the program retrieves the speed data for the selected region and saves the data to a local drive or a database.

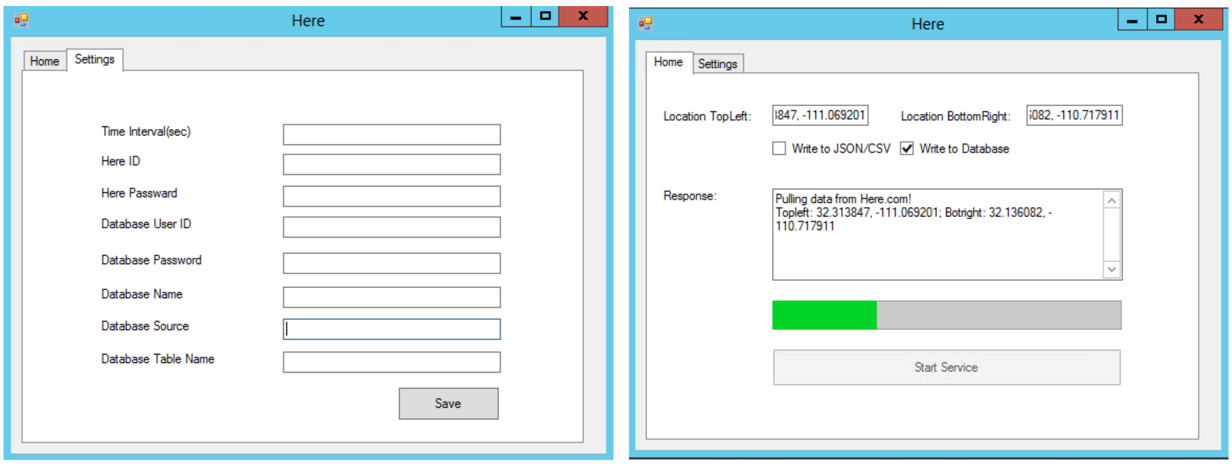


Figure 6-7 HERE data archiving program (Credit: Long Chen)

The HERE API provides the data collected from Traffic Message Channel segments but not XD segments. **Figure 6-8** shows sample HERE data. The abbreviations[3] in the attribute names are defined below:

- FIS: A list of Flow Item (FI) elements
- FI: A single flow item
- TMC: An ordered collection of TMC locations
- PC: Point code of the TMC location
- DE: Text description of the segment
- QD: Queuing direction. '+' or '-'. Note this is the opposite of the travel direction in the fully qualified ID
- LE: Length of the segment. The units are specified in the file header.

[3] https://developer.here.com/documentation/traffic/dev_guide/topics/common-acronyms.html

- CF: Current Flow. This element contains speed details and Jam Factor information for the given flow item.
- CN: The Confidence attribute, which is a number between 0.0 and 1.0 indicating the percentage of real-time data included in the speed calculation. A value greater than 0.7 indicates real-time speeds; a value greater than 0.5 and less than or equal to 0.7 indicates historical speeds; a value greater than 0.0 and less than or equal to 0.5 indicates speed limit.
- FF: The free flow speed on the segment.
- JF: Jam Factor, a value between 0.0 and 10.0 indicating the expected quality of travel. The Jam Factor will be 10 on a closed segment. As the Jam Factor approaches 10.0, the quality of travel worsens. The value of -1.0 indicates that a Jam Factor could not be calculated.
- SP: Speed (based on UNITS, either kmph or mph) capped by the speed limit.
- SU: Speed (based on UNITS, either kmph or mph) not capped by the speed limit.
- TY: Type information for the given location referencing container. This may be a freely defined string.

DateTime	PC	FIS_mid	FIS_LI	FIS_DE	FIS_PBT	TMC_DE	TMC_QD	TMC_LE	CF_TY	CF_SP	CF_SU	CF_FF	CF_JF	CF_CN	TopleftPosition	BotrightPosition	SHP_LeftBotLat	SHP_LeftBotLon	SHP_RightTopLat	SHP_RightTopLon
Mar 30 2020 4:30PM	9656	d3cabcbb-ad83-4422-81c0-194511d1a8c2	115-00833	Wilmot Rd	Mar 30 2020 11:29PM	E Speedway Blvd	+	0.50071	TR	23.18	23.18	32.56	1.84717	0.71	NULL	NULL	-110.85805	32.23574	-110.85761	32.24295
Mar 30 2020 4:30PM	9655	d3cabcbb-ad83-4422-81c0-194511d1a8c2	115-00833	Wilmot Rd	Mar 30 2020 11:29PM	E Broadway Blvd	+	1.00189	TR	32.99	32.99	34.18	0.27762	0.76	NULL	NULL	-110.85807	32.2212	-110.85805	32.23574
Mar 30 2020 4:30PM	9654	d3cabcbb-ad83-4422-81c0-194511d1a8c2	115-00833	Wilmot Rd	Mar 30 2020 11:29PM	E 22nd St	+	1.00123	TR	29.06	29.06	35.05	1.36595	0.73	NULL	NULL	-110.85814	32.20667	-110.85807	32.2212
Mar 30 2020 4:30PM	9653	d3cabcbb-ad83-4422-81c0-194511d1a8c2	115-00833	Wilmot Rd	Mar 30 2020 11:29PM	E Golf Links Rd	+	1.00608	TR	24.48	24.48	35.54	2.0693	0.81	NULL	NULL	-110.8581	32.19207	-110.85801	32.20667
Mar 30 2020 4:30PM	9620	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Freeman Rd	+	0.00234	TR	31.69	31.69	39.15	1.5238	0.7	NULL	NULL	-110.73811	32.23546	-110.73807	32.23546
Mar 30 2020 4:30PM	9619	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Houghton Rd	+	2.02465	TR	32.31	32.31	39.46	1.44881	0.7	NULL	NULL	-110.77268	32.23543	-110.73811	32.23547
Mar 30 2020 4:30PM	9618	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Harrison Rd	+	1.00003	TR	33.36	33.36	38.65	1.09392	0.75	NULL	NULL	-110.78974	32.23543	-110.77268	32.2355
Mar 30 2020 4:30PM	10188	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Camino Seco	+	0.99855	TR	39.77	41.36	39.52	0	0.76	NULL	NULL	-110.80679	32.2355	-110.78974	32.23553
Mar 30 2020 4:30PM	9617	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Pantano Rd	+	1.00389	TR	37.6	37.6	38.53	0.19116	0.81	NULL	NULL	-110.82393	32.23553	-110.80679	32.23563
Mar 30 2020 4:30PM	9616	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Kolb Rd	+	1.00735	TR	33.42	33.42	36.97	0.76751	0.86	NULL	NULL	-110.84113	32.23563	-110.82393	32.23567
Mar 30 2020 4:30PM	9615	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Wilmot Rd	+	1.01608	TR	39.74	39.74	37.66	0	0.8	NULL	NULL	-110.85843	32.23566	-110.84113	32.23602
Mar 30 2020 4:30PM	9614	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Craycroft Rd	+	1.00241	TR	34.92	39.92	32.31	0	0.82	NULL	NULL	-110.87553	32.23602	-110.85843	32.23625
Mar 30 2020 4:30PM	10187	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Swan Rd	+	1.00558	TR	30.35	30.35	33.31	0.70902	0.85	NULL	NULL	-110.8927	32.23625	-110.87553	32.2363
Mar 30 2020 4:30PM	9613	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Alvernon Way	+	0.98981	TR	21.13	21.13	32.68	2.37216	0.81	NULL	NULL	-110.9096	32.23625	-110.8927	32.2363
Mar 30 2020 4:30PM	9612	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Country Club Rd	+	1.00965	TR	27.58	27.58	34.05	1.52117	0.78	NULL	NULL	-110.92683	32.23609	-110.9096	32.23633
Mar 30 2020 4:30PM	9611	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Campbell Ave	+	1.01151	TR	22.42	22.42	32.12	1.95188	0.96	NULL	NULL	-110.9441	32.23609	-110.92683	32.23617
Mar 30 2020 4:30PM	9610	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N 4th Ave	+	1.26292	TR	22.47	22.47	30.88	1.69642	0.94	NULL	NULL	-110.96565	32.23593	-110.9441	32.23615
Mar 30 2020 4:30PM	11096	da6d2d57-4c15-4089-8c7e-2019810552c4	115-00828	Speedway Blvd	Mar 30 2020 11:29PM	N Main Ave	+	0.72065	TR	19.12	19.12	31.63	2.69268	0.91	NULL	NULL	-110.97794	32.2359	-110.96565	32.23603

Figure 6-8 Sample HERE data

6.2.2 Speed Data Comparison

To further evaluate and compare both the HERE speed data and the INRIX speed data, ground-truth speed data was collected on 45 trajectories on Kolb Rd during the periods of 7-9 AM, Noon-2 PM, and 4-6 PM on 03/21/2019. **Figure 6-9** compares HERE speed data, INRIX speed data, and ground-truth GPS data. The statistical measure MAPE is used to validate the INRIX and HERE average speed data during 15-minute intervals. HERE speed data has a MAPE of 26%, and INRIX speed data has a MAPE of 25%, showing that both INRIX and HERE data overestimate actual speed, although the INRIX speed data on Kolb Road are slightly more accurate than HERE data. In comparison with the results shown in **Figure 6-5**, the MAPE of the INRIX speed data on 03/21/2019 is significantly higher than that on 06/19/2019. This inconsistent evaluation result is probably because a higher percentage of the data reported after June 2019 had a score of 30 than did the data reported during March 2019, as shown in **Figure 6-4**.

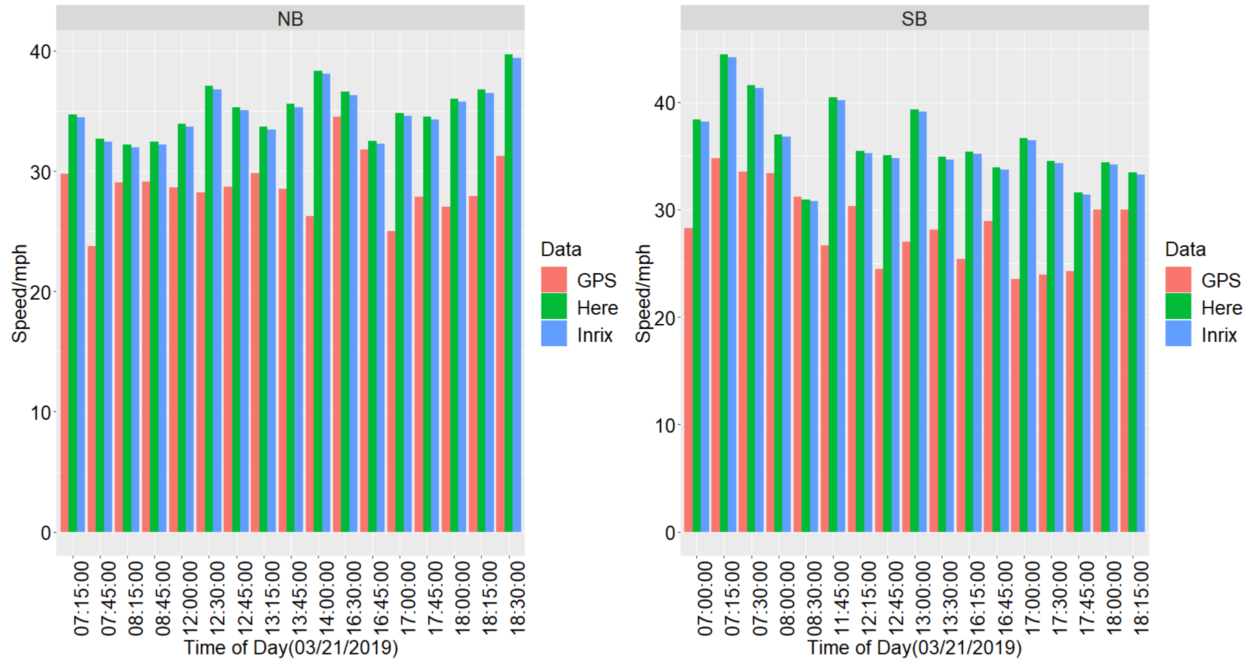


Figure 6-9 Comparison of speed data from HERE, INRIX, and GPS

In summary, INRIX data is more reliable during the daytime on weekdays because of a sufficient number of sample vehicles, and the accuracy is directly related to sample size. With the increase in the percentage of data reported with a score of 30, the INRIX speed data is more accurate. Both INRIX and HERE data have a lower cost for large-scale traffic monitoring and operation than sensor-based data. HERE provides a public API, so HERE data is almost free. However, the HERE data has the limitation of data transactions when using this free API license. INRIX and HERE speed data have similar accuracy, except for the slight accuracy difference from the use of XD segments by INRIX. Both INRIX and HERE data need to be tested and calibrated before being applied because these both tend to overestimate the actual speed for most periods.

6.3 STREETLIGHT DATA EXPLORATION

StreetLight Data is crowdsourced data collected by using smartphones as mobility sensors to measure various multimodal metrics, such as origin-destination trip counts, segment vehicular volumes, and turning movement counts. These metrics are estimated by machine learning algorithms with the data collected from smartphones. Currently, StreetLight Data provides only long-term average data and not any real-time or short-term data. One of the major advantages of StreetLight Data is that no expensive fixed traffic sensors are needed. To assess StreetLight data quality, one year of TMC data collected by Miovision sensors is aggregated into the annual average hourly TMC and compared with StreetLight Data. 115 study intersections equipped with Miovision sensors are located within the PAG region, as shown in **Figure 6-10**, and these sensors are managed by the Town of Marana and PCDOT.

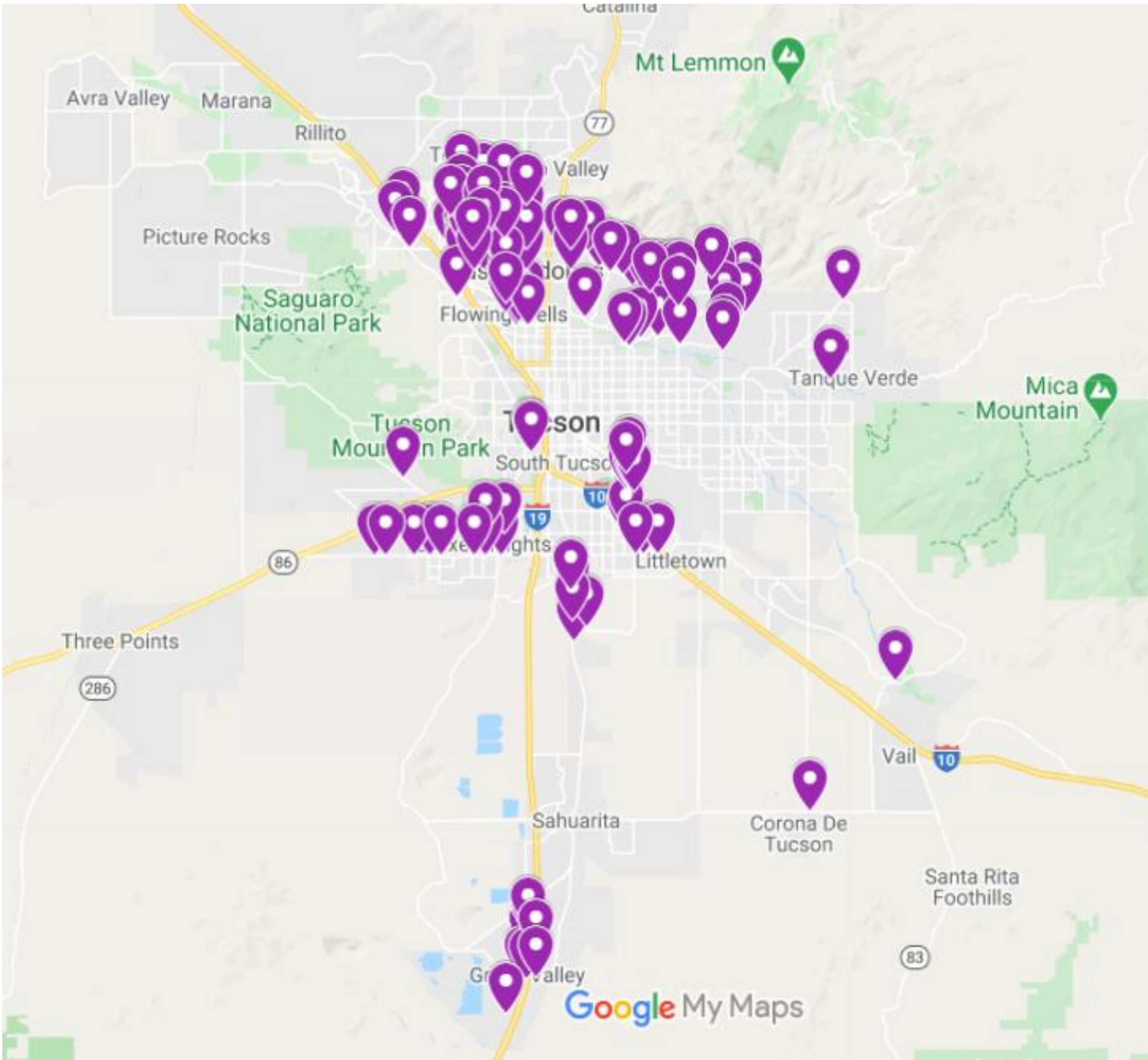


Figure 6-10 Miovision sensor locations

Both Miovision and StreetLight Data TMC data were collected for the year 2020. **Figure 6-11** compares StreetLight Data and Miovision data. The overall R-squared value is 0.84, which shows that StreetLight Data and Miovision data have similar trends. However, StreetLight Data was 15% lower overall than Miovision data. And relatively many StreetLight zero volumes for positive volumes on Miovision were identified and vice versa.

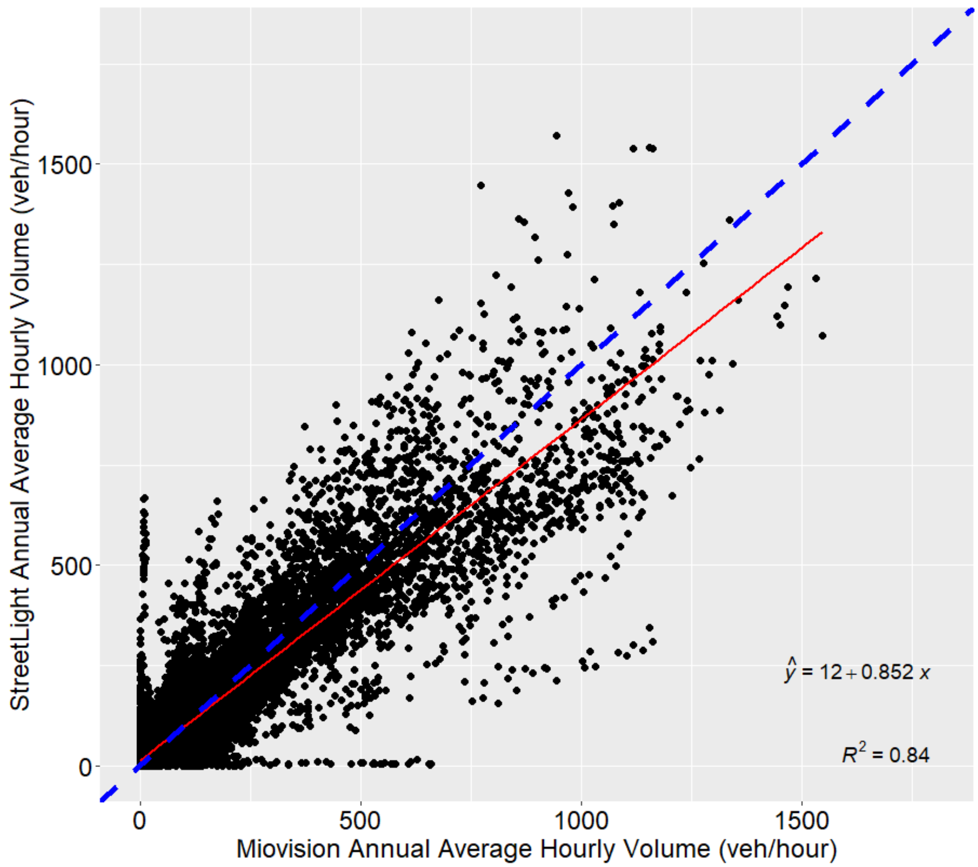
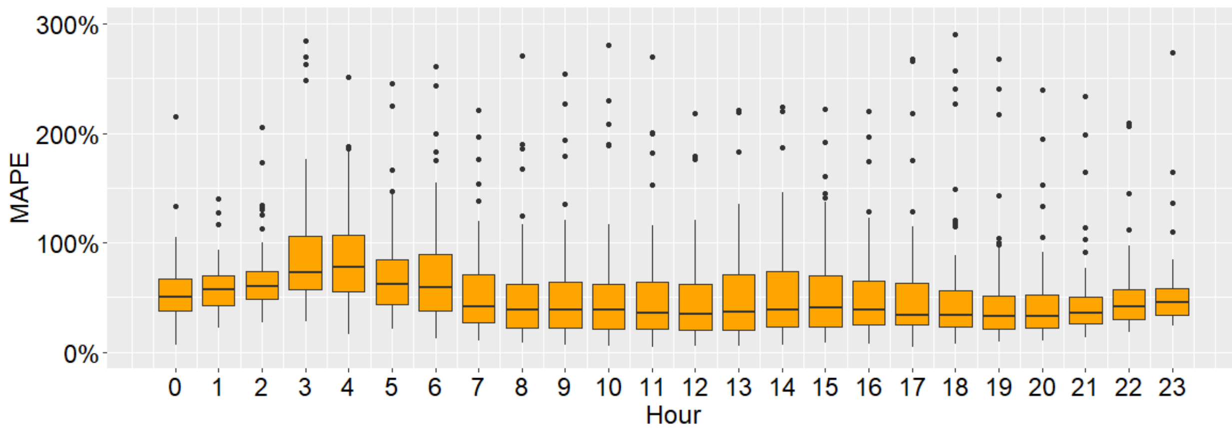


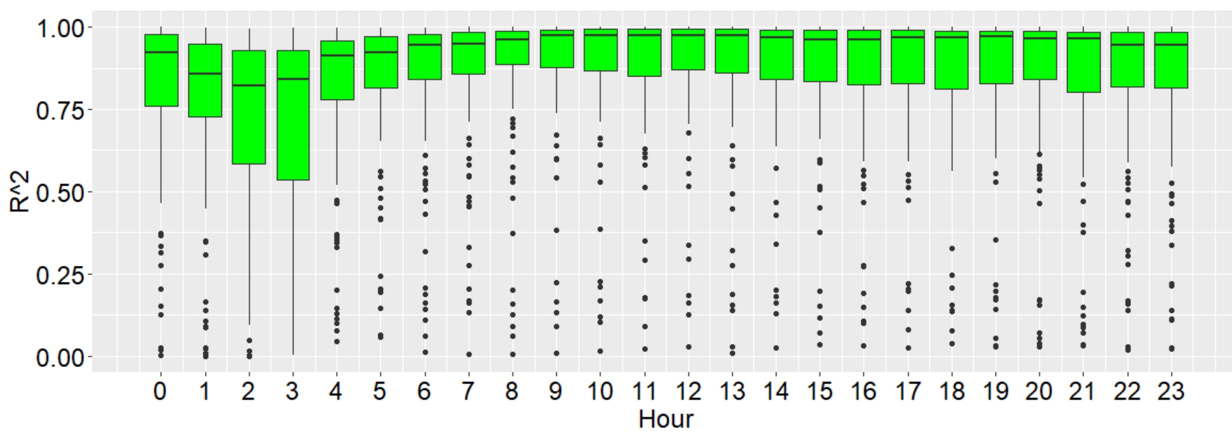
Figure 6-11 Comparison of Miovision data and StreetLight data

StreetLight and Miovision data were also compared at each intersection for each hour of the day. Our target interval is 15 minutes, but 1 hour was the lowest temporal resolution at which Street Light provided data at the time. **Figure 6-12 (a)** shows the MAPE values by the hour of the day for StreetLight data. Even though the MAPE values at some intersections are higher than 100%, most intersections have a MAPE of less than 50%. StreetLight Data has a higher MAPE during the nighttime than during the daytime due to reasons such as less overall traffic during the nighttime, and so StreetLight has less sample data during the nighttime. Data collected by video-based sensors are also less accurate during the nighttime.

Figure 6-12 (b) shows the R-squared values by the hour of the day for StreetLight data. Most intersections have an R-squared value larger than 0.8. Similar to the MAPE, StreetLight data compares better during the daytime than the nighttime. The high R-squared values show that StreetLight data captures similar trends of traffic volume as Miovision data at most intersections even though the MAPE is relatively high.



(a)



(b)

Figure 6-12 StreetLight data performance in comparison with Miovision data by the hour of the day, (a) MAPE; (b) R-squared

CHAPTER 7: INTEGRATION METHOD AND ACCEPTANCE CRITERIA

This chapter explores how the multiple data sources are integrated and used to obtain region-wide traffic volume including turning movement counts (TMC) and segment volumes. TMC data can be estimated by integrating event-based data and road infrastructure data as shown in Chapter 5. In order to test if crowdsourced data improves the accuracy of the TMC estimation model, the impacts of adding INRIX speed data as an input on the performance of the TMC estimation model are discussed and analyzed. Also, the segment volume estimation method is developed by integrating video-based TMC data and estimated TMC data.

A quality assurance and quality control (QA/QC) procedure is then developed to assess the traffic volume data directly collected from video-based sensors and the traffic volume data outputs from the proposed estimation model. Acceptance criteria are developed based on the sample traffic data assessment and a literature review. Next, the developed acceptance criteria are applied to validate the traffic volume data at the sample locations identified in Chapter 3.

7.1 DATA INTEGRATION ANALYSIS

7.1.1 TMC Estimation

The proposed TMC estimation method in Chapter 5 mainly uses event-based data to estimate volume at signalized intersections. In addition to event-based data, INRIX speed data is available on major corridors within the PAG region and can be used as a model input in conjunction with other data sources to estimate TMC. This section evaluates whether the addition of INRIX speed data as an input improves the model's estimation performance.

To include INRIX speed data as model input, INRIX segments were first integrated with signalized intersections. Study intersections where ground-truth data were collected in 2019 and 2020 were overlapped with INRIX segments and yielded 44 intersections with INRIX speed data used to calibrate and test the inclusion of the speed data as model input. Because INRIX segments do not cover some minor roads, some study intersections lacked INRIX data for one or two approaches. The 44 study intersections and associated INRIX segments are shown in **Figure 7-1**.

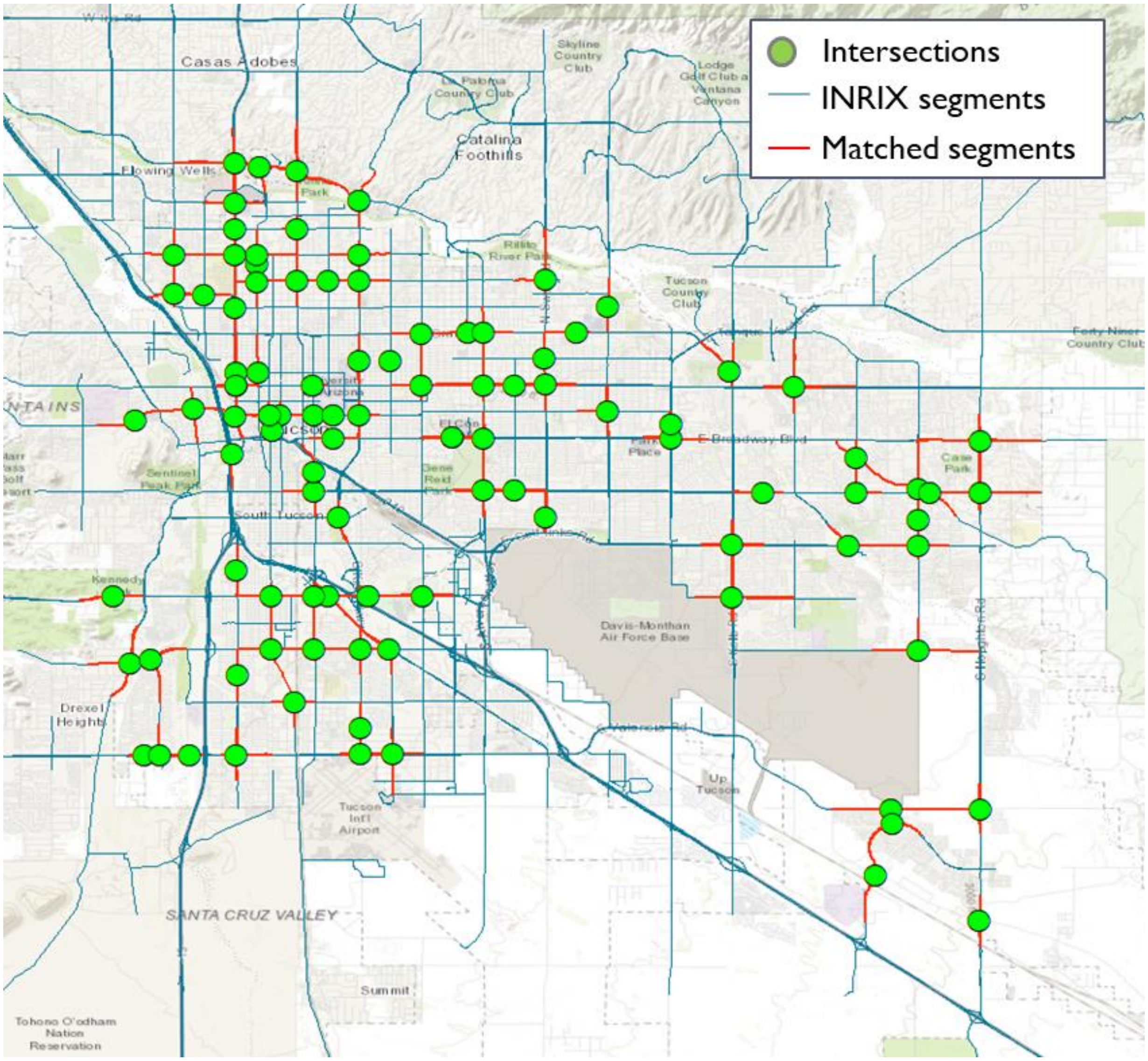


Figure 7-1 Study intersections and associated INRIX segments

The proposed MLP-based TMC estimation models with and without INRIX speed data were compared with 5-fold cross-validation. **Table 7-1** and **Table 7-2** show the model performances with and without INRIX speed data, respectively. The validation results show that no significant improvement in model performance is observed for TMC estimation for 15-minute intervals with the inclusion of INRIX speed data. There are several possible reasons why INRIX speed data does not contribute significantly to the TMC estimation model. One possible reason is that the reported INRIX speed has a latency of several minutes (Kim & Coifman, 2014), and so the speed data for a given 15-minute interval may not exactly match the event-based data during the same 15-minute interval. Another possible reason is that the INRIX speed for a 15-minute interval may not accurately capture traffic pattern changes during a short period, especially near the intersection.

Due to the lack of importance of INRIX speed data in the model and the coverage limitations of the INRIX segments, the proposed model mainly uses event-based data without INRIX data to estimate volume at signalized intersections. In the future, INRIX speed data could be considered for long-term volume estimation, such as AADT.

Table 7-1 Five-Fold Cross-Validation with INRIX Speed Feature

Fold	RMSE_L	RMSE_T	RMSE_R	r2_L	r2_T	r2_R	%RMSE_L	%RMSE_T	%RMSE_R
0	14.93	35.36	19.63	0.53	0.83	0.20	56.38%	26.73%	69.77%
1	17.84	37.50	22.56	0.69	0.83	0.38	61.30%	30.26%	75.56%
2	19.80	44.03	22.34	0.33	0.87	0.23	60.18%	29.74%	85.03%
3	17.91	42.03	21.79	0.50	0.89	0.08	63.03%	34.28%	83.02%
4	18.94	50.33	16.71	0.13	0.66	0.05	66.77%	33.62%	70.78%

Table 7-2 Five-Fold Cross-Validation without INRIX Speed Feature

Fold	RMSE_L	RMSE_T	RMSE_R	r2_L	r2_T	r2_R	%RMSE_L	%RMSE_T	%RMSE_R
0	14.58	35.63	19.68	0.54	0.83	0.20	55.09%	26.93%	69.97%
1	19.14	39.76	21.72	0.66	0.82	0.44	65.76%	32.09%	72.75%
2	20.64	39.69	21.60	0.28	0.90	0.28	62.74%	26.81%	82.22%
3	18.52	38.83	20.75	0.50	0.90	0.13	65.18%	31.67%	79.08%
4	18.15	49.64	17.35	0.18	0.69	0.01	64.00%	33.16%	73.51%

Note: r2 _L: R-squared of left-turn movement;
%RMSE_L: Percentage of RMSE of left-turn movement

7.1.2 Segment Volume Estimation

Another important application of the estimated TMC and video-based TMC at signalized intersections is the estimation of traffic volume on arterial segments. In this section, we develop a model based on the relationship between segment volume and TMC at adjacent intersections and evaluate its performance.

(1) Selection of Study Locations

First, study locations were chosen in the PAG region according to ground truth and estimated TMC availability. The 11 segments with their associated upstream and downstream intersections that were chosen and used to evaluate the model performance are shown in **Figure 7-2**.

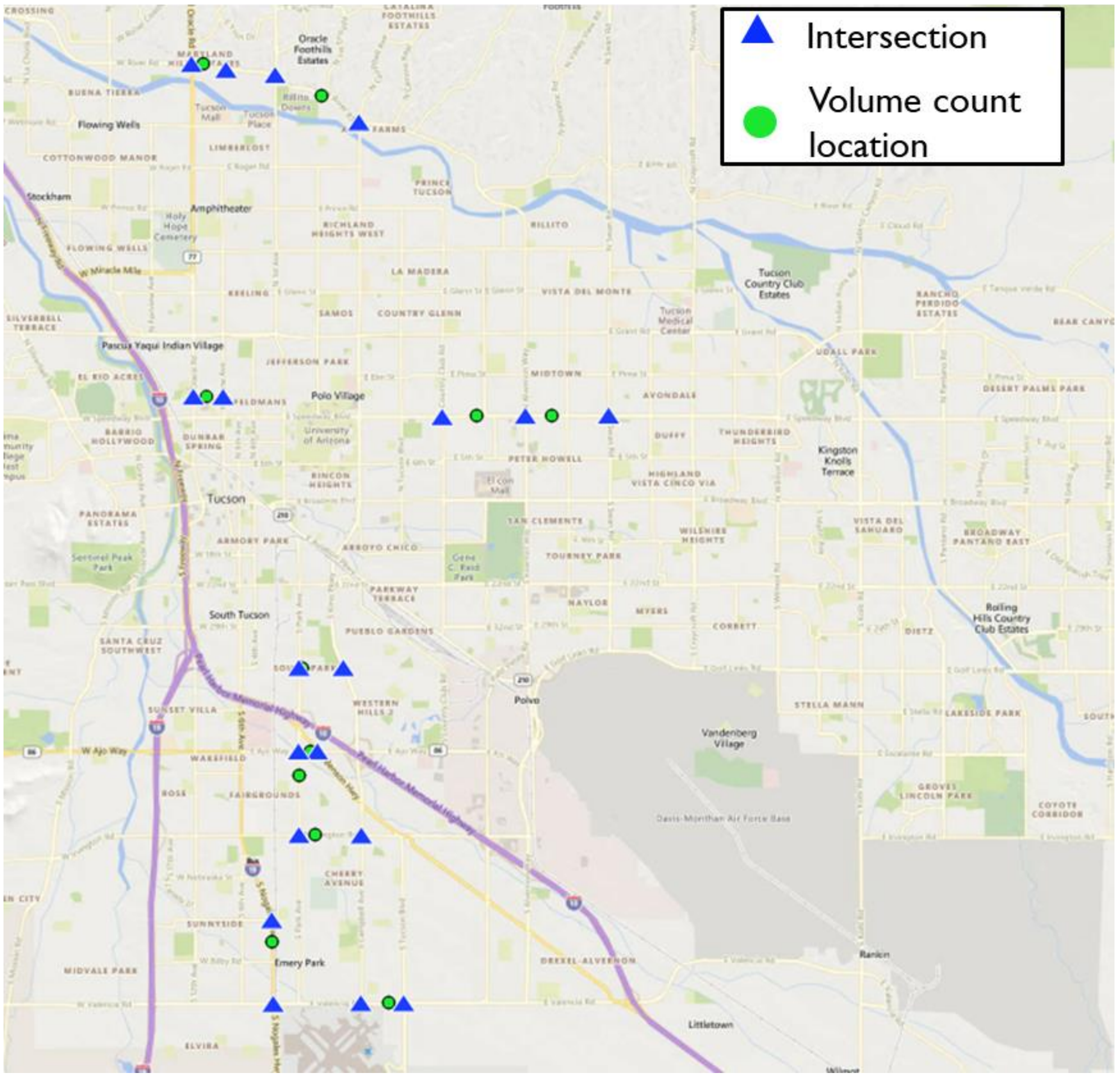


Figure 7-2 Study segment locations with corresponding upstream and downstream intersections

(2) Proposed Model

Segment volume is estimated from the traffic volume at the upstream intersection and traffic volume at the downstream intersection. To facilitate the description of our model, the variable notations for the relevant data are summarized in **Table 7-3**.

Table 7-3 Variable Notation Description

Notation	Definition
x	Distance from the segment traffic count location to the upstream intersection
y	Distance from the segment traffic count location to the downstream intersection
Up_L	Left-turn volume at the upstream intersection entering the segment
Up_T	Through volume at the upstream intersection entering the segment
Up_R	Right-turn volume at the upstream intersection entering the segment
Down_L	Left-turn volume at the downstream intersection exiting the segment
Down _T	Through volume at the downstream intersection exiting the segment
Down _R	Right-turn volume at the downstream intersection exiting the segment
Q	Segment traffic count collected at the segment traffic count location
OUT_x	Exiting volume between the upstream intersection and the count location
OUT_y	Exiting volume between the downstream intersection and the count location
IN_x	Entering volume between the upstream intersection and the count location
IN_y	Entering volume between the downstream intersection and the count location

Figure 7-3 shows all traffic components of an arterial segment. The entering traffic consists of the traffic that enters from the upstream intersection and the traffic that enters along the segment, and the exiting traffic includes the traffic that exits along the segment and the traffic that exits at the downstream intersection. Once the segment traffic count location is determined, the segment traffic count Q can be calculated with the following equations.

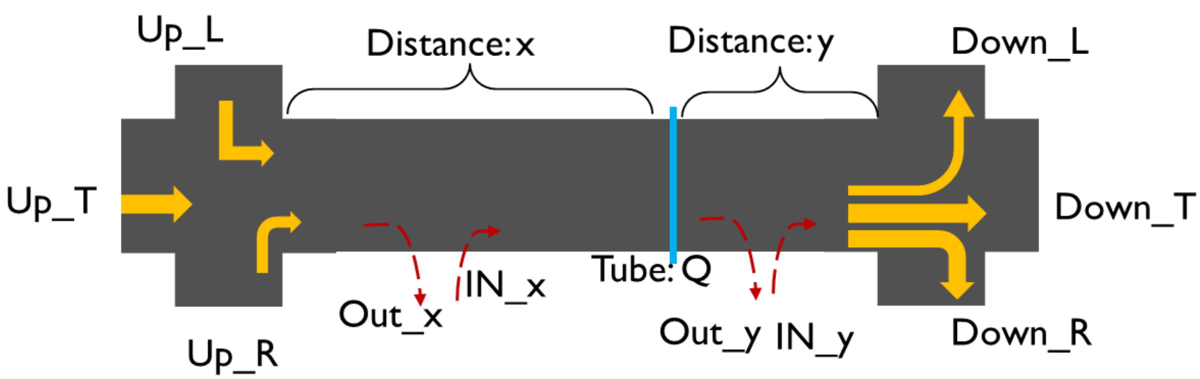


Figure 7-3 Traffic components on a segment

$$\begin{cases} Q = Up\_T + Up\_L + Up\_R + (IN\_x - OUT\_x) \\ Q = Down\_T + Down\_L + Down\_R + (OUT\_y - IN\_y) \end{cases} \quad \text{Eq. 7-1}$$

Combining these two equations above yields Eq. 7-2:

$$\boldsymbol{Down\_Q - Up\_Q = IN - OUT} \quad \text{Eq. } \mathbf{7\text{-}2}$$

Where:

$$\begin{cases} Down\_Q = Down\_T + Down\_L + Down\_R \\ Up\_Q = Up\_T + Up\_L + Up\_R \end{cases} \quad \text{Eq. 7-3}$$

And

$$\begin{cases} IN = IN\_x + IN\_y \\ OUT = OUT\_x + OUT\_y \end{cases} \quad \text{Eq. 7-4}$$

Assuming that trip attraction and generation are evenly distributed along a segment, the difference between attraction and generation along subsegments *x* and *y* can be calculated with the following Eq. 7-5:

$$\begin{cases} IN\_x - OUT\_x = \dfrac{x}{x+y}(IN - OUT) \\ IN\_y - OUT\_y = \dfrac{y}{x+y}(IN - OUT) \end{cases} \quad \text{Eq. 7-5}$$

(3) Evaluation Results

We first estimated daytime (7 am – 6 pm) TMC at all upstream and downstream intersections with event-based data and the model proposed in Chapter 5. Then, those estimated TMC were used to estimate segment volumes with the method proposed immediately above. **Figure 7-4** compares the estimated and ground-truth data by location. Most study locations have a relatively high R-Squared value, showing that the estimated segment volume highly correlates with the actual volume. However, the three locations (A-202, A-38, and A-12) have lower R-squared values than other locations, possibly due to that the training dataset for the TMC estimation model only contained data from peak hours for these three segments. When the calibrated TMC estimation model is used to estimate off-peak TMC at upstream and downstream intersections, the TMC estimation model may not capture the off-peak traffic trend and thus cause large errors for the segment volume estimation model.

To analyze the impacts of time period selection on model performance, the segment volumes during only the peak hours (7 - 9 AM and 4 - 6 PM) were also estimated and compared with ground-truth data. The MAPE measure is used to quantify and compare the model performance during only the peak hours with the entire daytime. **Figure 7-5** compares the MAPE values by location. Some locations, such as A-132, do not have a significant change in model performance because their associated upstream and downstream intersections have similar traffic patterns during peak and off-peak hours. The model performance of some locations, such as A-194 and A-38, significantly increases when only using peak hour TMC. Because traffic patterns during peak and off-peak hours at these locations may be significantly different, the calibrated TMC estimation model cannot be used to estimate segment volume during off-peak hours.

It was found that the location of B-265_NB with the highest MAPE value during the entire daytime does not experience a significant decrease in MAPE during peak hours. This result shows that the time period selection is not the main cause of the large error at B-265_NB. After checking the geometric design and environmental building of this segment, it was observed that multiple side streets connect with this segment and cause more trip attraction and generation. Trip generation and attraction are not evenly distributed along this segment, and therefore, the proposed model has a large estimation error for this segment.

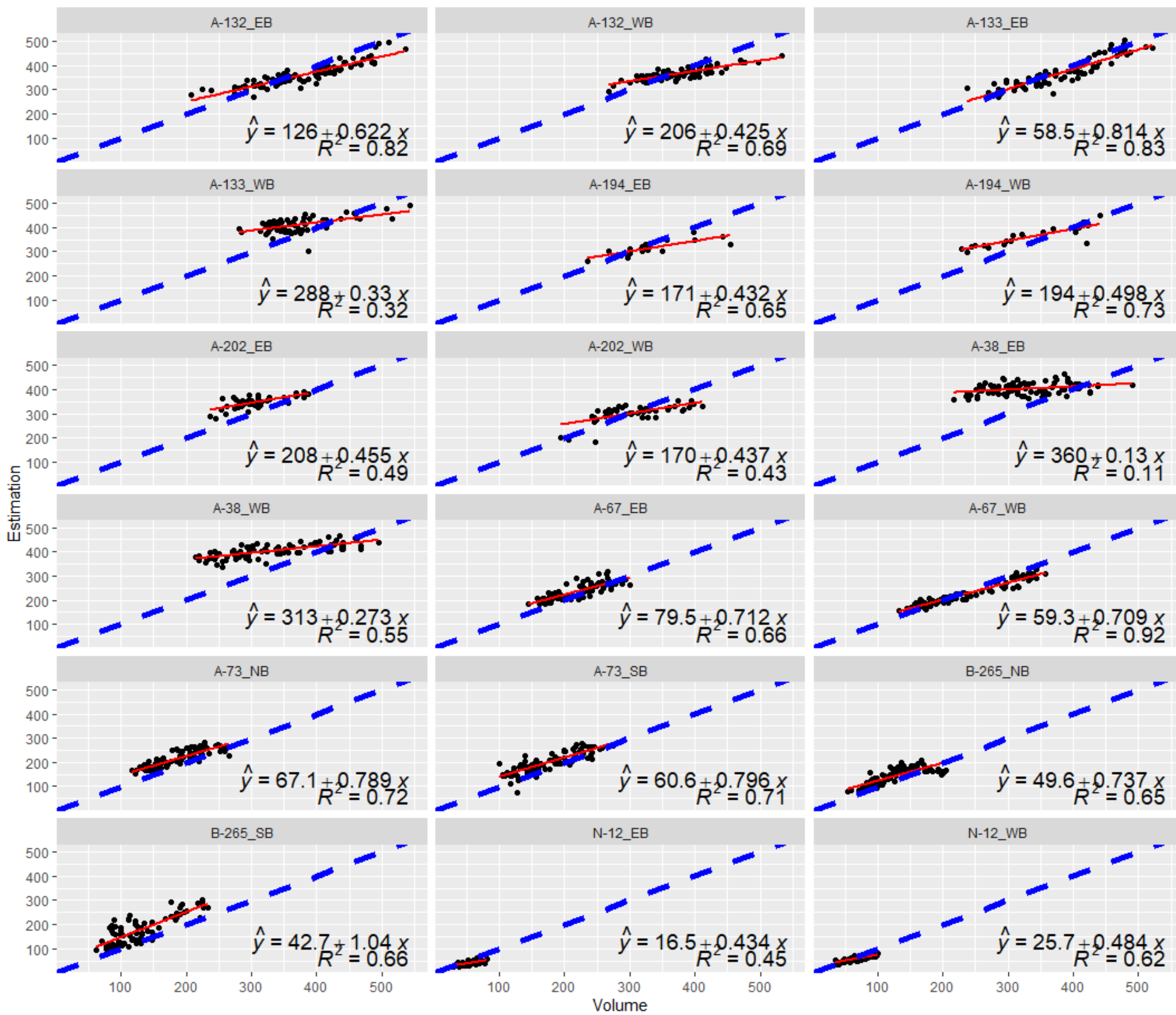


Figure 7-4 Comparison of estimated and ground-truth hourly segment volumes for 7 am – 6 pm

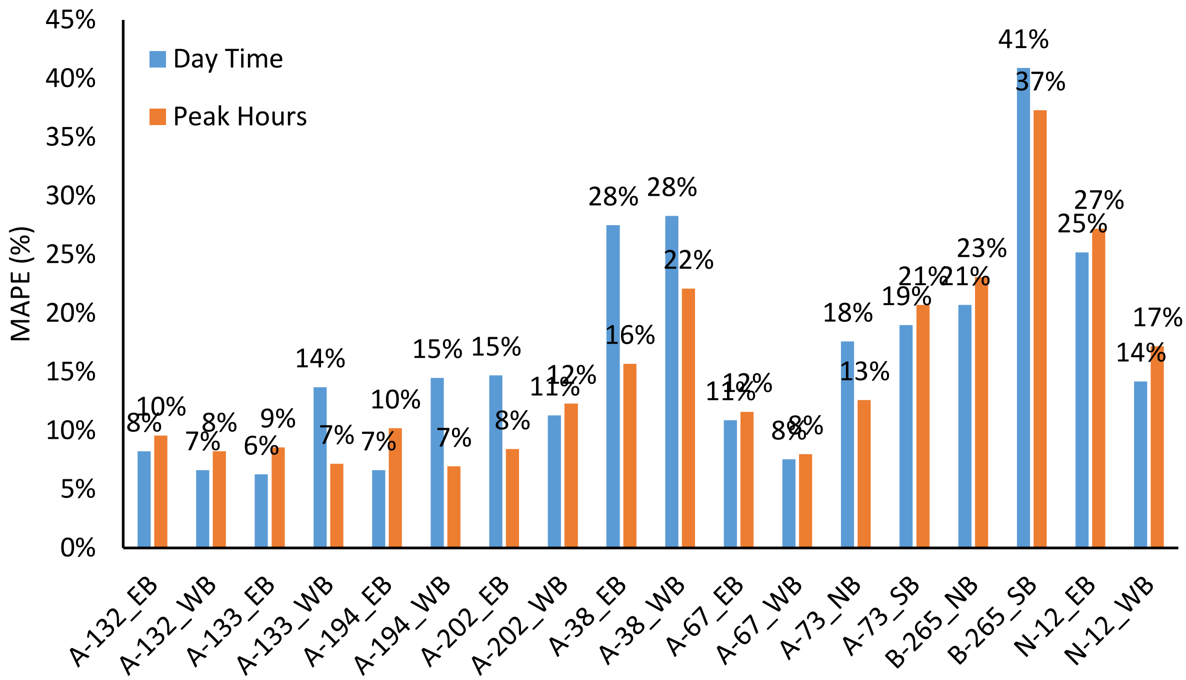


Figure 7-5 Model performance by location

7.2 QUALITY ASSURANCE AND QUALITY CONTROL PROCESSES

7.2.1 QA/QC Procedures

The three major data sources used in this project need QA/QC procedures to control the quality and ensure output of high quality. The first data source is traffic volume data directly collected by video-based sensors, which can be used for long-term traffic monitoring. The second data source is event-based data collected by traffic controllers. This data is mainly used to estimate turning movement counts (TMC) at signalized intersections. The third data source is ground-truth volume data, which is used for the proposed TMC estimation method and video-based volume evaluation.

Figure 7-6 shows the QA/QC procedures applied to these three traffic data sources, including data collection, quality check, and data cleaning.

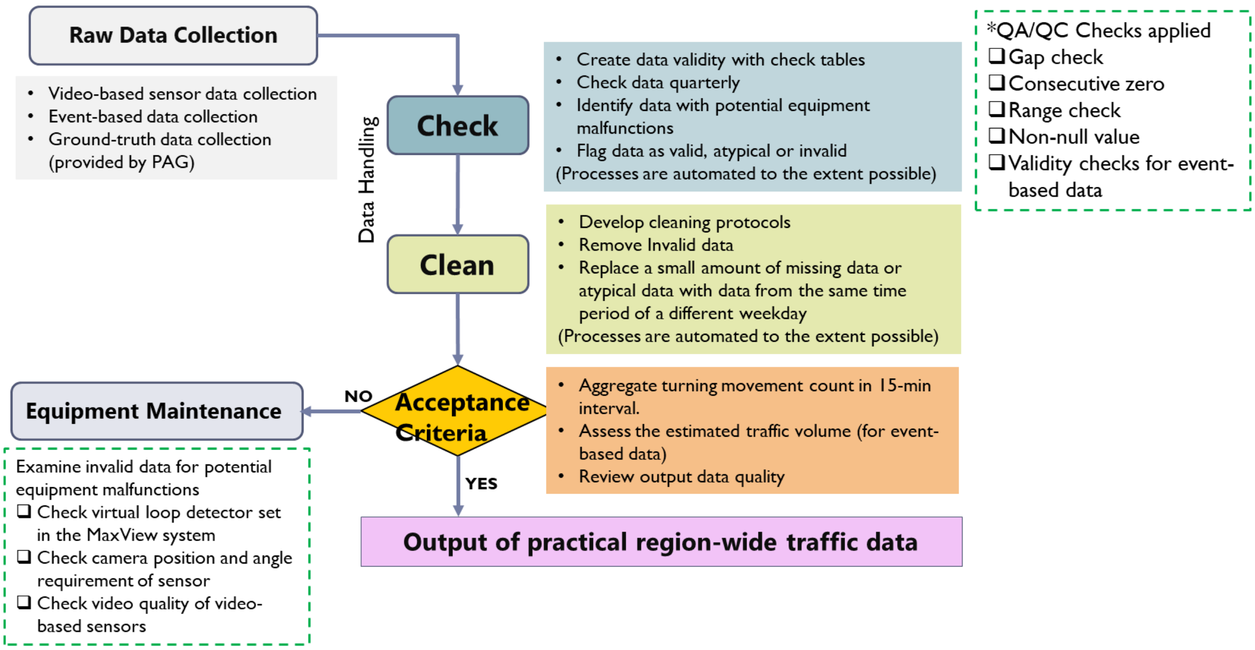


Figure 7-6 QA/QC Procedures for traffic data in the PAG region

The first step of the QA/QC procedure is to collect raw traffic data in the PAG region, including the video-based sensor data via the Miovision API and event-based data archived in the MaxView database. The ground-truth data provided by PAG includes turning movement counts at signalized intersections. Next, multiple criteria are applied to check the quality of these three data sources. Three basic validity checks are developed to filter volume data collected by video-based sensors:

- Gap check: Identify all missing periods and locations.
- Consecutive zero check: The video-based sensors may report zero cars consecutively. When consecutive zeros are reported, the data needs to be checked with historical data to identify the reason causing consecutive zeros, as it could be because of no cars present or data collection issues.
- Range check: Identify all outliers.

The outliers in raw video-based volume data could either be removed or checked by studying videos, as low-quality ground-truth data could have a negative impact on model calibration and evaluation. To ensure high-quality event-based data with which to estimate traffic volume, six validity checks were developed to check the raw event-based data:

- **Controller type**: The controller type at a location must be checked to determine if it is a controller for a signalized intersection, a pedestrian crosswalk, or a HAWK. Only controllers at signalized intersections can collect vehicle detection events.

- **Signal strategy:** Most signalized intersections apply eight or fewer signal phases. If the number of signal phases is larger than eight, the extra signal phases must be identified and removed.
- **Detector layout**: For an approach at a typical signalized intersection, one detector is commonly configured on the left-turn lanes and another detector on the through lanes. Therefore, each approach should have two detectors. If only one detector is configured on an approach for detecting vehicles from all movements, the data on the approach is not applied to the model. Also, when the number of detectors is greater than two on an approach, the detector layout must be checked. Event-based data for the intersections with unclear detector layouts can be removed. The intersections equipped with Miovision sensors is one of the special types of intersections with a different detector layout. Although the event-based data from these intersections is not applied to the TMC estimation model, the TMC data can be directly collected from the Miovision platform.
- **Fixed signal timing**: An intersection operating with fixed signal timing is commonly not configured with detectors and needs to be removed, because no actuation events are generated.
- **Communication loss check**: A controller may have communication loss, causing event-based data records to be lost. The data during periods with communication loss must be removed after checking communication events.
- **Data completeness check**: After matching detection events and signal events, data completeness must be checked to ensure both detection events and signal events for each approach of an intersection exists during all periods. If some periods have missing detection events data or signal events, these periods must be removed; if data is consistently missing at an intersection, the corresponding intersection must be removed.

After checking the validity of these three data sources, the invalid data and atypical data will be processed further based on the data cleaning protocols. The small amount of missing video-based volume and ground-truth volume data must be replaced with data from the same time period of a different week or month. For missing and invalid event-based data, the collection period will simply be removed without replacement. After cleaning and processing the raw data, the video-based sensor volume data will be aggregated into 15-minute intervals, and the event-based data will be used to estimate 15-minute volumes. The next step is to check if these 15-minute volumes meet the developed acceptance criteria. If not, further data cleaning and equipment checks are needed.

7.2.2 Acceptance Criteria Development

Developing acceptance criteria is one of the most important steps in the QA/QC procedures. Acceptance criteria for QA/QC refer to a set of predefined data quality requirements that must be met for the video-based volume data and estimated volume data to be used for specific analyses. **Figure 7-7** illustrates the processes through which the acceptance criteria are being developed for video-based volume data and estimated volume data.

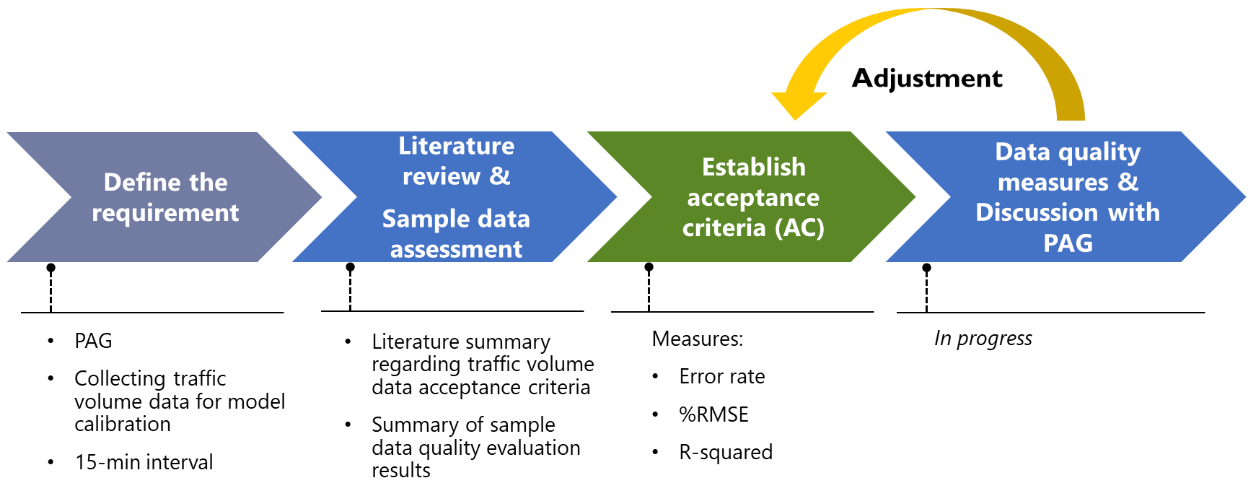


Figure 7-7 Process of acceptance criteria development for traffic volume data

- **Step 1: Define the requirement**

Defining a requirement is the first step in the acceptance criteria development. In this project, 15-minute interval TMC data and road segment volume data are required by PAG to calibrate the regional transportation model. TMC data can be directly collected from smart sensors implemented in the PAG region or estimated from traffic signal controller event-based data and the model developed in Chapter 5.2.1. Road segment traffic volume data can be estimated by integration of multiple sources data and the model developed in Chapter 7.1.2.

- **Step 2: Literature review and sample data assessment**

The quality of TMC collected by smart sensors depends on multiple factors such as traffic sensor brand, camera position, angle of sensors, and detection time. To fully understand general traffic volume estimation accuracy and the average data quality of traffic sensors, including Miovision, Autoscope, and Iteris sensors, a comprehensive literature review was done and is summarized in **Table 7-6** and **Table 7-7**. **Table 7-6** shows that the error rate varies substantially by brand and aggregation level. The traffic data accuracy report of Miovision Technologies Inc. reports 95% accuracy when the video quality and camera position requirements provided in the report are met. **Table 7-7** summarizes the findings of the accuracy of road segment traffic volume estimation.

Table 7-4 Summary of Traffic Volume Data Quality from Different Traffic Sensors

Reference	Applications	Data	Collection Method	Accuracy

(Miovision.com, 2020)	Transportation planning and operations	15-minute TMC	Miovision	Error rate: < 5%
(Feiqe et al., 2004)	Long-range planning	Hourly & Daily volume	NA	Principal arterials: 15% Minor arterials: 20% Collectors: 25%
	Traffic simulation	15-minute TMC	NA	Error rate: 5-10%
	Monthly count station volume reports	Hourly volume for consecutive days	NA	%RMSE: 2%
	Traffic data collection and archiving in Austin, Texas	Hourly volume	Loop detectors	MAPE: 4.4% RMSE: 131 veh
(Ahn et al., 2008)	Data quality white paper	Traffic sensor data	NA	Error Rate: < 15%
(Middleton et al., 2002)	Accuracy evaluation compared with baseline loop data	5-minute volume	Autoscope Solo	2.1-3.5% (per lane)
		5-minute volume	Iteris Vantage Pro	Error Rate: 5.1-12.5% (per lane)
(Kranig, 1997)	Accuracy evaluation compared with baseline loop data	Daily freeway volume	Autoscope 2004	Error Rate: 5.8 - 17% (per lane) RMSE: 22.9 - 60.4 veh (per lane)
		Daily intersection volume	Autoscope 2004	Error Rate: 1.3% - 10.3% (per lane) RMSE: 10.3 - 46.4 veh (per lane)

Table 7-5 Literature Summary of Segment Volume Estimation

Reference	**Applications**	**Data Sources**	**Estimation Method**	**Accuracy**
(Caceres et al., 2012)	Segment volume estimation for 1-hour intervals	Cellular Phone Data	Production functions	MAE: 200-240 veh/hr; Error Rate: 22%
(Zhang et al., 2020)	Segment volume estimation for 15-minute intervals	Insufficient TMC; Crowdsourcing speed data	Geometric matrix completion model	MAPE: 10%-45%

(Zhan et al., 2017)	Segment volume estimation for 5-minute intervals	GPS, POI	Bayesian network	MAE: 2-5 veh/5-min Error Rate: 24%-50%

To further analyze the data accuracy in the PAG region, the video-based sensor data and estimated volume data were compared with ground-truth data. **Table 7-8** summarizes the results of the traffic volume data accuracy assessment in the PAG region based on the results of previous tasks in this project. The average %RMSE of most Miovosion data is lower than 40% but varies by intersection. Of the Miovision intersections, those with two cameras have more accurate data than those with one camera. The volume data collected by Autoscope stop-bar detectors has an RMSE of 13 vehicles per lane and a %RMSE of 15% during peak hours.

Table 7-6 Traffic Volume Data Assessment in the PAG Region

Category	**Sensor type**	**Time interval**	**Data description**	**Measure**	**Accuracy**			
					Total	**T***	**LT***	**RT***
Video-based volume data	Miovision	15 minutes	4 intersections (1 day, peak hours)	RMSE/lane	16	19	11	18
				% RMSE	36%	29%	33%	41%
				MAPE	35%	19%	34%	53%
				R^2	0.8	0.5	0.7	0.7
	Autoscope	15 minutes	1 intersection (1 day, peak hours)	RMSE/lane	13	16	6	15
				% RMSE	15%	10%	16%	31%
				MAPE	19%	12%	13%	35%
				R^2	0.98	0.95	0.74	0.67
Estimated TMC data	Event-based data	15 minutes	84 intersections for model calibration (peak hours)	RMSE	28	51	15	17
				% RMSE	48%	17%	51%	75%
				R^2	0.55	0.81	0.57	0.27
Estimated segment volume data	Event-based data	15 minutes	18 locations (7am – 6pm)	RMSE/lane	21	\	\	\
				% RMSE	21%	\	\	\
				MAPE	18%	\	\	\
				R^2	0.83	\	\	\

T*: Through movement; LT*: Left-turn movement; RT*: Right-turn movement

- **Step 3: Acceptance criteria establishment**

Based on the summary of the relevant literature and sample traffic volume data accuracy assessment results, the preliminary acceptance criteria for different data sources were developed and are summarized in **Table 7-9**. The accuracy measures used included RMSE, %RMSE, R-Squared, and MAPE. The cameras of Miovision sensors may be sensitive to lighting; thus, the acceptance criteria for Miovision data were defined separately for daytime and nighttime. Final acceptance criteria will be determined after discussion with PAG and might be adjusted if more data becomes available for validation in the future.

Table 7-7 Preliminary Acceptance Criteria for 15-minute Interval Traffic Volume Data

Data Sources	Time of Day	Measures	Acceptance Criteria			
			Total	**T***	**LT***	**RT***
Miovision	7am-7pm (Daytime)	RMSE/lane	10	10	8	20
		%RMSE	25%	20%	25%	50%
		R-Squared	0.9	0.8	0.8	0.5
		MAPE	20%	15%	20%	40%
	7pm-7am (Nighttime)	RMSE/lane	8	5	5	8
		%RMSE	25%	20%	25%	50%
		R-Squared	0.9	0.9	0.9	0.6
		MAPE	20%	15%	15%	35%
Autoscope	/	RMSE/lane	20	25	15	20
		%RMSE	20%	15%	20%	35%
		R-Squared	0.9	0.9	0.7	0.6
		MAPE	25%	20%	20%	40%
Estimated using event-based data	/	RMSE/lane	25	30	20	5
		%RMSE	40%	45%	55%	65%
		R-Squared	0.80	0.7	0.5	0.3
		MAPE	40%	50%	60%	70%
Estimated segment volume	/	RMSE/lane	30	\	\	\
		%RMSE	30%	\	\	\
		R-Squared	0.75	\	\	\
		MAPE	25%	\	\	\
T*: Through movement; LT*: Left-turn movement; RT*: Right-turn movement						

7.2.3 Traffic Volume Validation

To further evaluate the traffic volume data quality of the proposed estimation model and smart sensors, more ground-truth TMC data at 50 intersections were collected in 2020. These 50 sample locations were chosen based on the sampling methodology in Chapter 3. Three of these 50 intersections were used to validate Miovision TMC data. Five intersections were excluded due to data quality issues, and the remaining 42 intersections were used to validate the TMC estimation model. The validation results are summarized in **Table 7-10**.

Table 7-8 Results of TMC Data Validation in the PAG Region

Category	Sensor type	Time interval	Data description	Measure	Accuracy			
					Total	T*	LT*	RT*
TMC collection	Miovision	15 minutes	3 intersections (5am – 9pm)	RMSE/lane	15	12	11	15
				% RMSE	30%	27%	40%	52%
				MAPE	34%	22%	36%	52%
				R^2	0.85	0.7	0.5	0.5
TMC estimation	Event-based data	15 minutes	42 intersections (peak hours)	RMSE/lane	17	20	13	18
				% RMSE	48%	32%	54%	75%
				MAPE	45%	35%	39%	64%
				R^2	0.89	0.86	0.61	0.34

T*: Through movement; LT*: Left-turn movement; RT*: Right-turn movement
Note: Segment volume estimation validation will be done if more data becomes available.

(1) Miovision TMC Data Validation

Validation of the Miovision TMC data included the three intersections of La Cholla Blvd & Orange Grove Rd (IntID of 121), La Cholla Blvd & River Rd (IntID of 138), and Craycroft Rd & River Rd (IntID of 151). The one-day TMC data of these three intersections were collected during daytime (5:00 am- 8:00 pm) and the validation results are shown in **Figure 7-8**.

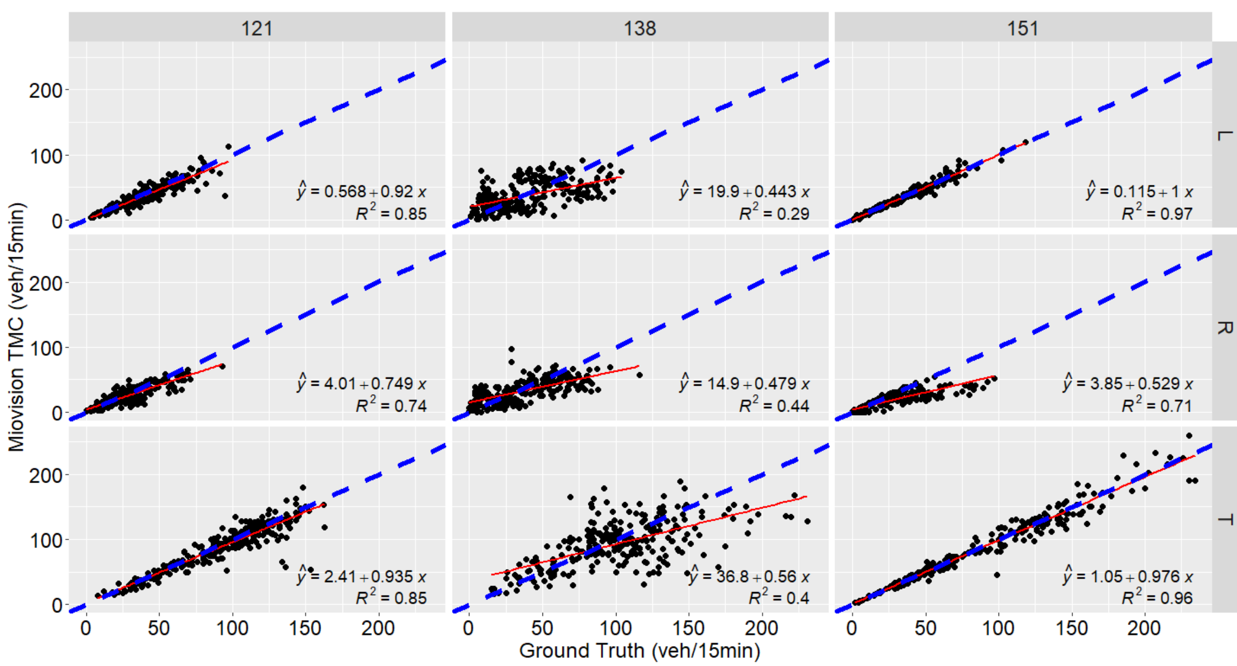


Figure 7-8 Validation of Miovision TMC data

(2) Estimated TMC Data Validation

PAG collected TMC data from 47 intersections to validate the TMC estimation model. After checking the quality of the event-based data at all 47 intersections, 5 were removed and the remaining 42 were used for validation as shown in **Figure 7-9**.

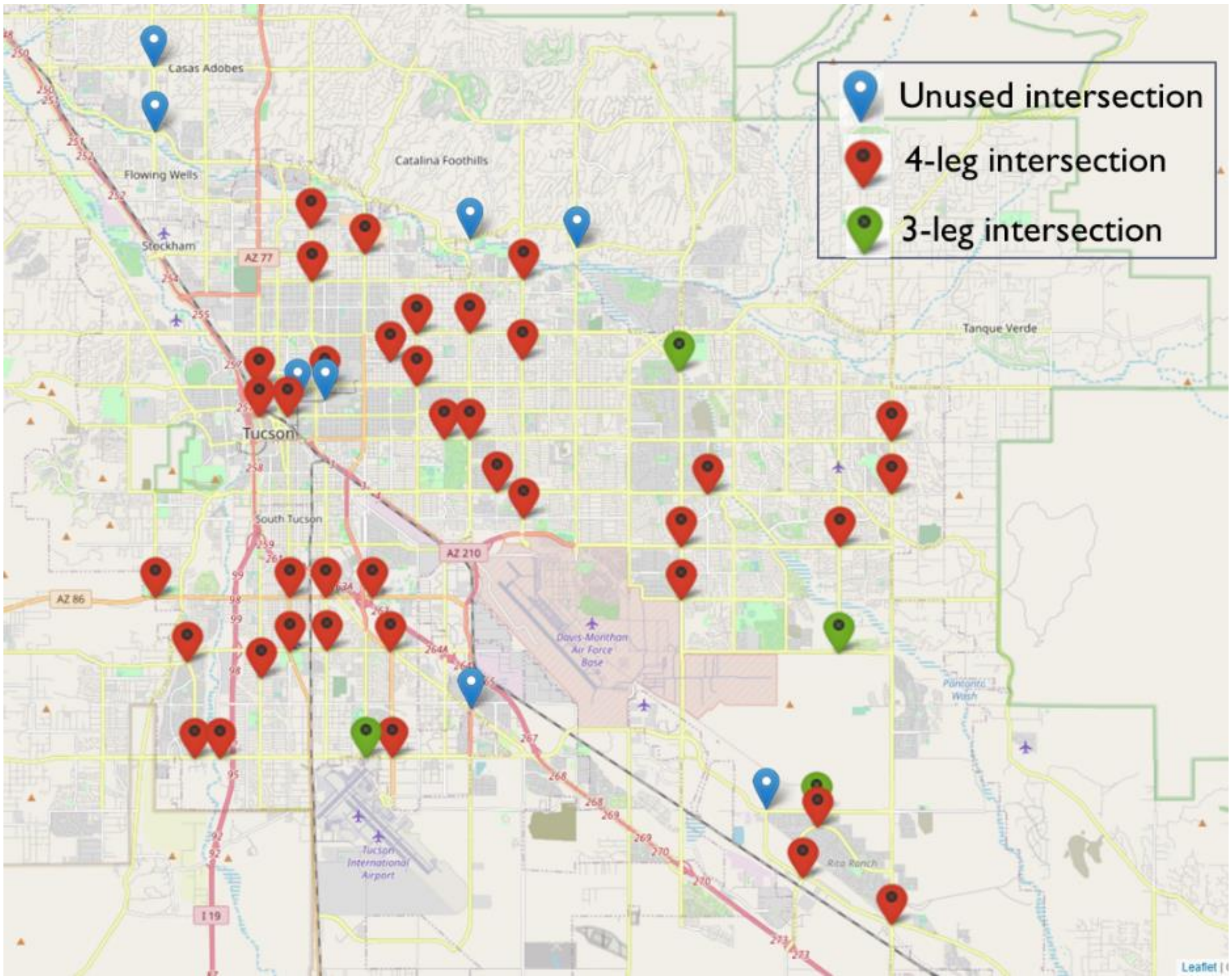


Figure 7-9 Intersections used to validate TMC estimation model with ground-truth data

Figure 7-10 shows the results of the estimated TMC model validation. The model performance varied by turning movement, with better through movement results than left and right turn movement results at most intersections. The model performance also varied by intersection, and some outliers in **Figure 7-10** shows that the proposed model has some limitations on its ability to estimate TMC at some intersections. **Figure 7-11** shows the evaluation results at 42 study intersections, and the overall R^2 is 0.85. In addition, **Figure 7-12** shows the evaluation results during peak hours and daytime by intersection.

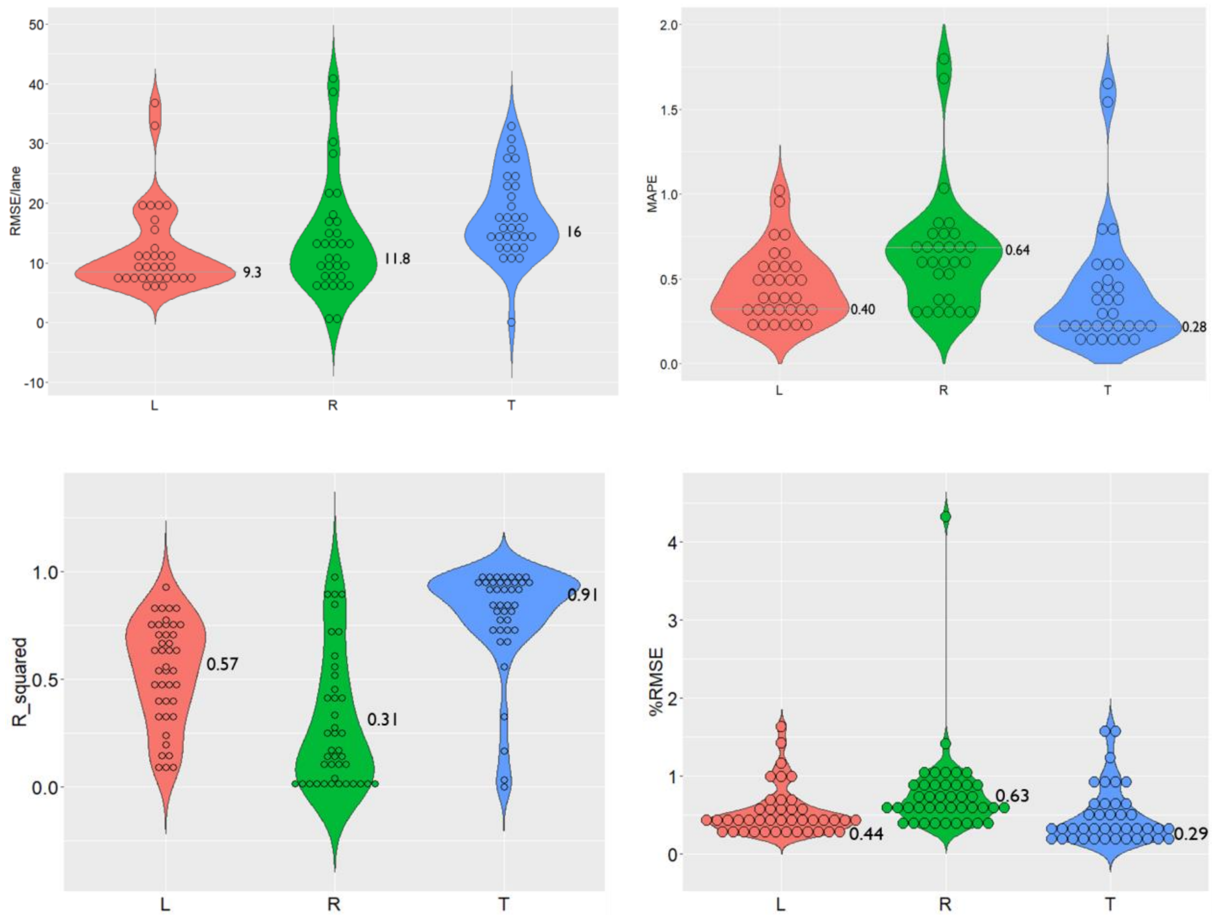


Figure 7-10 Violin plots of TMC estimation model validation by turning movement

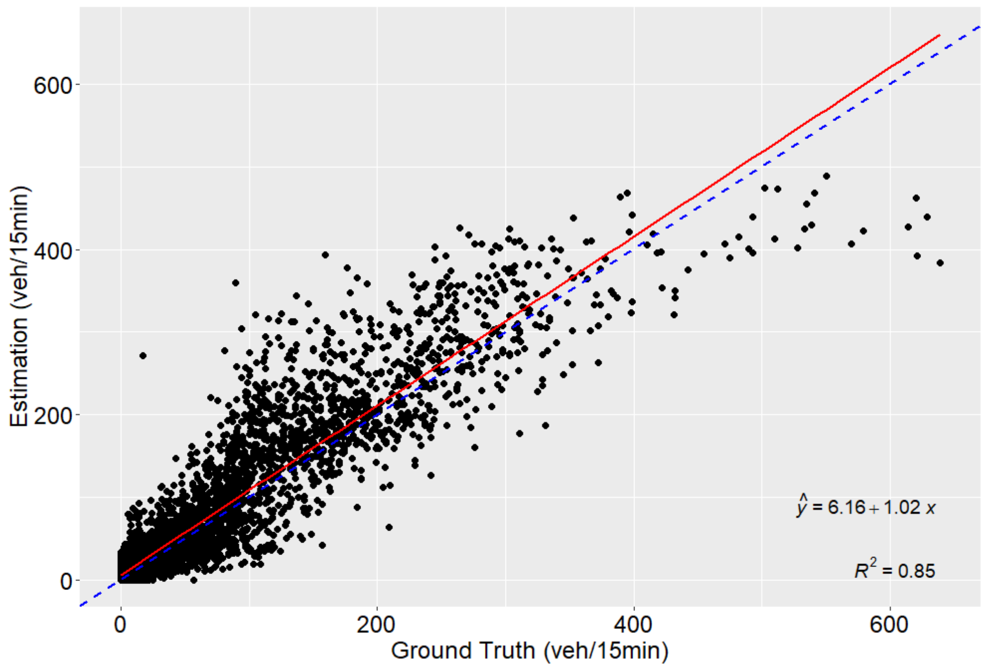
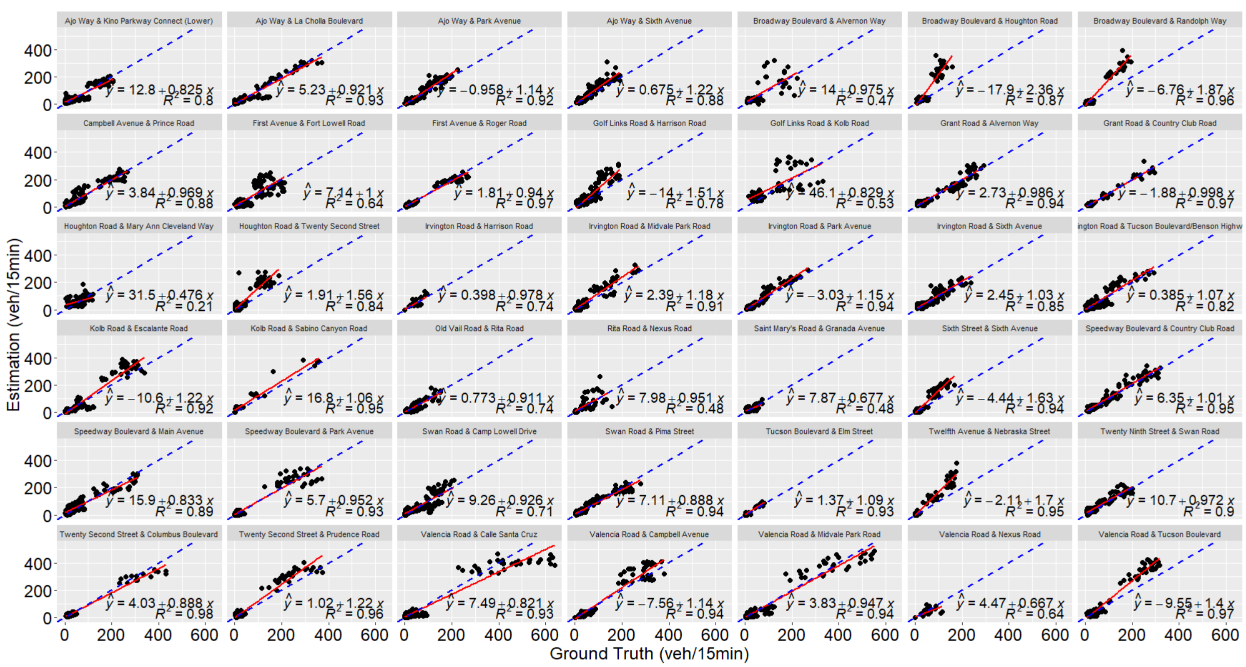
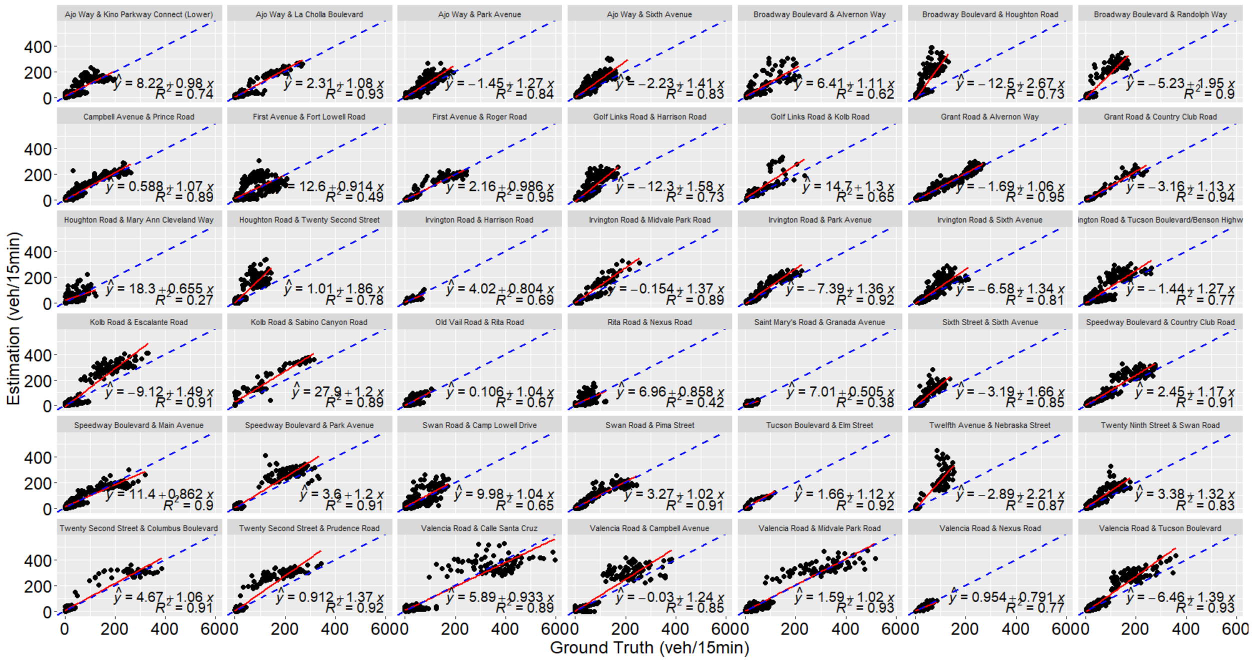


Figure 7-11 Evaluation results at 42 intersections



(a) Peak hours



(b) Daytime

Figure 7-12 Evaluation results by intersection

CHAPTER 8: LARGE-SCALE TRAFFIC DATA COLLECTION AND ANALYSIS

This chapter discusses the collection methods and analyses of large-scale traffic signal controller event-based data and video-based volume data. In the PAG region, the Town of Marana and the Pima County Department of Transportation (PCDOT) currently use the Miovision system, a large-scale video-based traffic detection, management, and analysis tool. Also, multiple jurisdictional partners use the MaxView system for traffic signal management, which stores event-based data in the MaxView database.

Chapter 8.1 and 8.2 focus on Miovision and MaxView data collection and analyses. The large-scale video-based volume data sourced from Miovision sensors was used to understand regional spatial and temporal traffic patterns. Large-scale traffic controller event-based data was collected from the City of Tucson MaxView database, and TMC at all signalized intersections in the region were estimated with the proposed MLP model in Chapter 5. This chapter also discusses the collection of region-wide intersection infrastructure data used to estimate TMC.

8.1 LARGE-SCALE VIDEO-BASED VOLUME DATA COLLECTION AND ANALYSIS

8.1.1 Data Collection

Miovision data was collected from January 1, 2020, to December 31, 2020. As of December 2020, there were a total of 122 Miovision-equipped intersections in the PAG region that were accessible using the Miovision API. Of these 122 intersections, 109 are managed by PCDOT, and 13 are located in and managed by the Town of Marana. The UArizona team used the API to retrieve the TMC collected at these intersections, which are shown in **Figure 8-1**. However, 2 intersections in Marana and 8 intersections managed by PCDOT were listed with no data in 2020. The possible reasons for missing data or information are summarized in **Table 8-1**.

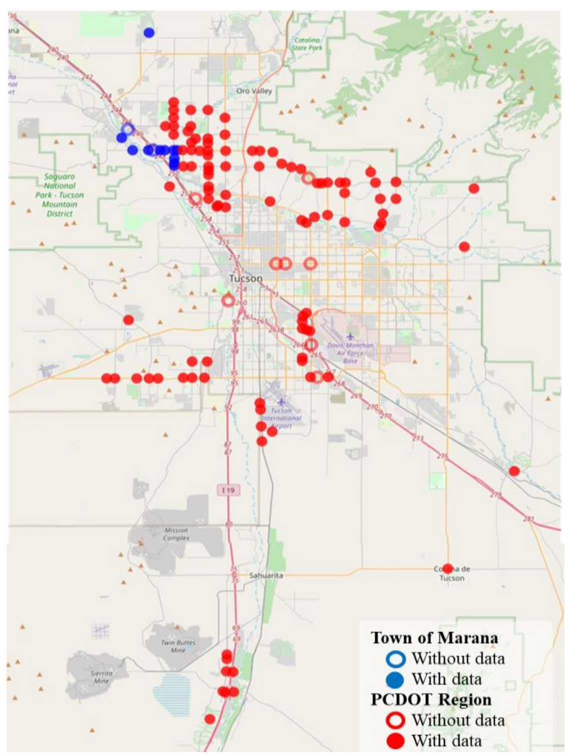


Figure 8-1 Intersections with Miovision sensors and data available via the API

The Miovision data collected from the Miovision cloud server can provide 1-min interval TMC data. The 1-min interval TMC data has been aggregated to a 15-min interval and stored in an MS Access database.

Table 8-1 Summary of Possible Reasons for Intersections without Miovision Data During 2020

	Intersection Name	Possible Reason
1	Alvernon Wy / Irvington Rd	Configured with all required devices but no data
2	Campbell Ave / Speedway Blvd	No Miovision sensor installed
3	Speedway Blvd / Alvernon Wy	No Miovision sensor installed
4	Speedway Blvd / Tucson Blvd	No Miovision sensor installed
5	Desert View HS Dw / Valencia Rd	SmartSense not actuated
6	Maryvale Ave / Ruthrauff Rd	No SmartSense[4] installed
7	Sunrise Dr / Via Palomita	No IO configuration; SmartSense not actuated
8	The Loop / West Starr Pass Blvd	Test site
9	North Cortaro Rd and West Arizona Pavilions Dr	No video detection
10	West Ina Rd and North Casa Grande Hwy	No video detection

8.1.2 Data Completeness Analysis

A Miovision TMC data completeness metric was developed to evaluate the level of data availability for a specific time period. For example, an intersection's data would be considered as "complete" if all 15-min interval TMC data were available for a given period. Three measures of data completeness are introduced to measure Miovision TMC data completeness. These measures can reflect the degree of data missing at a 15-min interval level, daily level, and monthly level:

- **The percentage of data loss (**per_loss**)**: the number of 15-min periods without any data divided by the total number of 15-min periods during the entire year of 2020, as shown in Table 2 and Table 3.
- **The number of days with data (**number_days**)**: the number of days with any Miovision data, as shown in Table 2 and Table 3.
- **Data missing for an entire month (**whole_month_missing**)**: refers to months with no TMC data at all, as shown in **Table 8-2** and **Table 8-3**.

[4] Miovision SmartSense is the device that processes the videos collected by Miovision SmartView cameras.

Based on the summary of intersection data completeness in the Town of Marana (as shown in **Table 8-2**), the data at two intersections, North Cortaro Road / West Arizona Pavillions Drive and West Ina Road / North Casa Grande Highway, were evaluated as 100% “per_loss” and had no available data for 2020. In addition, the intersection of North Dove Mountain Boulevard / West Moore Road had relatively low data quality with 89% total data missing, and only November and December 2020 with any available data. One possible reason is that the data collection module and hardware were not correctly configured at that location until November 2020.

Table 8-3 shows the summary of data completeness at intersections managed by PCDOT. Nine intersections, (Alvernon Wy/Irvington Rd, Campbell Ave/Speedway Blvd, Desert View HS Dw/Valencia Rd, Maryvale Ave/Ruthrauff Rd, Speedway Blvd/Alvernon Wy, Speedway Blvd/Tucson Blvd, Sunrise Dr/Via Palomita, The Loop/West Starr Pass Blvd, and Broadmont Dr/Palo Verde Rd[5]) have no data available, noted as 100% “per_loss”. 39 intersections have relatively reliable data quality with at least partial data available every month.

Table 8-2 Miovision TMC Data Completeness Summary in Town of Marana

	name	latitude	longitude	owner	number_cameras	data_collection	per_loss	number_days	whole_month_missing
1	West Ina Road and North Thornydale Road	32.33774	-111.04732	Town of Marana	1	yes	13.8%	365	None
2	West Ina Road and North Starcommerce Way	32.337395	-111.07274	Town of Marana	1	yes	0.6%	364	None
3	West Ina Road and North Oldfather Road	32.337433	-111.055725	Town of Marana	1	yes	4.1%	351	None
4	West Ina Road and North Meredith Boulevard	32.337334	-111.04335	Town of Marana	1	yes	2.8%	359	None
5	North Dove Mountain Boulevard and West Moore Road	32.44278	-111.071773	Town of Marana	1	yes	89.0%	42	**January ~ October**
6	West Ina Road and North Camino de los Capas	32.337826	-111.061035	Town of Marana	1	yes	0.1%	365	None
7	North Thornydale Road and West Orange Grove Road	32.323593	-111.04625	Town of Marana	2	yes	25.9%	314	**January**
8	North Thornydale Road and West Horizon Hills Drive	32.330265	-111.04639	Town of Marana	1	yes	3.5%	353	None
9	North Thornydale Road and West Costco Drive	32.32628	-111.046234	Town of Marana	1	yes	4.8%	349	None
10	North Silverbell Road and West Ina Road	32.337406	-111.08835	Town of Marana	1	yes	0.5%	364	None
11	North Silverbell Road and North Cortaro Road	32.34848	-111.09943	Town of Marana	2	yes	5.9%	344	None
12	North Cortaro Road and West Arizona Pavillions Drive	32.35609	-111.093376	Town of Marana	2	no	100.0%	0	All
13	West Ina Road and North Casa Grande Highway	32.3378	-111.0679	Town of Marana	1	no	100.0%	0	All

[5] There was only one data record in 2020.

Table 8-3 PCDOT Miovision TMC Data Completeness Summary (1/2)

	name	latitude	longitude	owner	number_cameras	data_collection	per_loss	number_days	whole_month_missing
1	1st Av / Christie Dr / Ina Rd	32.33725896	-110.9607296	PCDOT	1	yes	0.3%	364	None
2	1st Av / Orange Grove Rd	32.32290563	-110.961137	PCDOT	1	yes	52.3%	175	July ~ December
3	36th St / Palo Verde Rd	32.18878338	-110.9171636	PCDOT	1	yes	54.6%	167	July ~ December
4	37th St / Golf Links Rd / Palo Verde Rd	32.19214278	-110.9139865	PCDOT	1	yes	1.3%	361	None
5	Abrego Dr / Continental Rd	31.8521251	-110.9877744	PCDOT	1	yes	22.1%	289	January ~ February
6	Abrego Dr / Esperanza Bl	31.87023977	-110.9886053	PCDOT	1	yes	52.3%	183	January ~ June
7	Aero Park Bl / Nogales Hy / Vamori St	32.11079287	-110.9603317	PCDOT	1	yes	21.3%	289	January ~ February
8	Aerospace Pw / Nogales Hy	32.09022563	-110.9593443	PCDOT	1	yes	20.8%	290	January ~ February
9	Aerospace Pw / Raytheon Pw	32.08559261	-110.9483848	PCDOT	1	yes	21.1%	290	January ~ February
10	Ajo Wy / Alvernon Wy	32.17545376	-110.9106568	PCDOT	1	yes	27.7%	290	January ~ February
11	Ajo Wy / Dodge Bl	32.17697484	-110.9139506	PCDOT	1	yes	21.2%	290	January ~ February
12	Ajo Wy / Palo Verde Rd	32.17795523	-110.9177047	PCDOT	1	yes	30.3%	288	January ~ February
13	Alvernon Wy / Brandi Fenton Dw / River Rd	32.27489372	-110.9187301	PCDOT	2	yes	21.1%	289	January ~ February
14	Alvernon Wy / Dodge Bl	32.27285061	-110.9141501	PCDOT	1	yes	19.1%	296	January ~ February
15	Alvernon Wy / Irvington Rd	32.16312576	-110.9092097	PCDOT	1	no	100.0%	0	All
16	Alvernon Wy / Valencia Rd	32.13423016	-110.9095068	PCDOT	1	yes	9.9%	363	None
17	Benson Hy / Palo Verde Rd	32.15203787	-110.9176529	PCDOT	1	yes	81.0%	70	January ~ September
18	Benson Hy / Swan Rd / Valencia Rd	32.13439081	-110.891969	PCDOT	1	yes	8.4%	363	None
19	Broadmont Dr / Palo Verde Rd	32.18437707	-110.9177743	PCDOT	1	yes	100.0%	1	February ~ December
20	Calle Bosque / Territory Dr / Craycroft Rd	32.29949491	-110.875294	PCDOT	1	yes	49.7%	184	January ~ May
21	Calle del Marques / Sunrise Dr	32.30831698	-110.898742	PCDOT	1	yes	0.4%	364	None
22	Camino Casa Verde / La Canada Dr / Paseo del	31.88566734	-110.9949061	PCDOT	1	yes	23.2%	287	January ~ February
23	Camino de la Tierra / Ina Rd	32.3374711	-111.0378178	PCDOT	1	yes	1.1%	362	None
24	Camino De La Tierra / Orange Grove Rd	32.3232125	-111.0373654	PCDOT	1	yes	0.1%	365	None
25	Camino de la Tierra / Valencia Rd	32.13374972	-111.037336	PCDOT	1	yes	19.4%	297	January ~ February
26	Camino de Oeste / Valencia Rd	32.13343924	-111.0628477	PCDOT	1	yes	20.3%	293	January ~ February
27	Camino Del Sol and Camino Encanto	31.82762282	-111.0123131	PCDOT	1	yes	28.9%	296	January ~ February
28	Camino Verde / Valencia Rd	32.13339829	-111.105996	PCDOT	1	yes	21.2%	295	January ~ February
29	Campbell Av / Skyline Dr	32.32263521	-110.9291383	PCDOT	1	yes	5.8%	353	None
30	Campbell Av / Speedway Bl	32.23595098	-110.9438957	PCDOT	1	no	100.0%	0	All
31	Campo Abierto / Sunrise Dr	32.32052627	-110.919	PCDOT	1	yes	0.9%	363	None
32	Campus Park Wy / Shannon Rd	32.34468432	-111.0290505	PCDOT	1	yes	51.8%	177	January ~ June
33	Cardinal Av / Drexel Rd	32.14830067	-111.0286945	PCDOT	1	yes	50.0%	183	January ~ June
34	Cardinal Av / Valencia Rd	32.13377634	-111.0287672	PCDOT	1	yes	28.1%	296	January ~ February
35	Casino del Sol Dr / Valencia Rd	32.13344351	-111.0841555	PCDOT	1	yes	18.9%	297	January ~ February
36	Cloud Rd / Sabino Canyon Rd	32.26905761	-110.8410738	PCDOT	1	yes	20.7%	290	January ~ February
37	Club Dr / Shannon Rd	32.35901073	-111.029655	PCDOT	1	yes	49.7%	185	January ~ May
38	Colossal Cave Rd / Mary Ann Cleveland Wy	32.0501602	-110.7054244	PCDOT	1	yes	0.3%	364	None
39	Continental Rd / Continental Plaza / I19 Fronta	31.85152796	-110.9959443	PCDOT	1	yes	85.1%	58	January ~ February, June ~ December
40	Continental Rd / La Canada Dr	31.85243017	-110.9993238	PCDOT	1	yes	41.5%	224	January ~ February
41	Cortaro Farms Rd / Magee Rd / Shannon Rd	32.35434245	-111.0325166	PCDOT	1	yes	2.1%	359	None
42	Cortaro Farms Rd / Oldfather Dr	32.35900325	-111.0554236	PCDOT	1	yes	53.8%	169	January ~ June
43	Cortaro Farms Rd / Thornydale Rd	32.35905216	-111.0468971	PCDOT	1	yes	3.9%	358	None
44	Craycroft Rd / River Rd	32.27345336	-110.8750915	PCDOT	1	yes	20.0%	294	January ~ February
45	Craycroft Rd / Sunrise Dr	32.30873229	-110.8750117	PCDOT	1	yes	0.4%	365	None
46	Curtis Rd / La Cholla Bl	32.30147944	-111.0120965	PCDOT	1	yes	19.9%	293	January ~ February
47	Desert Bell Dr / La Canada Dr / La Canoa	31.88153409	-110.9949108	PCDOT	1	yes	67.8%	120	January ~ August
48	Desert View HS Dw / Valencia Rd	32.13431494	-110.9029799	PCDOT	1	no	100.0%	0	All
49	Drexel Rd / Mission Rd	32.14837788	-111.0130987	PCDOT	1	yes	80.7%	71	January ~ September
50	Drexel Rd / Palo Verde Rd	32.14886788	-110.9177837	PCDOT	1	yes	2.2%	359	None
51	East Catalina Highway / North Mount Lemmon	32.303238	-110.74594	PCDOT	1	yes	72.7%	135	January ~ June, Decemebr
52	Esperanza Bl / La Canada Dr	31.87046909	-110.9953129	PCDOT	1	yes	21.3%	294	January ~ February
53	Flowing Wells Rd / Wetmore Rd	32.28680766	-110.9950695	PCDOT	1	yes	28.7%	294	January ~ February
54	Foothills Mall Dr / La Cholla Bl	32.34391059	-111.012763	PCDOT	1	yes	20.1%	294	January ~ February
55	Hardy Rd / La Canada Dr / Overton Rd	32.3665018	-110.9956794	PCDOT	1	yes	33.7%	244	October ~ December

Table 8-3 PCDOT Miovision TMC Data Completeness Summary (2/2)

56	Hardy Rd / Thornydale Rd	32.36637564	-111.0468458	PCDOT	1	yes	1.8%	360	None
57	Hermans Rd / Nogales Hy	32.10516563	-110.9600546	PCDOT	1	yes	19.6%	294	January ~ February
58	Hospital Dr / La Cholla Bl	32.31937347	-111.0121271	PCDOT	1	yes	19.6%	294	January ~ February
59	Houghton Rd / Sahuarita Rd	31.96304915	-110.7725582	PCDOT	1	yes	20.0%	293	January ~ February
60	Ina Rd / La Canada Dr	32.33718953	-110.9951466	PCDOT	1	yes	10.3%	364	None
61	Ina Rd / La Cholla Bl	32.33728245	-111.0127097	PCDOT	1	yes	10.1%	360	None
62	Ina Rd / Mona Lisa Rd	32.33732949	-111.0206936	PCDOT	1	yes	0.3%	364	None
63	Ina Rd / Pima Canyon Dr / Skyline Dr	32.33603431	-110.947179	PCDOT	1	yes	6.3%	344	None
64	Ina Rd / Shannon Rd	32.3373935	-111.0294575	PCDOT	1	yes	13.2%	343	None
65	Ina Rd / Westward Look Dr	32.33715135	-110.9680662	PCDOT	1	yes	0.4%	364	None
66	Kinney Rd / Western Wy	32.18565688	-111.0925749	PCDOT	1	yes	88.5%	43	January ~ October
67	Knollwood Dr / River Rd / Sabino Canyon Rd	32.27245263	-110.8392368	PCDOT	1	yes	22.0%	287	January ~ February
68	Kolb Rd / Mountain Shadows Pl / Ventana Cany	32.31804499	-110.849252	PCDOT	1	yes	24.3%	292	January ~ February
69	Kolb Rd / Sabino Canyon Rd	32.28080118	-110.8369351	PCDOT	1	yes	31.1%	253	January ~ March
70	Kolb Rd / Snyder Rd	32.29433952	-110.8395858	PCDOT	1	yes	19.6%	295	January ~ February
71	Kolb Rd / Sunrise Dr	32.30885378	-110.8443967	PCDOT	1	yes	0.1%	365	None
72	La Canada Dr / Magee Rd	32.35179747	-110.9957011	PCDOT	1	yes	20.8%	294	January ~ February
73	La Canada Dr / Orange Grove Rd	32.32321188	-110.9952124	PCDOT	1	yes	2.8%	360	None
74	La Canada Dr / River Rd	32.29746397	-110.9951932	PCDOT	1	yes	10.6%	364	None
75	La Cholla Bl / Magee Rd	32.34797055	-111.0127703	PCDOT	1	yes	1.8%	359	None
76	La Cholla Bl / Omar Dr	32.33273816	-111.0129708	PCDOT	1	yes	19.8%	295	January ~ February
77	La Cholla Bl / Orange Grove Rd	32.32316188	-111.0121768	PCDOT	2	yes	3.2%	364	None
78	La Cholla Bl / Overton Rd	32.37356711	-111.0127937	PCDOT	1	yes	1.7%	360	None
79	La Cholla Bl / River Rd	32.3051816	-111.0120929	PCDOT	2	yes	15.2%	330	None
80	La Cholla Bl / Rudasill Rd	32.31569658	-111.0120094	PCDOT	1	yes	21.2%	288	January ~ February
81	La Cholla Bl / Ruthrauff Rd	32.29436209	-111.0121012	PCDOT	2	yes	1.3%	365	None
82	Linda Vista Bl / Thornydale Rd	32.38074063	-111.0469182	PCDOT	1	yes	0.4%	364	None
83	Magee Rd / Shannon Rd / Tuscany Dr	32.34801166	-111.0248093	PCDOT	1	yes	1.9%	360	None
84	Magee Rd / Thornydale Rd	32.35177494	-111.0468792	PCDOT	1	yes	20.6%	292	January ~ February
85	Mark Rd / Valencia Rd	32.13342132	-111.0719102	PCDOT	1	yes	19.1%	296	January ~ February
86	Maryvale Av / Ruthrauff Rd	32.29425322	-111.0248576	PCDOT	1	no	100.0%	0	All
87	Mission Rd / Valencia Rd	32.13385869	-111.0160387	PCDOT	1	yes	27.8%	290	January ~ February
88	Nogales Hy / Old Nogales Hy	32.0765438	-110.9585891	PCDOT	1	yes	19.3%	295	January ~ February
89	Orange Grove Rd / Shannon Rd	32.32315812	-111.0289581	PCDOT	1	yes	29.5%	258	October ~ December
90	Orange Grove Rd / Skyline Dr	32.32569467	-110.9386701	PCDOT	1	yes	0.8%	364	None
91	Overton Rd / Shannon Rd	32.37360614	-111.0300116	PCDOT	1	yes	1.9%	359	None
92	Overton Rd / Thornydale Rd	32.37354945	-111.0469092	PCDOT	1	yes	1.6%	361	None
93	Pontatoc Rd / River Rd	32.27759308	-110.9053886	PCDOT	1	yes	21.1%	291	January ~ February
94	Pontatoc Rd / Sunrise Dr	32.3082625	-110.9025325	PCDOT	1	yes	0.1%	365	None
95	River Rd / Swan Rd	32.27934248	-110.8926769	PCDOT	1	yes	19.3%	295	January ~ February
96	River Rd / Via Entrada	32.29150205	-110.9500287	PCDOT	1	yes	19.3%	295	January ~ February
97	Romero Rd / Ruthrauff Rd	32.28819589	-111.0025434	PCDOT	1	yes	0.1%	365	None
98	Romero Rd / Wetmore Rd	32.28688616	-111.003476	PCDOT	1	yes	21.0%	289	January ~ February
99	Sabino Canyon Rd / Snyder Rd	32.29431554	-110.8239966	PCDOT	1	yes	65.2%	128	January ~ July
100	Sabino Canyon Rd / Sunrise Dr	32.30894525	-110.8240608	PCDOT	1	yes	1.9%	365	None
101	Silverbell Rd / Sunset Rd	32.30515212	-111.0510418	PCDOT	1	yes	15.2%	311	January
102	Speedway Bl / Alvernon Wy	32.23610741	-110.9095289	PCDOT	1	no	100.0%	0	All
103	Speedway Bl / Tucson Bl	32.23596924	-110.9351999	PCDOT	1	no	100.0%	0	All
104	Suncrest Pl / Sunrise Dr	32.30861318	-110.8800917	PCDOT	1	yes	11.9%	323	None
105	Sunrise Dr / Swan Rd	32.30838944	-110.892533	PCDOT	1	yes	4.1%	365	None
106	Sunrise Dr / Via Palomita	32.31272751	-110.9120548	PCDOT	1	no	100.0%	0	All
107	Tanque Verde Loop Road / Tanque Verde Roac	32.25093271	-110.7555725	PCDOT	1	yes	50.0%	184	January ~ May
108	The Loop / West Starr Pass Boulevard	32.202755	-110.99237	PCDOT	1	no	100.0%	0	All
109	Valencia Rd / Wade Rd	32.13334165	-111.1145527	PCDOT	1	yes	32.4%	248	January, February, April

8.1.3 Traffic Volume Analysis

With the Miovision TMC data collected from 111 intersections throughout 2020, this section discusses temporal and spatial traffic patterns in the PAG region. First, traffic volume at all 111 intersections is represented in 15 minute intervals in **Figure 8-2**. The result shows that the traffic volume at all intersections has significantly decreased since the state's stay-at-home order was enacted in March 2020. In August 2020 traffic volume started to increase slightly and continued to do so until the end of the year.

In addition, Miovision data was used to analyze traffic pattern changes. **Figure 8-3** shows daily traffic patterns at La Cholla Blvd / River Rd. The letters of M to S on the X-axis stand for Monday to Sunday in order. Abnormal daily traffic patterns were included and represented by a single line or left blank for a day of missing data. The figure shows that the daily traffic patterns on weekdays (Monday to Friday) and weekends (Saturday and Sunday) are distinctly different with morning and afternoon traffic peaks on weekdays in contrast with traffic peaks on weekends, surging Saturday evening and late morning on Sunday. It is especially noticeable that daily traffic patterns changed after April 2020, with a large reduction in the morning and afternoon peaks shown in January through March 2020.

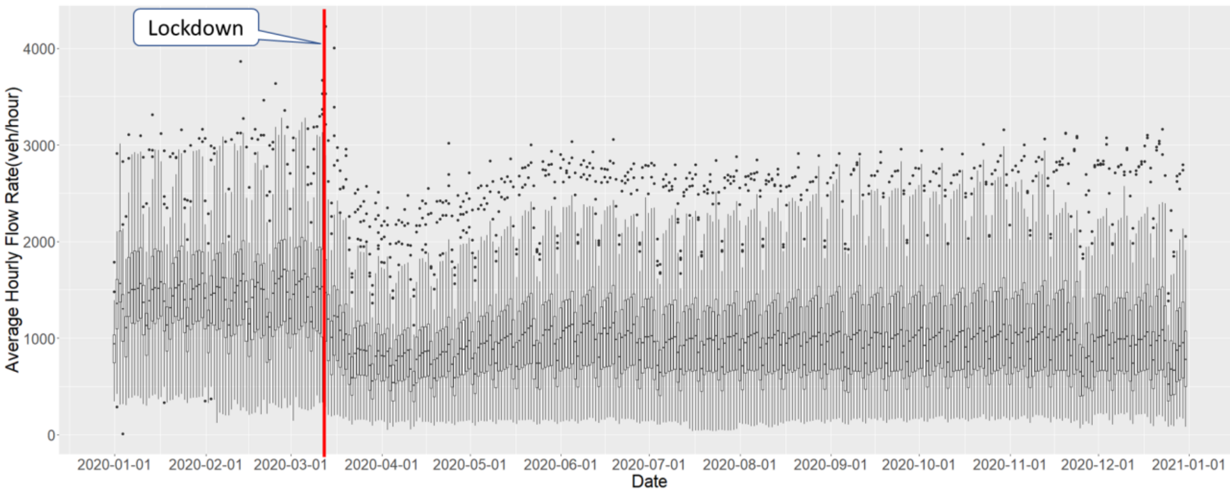


Figure 8-2 Average hourly volume trend for 111 intersections with Miovision data

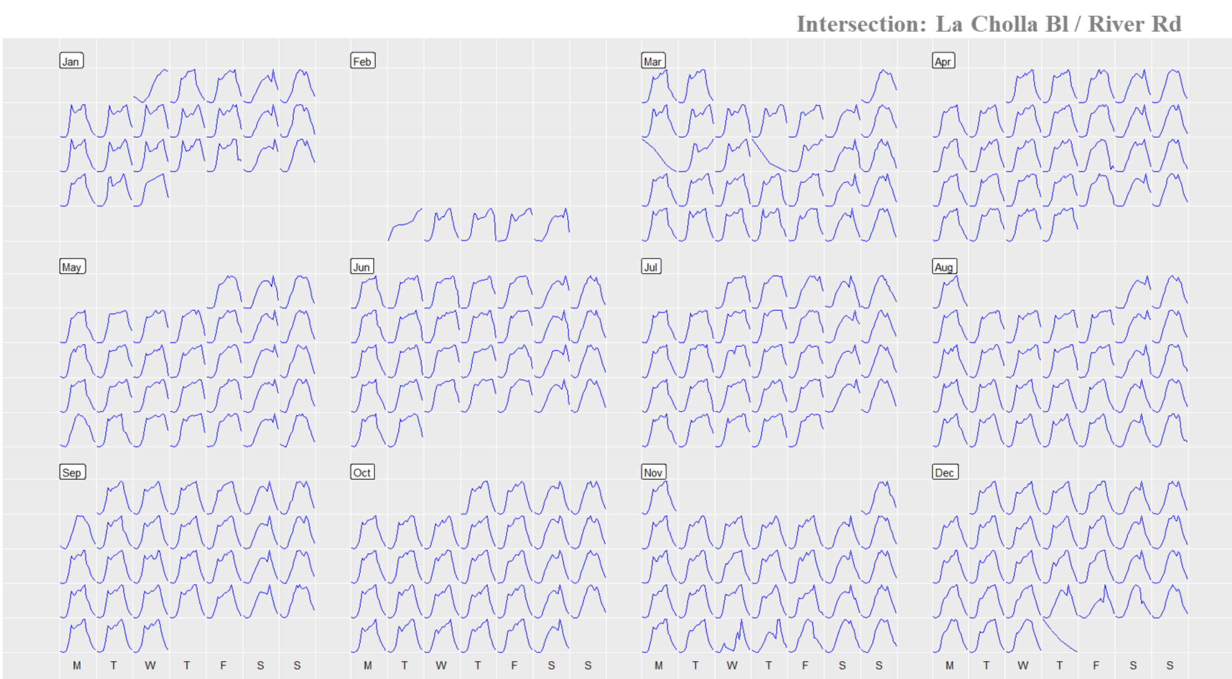
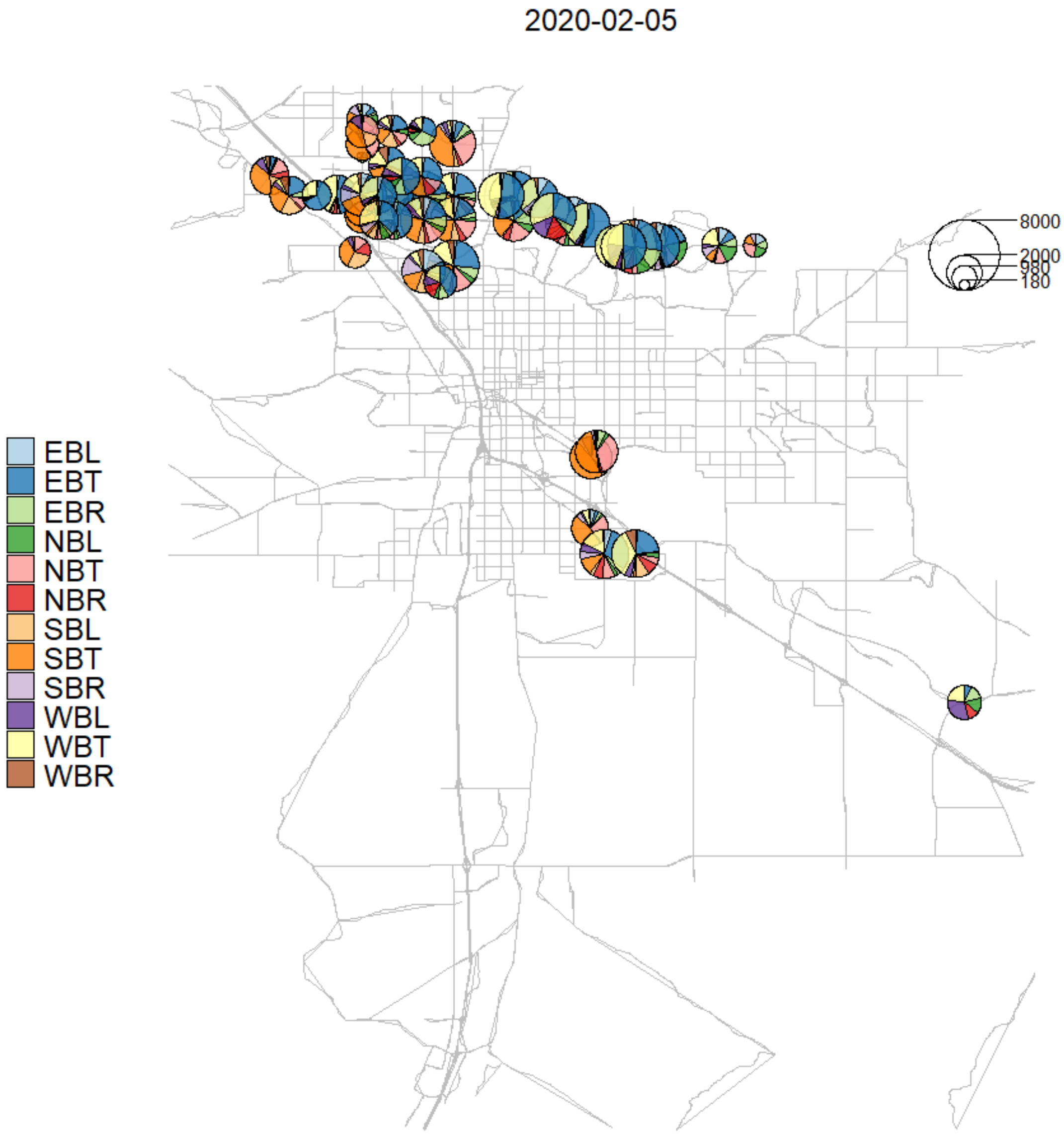
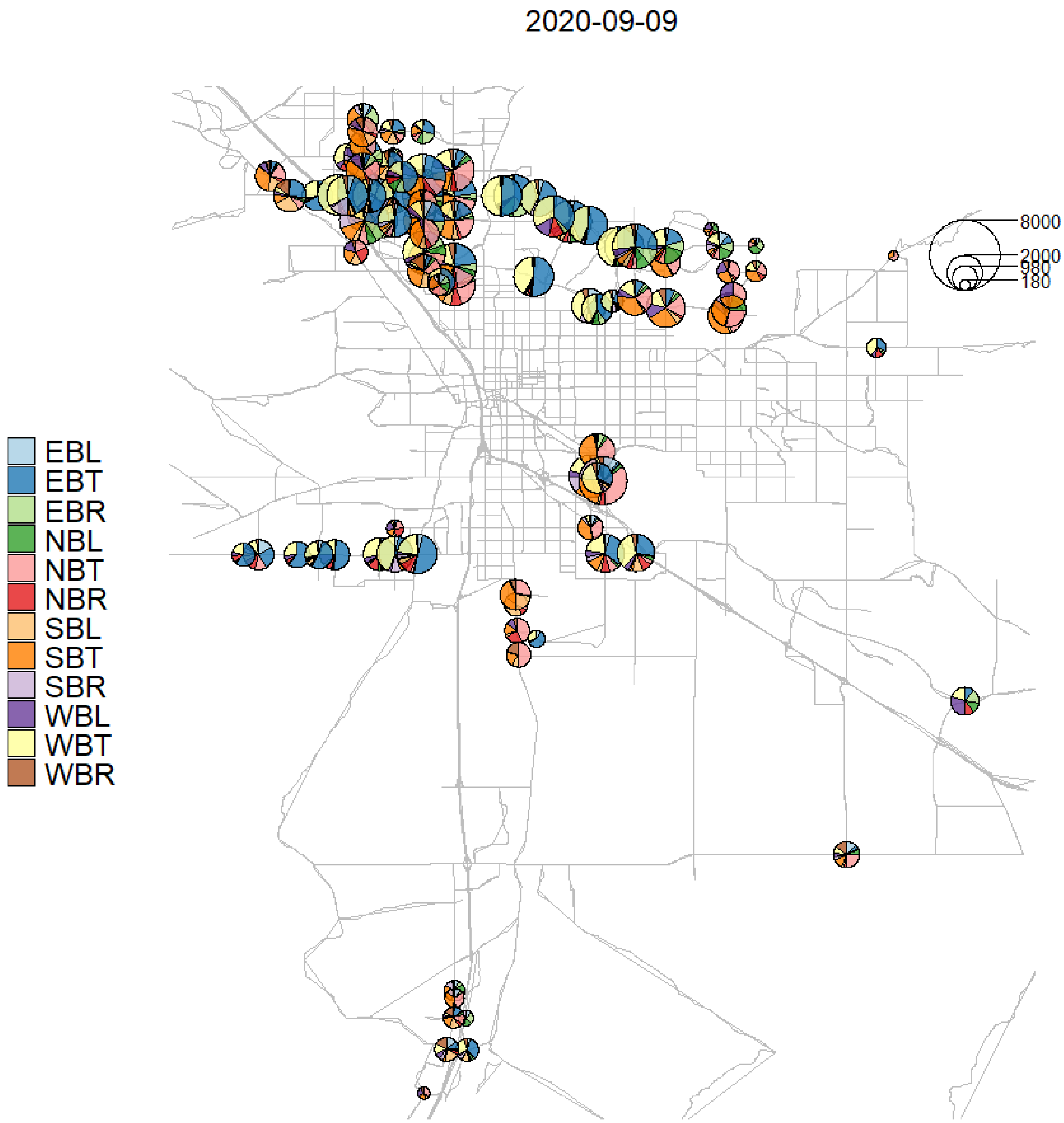


Figure 8-3 2020 calendar map of total hourly intersection volume at La Cholla Blvd and River Rd

Miovision data was also used to represent the spatial distribution of region-wide traffic. February 5 and September 9, 2020, were selected as sample days to illustrate the spatial traffic distribution at 7 am. Each pie chart located on the map in **Figure 8-4** illustrates the turning movement volumes at each intersection, and each color represents a separate turning movement. The pie radius represents the total volume; specifically, a larger radius indicates a larger total volume at the intersection.



(a) 2020-02-05



(c) 2020-09-09

Figure 8-4 Maps of Miovision individual movement counts from 7:00 – 7:15 am

8.2 REGIONAL TRAFFIC SIGNAL CONTROLLER EVENT-BASED DATA COLLECTION AND ANALYSIS

Traffic controller event-based data was collected from the MaxView Advanced Transportation Management System (ATMS) and stored in the UArizona STL-SQL[6] database. The STL-SQL database was used to store a monthly backup of data from the MaxView database server owned and managed by the City of Tucson. This event-based data was used to estimate 15 minute interval TMC. Other infrastructure data used in the proposed model include the intersection layout, the movement types, and the left-turn type, which were manually collected from different sources and are summarized in **Table 8-4**. For the data processing and delivery to PAG, the event-based data was transferred to an MS Access database, and intersection infrastructure data was saved in CSV format.

Table 8-4 Summary of Event-based Data and Infrastructure Data Collection

	Categories	**Data Explanation**	**Collection Method**	**Data Format**
Event-based data	Detector Events	Detector On; Detector Off	STL-SQL Query	RDS/ACCDB
	Phase Events	Phase Begin Red; Phase Begin Green	STL-SQL Query	RDS/ACCDB
	Communication Events	Total Comm Attempts; Failed Comm Attempts	STL-SQL Query	RDS/ACCDB
Intersection infrastructure data	Intersection layout	Number of Lanes of Each Approach; Shared Lanes or Exclusive Lanes	Manually collected using Google Earth	CSV
	Movement type	Sets the Relationship Between the Parameter in Event-Based Data and Movement Directions	Manually collected using MaxView system	CSV
	Left-turn phase type	Permissive-Only; Protect-Only; Protect-Permissive	Manually collected using MaxView system	CSV

RDS: RData files; ACCDB: Access 2007/2010 database file; CSV: a delimited text file that uses a comma-separated values

[6] STL-SQL: Smart Transportation Lab - Structured Query Language

- **Event-based Data**

Event-based data was collected from January 1, 2020, to December 31, 2020. There were approximately 670 controllers in the MaxView system as of December 2020. Event-based data was collected from 354 controllers for regional TMC volume estimation, excluding the controllers used for HAWKs and midblock pedestrian crossing signals, the controllers used for Miovision sensors, and the controllers with communication disabled. These 354 controllers are shown in **Figure 8-5**.

- **Intersection Layout Data**

Intersection layout data includes the number of left-turn lanes, the number of shared left-turn lanes, the number of right-turn lanes, the number of shared right-turn lanes, and the number of through lanes. The layout data of all 354 intersections were manually collected through Google Earth. This information is also available in the MaxView interface.

- **Movement Type**

Each movement at an intersection is associated with a signal phase number and detector number for signal control. The event-based data only records these numbers rather than direction and movement information. For example, event-based data records that detector 4 is actuated by vehicles, and signal 4 is then changed to green, but the movement information is unknown and needs to be identified by mapping signal ID and movement. At a typical four-leg intersection, IDs 1-8 are commonly assigned to all through and left-turn movements. At signalized intersections in the PAG region, IDs 1, 6, 2, and 5 are usually assigned to major roads, and the other IDs are assigned to minor roads. In order to determine the traffic movement, the UArizona team reviewed the mappings between movements and associated signal phase IDs at all intersections in the MaxView interface. We found that there are four mapping types between movements and phase IDs used at all *signalized i*ntersections, and these four mapping types are summarized in **Table 8-5**. With the defined mapping types in Table 8-5, the movement and direction can be directly identified from the event-based data rather than from the MaxView interface.

- **Left-turn Phase Type**

The types of left-turn signal phases during peak hours of each approach at the 354 signalized intersections were collected and reviewed through the MaxView system. Currently, three types of left-turn phasing are widely used in the PAG region: permissive-only, protected-only, and protected-permissive. Specifically, 49.1% of all intersection approaches use a permissive-only left-turn signal phase, 40.5% of approaches use a protected-permissive left-turn phase, and 10.4% of approaches use a protected-only left-turn phase. Left-turn traffic signal phases at intersections can also be changed by time of day to accommodate changes in peak/off-peak and weekday/weekend traffic patterns. In this project, the left-turn phase type data was collected only for peak hours because of the availability of the validation data for the proposed MLP model.

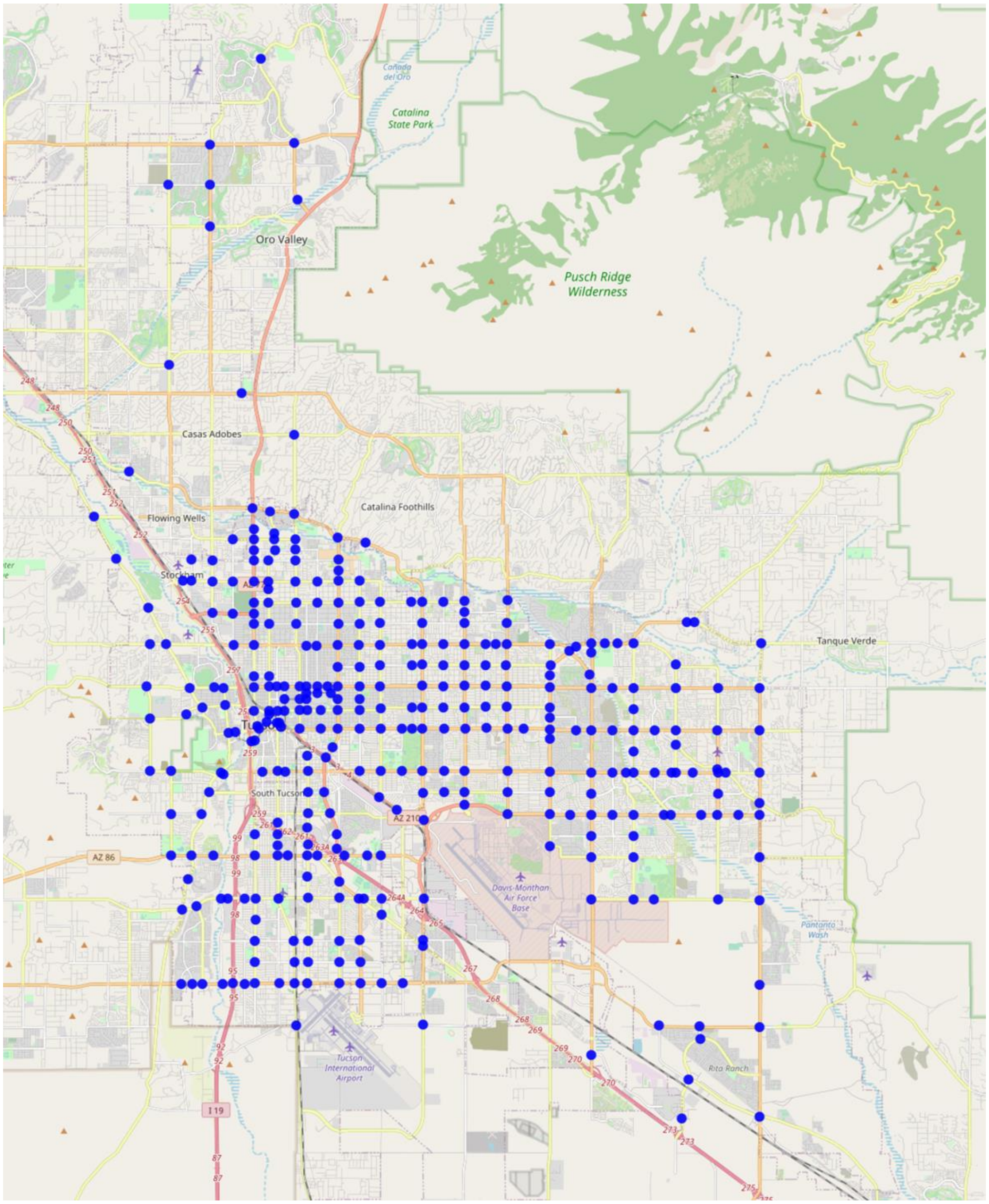
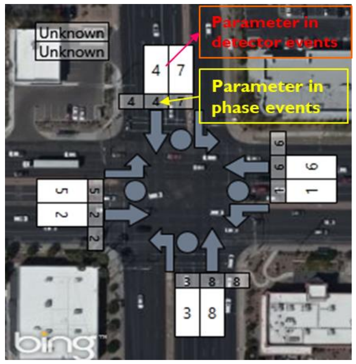
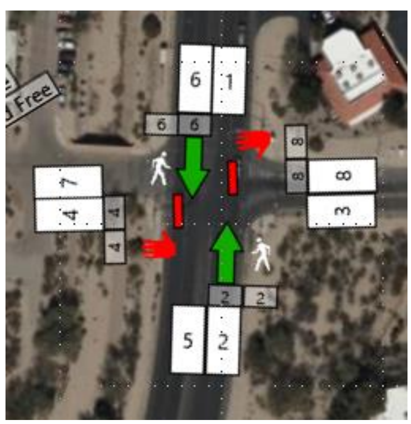
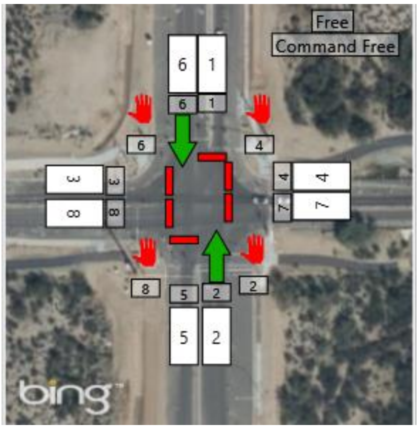


Figure 8-5 Locations of event-based data collection

Table 8-5 Description of Mapping Type between Movement and Phase ID

Mapping Type	Screen shot from the MaxView System	Bound: Parameter (Phase ID)
Type 0		SB: 4,7 NB: 8,3 EB: 2,5 WB: 6,1
Type 1		SB: 2,5 NB: 6,1 EB: 8,3 WB: 4,7
Type 2		SB: 6,1 NB: 2,5 EB: 4,7 WB: 8,3

Type 3		SB: 6,1 NB: 2,5 EB: 8,3 WB: 4,7

CHAPTER 9: LARGE-SCALE DATA INTEGRATION AND ANALYSIS

This chapter dicusses the integration and processing of regional traffic data using the methods proposed in previous chapters as well as relevant analysis of the data. Specifically, the event-based data collected from the MaxView system and infrastructure data were used to estimate turning movement counts (TMC) at signalized intersections with the proposed MLP model and merged with video-based TMC data collected from Miovision sensors. The merged regional TMC data set was then used with the method proposed in Chapter 7 to estimate road segment volumes.

9.1 LARGE-SCALE TURNING MOVEMENT COUNTS

9.1.1 Data Collection

Event-based data, consisting of detection, signal, and communication events, was collected for the entire year of 2020. The traffic controllers with reliable communication provided high-quality event-based data which is critical for TMC estimation, as using event-based data from controllers with unreliable communication could yield poor estimation results due to missing data. Therefore, we first analyzed the availability and quality of event-based data in the PAG region by date. **Figure 1** shows the "*Number of Intersections*" with controllers that have communication on any given day. Before June 2020, around 150 intersections were reliably providing event-based data, and after June 2020, improvements led to around 225 intersections reliably providing event-based data.

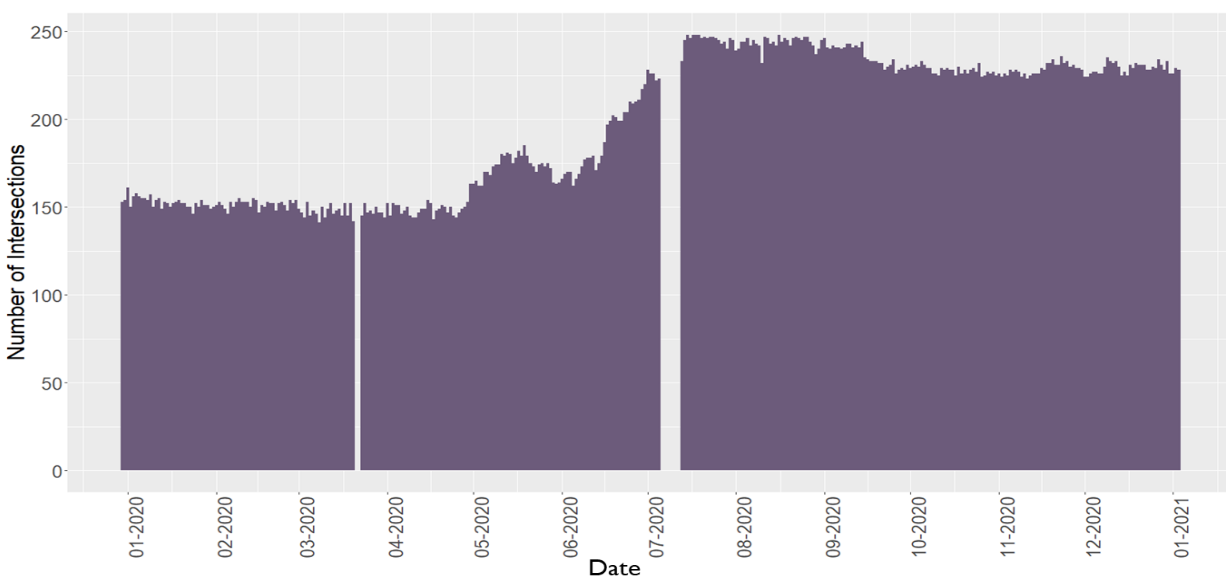
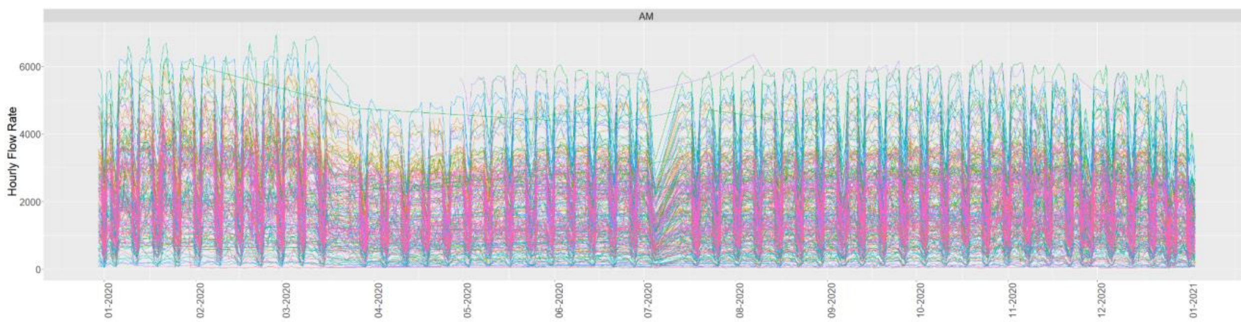


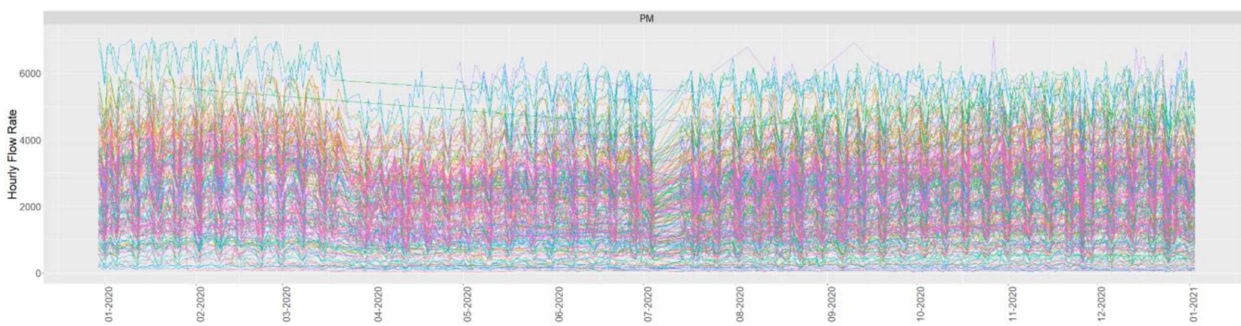
Figure 9-1 Number of intersections with available event-based data in 2020

9.1.2 Large-Scale Estimated Turning Movement Count Analysis

The raw event-based data was processed to use as the input of the proposed MLP-based estimation method described in Chapter 5, from which 15 minute interval TMC data was estimated. These estimated TMC data were further used to explore the spatial and temporal traffic patterns in the PAG region. **Figure 9-2** shows the temporal trends of hourly traffic flow rate for 263 intersections. The hourly traffic flow used in this analysis is at the intersection level, which consists of all TMC from all approaches. **Figure 9-2 (a)** shows the average hourly traffic flow rate during the AM peak (7-9 am), during which the average hourly traffic flow rate ranges from 0 to 6,000 vehicles per hour. Notice how the hourly traffic flow rate significantly decreased in March 2020 due to the pandemic and lockdown. Since May 2020, the hourly traffic flow rate did increase somewhat but still remained lower than the rate in March 2020 through the end of 2020. **Figure 9-2 (b)** shows the temporal trend during the PM peak, which is similar to the AM peak. The hourly traffic flow rates were then aggregated into weekly average flow rates, and the results are shown in **Figure 9-3**.

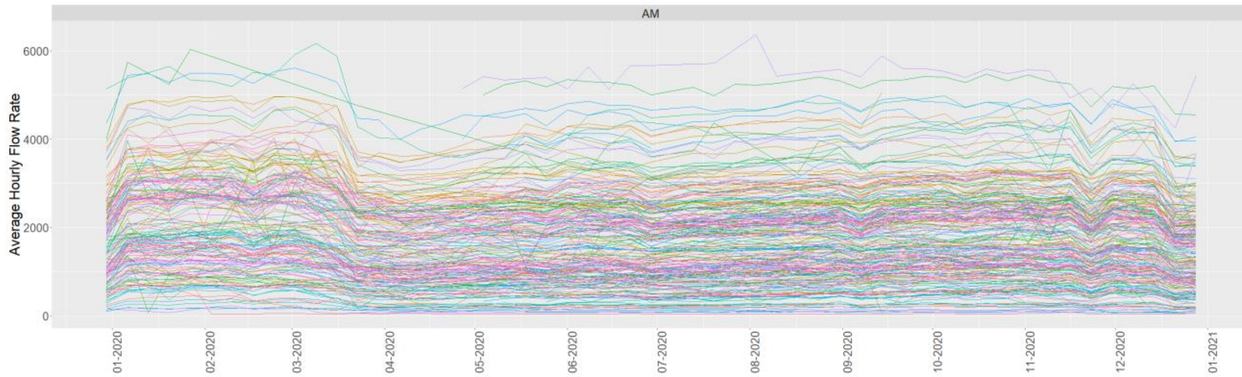


(a) AM Peak (7-9 am)

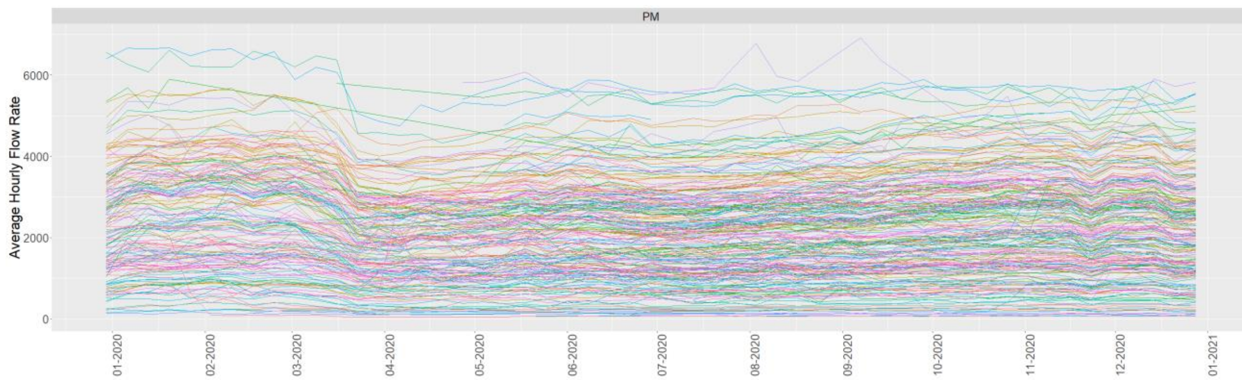


(b) PM Peak (4-6 pm)

Figure 9-2 Trend of hourly traffic flow by intersection during 2020



(a) AM Peak (7-9 am)

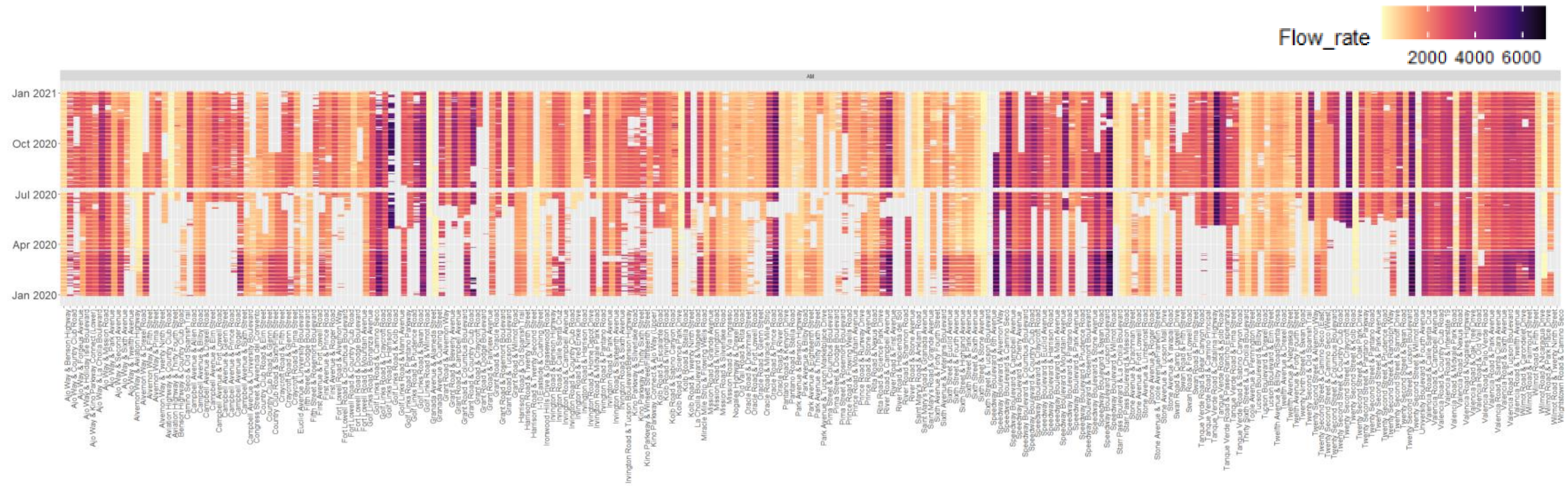


(a) PM Peak (4-6 pm)

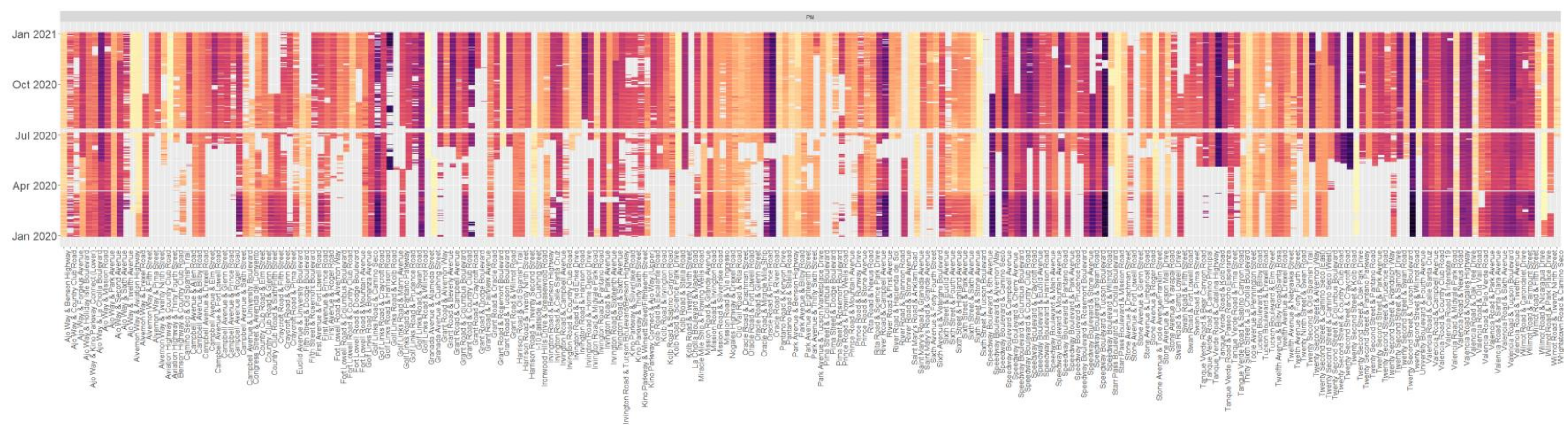
Figure 9-3 Trend of the weekly average traffic flow by intersection during 2020

Even though the TMCs for 263 intersections were estimated, the quality of the output is affected by individual intersection communication quality. **Figure 9-4** summarizes the data missing and estimated flow rates for the intersections during the AM and PM peak periods. Prior to May 2020, some intersections had generally unreliable communication which caused a loss of recorded data. After May 2020, many of these connectivity issues were resolved and more data was available.

Furthermore, Figure 9-4 shows that intersections on several major corridors, such as Speedway Boulevard, Golf Links Road, Wilmot Road, and Valencia Road, have much higher traffic flow rates.



(a) AM Peak (7-8am)



(b) PM Peak (4-5pm)

Figure 9-4 Trend of hourly traffic flow and missing data by intersection during 2020 (The gray color represents missing data)

In addition to analyzing the temporal traffic pattern, the estimated TMC and Miovision TMC were used to analyze the spatial distribution of traffic in the PAG region. We selected two sample days (February 5 and September 9) in 2020 to analyze the spatial distribution of traffic and the change from before the pandemic to during the pandemic. **Figure 9-5** shows pie charts at intersections where the pie radius represents the total traffic flow rate per hour of the intersection, and the different colors represent the TMC from different approaches. More intersections have data on September 9 than on February 5. Also, the spatial distribution map identifies the major and minor roads and approaches according to the TMC. **Figure 9-6** shows the average total hourly volume (average of total hourly TMC for all movements and approaches) at intersections during September 2020. The top 10 busiest intersections during September 2020 are summarized in **Table 9-1**.

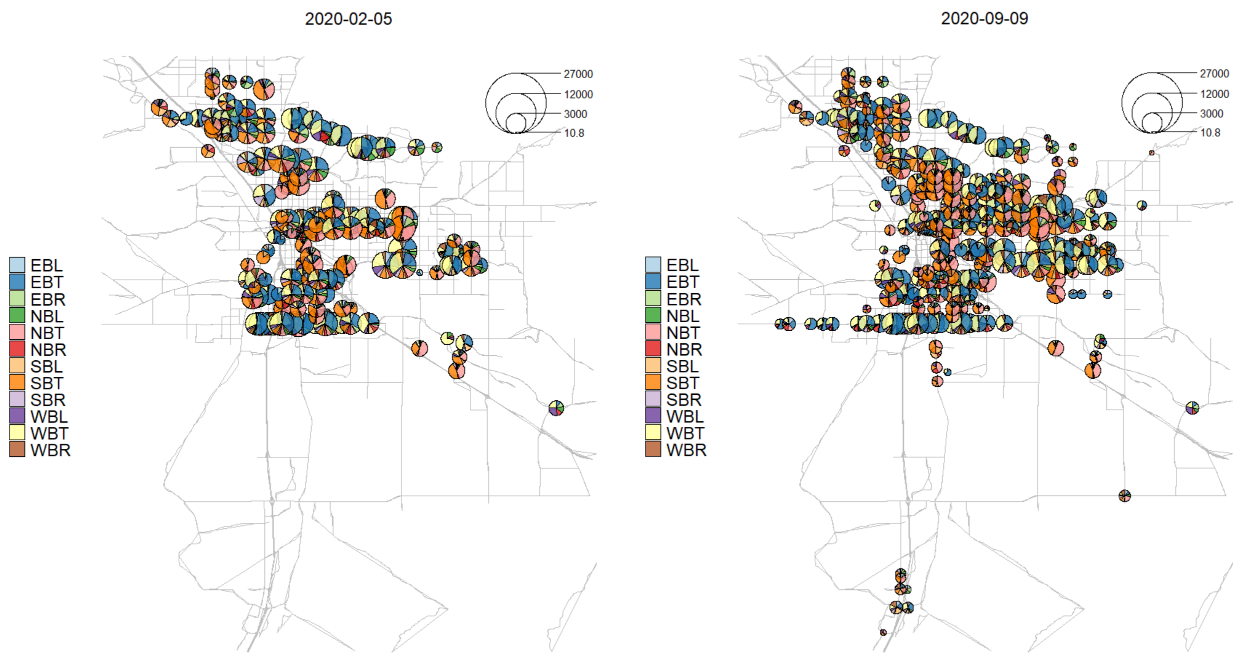


Figure 9-5 Maps of estimated and Movision hourly individual movement counts

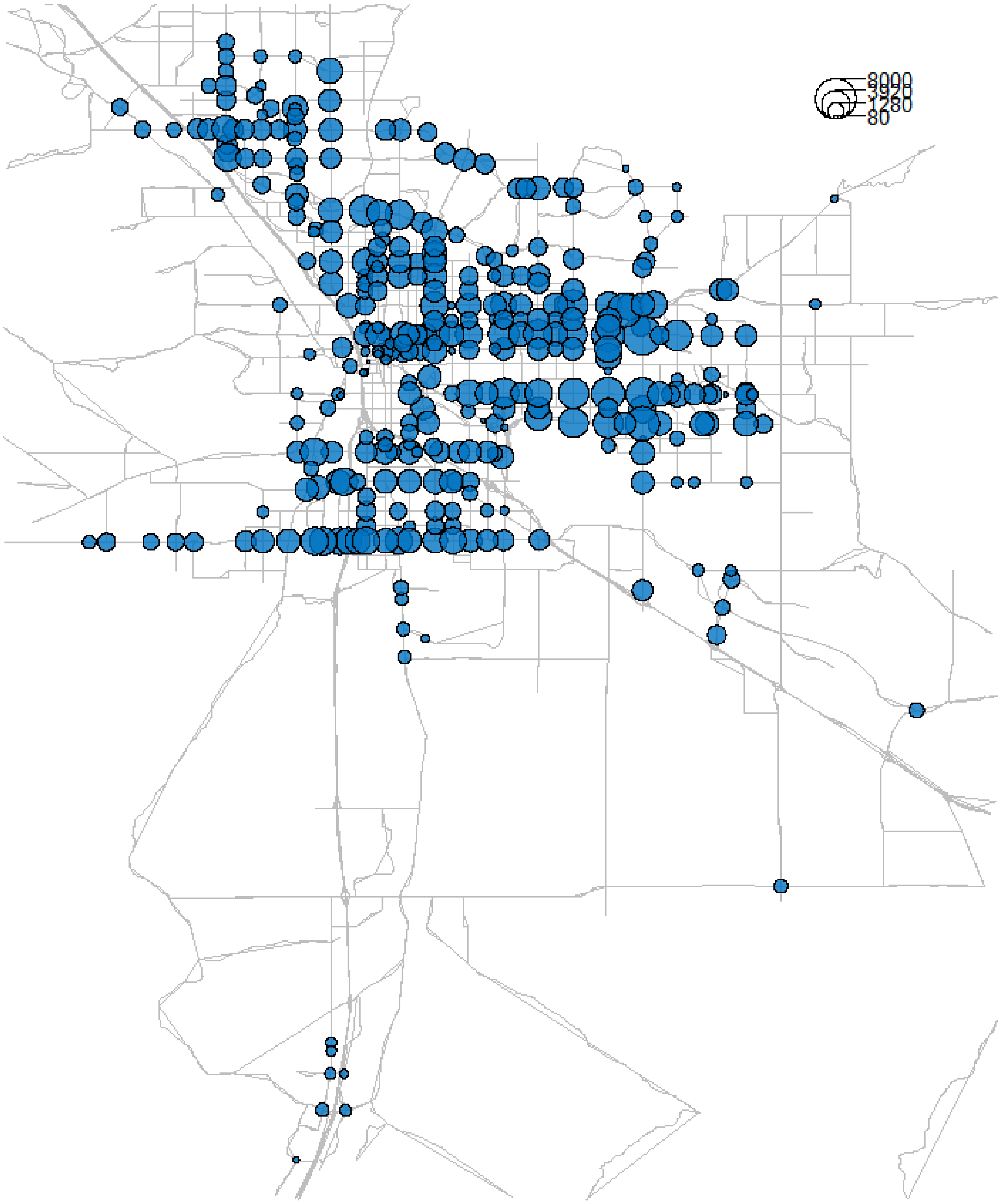


Figure 9-6 Map of total volume during peak hours by intersection in September 2020

Table 9-1 Top 10 Intersections with the Highest Average Hourly Volume during Peak Hours in September 2020

intID	Name	Longitude	Latitude	Average Hourly Volume	Rank
464	Speedway Boulevard & Kolb Road	-110.841	32.23557	7,396	1
754	Golf Links Road & Kolb Road	-110.841	32.19197	5,649	2
392	Tanque Verde Road & Kolb Road	-110.85	32.24809	5,576	3
679	Twenty Second Street & Kolb Road	-110.841	32.20651	5,317	4
462	Speedway Boulevard & Wilmot Road	-110.858	32.23582	5,274	5
677	Twenty Second Street & Wilmot Road	-110.858	32.20676	5,224	6
445	Speedway Boulevard & Campbell Avenue	-110.944	32.23607	4,799	7
453	Speedway Boulevard & Alvernon Way	-110.91	32.23619	4,600	8
150	Oracle Road & River Road	-110.978	32.29726	4,569	9
674	Twenty Second Street & Craycroft Road	-110.875	32.20691	4,488	10

Note: Full intersection ranking by average hourly volume can be found in Appendix D

9.2 LARGE-SCALE ROAD SEGMENT VOLUME

9.2.1 Data Collection

To apply the segment volume estimation method developed in Chapter 7, each roadway segment was paired with its upstream and downstream intersections. Using intersections with either available Miovision data or estimated TMC from the MLP model and roadway segments defined by PAG, 542 segments with their corresponding upstream and downstream intersections were identified, as shown in **Figure 9-7**.

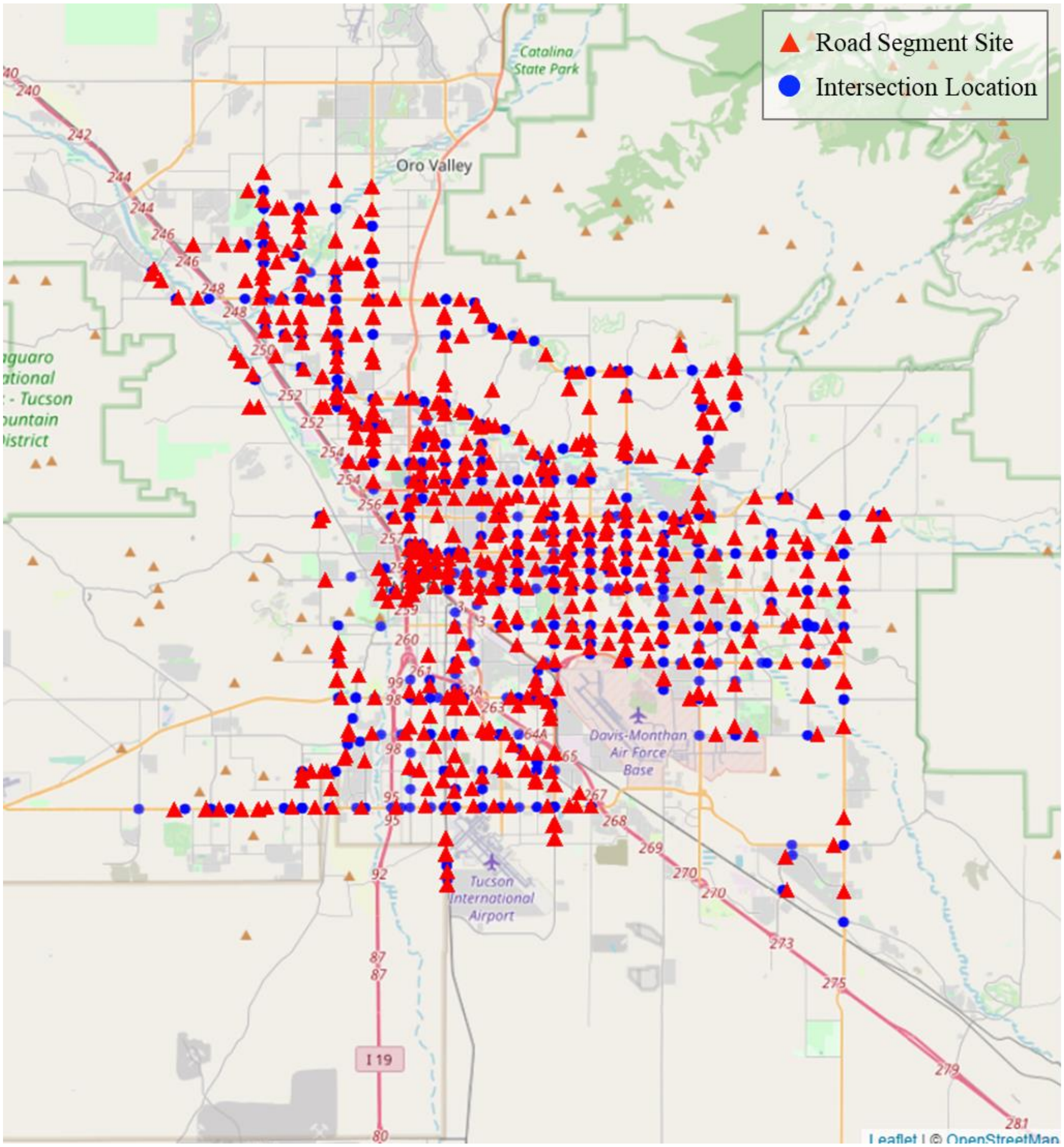


Figure 9-7 Segment sites and the corresponding upstream and downstream intersections

9.2.2 Large-Scale Segment Traffic Volume Analysis

Using the proposed segment volume estimation method, 358 directional segment volumes were generated, as some segments were missing data at either the upstream or downstream intersection and could not be estimated. As an example, the UArizona team picked the day of September 9, 2020, to illustrate the spatial distribution and temporal change of segment volume. **Figure 9-8** shows the AM and PM segment volumes in pie charts with different traffic directions. **Figure 9-9** shows the average hourly segment volume combining both directions during September 2020. The top 10 busiest segment locations are summarized in **Table 9-2**.

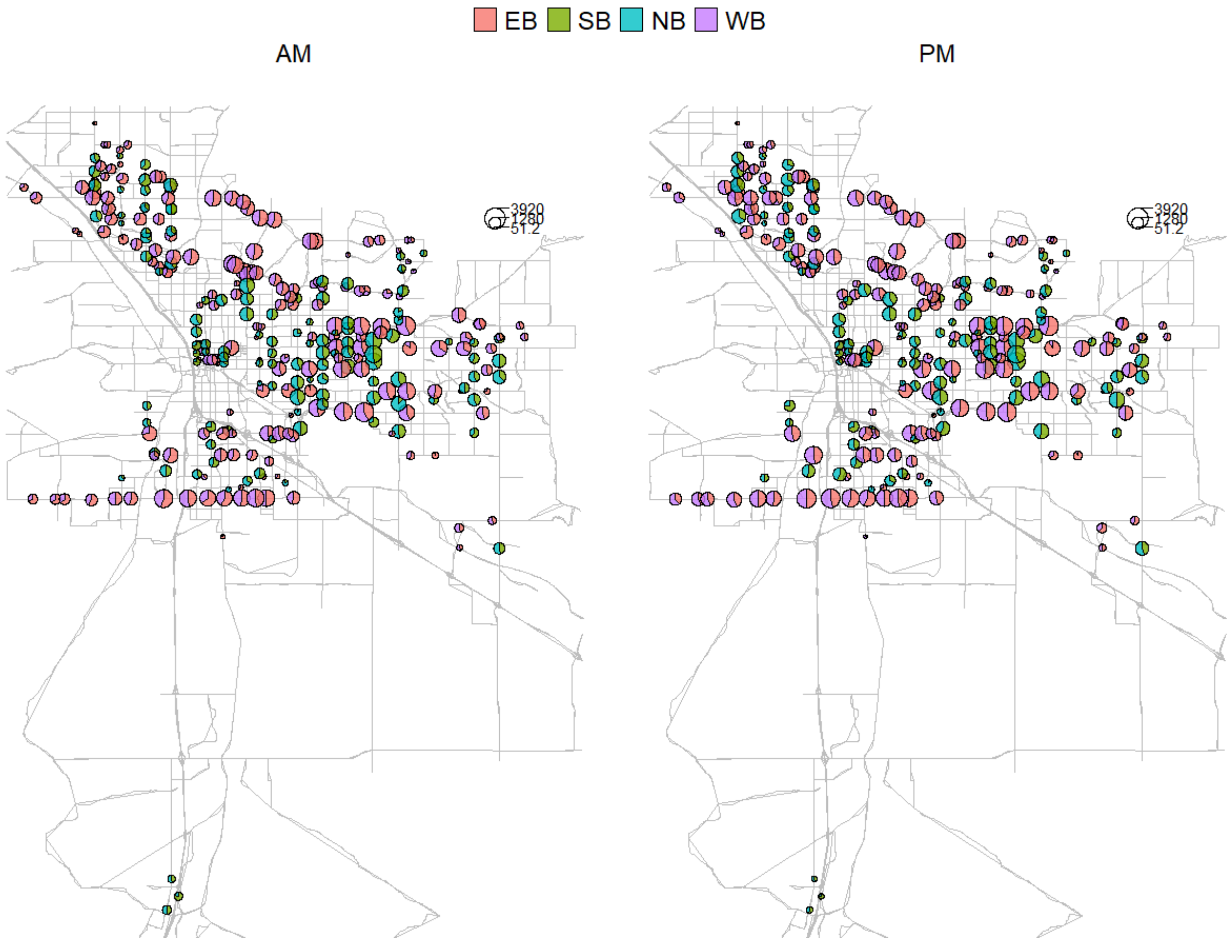


Figure 9-8 Maps of estimated directional segment volume during peak hours

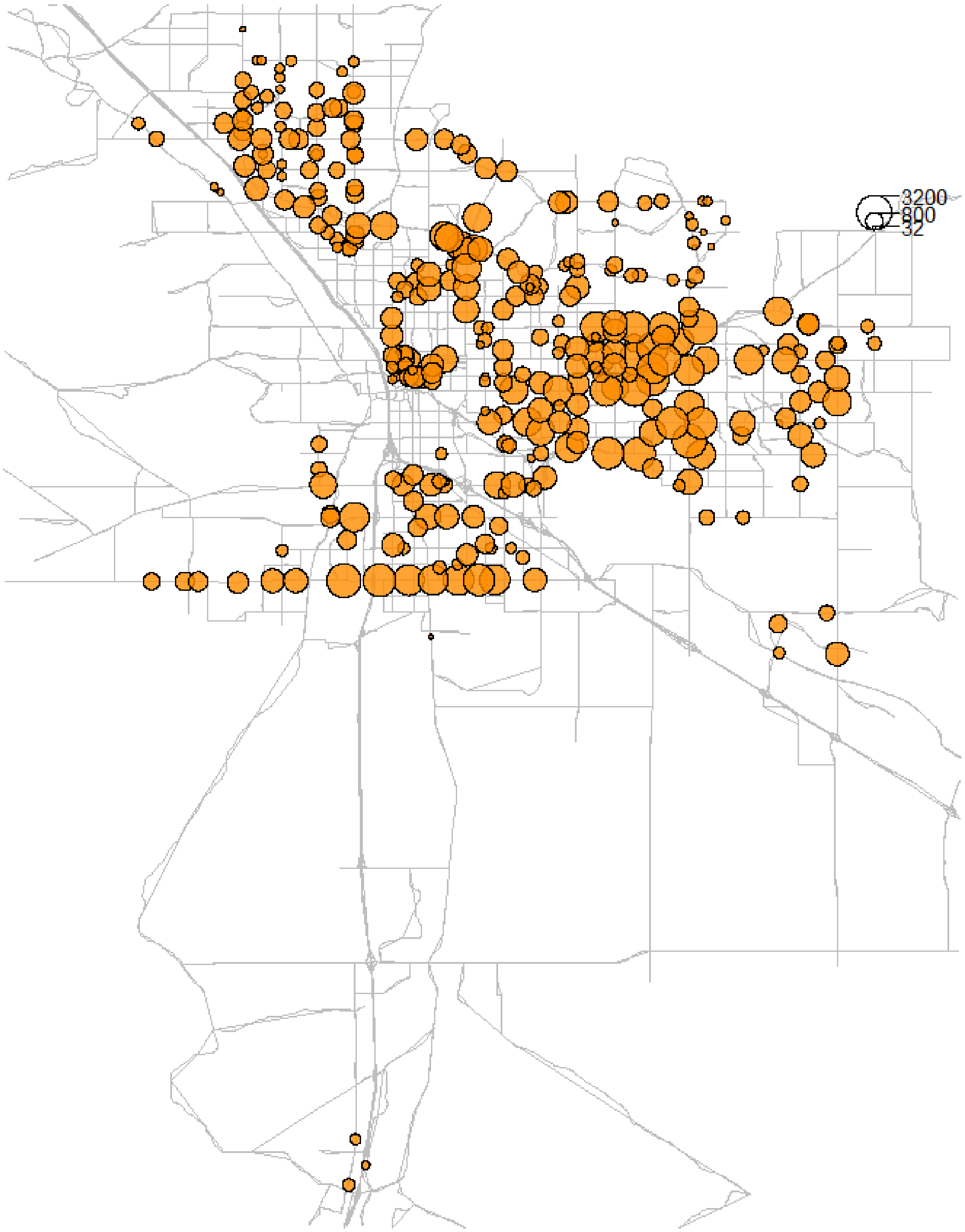


Figure 9-9 Map of total volume during peak hours by segment in September 2020

Table 9-2 Top 10 Segments with the Highest Hourly Average Volume during Peak Hours in September 2020

ID	**On_Road**	**From Intersection**	**To Intersection**	**Hourly Average Volume**	**Rank**
B-183	Tanque Verde Rd	Sabino Canyon Rd	Tanque Verde Rd WB	3,251	1
B-106	Kolb Rd	22nd St	Golf Links Rd	3,074	2
A-37	Valencia Rd	Mission Rd	I-19 SB On Ramp Valencia Rd	3,052	3
A-91	Golf Links Rd	Craycroft Rd	Wilmot Rd	2,933	4
B-191	Wilmot Rd	5th St	Broadway Blvd	2,847	5
C-97	Valencia Rd	I-19 SB On Ramp Valencia Rd	12th Ave	2,840	6
B-21	22nd St	Wilmot Rd	Kolb Rd	2,784	7
A-134	Speedway Blvd	Craycroft Rd	Wilmot Rd	2,759	8
A-124	Speedway Blvd	Wilmot Rd	Kolb Rd	2,747	9
B-56	Broadway Blvd	Swan Rd	Craycroft Rd	2,688	10

Note: Full segment ranking by average hourly volume can be found in Appendix E

CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS

This project focused on region-wide data analysis and integration through the exploration of multiple available sensors and data sources in the PAG region. The inventory of the sensor locations, brands, and technologies in six jurisdictions was comprehensively summarized. Sensor vendors were interviewed by email or phone to obtain the information needed to summarize the technology of the major sensors that are used in the PAG region. Then, the availability and accuracy of multiple types of data collected by these sensors and data provided by third parties were further explored and analyzed. A machine learning method was proposed to estimate TMC with the existing event-based data, avoiding the purchase of new sensors. In addition, segment volumes were estimated with estimated TMC and video-based TMC data at intersections, improving the data collection efficiency.

10.1 CONCLUSIONS

The major conclusions from the traffic sensor inventory and vendor interviews are summarized below:

- About 588 signalized intersections in the PAG region are equipped with intelligent sensors. Most intersections use a single type of sensor; only 4% of intersections use more than one type of sensor.
- Video-based sensors are the most common type of sensor used in the PAG region, with about 79% of intersections using video-based sensors, including Autoscope® and Miovision® sensors.
- About 70% of video-based sensors are outdated and have limited ability to collect and store remote traffic data.
- Outdated sensors are only configured with the traffic detection module for signal control and are not configured with the module for traffic data collection.

A limited number of intersections are configured with the traffic collection module, which can provide traffic volume data as well as other traffic parameters. Sample traffic volume data was collected from different video-based sensors for data quality verification. The major findings are summarized below:

- In comparison with ground-truth volume data, the %RMSE of volume data collected by advance detectors and "Volume count & Stop bar" detectors are 40% and 15%, respectively. The data collected by detectors that are close to the stop bar is more accurate than data collected by advance detectors.
- Of the TMC collected by "Volume count & Stop Bar" detectors, the through movement has the lowest error with a %RMSE of 10.1%. The %RMSE of the left-turn and right-turn movements are 16.8% and 31.2%, respectively. The right-turn movement has the highest error, likely because the right-turn volume is low during most periods.

- Miovision sensors have a higher error in traffic volume collection than Autoscope sensors, with a %RMSE of about 30%. One possible reason is that an intersection requires only one or two Miovision sensors, but an intersection uses one Autoscope sensor for each approach.
- The accuracy of Miovision sensors was found to be affected by the image background and requires more ground-truth data for further evaluation.

Most intersections have sensors that are not configured with the data collection module and cannot provide TMC data automatically. Even though these intersections are without a data collection module, the traffic detection module has been correctly configured for signal control. This traffic detection module can generate a large amount of event-based data, which is highly correlated with traffic volume. In this project, this event-based data collection and description were first summarized, and a model was developed to leverage the existing event-based data to estimate TMC.

- Related variables, such as occupancy time and green duration, were extracted from raw event-based data. Additionally, intersection layout and points of interest (POI) surrounding the intersection are independent variables for the TMC estimation model.
- A multi-output MLP-based model with four layers was developed to estimate through, left-turn, and right-turn volumes using selected variables.
- The proposed model was first calibrated using the ground-truth volume data from 84 intersections. Then, more ground-truth data were collected from 50 intersections in 2020 for model validation. The validation results show the average values of %RMSE of the through, left-turn, and right-turn movements are around 30%, 45%, and 60%, respectively. However, a few intersections have a very large error because the traffic patterns were changed due to road construction and other factors.

No mid-block sensors have been configured for segment volume data collection in the PAG region. Since the volume on a segment correlates highly with the volumes at the intersections upstream and downstream of the segment, and the volumes at intersections can be obtained by either estimation or sensors, a method was proposed to estimate segment volumes using traffic volumes at upstream and downstream intersections.

- 18 locations were selected to evaluate the performance of the proposed method. The evaluation results show that most locations have a mean absolute percent error (MAPE) lower than 20%, but one location has a higher MAPE of 41%.

In addition to traffic volume data, crowdsourced data in the PAG region was explored and analyzed in terms of data quality and availability.

- INRIX and HERE data can provide segment-based traffic speed, covering most major roads in the PAG region.

- INRIX reports higher quality of data during the daytime on weekdays. The data during nighttime and weekends is unreliable with a low confidence score.
- Speed data for most segments in the PAG region was reported with a low confidence score, indicating that the data quality was low. INRIX started to report high quality data for more segments in the PAG region after June 2019.
- In comparison with ground-truth GPS data, both INRIX data and HERE data overestimated the traffic speed during most periods. Both data sources have the same level of error with a MAPE of 26%.

10.2 RECOMMENDATIONS

Based on the results, some recommendations regarding the use of these data sources are provided. Also, some recommendations are made for further improvement of the project. All recommendations are summarized below.

- Currently, only Miovision sensors in the PAG region provide the remote data collection option. These signalized intersections with Miovision sensors could be continuous volume collection stations because of the convenience of data collection.
- The detectors in updated video-based sensors that are close to the stop bar yield higher accuracy. Therefore, it is suggested to use the volume data collected by detectors close to the stop bar.
- Estimated TMC and segment volumes have wide coverage because event-based data can be collected from most signalized intersections. Because the accuracy of the estimation results varies by location, this data source can be used as a supplemental data source for the PAG traffic count program.
- For TMC and segment volume estimation models, the inclusion of INRIX speed data in these two models did not significantly improve the model performance. It is unnecessary to add INRIX speed data as another input variable for these two proposed models.
- The proposed MLP model was calibrated using peak hour volume. Off peak hour volumes could be collected for model calibration.
- Most event-based data is generated by video-based sensors, and these video-based sensors are sensitive to vehicle headlights during the night; therefore, it is not suggested to use the proposed MLP model to estimate nighttime volumes.
- Additionally, estimated segment volume from TMC outputs found a high correlation between the estimated TMC or video-based TMC and ground-truth segment volume data, and the model to estimate AADT using existing data sources can be further developed..
- More sample data are required to evaluate Miovision data quality. The results so far show data quality issues that might be related to the background of the camera image.
- Event-based data has shown its use in TMC estimation and has the advantages of high availability and large coverage. In addition to TMC data, other traffic performance measures at signalized intersections (such as delay and level-of-service) are important for

regional Transportation Systems Management and Operations (TSMO). Further study is needed to further explore the potential use of event-based data in the development of cost-effective regional TSMO-related performance measures.

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APPENDIX A: LITERATURE REVIEW OF TRAFFIC DATA PROCESSING

- **DATA CLEANING**

Big traffic data may have data quality issues such as missing data and outliers. To obtain high quality traffic data, the raw data must be processed and cleaned first. Multiple studies have been conducted to clean traffic data. The Traffic Monitoring Guide (Traffic Monitoring Guide, 2016) suggests using the average method to process missing and invalid traffic count data. For example, the missing and invalid data during a period on a day can be replaced with the average of the data from the same time period of the same weekday but from other weeks. In addition to traffic count data, the floating car (probe vehicle) data must also be processed due to the issue of missing data. The missing floating car data can be replaced with the output of nonparametric regression using historical data under various traffic conditions(Lv et al., 2009). The missing floating car data can also be replaced using a weighted average method and exponential smoothing method, and the abnormal traffic data can be cleaned using a normalization transform (Zhang et al., 2013). We also summarized the methods for cleaning crowdsourced data. HERE data, one of the available crowdsourced data sources in the PAG region, may report abnormal speeds. Some studies suggest simply removing any data with a speed above 60 mph or below 5 mph on arterials. Some crowdsourced data can provide raw GPS data, but some outliers may be generated, and these outliers can be interpolated and smoothed using a rational transfer function proposed by (Wang et al., 2017).

- **DATA FUSION AND INTEGRATION**

Various traffic data sources have become available, and these data sources have been fused and integrated to solve transportation problems, which is more efficient than using a single data source. (Huang et al., 2009) used a dynamic traffic assignment mode to develop a data fusion framework, which can fuse the data collected by loop detectors, video-based sensors, and toll counters. The data collected by loop detectors and Bluetooth can yield higher performance in traffic speed estimation than single data sources (Bachmann et al., 2012, 2013). The GPS data can be integrated with social media data (such as Twitter data) for congestion estimation (Wang et al., 2016). Different data sources provide different traffic parameters. These different parameters provided by different data sources can be integrated to comprehensively understand traffic performance. For example, different data collected by loop detectors is used with floating car data to estimate the macroscopic fundamental diagram (Ambühl & Menendez, 2016). Additionally, the data collected by video-based sensors and GPS data are used for density estimation with a lower error (Anand et al., 2011).

APPENDIX B: DATA COLLECTION DESCRIPTION

Table B-1: The Summary of Data Collection Method

Data Source	Data Collection Method	Requirements	Collection Code File Name	Code Description
Event-based data	Query from MaxView database	VPN account & Database account	Read Event-based data. R	Read raw events of detection, signal, and communication
INRIX data	Query from UArizona database	VPN account & Database account	Segment_Inrix.R	Read speed data from multiple segments in the PAG region
HERE data	Using a free API	Get the API key from the HERE website	/	/
Miovision data	Using an API	API key	PCDOT_Miovision. R	Read intersection ID first. Then, read volume data based on intersection ID.
Autoscope data	Provided by the City of Tucson	/	/	/
Left-turn signal type	Manually collected from MaxView interface	VPN account & MaxView account	/	/
Intersection movement type	Manually collected from MaxView interface	VPN account & MaxView account	/	/
Intersection layout	Manually collected from Google Earth and MaxView interface	VPN account & MaxView account	/	/
POI data	Provided by PAG	/	/	/

APPENDIX C: MULTILAYER PERCEPTRON MODEL DESCRIPTION

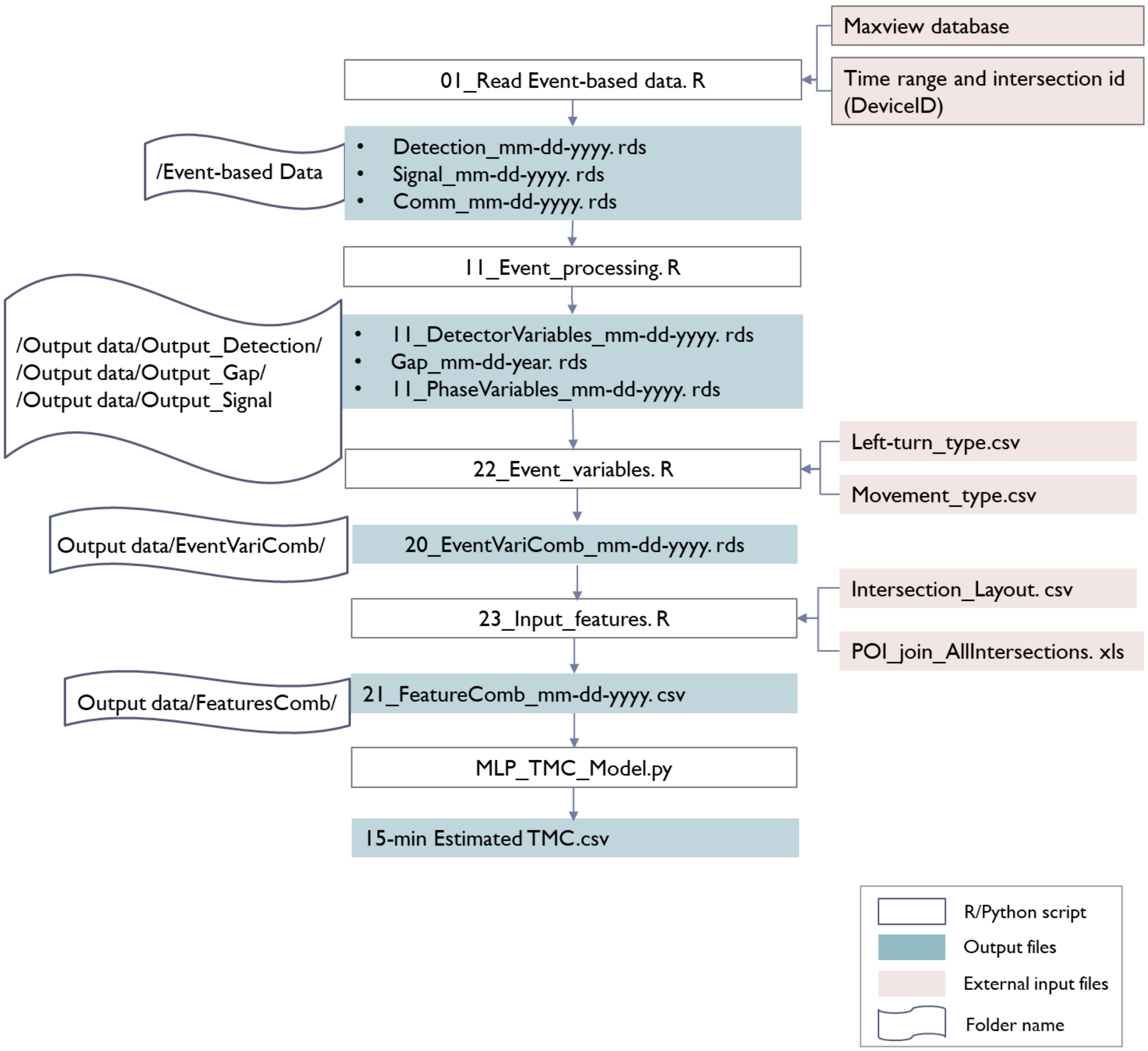

Figure C-1: Frame of MLP-based model code script

Table C-1: Description of the MLP-based Model

Input	Input Description	Code File Name	Code Description	Output	Output Description
• Maxview database • Time range and Intersection id list	Setting the time range and intersection id list based on requirements	01_Read Event-based data.R	Read three types of event-based data from UArizona database	Detection_mm-dd-yyyy.rds	Obtain detector event-based data with start date of mm-dd-yyyy
				Signal_mm-dd-yyyy.rds	Obtain signal change event-based data with start date of mm-dd-yyyy
				Comm_mm-dd-yyyy.rds	Obtain communication loss event-based data with start date of mm-dd-yyyy
• Detection_mm-dd-yyyy.rds • Signal_mm-dd-yyyy.rds • Comm_mm-dd-yyyy.rds	Raw data of detection, signal, and communication events are input by month	11_Event_processing.R	Processing raw events to calculate the input variables for MLP model	11_DetectorVariables_mm-dd-yyyy.rds	Obtain occupancy time, number of detections, and gap time
				11_PhaseVariables_mm-dd-yyyy.rds	Obtain green time and number of cycles
• 11_DetectorVaiables_mm-dd-yyyy.rds • 11_PhaseVariables_mm-dd-yyyy.rds • left_turn_type.csv • movement_type.csv	Four different types of variables	22_Event_variables.R	Combine these variables and organize the data format for model inputs.	20_Event_VariComb_mm-dd-yyyy.rds	Output the data containing most input variables by month

• 20_Event_VariComb_mm-dd-yyyy.rds • Intersection_Layout.csv • POI_join_AllIntersections.xls	Two more types of variables	23_Input_features.R	Combine intersection layout and POI.	21_FeatureComb_mm-dd-yyyy.csv	Output the final input by month
• 21_FeatureComb_mm-dd-yyyy.csv	Final input variables	MLP_TMC_Model.py	TMC estimation using MLP-based model	Estimated TMC data	15-min estimated TMC value

APPENDIX D: INTERSECTION RANKING BY AVERAGE HOURLY VOLUME DURING PEAK HOURS IN SEPTEMBER 2020

IntID	Name	Longitude	Latitude	Average Hourly Volume	Rank
464	Speedway Boulevard & Kolb Road	-110.841	32.23557	7396	1
754	Golf Links Road & Kolb Road	-110.841	32.19197	5649	2
392	Tanque Verde Road & Kolb Road	-110.85	32.24809	5576	3
679	Twenty Second Street & Kolb Road	-110.841	32.20651	5317	4
462	Speedway Boulevard & Wilmot Road	-110.858	32.23582	5274	5
677	Twenty Second Street & Wilmot Road	-110.858	32.20676	5224	6
445	Speedway Boulevard & Campbell Avenue	-110.944	32.23607	4799	7
453	Speedway Boulevard & Alvernon Way	-110.91	32.23619	4600	8
150	Oracle Road & River Road	-110.978	32.29726	4569	9
674	Twenty Second Street & Craycroft Road	-110.875	32.20691	4488	10
466	Speedway Boulevard & Pantano Road	-110.824	32.23557	4476	11
366	Grant Road & Craycroft Road	-110.875	32.25069	4401	12
667	Twenty Second Street & Alvernon Way	-110.91	32.20703	4399	13
752	Golf Links Road & Wilmot Road	-110.858	32.19213	4312	14
750	Golf Links Road & Craycroft Road	-110.875	32.19226	4263	15
154	River Road & First Avenue	-110.961	32.29536	4076	16
456	Speedway Boulevard & Swan Road	-110.893	32.23624	4045	17
460	Speedway Boulevard & Craycroft Road	-110.876	32.23618	3974	18
352	Grant Road & Campbell Avenue	-110.944	32.25023	3860	19
795	Ajo Way & Mission Road	-111.003	32.17791	3796	20
913	Valencia Road & Midvale Park Road	-110.999	32.13379	3741	21
671	Twenty Second Street & Swan Road	-110.892	32.20697	3724	22
917	Valencia Road & Twelfth Avenue	-110.978	32.13399	3679	23
918	Valencia Road & Twelfth Avenue	-110.978	32.13399	3679	24
104	North Thornydale Road and West Orange Grove Road	-111.046	32.32359	3665	25
837	Irvington Road & Home Depot Drive	-110.989	32.16325	3655	26
3468	Valencia Road & Oak Tree Drive	-111.003	32.13382	3655	27
372	Tanque Verde Road & Paseo Rancho Esperanza	-110.836	32.25075	3642	28
914	Valencia Road & Calle Santa Cruz	-110.991	32.13382	3610	29
749	Golf Links Road & Swan Road	-110.893	32.19531	3599	30
920	Valencia Road & Nogales Highway	-110.962	32.13402	3541	31
664	Twenty Second Street & Country Club Road	-110.927	32.20692	3540	32
449	Speedway Boulevard & Country Club Road	-110.927	32.236	3504	33
724	Kolb Road & Twenty Ninth Street	-110.841	32.19902	3483	34

522	Wilmot Road & Fifth Street	-110.858	32.2289	3471	35
242	Oracle Road & Prince Road	-110.978	32.27195	3455	36
86	West Ina Road and North Thornydale Road	-111.047	32.33774	3450	37
915	Valencia Road & Interstate 19	-110.987	32.13401	3414	38
924	Valencia Road & Tucson Boulevard	-110.935	32.13413	3363	39
391	Tanque Verde Road & Camino Principal	-110.847	32.24966	3337	40
181	River Road & Campbell Avenue	-110.944	32.28716	3300	41
552	Wilmot Road & Carondelet Drive	-110.858	32.22526	3254	42
1002	Wilmot Road & Carondelet Drive	-110.858	32.22526	3254	43
369	Grant Road & Wilmot Road	-110.858	32.25065	3245	44
73	La Cholla Bl / Magee Rd	-111.013	32.34797	3173	45
441	Speedway Boulevard & Euclid Avenue	-110.96	32.23601	3163	46
358	Grant Road & Alvernon Way	-110.91	32.25062	3151	47
55	Hardy Rd / La Canada Dr / Overton Rd	-110.996	32.3665	3148	48
683	Twenty Second Street & Pantano Parkway	-110.824	32.20645	3145	49
916	Valencia Road & Santa Clara Avenue	-110.982	32.1339	3117	50
220	Campbell Avenue & Allen Road	-110.944	32.27586	3102	51
152	River Road & Stone Avenue	-110.971	32.29627	3098	52
424	Wilmot Road & Fairmount Street	-110.858	32.23969	3094	53
279	Campbell Avenue & Fort Lowell Road	-110.944	32.26486	3016	54
919	Valencia Road & Sixth Avenue	-110.968	32.13402	2998	55
923	Valencia Road & Campbell Avenue	-110.944	32.13413	2970	56
148	La Canada Dr / River Rd	-110.995	32.29746	2965	57
447	Speedway Boulevard & Tucson Boulevard	-110.935	32.2361	2954	58
508	Campbell Avenue & Sixth Street	-110.944	32.22786	2950	59
681	Twenty Second Street & Prudence Road	-110.832	32.20649	2950	60
438	Speedway Boulevard & Stone Avenue	-110.972	32.23594	2895	61
763	Golf Links Road & Harrison Road	-110.79	32.19178	2893	62
836	Irvington Road & Calle Santa Cruz	-110.991	32.16318	2886	63
455	Speedway Boulevard & Columbus Boulevard	-110.901	32.23618	2885	64
845	Irvington Road & Campbell Avenue	-110.943	32.1633	2883	65
355	Grant Road & Country Club Road	-110.927	32.25037	2867	66
364	Grant Road & Rosemont Boulevard	-110.884	32.25067	2847	67
921	Valencia Road & Park Avenue	-110.956	32.1341	2847	68
293	Miracle Mile Strip & Flowing Wells Road	-110.995	32.26122	2811	69
804	Ajo Way & Park Avenue	-110.956	32.17788	2803	70
139	Sunrise Dr / Swan Rd	-110.893	32.30839	2781	71
345	Grant Road & Fairview Avenue	-110.986	32.2503	2778	72
758	Golf Links Road & Camino Seco	-110.812	32.19186	2770	73
458	Speedway Boulevard & Rosemont Boulevard	-110.884	32.2362	2760	74

911	Mission Rd / Valencia Rd	-111.016	32.13386	2754	75
92	Ina Rd / La Canada Dr	-110.995	32.33719	2726	76
814	Kolb Road & Escalante Road	-110.841	32.17741	2726	77
371	Tanque Verde Road & Sabino Canyon Road	-110.841	32.25079	2717	78
412	Tanque Verde Road & Pima Street	-110.857	32.24319	2710	79
835	Irvington Road & Midvale Park Road	-111.001	32.16037	2708	80
813	Ajo Wy / Alvernon Wy	-110.911	32.17545	2705	81
802	Ajo Way & Sixth Avenue	-110.968	32.17782	2704	82
755	Golf Links Road & Prudence Road	-110.832	32.19196	2700	83
627	Kino Parkway & Winsett Street/Fifthteenth Street	-110.946	32.21505	2692	84
277	First Avenue & Fort Lowell Road	-110.961	32.26481	2671	85
846	Irvington Road & Tucson Boulevard/Benson Highway	-110.936	32.16322	2663	86
843	Irvington Road & Sixth Avenue	-110.968	32.16326	2640	87
759	Golf Links Road & Pantano Parkway	-110.809	32.19184	2626	88
239	Prince Road & Flowing Wells Road	-110.995	32.27214	2623	89
715	Kino Parkway & Silverlake Road	-110.95	32.1996	2619	90
834	Mission Road & Irvington Road	-111.007	32.15937	2607	91
408	Craycroft Road & Pima Street	-110.876	32.24343	2592	92
437	Speedway Boulevard & Main Avenue	-110.978	32.23586	2590	93
91	Ina Rd / La Cholla Bl	-111.013	32.33728	2582	94
844	Irvington Road & Park Avenue	-110.956	32.16335	2578	95
146	La Cholla Bl / River Rd	-111.012	32.30518	2576	96
810	Ajo Way & Country Club Road	-110.926	32.17798	2566	97
248	Campbell Avenue & Prince Road	-110.944	32.27222	2558	98
740	Kino Parkway & Thirty Sixth Street	-110.947	32.19241	2556	99
910	Cardinal Av / Valencia Rd	-111.029	32.13378	2531	100
925	Valencia Road & Country Club Road	-110.926	32.13412	2526	101
657	Twenty Second Street & Park Avenue	-110.956	32.20687	2514	102
357	Grant Road & Dodge Boulevard	-110.914	32.25057	2502	103
665	Twenty Second Street & Randolph Way	-110.918	32.20703	2494	104
520	Craycroft Road & Fifth Street	-110.876	32.22893	2482	105
717	Alvernon Way & Twenty Ninth Street	-110.91	32.1995	2475	106
287	Swan Road & Camp Lowell Drive	-110.892	32.26538	2468	107
856	Kolb Road & Irvington Road	-110.841	32.16283	2466	108
245	First Avenue & Prince Road	-110.961	32.27205	2456	109
322	Craycroft Road & Glenn Street	-110.875	32.25792	2432	110
190	Flowing Wells Rd / Wetmore Rd	-110.995	32.28681	2431	111
515	Alvernon Way & Fifth Street	-110.91	32.22891	2422	112
285	Fort Lowell Road & Alvernon Way	-110.91	32.26513	2420	113

116	Campbell Av / Skyline Dr	-110.929	32.32264	2419	114
68	La Canada Dr / Magee Rd	-110.996	32.3518	2408	115
313	Campbell Avenue & Glenn Street	-110.944	32.25755	2392	116
517	Swan Road & Fifth Street	-110.893	32.22881	2386	117
360	Grant Road & Columbus Boulevard	-110.901	32.25062	2354	118
719	Twenty Ninth Street & Swan Road	-110.892	32.19973	2347	119
329	Tanque Verde Road & Catalina Highway	-110.799	32.25803	2338	120
444	Speedway Boulevard & Cherry Avenue	-110.948	32.23599	2337	121
405	Swan Road & Pima Street	-110.893	32.2434	2336	122
468	Speedway Boulevard & Camino Seco	-110.807	32.23547	2320	123
442	Speedway Boulevard & Park Avenue	-110.957	32.23603	2314	124
753	Golf Links Road & Mann Avenue	-110.85	32.19196	2314	125
811	Ajo Wy / Palo Verde Rd	-110.918	32.17796	2311	126
328	Tanque Verde Road & Bear Canyon Road	-110.802	32.25808	2290	127
809	Ajo Way & Forgeus Avenue	-110.932	32.17795	2284	128
96	1st Av / Christie Dr / Ina Rd	-110.961	32.33726	2283	129
470	Speedway Boulevard & Harrison Road	-110.79	32.23544	2263	130
794	Ajo Way & La Cholla Boulevard	-111.012	32.17789	2258	131
503	Sixth Street & Euclid Avenue	-110.96	32.22777	2256	132
690	Harrison Road & Twenty Second Street	-110.79	32.20632	2237	133
180	River Rd / Via Entrada	-110.95	32.2915	2217	134
926	Valencia Road & Palo Verde Road	-110.918	32.13418	2209	135
800	Ajo Way & Twelfth Avenue	-110.978	32.17782	2205	136
796	Ajo Way & Holiday Isle Boulevard	-110.994	32.17785	2193	137
108	La Cholla Bl / Orange Grove Rd	-111.012	32.32316	2187	138
685	Twenty Second Street & Sarnoff Drive	-110.815	32.20643	2182	139
300	Swan Road & Fort Lowell Road	-110.893	32.26148	2177	140
807	Ajo Way & Kino Parkway Connect (Lower)	-110.941	32.1779	2173	141
85	West Ina Road and North Oldfather Road	-111.056	32.33743	2165	142
216	Campbell Avenue & Roger Road	-110.944	32.2795	2133	143
64	Cortaro Farms Rd / Thornydale Rd	-111.047	32.35905	2130	144
669	Twenty Second Street & Columbus Boulevard	-110.901	32.20699	2124	145
95	Ina Rd / Westward Look Dr	-110.968	32.33715	2110	146
9569	Kolb Road & Science Park Drive	-110.841	32.10946	2094	147
115	Orange Grove Rd / Skyline Dr	-110.939	32.32569	2088	148
398	Campbell Avenue & Elm Street	-110.944	32.24269	2063	149
137	Pontatoc Rd / Sunrise Dr	-110.903	32.30826	2062	150
243	Prince Road & Stone Avenue	-110.972	32.27198	2062	151
909	Camino de la Tierra / Valencia Rd	-111.037	32.13375	2057	152
89	Ina Rd / Shannon Rd	-111.029	32.33739	2037	153

229	Craycroft Rd / River Rd	-110.875	32.27345	2031	154
927	Alvernon Wy / Valencia Rd	-110.91	32.13423	2023	155
138	Calle del Marques / Sunrise Dr	-110.899	32.30832	2012	156
110	La Canada Dr / Orange Grove Rd	-110.995	32.32321	2008	157
275	Stone Avenue & Fort Lowell Road	-110.972	32.26474	2003	158
214	First Avenue & Roger Road	-110.961	32.27935	1993	159
929	Benson Hy / Swan Rd / Valencia Rd	-110.892	32.13439	1980	160
687	Twenty Second Street & Camino Seco (East)	-110.807	32.20644	1973	161
365	Grant Road & Beverly Avenue	-110.88	32.25068	1970	162
495	Saint Mary's Road & Grande Avenue	-110.99	32.22961	1960	163
87	West Ina Road and North Meredith Boulevard	-111.043	32.33733	1956	164
T003	West Ina Road and North Camino de los Capas	-111.061	32.33783	1942	165
118	Campo Abierto / Sunrise Dr	-110.919	32.32053	1921	166
723	Wilmot Road & Twenty Ninth Street	-110.858	32.19969	1921	167
443	Speedway Boulevard & Mountain Avenue	-110.952	32.23597	1918	168
512	Country Club Road & Sixth/Fifth Street	-110.927	32.22853	1857	169
88	Camino de la Tierra / Ina Rd	-111.038	32.33747	1856	170
257	Kolb Road & Sabino Canyon Road	-110.842	32.24007	1851	171
4131	Kolb Road & Sabino Canyon Road	-110.842	32.24007	1851	172
263	Cloud Rd / Sabino Canyon Rd	-110.841	32.26906	1829	173
141	Suncrest Pl / Sunrise Dr	-110.88	32.30861	1822	174
99	North Thornydale Road and West Horizon Hills Drive	-111.046	32.33027	1820	175
728	Harrison Road & Twenty Ninth Street	-110.79	32.19904	1818	176
100	North Thornydale Road and West Costco Drive	-111.046	32.32628	1811	177
884	Twelfth Avenue & Drexel Road	-110.978	32.14869	1804	178
309	Stone Avenue & Glenn Street	-110.972	32.2576	1784	179
346	Grant Road & Oracle Road	-110.978	32.25022	1780	180
105	Camino De La Tierra / Orange Grove Rd	-111.037	32.32321	1777	181
888	Campbell Avenue & Drexel Road	-110.944	32.14868	1766	182
90	Ina Rd / Mona Lisa Rd	-111.021	32.33733	1752	183
403	Alvernon Way & Pima Street	-110.91	32.24345	1739	184
66	Magee Rd / Thornydale Rd	-111.047	32.35177	1735	185
142	Craycroft Rd / Sunrise Dr	-110.875	32.30873	1733	186
640	Harrison Road & Old Spanish Trail	-110.79	32.20763	1725	187
315	Country Club Road & Glenn Street	-110.927	32.25769	1715	188
NA	Rita Road & Science Park Drive	-110.804	32.08738	1702	189
465	Speedway Boulevard & Prudence Road	-110.833	32.23558	1701	190
900	Twelfth Avenue & Bilby Road/Santa Rosa	-110.978	32.14132	1690	191
97	Ina Rd / Pima Canyon Dr / Skyline Dr	-110.947	32.33603	1685	192

282	Fort Lowell Road & Country Club Road	-110.927	32.26497	1684	193
213	Stone Avenue & Roger Road	-110.972	32.27917	1668	194
286	Fort Lowell Road & Columbus Boulevard	-110.901	32.26511	1645	195
849	Irvington Road & Country Club Road	-110.926	32.1632	1640	196
908	Camino de Oeste / Valencia Rd	-111.063	32.13344	1637	197
765	Golf Links Road & Bonanza Avenue	-110.781	32.19176	1632	198
7691	37th St / Golf Links Rd / Palo Verde Rd	-110.914	32.19214	1625	199
278	Fort Lowell Road & Mountain Avenue	-110.952	32.2648	1622	200
485	Euclid Avenue & University Boulevard	-110.96	32.23166	1621	201
224	Alvernon Wy / Brandi Fenton Dw / River Rd	-110.919	32.27489	1601	202
178	Stone Avenue & Tucson Mall Drive	-110.97	32.28871	1598	203
806	Kino Parkway Connect & Ajo Way (Upper)	-110.945	32.18019	1596	204
226	River Rd / Swan Rd	-110.893	32.27934	1585	205
258	Knollwood Dr / River Rd / Sabino Canyon Rd	-110.839	32.27245	1583	206
502	Sixth Street & Fourth Avenue	-110.966	32.22775	1579	207
682	Twenty Second Street & Pantano Road	-110.827	32.20639	1564	208
504	Sixth Street & Park Avenue	-110.956	32.22779	1555	209
847	Irvington Road & Benson Highway	-110.934	32.16322	1533	210
686	Twenty Second Street & Camino Seco (West)	-110.809	32.20642	1525	211
506	Sixth Street & Highland Avenue	-110.951	32.22782	1523	212
9068	Camino Verde / Valencia Rd	-111.106	32.1334	1518	213
106	Orange Grove Rd / Shannon Rd	-111.029	32.32316	1514	214
501	Sixth Street & Sixth Avenue	-110.969	32.22771	1500	215
132	River Road & Shannon Road	-111.029	32.31009	1467	216
907	Mark Rd / Valencia Rd	-111.072	32.13342	1467	217
163	La Cholla Bl / Ruthrauff Rd	-111.012	32.29436	1442	218
869	Twelfth Avenue & Nebraska Street	-110.978	32.15592	1441	219
78	Foothills Mall Dr / La Cholla Bl	-111.013	32.34391	1423	220
400	Country Club Road & Elm Street	-110.927	32.24323	1423	221
904	Campbell Avenue & Bilby Road	-110.944	32.14133	1423	222
246	Prince Road & Mountain Avenue	-110.952	32.27212	1405	223
973	Rita Road & Nexus Road	-110.797	32.11493	1400	224
721	Magee Rd / Shannon Rd / Tuscany Dr	-111.025	32.34801	1395	225
886	Nogales Highway & Drexel Road	-110.962	32.14856	1370	226
65	Cortaro Farms Rd / Magee Rd / Shannon Rd	-111.033	32.35434	1356	227
1013	Park Avenue & Tucson Marketplace Drive	-110.956	32.18739	1356	228
739	Park Avenue & Thirty Sixth Street	-110.956	32.19243	1352	229
71	North Silverbell Road and North Cortaro Road	-111.099	32.34848	1346	230
889	Tucson Boulevard & Drexel Road	-110.935	32.14873	1343	231
147	Curtis Rd / La Cholla Bl	-111.012	32.30148	1331	232

774	Sixth Avenue & Forty Fourth Street	-110.968	32.18507	1321	233
236	Prince Road & Runway Drive	-111.007	32.27242	1319	234
43	Linda Vista Bl / Thornydale Rd	-111.047	32.38074	1313	235
81	North Silverbell Road and West Ina Road	-111.088	32.33741	1310	236
222	Alvernon Wy / Dodge Bl	-110.914	32.27285	1290	237
9069	Casino del Sol Dr / Valencia Rd	-111.084	32.13344	1264	238
905	Tucson Boulevard & Bilby Road	-110.935	32.14135	1242	239
639	Park Avenue & Eighteenth Street	-110.956	32.2121	1238	240
45	Overton Rd / Thornydale Rd	-111.047	32.37355	1235	241
295	Oracle Road & Miracle Mile Strip	-110.978	32.26104	1228	242
407	Pima Street & Rosemont Boulevard	-110.884	32.24342	1218	243
487	Campbell Avenue & University Boulevard	-110.944	32.23175	1213	244
623	Camino Seco & Old Spanish Trail	-110.807	32.2161	1191	245
121	Hospital Dr / La Cholla Bl	-111.012	32.31937	1190	246
183	River Road & Hacienda del Sol	-110.933	32.28527	1190	247
662	Twenty Second Street & Tucson Boulevard	-110.935	32.20689	1185	248
707	Mission Road & Silverlake Road	-110.996	32.19975	1185	249
308	Oracle Road & Glenn Street	-110.978	32.25755	1183	250
840	Irvington Road & Sixteenth Avenue	-110.982	32.16323	1176	251
274	Oracle Road & Fort Lowell Road	-110.978	32.2647	1171	252
145	Calle Bosque / Territory Dr / Craycroft Rd	-110.875	32.29949	1164	253
974	Old Vail Road & Rita Road	-110.802	32.10092	1134	254
143	Kolb Rd / Sunrise Dr	-110.844	32.30885	1132	255
9771	Colossal Cave Rd / Mary Ann Cleveland Wy	-110.705	32.05016	1124	256
63	Cortaro Farms Rd / Oldfather Dr	-111.055	32.359	1120	257
202	Stone Avenue & Limberlost Road	-110.97	32.28284	1116	258
803	Ajo Way & Second Avenue	-110.964	32.17788	1116	259
956	Aero Park Bl / Nogales Hy / Vamori St	-110.96	32.11079	1089	260
519	Fifth Street & Rosemont Boulevard	-110.884	32.22893	1085	261
1012	Mission Road & Via Ingresso	-111.005	32.16971	1085	262
68	Hardy Rd / Thornydale Rd	-111.047	32.36638	1084	263
124	La Cholla Bl / Rudasill Rd	-111.012	32.3157	1076	264
404	Pima Street & Columbus Boulevard	-110.901	32.24343	1070	265
780	Pantano Road & Stella Road	-110.824	32.1846	1069	266
T001	West Ina Road and North Starcommerce Way	-111.073	32.3374	1068	267
164	Romero Rd / Ruthrauff Rd	-111.003	32.2882	1055	268
80	La Cholla Bl / Omar Dr	-111.013	32.33274	1047	269
874	Benson Highway & Country Club Road	-110.926	32.15745	1044	270
812	Ajo Wy / Dodge Bl	-110.914	32.17697	1015	271
3467	Congress Street & Avenida del Convento	-110.986	32.22035	1013	272

787	Sixth Avenue & Veterans Boulevard	-110.968	32.18143	1012	273
336	Ironwood Hills Drive & Greasewood Road	-111.02	32.25066	977	274
775	Twelth Avenue & Forty Fourth Street	-110.978	32.18506	967	275
702	Aviation Highway & Country Club Road	-110.927	32.19796	951	276
284	Fort Lowell Road & Dodge Boulevard	-110.914	32.26513	949	277
257	Kolb Rd / Sabino Canyon Rd	-110.837	32.2808	945	278
785	Wilmot Road & Nicaragua Drive	-110.858	32.18113	943	279
9591	Houghton Rd / Sahuarita Rd	-110.773	31.96305	916	280
891	Drexel Rd / Palo Verde Rd	-110.918	32.14887	907	281
9649	Nogales Hy / Old Nogales Hy	-110.959	32.07654	901	282
733	Thirty Sixth Street & La Cholla Boulevard	-111.012	32.1923	894	283
399	Tucson Boulevard & Elm Street	-110.935	32.24271	872	284
958	Aerospace Pw / Nogales Hy	-110.959	32.09023	867	285
9066	Valencia Rd / Wade Rd	-111.115	32.13334	860	286
965	Continental Rd / La Canada Dr	-110.999	31.85243	859	287
67	La Cholla Boulevard & Magee Road	-111.013	32.34717	855	288
73	La Cholla Boulevard & Magee Road	-111.013	32.34717	855	289
417	Oracle Road & Drachman Street	-110.978	32.23953	852	290
46	Overton Rd / Shannon Rd	-111.03	32.37361	851	291
1311	Silverbell Rd / Sunset Rd	-111.051	32.30515	825	292
647	Mission Road & Grande Avenue	-110.992	32.20646	799	293
439	Speedway Boulevard & 6th Avenue	-110.969	32.2359	796	294
957	Hermans Rd / Nogales Hy	-110.96	32.10517	783	295
47	La Cholla Bl / Overton Rd	-111.013	32.37357	762	296
632	Pantano Road & Kenyon Drive	-110.824	32.21367	751	297
168	Kolb Rd / Snyder Rd	-110.84	32.29434	715	298
970	Valencia Road & Old Vail Road	-110.814	32.11937	699	299
963	Abrego Dr / Continental Rd	-110.988	31.85213	692	300
267	Stone Avenue & Yavapai Road	-110.972	32.26956	686	301
225	Pontatoc Rd / River Rd	-110.905	32.27759	683	302
87	Cardinal Av / Drexel Rd	-111.029	32.1483	681	303
691	Twenty Second & Old Spanish Trail	-110.787	32.20632	671	304
420	Stone Avenue & Drachman Street	-110.972	32.23949	667	305
493	Saint Mary's Road & Anklam Road	-111.006	32.22634	659	306
861	Irvington Road & Harrison Road	-110.79	32.16288	642	307
514	Fifth Street & Dodge Boulevard	-110.914	32.22887	633	308
500	Sixth Street & Stone Avenue	-110.972	32.2277	632	309
169	Sabino Canyon Rd / Snyder Rd	-110.824	32.29432	628	310
966	Esperanza Bl / La Canada Dr	-110.995	31.87047	627	311
858	Irvington Road & Pantano Road	-110.824	32.16293	623	312

859	Irvington Road & Fred Enke Drive	-110.816	32.1629	621	313
402	Pima Street & Dodge Boulevard	-110.914	32.2434	615	314
805	Ajo Way & Benson Highway	-110.952	32.1779	606	315
9641	Camino Casa Verde / La Canada Dr / Paseo del Chino	-110.995	31.88567	606	316
188	Romero Rd / Wetmore Rd	-111.003	32.28689	604	317
376	Wrightstown Road & Camino Seco	-110.807	32.24364	599	318
646	Starr Pass Boulevard & La Cholla Boulevard	-111.012	32.20689	590	319
790	Park Avenue & Benson Highway	-110.956	32.18164	580	320
903	Park Avenue & Bilby Road	-110.956	32.14134	574	321
971	Valencia Road & Nexus Road	-110.797	32.11908	567	322
381	Tanque Verde Loop Road / Tanque Verde Road	-110.756	32.25093	561	323
648	Club Dr / Shannon Rd	-111.03	32.35901	555	324
484	University Boulevard & Fourth Avenue	-110.966	32.23164	551	325
77	Campus Park Wy / Shannon Rd	-111.029	32.34468	528	326
968	Desert Bell Dr / La Canada Dr / La Canoa	-110.995	31.88153	523	327
547	Toole Avenue & Pennington Street	-110.968	32.22361	446	328
967	Abrego Dr / Esperanza Bl	-110.989	31.87024	387	329
893	Alvernon Way & Drexel Road	-110.909	32.1489	384	330
498	Saint Mary's Road & Granada Avenue	-110.978	32.2276	381	331
535	Stone Avenue & Toole Avenue/Franklin Street	-110.972	32.2264	357	332
1003	Stone Avenue & Toole Avenue/Franklin Street	-110.972	32.2264	357	333
144	Sabino Canyon Rd / Sunrise Dr	-110.824	32.30895	352	334
985	Aerospace Pw / Raytheon Pw	-110.948	32.08559	329	335
T004	East Catalina Highway / North Mount Lemmon Short Road	-110.746	32.30324	287	336
634	I-10 Eastside & Cushing Street	-110.979	32.21705	286	337
353	Grant Road & Tucson Boulevard	-110.935	32.25035	269	338
746	Alvernon Way & Aviation Highway	-110.909	32.19012	249	339
620	Wilmot Road & Park Place Drive	-110.858	32.21811	240	340
621	Wilmot Road & Park Place Drive	-110.858	32.21811	240	341
649	Starr Pass Boulevard & Mission Road	-110.99	32.20583	230	342
1221	Kolb Rd / Mountain Shadows Pl / Ventana Canyon Dr	-110.849	32.31804	229	343
510	Sixth Street & Tucson Boulevard	-110.935	32.22794	214	344
962	Camino Del Sol and Camino Encanto	-111.012	31.82762	199	345
636	Granada Avenue & Cushing Street	-110.978	32.21753	152	346
688	Twenty Second Street & Oak Park Drive	-110.8	32.20635	133	347
778	Kolb Road & Stella Road	-110.841	32.18466	130	348
729	Aviation Highway & Thirty Fourth Street	-110.92	32.19349	98	349
539	Granada Avenue & Alameda Street	-110.977	32.22251	75	350

APPENDIX E: SEGMENT RANKING BY AVERAGE HOURLY VOLUME DURING PEAK HOURS IN SEPTEMBER 2020

Local_Id	On_Road	Lat	Lon	From Int	To	Average Hourly Volume	Rank
B-183	Tanque Verde Rd	32.25078	-110.836	Sabino Canyon Rd	Tanque Verde Rd Wb	3252	1
B-106	Kolb Rd	32.19812	-110.841	22nd St	Golf Links Rd	3074	2
A-37	Valencia Rd	32.13381	-111	Mission Rd	I-19 Sb On Ramp Valencia Rd	3053	3
A-91	Golf Links Rd	32.1923	-110.864	Craycroft Rd	Wilmot Rd	2934	4
B-191	Wilmot Rd	32.2267	-110.858	5th St	Broadway Bl	2847	5
C-97	Valencia Rd	32.13398	-110.984	I-19 Sb On Ramp Valencia Rd	12th Av	2841	6
B-21	22nd St	32.2065	-110.849	Wilmot Rd	Kolb Rd	2784	7
A-134	Speedway Bl	32.23615	-110.866	Craycroft Rd	Wilmot Rd	2759	8
A-124	Speedway Bl	32.2356	-110.852	Wilmot Rd	Kolb Rd	2747	9
B-56	Broadway Bl	32.22164	-110.879	Swan Rd	Craycroft Rd	2689	10
B-87	Grant Rd	32.25062	-110.867	Craycroft Rd	Wilmot Rd	2688	11
B-16	22nd St	32.20648	-110.836	Kolb Rd	Pantano Pw	2647	12
B-50	Broadway Bl	32.22156	-110.866	Craycroft Rd	Wilmot Rd	2629	13
A-92	Golf Links Rd	32.19261	-110.878	Swan Rd	Craycroft Rd	2620	14
B-196	Wilmot Rd	32.241	-110.858	Pima St	Speedway Bl	2611	15
A-38	Valencia Rd	32.13412	-110.938	Campbell Av	Tucson Bl	2606	16
A-136	Speedway Bl	32.23621	-110.883	Swan Rd	Craycroft Rd	2555	17
B-92	Grant Rd	32.25066	-110.884	Swan Rd	Craycroft Rd	2545	18
B-197	Wilmot Rd	32.23158	-110.858	Speedway Bl	5th St	2543	19
B-94	Grant Rd	32.25026	-110.853	Wilmot Rd	Tanque Verde Rd	2525	20
B-110	Kolb Rd	32.23078	-110.841	Speedway Bl	Broadway Bl	2499	21
C-94	Valencia Rd	32.13406	-110.97	12th Av	Nogales Hy	2462	22
C-100	Valencia Rd	32.13414	-110.947	Park Av	Campbell Av	2429	23
C-101	Valencia Rd	32.13416	-110.931	Tucson Bl	Palo Verde Rd	2416	24
C-98	Valencia Rd	32.13403	-110.959	Nogales Hy	Park Av	2390	25
B-107	Kolb Rd	32.21449	-110.841	Broadway Bl	22nd St	2378	26
C-56	Irvington Rd	32.16318	-110.995	Mission Rd	I-19 Sb On Ramp Irvington Rd	2321	27
Pcx-051	River Rd	32.28787	-110.946	Camino Luz	Campbell Av	2289	28
A-181	Campbell Av	32.27798	-110.944	River Rd	Prince Rd	2289	29
B-44	Broadway Bl	32.22153	-110.902	Alvernon Wy	Swan Rd	2234	30
A-122	Speedway Bl	32.23556	-110.813	Pantano Rd	Camino Seco	2204	31

Pcx-466	River Rd	32.29279	-110.954	1st Av	Camino Luz	2192	32
A-94	Golf Links Rd Eb	32.19512	-110.896	Aviation Pw Eb Off Ramp Golf Links Rd	Swan Rd	2191	33
B-11	22nd St	32.20701	-110.916	Country Club Rd	Alvernon Wy	2173	34
A-90	Golf Links Rd	32.19193	-110.835	Kolb Rd	Pantano Rd	2162	35
Pcx-297	Campbell Av	32.30121	-110.939	Camino Luz	Camino Miraval 45101	2148	36
C-45	Houghton Rd	32.21619	-110.773	Broadway Bl	22nd St	2134	37
B-49	Broadway Bl	32.2216	-110.922	Country Club Rd	Alvernon Wy	2121	38
A-194	River Rd	32.29186	-110.952	1st Av	Campbell Av	2114	39
N-29	Tanque Verde Rd	32.2581	-110.8	Bear Canyon Rd	Catalina Hy	2101	40
B-33	Alvernon Wy	32.20244	-110.91	22nd St	29th St	2074	41
A-129	Speedway Bl	32.23595	-110.974	Main Av	Stone Av	1933	42
Pcs-12	River Rd	32.29744	-110.982			1931	43
A-137	Speedway Bl	32.23595	-110.954	Euclid Av	Campbell Av	1930	44
Pcx-099	River Rd	32.2869	-110.94	Campbell Av	Camino Real 31265	1929	45
A-108	Craycroft Rd	32.22318	-110.875	5th St	Broadway Bl	1918	46
A-125	Speedway Bl	32.23558	-110.834	Kolb Rd	Pantano Rd	1892	47
Pcx-408	Campbell Av	32.28572	-110.944	River Rd	River Rd	1892	48
B-193	Wilmot Rd	32.20209	-110.858	22nd St	Golf Links Rd	1878	49
Dc-005	Ajo Hy	32.17791	-111.01	La Cholla Bl	Mission Rd	1858	50
A-83	Ajo Wy	32.17796	-110.93	I-10 Wb Ramp Ajo Wy	Palo Verde Rd	1857	51
B-111	Kolb Rd	32.244	-110.845	Tanque Verde Rd	Speedway Bl	1840	52
A-157	Campbell Av	32.25871	-110.944	Fort Lowell Rd	Grant Rd	1806	53
A-173	Campbell Av	32.26899	-110.944	Prince Rd	Fort Lowell Rd	1768	54
A-68	Irvington Rd	32.16336	-110.962	6th Av	Park Av	1752	55
A-120	Speedway Bl	32.23542	-110.797	Camino Seco	Harrison Rd	1741	56
B-108	Kolb Rd	32.1794	-110.841	Golf Links Rd	Irvington Rd	1737	57
A-203	River Rd	32.29746	-110.994	La Canada Dr	Oracle Rd	1717	58
C-51	Houghton Rd	32.22716	-110.773	Speedway Bl	Broadway Bl	1703	59
B-18	22nd St	32.20642	-110.816	Pantano Pw	Camino Seco	1696	60
A-154	Craycroft Rd	32.25269	-110.875	River Rd	Grant Rd	1662	61
A-87	Golf Links Rd	32.19179	-110.784	Harrison Rd	Houghton Rd	1621	62
B-35	Alvernon Wy	32.21248	-110.91	Broadway Bl	22nd St	1605	63

A-280	River Rd	32.28663	-110.937	Campbell Ave	Hacienda Del Sol Rd	1604	64
A-178	1st Av	32.27505	-110.961	Wetmore Rd	Prince Rd	1601	65
Pcx-365	Ajo Wy	32.17799	-110.922	Country Club Rd	Palo Verde Rd	1563	66
A-67	Irvington Rd	32.16333	-110.953	Park Av	Campbell Av	1559	67
A-172	1st Av	32.26825	-110.961	Prince Rd	Fort Lowell Rd	1556	68
B-95	Harrison Rd	32.20077	-110.79	22nd St	Golf Links Rd	1556	69
B-9	22nd St	32.20688	-110.933	Aviation Pw Wb On Ramp 22nd St	Country Club Rd	1552	70
B-175	Swan Rd	32.26927	-110.892	River Rd	Camp Lowell Dr	1531	71
Pcx-349	Valencia Rd	32.13382	-111.022	Cardinal Av	Mission Rd	1516	72
Pcx-266	Valencia Rd	32.13376	-111.033	Camino De La Tierra	Cardinal Av	1511	73
A-118	Craycroft Rd	32.23314	-110.876	Speedway Bl	5th St	1489	74
C-53	Houghton Rd	32.10008	-110.773	Valencia Rd	Mary Ann Cleveland Wy	1478	75
A-214	River Rd	32.31448	-111.041	Orange Grove Rd	Shannon Rd	1474	76
B-179	Swan Rd	32.23279	-110.893	Speedway Bl	5th St	1473	77
C-99	Valencia Rd	32.13423	-110.912	Palo Verde Rd	Alvernon Wy	1463	78
A-150	Craycroft Rd	32.2491	-110.875	Grant Rd	Pima St	1456	79
B-178	Swan Rd	32.24092	-110.893	Pima St	Speedway Bl	1455	80
N-608	Alvernon Wy Sb	32.18138	-110.908	Contractors Wy Sb	Golf Links Rd Wb	1435	81
A-138	Craycroft Rd	32.23937	-110.876	Pima St	Speedway Bl	1429	82
C-84	Tanque Verde Rd	32.24619	-110.853	Pima St	Grant Rd	1424	83
B-34	Alvernon Wy	32.22503	-110.909	5th St	Broadway Bl	1399	84
A-49	12th Av	32.15023	-110.978	Irvington Rd	Valencia Rd	1361	85
A-226	Ina Rd	32.33753	-111.048	I-10 Wb Frontage Rd	Thornydale Rd	1361	86
B-173	Swan Rd	32.22453	-110.892	5th St	Broadway Bl	1347	87
A-207	River Rd	32.30613	-111.019	Shannon Rd	La Cholla Bl	1335	88
A-179	River Rd	32.27602	-110.92	Campbell Av	Alvernon Wy	1334	89
B-8	22nd St	32.20699	-110.901	Alvernon Wy	Swan Rd	1328	90
A-82	Ajo Wy	32.17787	-110.96	6th Av	Park Av	1328	91
A-65	Irvington Rd	32.1633	-110.94	Campbell Av	Tucson Bl	1324	92
A-225	Ina Rd	32.33725	-110.967	Oracle Rd	1st Av	1314	93
B-79	Euclid Av	32.23332	-110.959	Speedway Bl	University Bl	1314	94
B-172	Swan Rd	32.20389	-110.892	22nd St	29th St	1308	95
A-324	Oracle Rd	32.24669	-110.978	Grant Rd	Drachman St	1292	96
A-128	Speedway Bl	32.23594	-110.97	Stone Av	6th Av	1268	97

A-77	Ajo Wy	32.17777	-110.973	12th Av	6th Av	1268	98
B-177	Swan Rd	32.19759	-110.892	29th St	Golf Links Rd	1267	99
Pcx-394	Sunrise Dr	32.30832	-110.897	Pontatoc Rd	Swan Rd	1262	100
A-240	La Canada Dr	32.35864	-110.996	Overton Rd	Magee Rd	1249	101
A-209	Sunrise Dr	32.30824	-110.901	Skyline Dr	Swan Rd	1246	102
A-299	Skyline Dr	32.32408	-110.935	Orange Grove Rd	Campbell Av	1245	103
A-217	Thornydale Rd	32.325	-111.046	Ina Rd	Orange Grove Rd	1226	104
B-52	Broadway Bl	32.22084	-110.781	Harrison Rd	Houghton Rd	1224	105
B-181	Tanque Verde Rd	32.25227	-110.786	Catalina Hy	Houghton Rd	1220	106
B-174	Swan Rd	32.21498	-110.892	Broadway Bl	22nd St	1220	107
A-47	Campbell Av	32.1458	-110.943	Irvington Rd	Valencia Rd	1216	108
B-96	Harrison Rd	32.21642	-110.79	Broadway Bl	22nd St	1215	109
A-383	Oracle Rd	32.25501	-110.978	Miracle Mile	Grant Rd	1209	110
B-27	6th St	32.22776	-110.964	6th Av	Euclid Av	1206	111
C-207	6th St	32.22769	-110.967	6th Ave	4th Ave	1205	112
Pcx-031	Tanque Verde Rd	32.25206	-110.786	Tanque Verde Acres Dr	Tomahawk Tr	1198	113
A-34	Valencia Rd	32.13295	-111.049	Camino De Oeste	Camino De La Tierra	1187	114
Pcs-34	River Rd	32.28208	-110.925	Hacienda Del Sol Rd	Alvernon Wy 163572	1183	115
Pcx-185	Skyline Dr	32.32269	-110.925	Campbell Av	Sunrise Dr	1180	116
A-142	Wrightstown Rd	32.24267	-110.795	Camino Seco	Harrison Rd	1179	117
Pcx-464	Ina Rd	32.33745	-111.038	Thornydale Rd	Shannon Rd	1168	118
B-73	Country Club Rd	32.24023	-110.927	Grant Rd	Speedway Bl	1168	119
C-35	Euclid Av	32.2296	-110.959	University Bl	6th St	1141	120
B-70	Country Club Rd	32.25868	-110.927	Fort Lowell Rd	Grant Rd	1121	121
Pcx-461	Camino De La Tierra	32.33033	-111.038	Orange Grove Rd	Ina Rd	1117	122
B-135	Prince Rd	32.27214	-110.951	1st Av	Campbell Av	1106	123
A-231	Thornydale Rd	32.34597	-111.047	Cortaro Farms Rd	Ina Rd	1101	124
C-60	Old Spanish Tr	32.20875	-110.796	Camino Seco	Harrison Rd	1099	125
A-166	Camp Lowell Dr/Fort Lowell Rd	32.26507	-110.896	Alvernon Wy	Swan Rd	1093	126
B-25	6th Av	32.18259	-110.968	I-10 Eb On Ramp 6th Av	Ajo Wy	1089	127
Pcs-03	Sunrise Dr	32.3086	-110.878			1085	128

A-228	Ina Rd	32.33736	-111.025	Thornydale Rd	La Cholla Bl	1083	129
Pcs-8	Sabino Canyon Rd	32.25993	-110.841	Tanque Verde Rd	Cloud Rd	1082	130
Pcx-190	Oldfather Dr	32.34467	-111.055	Ina Rd	Magee Rd	1075	131
B-194	Wilmot Rd	32.18558	-110.858	Golf Links Rd	Nicaragua Dr	1073	132
A-167	Fort Lowell Rd	32.26498	-110.921	Country Club Rd	Dodge Bl	1072	133
Pcx-358	Dodge Bl	32.27048	-110.914	Fort Lowell Rd	River Rd	1070	134
Pcx-241	Ina Rd	32.33731	-111.021	Shannon Rd	La Cholla Bl	1062	135
B-26	6th Av	32.17048	-110.968	Ajo Wy	Irvington Rd	1060	136
Pcs-6	Ina Rd	32.33731	-110.954	1st Av	Skyline Dr 26427	1048	137
Pcs-25	River Rd	32.30937	-111.028			1023	138
Pcx-449	Thornydale Rd	32.34111	-111.047	Ina Rd	Massingale Rd	993	139
A-206	River Rd	32.30206	-111.006	La Cholla Bl	La Canada Dr	987	140
Pcx-171	Valencia Rd	32.13343	-111.067	Mark Rd	Camino De Oeste	982	141
Pcx-172	Mission Rd	32.16289	-111.007	Irvington Rd	Mission Pl	977	142
Pcx-022	Skyline Dr	32.33062	-110.943	Ina Rd 26427	Orange Grove Rd	975	143
A-222	Skyline Dr	32.33477	-110.946	Ina Rd	Orange Grove Rd	969	144
N-127	Midvale Park Rd	32.15256	-110.999	Irvington Rd	Drexel Rd	966	145
B-192	Wilmot Rd	32.21321	-110.858	Broadway Bl	22nd St	963	146
A-50	Tucson Bl	32.15081	-110.935	Irvington Rd	Valencia Rd	962	147
A-237	Magee Rd	32.35179	-111.006	La Cholla Bl	La Canada Dr	961	148
A-223	Ina Rd	32.33717	-110.997	La Cholla Bl	La Canada Dr	959	149
C-103	Valencia Rd	32.13344	-111.074	Camino Verde	Camino De Oeste	950	150
A-57	Nogales Hy	32.15827	-110.966	Irvington Rd	Drexel Rd	947	151
A-168	Fort Lowell Rd	32.26514	-110.913	Dodge Bl	Alvernon Wy	946	152
A-232	La Canada Dr	32.3462	-110.996	Magee Rd	Ina Rd	938	153
A-196	Flowing Wells Rd	32.29306	-110.995	River Rd	Wetmore Rd	922	154
A-121	Speedway Bl	32.23547	-110.778	Harrison Rd	Houghton Rd	918	155
B-31	6th St	32.22766	-110.97	Stone Av	6th Av	892	156
B-72	Country Club Rd	32.23228	-110.927	Speedway Bl	6th St	872	157
B-98	Harrison Rd	32.22873	-110.79	Speedway Bl	Broadway Bl	866	158
Pcs-44	Magee Rd	32.35176	-111.003			864	159
B-69	Country Club Rd	32.21017	-110.927	Broadway Bl	22nd St	863	160
C-154	Main Av	32.23759	-110.978	Drachman St	Speedway Bl	861	161
A-235	La Cholla Bl	32.34975	-111.013	Magee Rd	Magee Rd	857	162

C-68	Rita Rd	32.11386	-110.8	Old Vail Rd	Nexus Dr	856	163
Pcx-176	La Canada Dr	32.31217	-110.995	Roller Coaster Rd	Orange Grove Rd	855	164
N-4	Orange Grove Rd	32.32322	-111.036	Thornydale Rd	Shannon Rd	847	165
A-58	Benson Hy	32.15904	-110.929	Irvington Rd	Country Club Rd	846	166
B-68	Country Club Rd	32.22508	-110.927	6th St	Broadway Bl	840	167
B-134	Pima St	32.24342	-110.885	Swan Rd	Craycroft Rd	839	168
B-77	Euclid Av	32.22611	-110.959	6th St	Broadway Bl	837	169
Pcs-29	Thornydale Rd	32.3554	-111.047	Magee Rd	Cortaro Farms Rd	823	170
A-164	Fort Lowell Rd	32.26478	-110.966	Stone Av	1st Av	822	171
B-133	Pima St	32.24333	-110.866	Craycroft Rd	Wilmot Rd	822	172
A-230	La Cholla Bl	32.34261	-111.013	Magee Rd	Ina Rd	818	173
Pc-Apk-1	Mission Rd	32.16443	-111.006			817	174
Pcx-233	Flowing Wells Rd	32.29072	-110.995	Wetmore Rd	Mohawk Dr 224766	813	175
Pcx-329	La Canada Dr	32.34449	-110.996	Ina Rd	Magee Rd	813	176
B-127	Pantano Pw	32.2007	-110.817	22nd St	Golf Links Rd	811	177
Pcs-47	Orange Grove Rd	32.32316	-111.016			811	178
B-167	Stone Av	32.26797	-110.972	Prince Rd	Fort Lowell Rd	803	179
B-139	Prince Rd	32.27194	-110.976	Oracle Rd	Stone Av	781	180
C-52	Houghton Rd	32.2425	-110.773	Tanque Verde Rd	Speedway Bl	776	181
Pcs-50	Valencia Rd	32.13343	-111.089	Camino Verde	Mark Rd	755	182
A-204	La Cholla Bl	32.29775	-111.012	River Rd	Ruthrauff Rd	745	183
A-155	Sabino Canyon Rd	32.25458	-110.841	River Rd	Tanque Verde Rd	744	184
A-176	Sabino Canyon Rd	32.27454	-110.838	Kolb Rd	River Rd	743	185
Dc-009	Aviation Pw Eb	32.19698	-110.926	Country Club Rd	34th St	741	186
Pcs-19	La Cholla Bl	32.31044	-111.012	River Rd	Rudasill Rd	737	187
B-131	Pima St	32.24342	-110.9	Alvernon Wy	Swan Rd	736	188
A-215	La Canada Dr	32.31495	-110.995	Orange Grove Rd	River Rd	725	189
Pc-Apl-2	Magee Rd	32.35058	-111.028			725	190
A-182	Craycroft Rd	32.27945	-110.875	Sunrise Dr	River Rd	720	191
B-36	Alvernon Wy	32.24607	-110.91	Grant Rd	Pima St	716	192
Pcs-48	La Canada Dr	32.33018	-110.995	Orange Grove Rd	Ina Rd	716	193
A-219	La Canada Dr	32.32993	-110.995	Ina Rd	Orange Grove Rd	715	194

A-272	12th Av	32.18044	-110.978	44th St	Ajo Wy	712	195
A-113	5th St	32.22895	-110.882	Swan Rd	Craycroft Rd	707	196
A-242	Thornydale Rd	32.36454	-111.047	Overton Rd	Cortaro Farms Rd	706	197
B-141	Prince Rd	32.27199	-110.967	Stone Av	1st Av	706	198
A-212	La Cholla Bl	32.31364	-111.012	Orange Grove Rd	River Rd	700	199
A-290	Orange Grove Rd	32.32313	-111.003	La Cholla Bl	La Canada Dr	692	200
A-220	La Cholla Bl	32.33113	-111.013	Ina Rd	Orange Grove Rd	689	201
B-163	Stone Av	32.23835	-110.972	Drachman St	Speedway Bl	681	202
B-220	La Cholla Bl	32.19673	-111.012	Starr Pass Bl	36th St	657	203
A-115	5th St	32.22884	-110.918	Country Club Rd	Alvernon Wy	652	204
Pcs-32	Ajo Way	32.17625	-110.913			650	205
N-7	Alvernon Wy	32.26955	-110.91	River Rd	Fort Lowell Rd	648	206
A-80	Ajo Wy	32.17789	-110.954	Park Av	Benson Hy	647	207
B-221	La Cholla Bl	32.18518	-111.012	36th St	Ajo Hy	647	208
A-81	Ajo Wy	32.17779	-110.916	Palo Verde Rd	Alvernon Wy	640	209
A-63	Irvington Rd	32.16299	-110.833	Kolb Rd	Pantano Rd	633	210
B-97	Harrison Rd	32.17835	-110.79	Golf Links Rd	Irvington Rd	618	211
A-227	Ina Rd	32.33755	-111.087	Silverbell Rd	I-10 Eb Frontage Rd	618	212
A-184	Swan Rd	32.28091	-110.893	Sunrise Dr	River Rd	618	213
A-238	La Cholla Bl	32.36004	-111.013	Overton Rd	Magee Rd	617	214
B-190	Valencia Rd	32.11889	-110.778	Nexus Dr	Houghton Rd	612	215
C-16	Alvernon Wy	32.1925	-110.909	Palo Verde Rd	Aviation Pw Eb Off Ramp Alvernon Wy	609	216
Pcx-205	Swan Rd	32.27721	-110.893	Calle Chueca	River Rd	606	217
Pcx-123	Wetmore Rd	32.28691	-110.998	Obetka Av	Flowing Wells Rd	597	218
A-191	Wetmore Rd	32.28687	-110.998	Romero Rd	Flowing Wells Rd	597	219
A-114	5th St	32.22893	-110.868	Craycroft Rd	Wilmot Rd	586	220
Pcx-303	River Rd	32.27582	-110.912	Alvernon Wy 163572	Pontatoc Rd	579	221
B-169	Stone Av	32.23323	-110.972	Speedway Bl	6th St	575	222
A-208	Sunrise Dr	32.30791	-110.861	Craycroft Rd	Kolb Rd	565	223
B-85	Grant Rd	32.25033	-110.937	Campbell Av	Tucson Bl	553	224
Dc-025	Aviation Pw Wb	32.19602	-110.924	Country Club Rd	34th St	553	225
Pcs-45	Cortaro Farms Rd	32.359	-111.043			548	226
Pcs-33	Ruthrauff Rd	32.29113	-111.004	La Cholla Bl	Obetka Av	545	227
Pcs-43	Sunrise Dr	32.30878	-110.854			542	228
A-145	Tucson Bl	32.24471	-110.935	Grant Rd	Speedway Bl	537	229

A-177	River Rd	32.27456	-110.868	Craycroft Rd	Sabino Canyon Rd	532	230
A-85	Park Av	32.1796	-110.956	Benson Hy	Ajo Wy	521	231
A-200	Ruthrauff Rd	32.29425	-111.008	La Cholla Bl	Romero Rd	517	232
Pcx-363	Tanque Verde Loop Rd	32.24321	-110.756	Speedway Bl	Tanque Verde Rd	506	233
B-99	Harrison Rd	32.2394	-110.79	Wrightstown Rd	Speedway Bl	503	234
Pcx-357	River Rd	32.27464	-110.864	Craycroft Rd	Tanuri Dr	501	235
A-239	Cortaro Farms Rd	32.35705	-111.036	Thornydale Rd	Shannon Rd	495	236
Pcx-374	La Canada Dr	32.3591	-110.996	Magee Rd	Hardy Rd	495	237
A-39	Palo Verde Rd	32.1444	-110.918	Benson Hy	Valencia Rd	495	238
Pcx-087	Houghton Rd	32.24321	-110.772	Speedway Bl	Tanque Verde Rd	493	239
N-30	Tanque Verde Rd	32.25097	-110.759	Houghton Rd	Tanque Verde Loop Rd	487	240
C-55	Irvington Rd	32.16292	-110.816	Pantano Rd	Camino Seco	475	241
Pcx-091	Thornydale Rd	32.34822	-111.047	Massingale Rd	Magee Rd	462	242
A-43	Park Av	32.13999	-110.956	Drexel Rd	Valencia Rd	450	243
C-73	Roger Rd	32.27924	-110.966	Stone Av	1st Av	431	244
A-3	La Canada Dr	31.85514	-110.998	Continental Rd	Esperanza Bl	430	245
A-278	Kolb Rd	32.28948	-110.839	Snyder Rd	Sabino Canyon Rd	415	246
C-75	Silverbell Rd	32.34462	-111.095	Cortaro Rd	Ina Rd	403	247
B-109	Kolb Rd	32.29809	-110.84	Sunrise Dr	Snyder Rd	397	248
N-114	Main Av	32.2322	-110.978	Speedway Bl	Saint Marys Rd	393	249
C-106	Drexel Rd	32.1486	-110.973	12th Av	Nogales Hy	389	250
B-76	Escalante Rd	32.17758	-110.845	Kolb Rd	Calle Polar	388	251
N-44	Cardinal Av	32.14777	-111.029	Irvington Rd	Valencia Rd	379	252
B-213	Magee Rd	32.35188	-111.04	Thornydale Rd	Cortaro Farms Rd	377	253
Pcx-148	River Rd	32.27252	-110.849	Tanuri Dr	Sabino Canyon Rd	376	254
B-93	Grant Rd	32.25034	-110.934	Tucson Bl	Country Club Rd	375	255
N-46	Country Club Rd	32.17418	-110.926	Ajo Wy	Irvington Rd	371	256
N-11	Columbus Bl	32.23891	-110.901	Grant Rd	Speedway Bl	369	257
N-10	Columbus Bl	32.25338	-110.901	Fort Lowell Rd	Grant Rd	368	258
B-13	22nd St	32.20634	-110.781	Harrison Rd	Houghton Rd	362	259
N-12	36th St	32.19239	-110.955	Park Av	Kino Pw	362	260
A-180	River Rd	32.27688	-110.877	Swan Rd	Craycroft Rd	360	261
C-166	Rosemont Bl	32.23207	-110.884	Speedway Bl	Broadway Bl	356	262
C-127	Columbus Bl	32.21442	-110.901	Broadway Bl	22nd St	354	263

N-78	Old Vail Rd	32.10052	-110.8	Rita Rd	Houghton Rd	352	264
B-214	Shannon Rd	32.34312	-111.03	Magee Rd	Ina Rd	348	265
A-162	Fort Lowell Rd	32.26471	-110.976	Oracle Rd	Stone Av	341	266
C-28	Drexel Rd	32.14874	-110.932	Campbell Av	Country Club Rd	337	267
C-88	Tucson Bl	32.22559	-110.935	6th St	Broadway Bl	323	268
C-69	Roger Rd	32.27945	-110.951	1st Av	Campbell Av	320	269
Pcx-111	River Rd	32.27902	-110.899	Pontatoc Rd	Swan Rd	320	270
A-5	La Canada Dr	31.87622	-110.995	Duval Mine Rd	Esperanza Bl	320	271
A-183	River Rd	32.28075	-110.896	Alvernon Wy	Swan Rd	319	272
A-294	Overton Rd	32.3735	-111.025	Shannon Rd	La Cholla Bl	313	273
A-274	Bilby Rd	32.14129	-110.948	Nogales Hy	Tucson Bl	310	274
N-50	Drexel Rd	32.14884	-110.923	Country Club Rd	Palo Verde Rd	309	275
A-192	Romero Rd	32.28762	-111.003	Ruthrauff Rd	Wetmore Rd	303	276
Pcx-286	Romero Rd	32.28767	-111.003	Wetmore Rd	Ruthrauff Rd	303	277
Pcx-141	La Cholla Bl	32.33021	-111.013	Orange Grove Rd	Ina Rd	298	278
A-293	Overton Rd	32.36845	-111.001	La Cholla Bl	La Canada Dr	296	279
Pcx-150	La Canada Dr	32.37308	-110.996	Hardy Rd	Rancho Feliz Dr	294	280
C-23	Camino Seco	32.23998	-110.807	Wrightstown Rd	Speedway Bl	285	281
N-18	Shannon Rd	32.3658	-111.03	Overton Rd	Magee Rd	268	282
Pcx-425	Shannon Rd	32.36993	-111.03	Hardy Rd	Overton Rd	252	283
B-148	Shannon Rd	32.32572	-111.029	Ina Rd	Orange Grove Rd	247	284
C-9	6th Av	32.23096	-110.969	Speedway Bl	6th St	239	285
Pc-Apd-7	Sunrise Dr	32.30888	-110.835			238	286
N-2	Shannon Rd	32.32029	-111.029	Orange Grove Rd	River Rd	234	287
B-30	6th St	32.22767	-110.977	Granada Av	Stone Av	233	288
Pcx-306	Sabino Canyon Rd	32.2708	-110.84	Cloud Rd	River Rd	227	289
C-41	Granada Av	32.22648	-110.978	Saint Marys Rd	Franklin St	225	290
A-205	Sabino Canyon Rd	32.29993	-110.824	Sunrise Dr	Kolb Rd	225	291
A-210	Sunrise Dr	32.30891	-110.833	Kolb Rd	Sabino Canyon Rd	224	292
N-17	Overton Rd	32.37357	-111.04	Thornydale Rd	Shannon Rd	223	293
Pcx-059	Overton Rd	32.37358	-111.038	Thornydale Rd	Shannon Rd	221	294
N-70	Rosemont Bl	32.24612	-110.884	Grant Rd	Speedway Bl	211	295
C-89	Tucson Bl	32.21203	-110.935	Broadway Bl	22nd St	211	296
A-175	Dodge Bl	32.2691	-110.914	River Rd	Fort Lowell Rd	204	297

N-3	Camino De La Tierra	32.33035	-111.038	Ina Rd	Orange Grove Rd	196	298
N-124	Abrego Dr	31.86441	-110.99	Esperanza Bl	Continental Rd	195	299
B-67	Country Club Rd	32.19902	-110.927	22nd St	Aviation Pw Wb	177	300
A-84	Benson Hy	32.17928	-110.954	Park Av	Ajo Wy	174	301
Pcx-224	Shannon Rd	32.36033	-111.03	Magee Rd 8362	Hardy Rd	174	302
Pcx-285	Silverbell Rd	32.31539	-111.06	Sunset Rd 162367	Abington Rd	173	303
Dc-027	Aviation Pw Wb	32.19027	-110.914	Richey Bl	Aviation Pw Wb On Ramp Alvernon Wy	161	304
N-74	Elm St	32.24272	-110.937	Country Club Rd	Campbell Av	157	305
Pcx-115	Kolb Rd	32.30197	-110.841	Snyder Rd	Sunrise Dr	155	306
B-28	6th St	32.22785	-110.935	Campbell Av	Country Club Rd	155	307
B-160	Stone Av	32.2266	-110.972	6th St	Franklin St	137	308
Pcx-086	Sabino Canyon Rd	32.28779	-110.831	Kolb Rd	Snyder Rd	127	309
C-77	Silverbell Rd	32.31296	-111.057	Ina Rd	El Camino Del Cerro	127	310
Pcx-189	Craycroft Rd	32.29884	-110.875	Heatherwood Wy	Sunrise Dr	120	311
B-153	Snyder Rd	32.29432	-110.834	Kolb Rd	Sabino Canyon Rd	107	312
B-10	22nd St	32.20633	-110.799	Camino Seco	Harrison Rd	97	313
Pcx-192	Thornydale Rd	32.38805	-111.047	Linda Vista Bl	Lambert Ln 14402	78	314
A-139	Drachman St	32.23942	-110.975	Oracle Rd	Stone Av	67	315
Pcx-182	Kolb Rd	32.28748	-110.839	Sabino Canyon Rd	Snyder Rd	63	316
Pcx-454	Nogales Hy	32.10798	-110.96	Hermans Rd	Aero Park Bl	60	317
Pcx-378	Sabino Canyon Rd	32.27647	-110.837	River Rd	Kolb Rd	35	318