Analysis of the Operational Impacts of Left-In Left-Out Intersection/Driveway Treatments

Final Report

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1.0 INTRODUCTION AND STUDY OBJECTIVES

The City of Scottsdale, Arizona contains numerous examples of left-in left-out (LILO) treatments at intersections or driveways. An aerial view of a typical LILO treatment in the City of Scottsdale is shown in Figure 1.1. These treatments are typically applied on arterial roadways with medians and consist of a channelizing island in the median which helps direct vehicles turning left both on to and out of minor roads or driveways. Additionally, the treatment contains a left turn refuge with varying acceleration lengths for vehicles turning left out of minor roads/ driveways (these left-turning vehicles then merge with major road traffic).

The LILO treatment is a relatively uncommon intersection treatment compared with others such as right-in right-out (RIRO), and therefore there is limited research regarding the operational impacts of the LILO treatment. While a previous project funded by the City of Scottsdale showed LILO treatments perform well with respect to safety, the operational impacts (i.e. delay, etc.) have not yet been assessed. It is hypothesized that LILO treatments have the potential to improve operations (i.e. reduce delay) for left-turning vehicles by allowing motorists to focus more on one direction of traffic at a time when determining whether gaps in major road traffic are adequate to complete the turn. The City of Scottsdale was interested in conducting a study of their existing LILO sites with the goal of quantifying the operational impacts of the LILO treatment and determining conditions under which this treatment may be advantageous with respect to operations. It should be noted that there is currently no formal method to predict delay at LILO intersections in the Highway Capacity Manual (HCM).

Therefore, to better understand the operational impacts of LILO treatments, this study had the following primary objective:

- Using microsimulation modeling calibrated with field data, determine the effects of different major and minor road volumes (and select LILO design features) on the operational performance of LILO sites. This will be achieved through a sensitivity analysis with a goal of developing predictive delay models which can be used in determining when operational performance at LILO sites is expected to become unacceptable.

The subsequent chapters of this report will describe the literature review, data collection, microsimulation model development and calibration, sensitivity analysis, predictive delay model development, and conclusions and recommendations.

Figure 1.1: LILO treatment at Shea Blvd and 104th Street (Google Maps)

2.0 LITERATURE REVIEW

During a previous project in 2021 focused on the safety impacts of the LILO treatment, it was found that very little research existed that focused specifically on this treatment (Russo et al., 2021). In conducting a literature review for the current study this is still the case; there were no previous studies documenting the operational impacts of the LILO treatment, which was not a surprising result given the treatment is relatively unique. Therefore, based on the scope of this current study, the literature review focused on operations at stop-controlled intersections, sensitivity analyses, microsimulation modeling and calibration.

2.1 OPERATIONS AT STOP-CONTROLLED INTERSECTIONS

According to the Highway Capacity Manual (HCM) (Transportation Research Board, 2016), the gap acceptance theory recognizes that TWSC intersections give no positive indication or control to minor street drivers as to when it is appropriate to leave the stop line and enter the major street. It mentions that there are three elements to the analysis, the availability of gaps, the usefulness of gaps, and the relative priority of various movements at the intersection. The priority of movements for a t-intersection with no major street pedestrian crossing movements (which would be the same for a LILO intersection) has three levels of priority. Rank 1 is the through movement on the major street, the right turning traffic from the major street, and pedestrian movements crossing the minor street. Rank 2 includes the left-turning and U-turning traffic from the major street, and right-turning traffic from the minor street onto the major street. This rank also includes pedestrian movements crossing the major street, which is not typical with the LILO treatment. Rank 3 is the left-turning traffic from the minor street. Given this priority, if the left-turning traffic volume from the major street is in high enough it is possible to cause delays to minor street left-turning traffic.

The HCM has steps for completing a capacity analysis for TWSC intersections, but it does state that the procedures do have the limitation when it comes to atypical intersection configurations (such as the LILO treatment). For the mentioned procedures it does state that geometric data is needed, such as number and configuration of lanes, and any other unique geometric factors, as well as hourly turning movement demand volumes. Other data can be added to the analysis to make it more accurate but are not required (Transportation Research Board, 2016).

As there were no existing results of similar analyses of LILO operational impacts, a review of research on similar intersections was conducted. Some studies assessing delay at TWSC intersections and at locations with two-way left-turn lanes (TWLTLs) found, as expected, that increased approach flow rates and percentages of left-turning vehicles increased delay at these types of intersections (Bonneson & Fitts, 1999; Ma et al., 2014).

2.2 SENSITIVITY ANALYSES

A sensitivity analysis is a method to determine how different values of an independent variable affect a particular dependent variable under a set of given assumptions. In a study that looked at multiple different intersection designs, delay was used as the deciding factor of what was an acceptable design. This study changed a single variable, then ran a microsimulation model 6 times, changing the random seed each time. The different variables changed as part of the sensitivity analysis were the volumes for all the approaches, the percentage of left-turning vehicles from the major approach, and a combination of the left-turning vehicles percentage for the major and minor movements. Although the LILO treatment was not part of this study, it was found that average delay at roundabouts (compared to other intersection designs) tended to have the lowest delay before a certain approach volume (Sangster, 2015). Relatedly, a study that examined TWLTL intersections used a similar process of adjusting volume and examining the impacts on delay and level of service (Ma et al., 2014).

2.3 MICROSIMULATION MODELING

2.3.1 Microsimulation Model Creation

When creating a microsimulation model, there is guidance available from multiple state DOTs, and overall, the information that they provide is similar or the same. The information conveyed is also similar to what NAU researchers have completed in previous projects. They all state that what is needed for the initial model creation is geometry data, either from the actual building plans, or from using aerial images such as Satellite view in Google Maps. This information should include things like lane width, number of lanes, lane type (left, through, right, etc.), the length of the lane, any pertinent signage or signals such as stop signs, stated speed of the roadway, and any other information that is needed for the model to be able to run properly (CODOT, 2023; ODOT, 2023; Russo et al., 2022).

Related to the ‘pertinent signage’ note above, one LILO site in this study was for a shopping center’s driveway and does not contain any signage (e.g. no stop sign on the minor road). Based on the Arizona Revised Statute Sec 28-856, “The driver of a vehicle merging from an alley, driveway, or building within a business or residence district shall: 1. Stop the vehicle immediately before driving onto a sidewalk or onto the sidewalk area extending across any alleyway or private driveway … 3. On entering the roadway, yield right-of-way to all closely approaching vehicles on the roadway” (Emerging from Alley, Driveway or Building, n.d.).

Therefore, the aforementioned study LILO site was treated as though it had a stop sign during microsimulation modeling.

2.3.2 Microsimulation Model Calibration

After a microsimulation model has been created, it needs to be calibrated to make it match existing real-world conditions, and this requires more information than just what was needed when creating the microsimulation model. Some of the additional information needed is recent vehicle volumes for the movements, the vehicle distribution between cars, heavy vehicles, and other vehicle types, along with any driving behavior that is not designed to be in the base model, such as if there are frequent U-turns or if drivers act like there is a dedicated lane for an action such as turning right. Queue lengths should also be compared; in the Russo et al. ODOT report, they compared the average queue lengths that were manually observed to the queue lengths found in the model (CODOT, 2023; ODOT, 2023; Russo et al., 2022; WSDOT, 2021). Additional information can be added to make the model more accurate but is typically not required, such as actual speeds that vehicles use on the roadway (CODOT, 2023; WSDOT, 2021).

Sometimes, after initial calibration, the model does still not acceptably represent field-observed conditions and additional parameters need to be adjusted. Potential parameters that can be modified for further calibration include the speed distribution, routing decisions, or driving behaviors such as aggressiveness or gap acceptance behavior. Many of the guidance documents examined for this literature review stated that changing driving behavior parameters should be some of the last parameters adjusted in the calibration process (CODOT, 2023; ODOT, 2023; WSDOT, 2021). With respect to when adequate calibration has been achieved, Manjunatha, Vortisch, and Mathew noted the simulation results can be considered valid and the simulation can be used confidently when field measured and simulated values such as delay and the variation between simulation and field results are within 15% of each other (Manjunatha et al., 2012).

After models are calibrated, there are also recommendations for running the calibrated models to conduct analyses. One of the first items that should be noted is the initial random seed, and Vissim sets the initial random seed to 42. Each time the simulation is run, the random seed should be increased by increments of one based on existing guidance. The results of multiple runs with different random seeds should then be averaged. Guidance on how many runs (with different random seeds) vary slightly by guidance source. Multiple guidance documents recommend doing a minimum of 5 simulation runs, some say between 5-10 simulation runs, and others provide an equation to determine the number of runs required (CODOT, 2023; ODOT, 2023; WSDOT, 2021). The general consensus is to keep running simulations until the results have stabilized, and for more basic models that is possible in 5-10 runs while more complex models may require more simulation runs.

2.4 LITERATURE REVIEW SUMMARY

This literature review provided a brief summary of information on delay and capacity for similar more common intersection treatments such as TWSC and TWLTL road treatments. It has also provided an overview of what data and processes are used in the creation of microsimulation models, specifically to the creation of models in Vissim created by the PTV Group. The review finally provided information on calibration of the model, such as the data needed to calibrate, and the process used to ensure that the model is as close to real-world results as possible. Finally, this memo provides information on how a sensitivity analysis is accomplished from similar projects that looked at road and intersection treatments that were not normally used or simulated to determine average delay and LOS. Ultimately, the guidance found in the existing literature is primarily used to inform the processes for microsimulation model development, microsimulation model calibration, and performing a sensitivity analysis.

3.0 FIELD-COLLECTED DATA DESCRIPTION

3.1 STUDY SITE SELECTION AND VIDEO DATA COLLECTION

The scope of this project included analysis of ten existing LILO sites in the city of Scottsdale. Therefore, in consultation with Scottsdale staff, ten typical LILO sites were identified for inclusion in the study, and they are shown in Table 3.1. Additionally, the year the LILO treatment was installed at each site, the center treatment/median width, the major road speed limit, the LILO acceleration length, and the presence of LILO specific signs are also noted for each site in Table 3.1. The site characteristics were collected as part of a previous study on the safety impacts of LILO treatments using Google Maps/Street View (Russo et al., 2021). As shown in Table 3.1, all the study sites have had the LILO treatment installed for a decade or more, so drivers in these areas are generally assumed to be familiar with the treatment. Additionally, the study sites were selected to include variation amongst the independent variables shown in Table 3.1.

Table 3.1: LILO Study Sites and Site Characteristics

Site	Year LILO Installed	Center treatment /median width (ft)	Speed Limit (mph)	Acell Length (ft)	LILO Signs Present?
Via De La Sendero & Indian Bend	2010	15	40	200	No
100th & Shea	1990	18	45	285	Yes
Chaparral & Chaparral Plaza	2003	10	30	125	No
104th & McDowell Mtn Ranch	2009	23	40	130	Yes
Frank Lloyd Wright (FLW) & Redfield	2013	18	45	185	No
Hayden & 74th	2002	18	45	300	Yes
Indian Bend & Paradise View	2009	10	40	100	Yes
Pima & DC Marketplace	2007	25	45	315	Yes
Shea & 118th	1990	20	50	290	Yes
Shea & 120th	1990	20	50	290	Yes

Videos were recorded at the ten study sites in in October and November of 2023 which were then used to obtain field observed volumes, minor road left-turn delay, and queue lengths. Videos were recorded for one day at each study site during AM peak hours (7-9am) and PM peak hours (4-6pm) for a total of 40 site-hours of video. In this context, a site-hour refers to one hour of video/data at one study site. Videos were collected by city of Scottsdale staff using StreetLogic Pro cameras and then shared with NAU for analysis.

3.2 VOLUME DATA

Turning movement volume counts were conducted for each hour at each study site through a combination of automated counts using countCLOUD software provided by the city of Scottsdale (for six study sites) and manual data reduction from the video (for the remaining four sites). Volumes were counted in 15-minute bins and then ultimately combined to obtain hourly turning movement volumes for site-hour. The turning movement volumes collected for each hour at each site include:

- Minor Road Right Turn Volume
- Minor Road Left Turn Volume
- Major Road Near-side (closest to minor rd.) Right Turn Volume
- Major Road Near-side (closest to minor rd.) Through Volume
- Major Road Far-side (further from minor rd.) Left Turn Volume (onto the minor road)
- Major Road Far-side (further from minor rd.) Through Volume

The volume data ultimately is used for microsimulation modeling and to explore impacts on minor road left-turn delay in this study, and a summary of volumes by site-hour is shown in Table 3.2.

3.3 DELAY AND QUEUE DATA

The overall objective of this study is to examine the impacts of different volumes on minor road left-turn delay, and therefore field-observed delay was collected using a series of time stamps from the field-collected videos. Additionally, queue lengths were collected for use in the microsimulation modeling process. This data collected included collection of twelve fields for every minor road left-turning vehicle observed at the LILO sites. These fields include:

1. Color of vehicle (used by data collector for tracking vehicles)
2. Vehicle type (car or truck - used by data collector for tracking vehicles)
3. Time stamp when vehicle arrives at back of queue
4. Number of vehicles in queue in front of vehicle when they arrive at back of queue
5. Time stamp when vehicle arrives at stop bar
6. Time stamp when vehicle departs stop bar
7. Rolling Stop (Yes or No)
8. Conflict between major / minor left-turning vehicles (Yes or No)
9. Number of vehicles in queue behind vehicle when it departs stop bar
10. Time stamp when vehicle arrives in the median acceleration area
11. Time stamp when vehicle merges into traffic completing left turn

12. Comments

These items were reduced from the videos in an office setting, and data collectors could stop, pause, and rewind video as needed to allow for accurate data collection. Ultimately, using differences between the time stamps, delay for left-turning vehicles was determined for the time it took for vehicles to move from back of queue (BoQ) to the stop bar, stop bar to the median acceleration area, and from the median acceleration area to when the vehicle ultimately merges to complete the left turn. These components added together represent the total delay for minor road left-turning vehicles, and the delay for all vehicles within each site-hour were averaged to determine the average delay in seconds per vehicle for site-hour. Queue lengths were collected by observing the number of vehicles queued, then averaged for each site hour and converted to length in feet using the assumption of 19ft per passenger vehicle (AASHTO, 2011). Table 3.2 shows a summary of average total delay for minor road left-turning vehicles and queue lengths for each study site-hour.

Table 3.2: Summary of Field-Collected Delay, Volume, and Queue Data

Site	Hour of Day (4=4pm, 5=5pm, 7=7am, 8=8am)	Total Minor Left Turn Field-Observed Delay (s/veh)	Minor Approach Volume (vph)	Percent Minor Approach Left Turn (%)	Near Side Major Volume (vph)	Far Side Major Volume (vph)	Percent Far Side Major Left Turn (%)	Cross Product Minor LT-Total Major Vol/1000	Average Minor Left Turn Queue Length (ft)
Via De La Sendero & Indian Bend	4	27	121	56.0	898	628	9.0	103.4	16.3
Via De La Sendero & Indian Bend	5	31	113	62.0	846	698	8.0	108.2	10.9
Via De La Sendero & Indian Bend	7	18	148	70.0	504	455	5.0	99.4	6.9
Via De La Sendero & Indian Bend	8	20	142	66.0	561	515	9.0	100.8	10.4
100th & Shea	4	32	53	68.0	1328	1211	1.5	91.5	5.3
100th & Shea	5	23	49	57.0	1375	1084	1.9	68.7	6.6
100th & Shea	7	22	34	68.0	1076	1216	0.9	53.0	7.5
100th & Shea	8	29	38	66.0	1231	1409	0.8	66.2	9.2
Chaparral & Chaparral Plaza	4	19	127	25.0	613	711	12.0	42.0	1.0
Chaparral & Chaparral Plaza	5	17	126	26.0	641	701	10.0	44.0	4.6
Chaparral & Chaparral Plaza	7	20	38	21.0	582	387	6.0	7.7	3.4
Chaparral & Chaparral Plaza	8	18	57	26.0	695	418	11.0	16.5	0.9
104th & McDowell Mtn Ranch	4	18	103	82.0	723	486	3.0	102.1	1.2

104th & McDowell Mtn Ranch	5	28	134	86.0	668	443	4.0	128.0	2.9
104th & McDowell Mtn Ranch	7	17	101	85.0	384	750	3.0	97.4	4.1
104th & McDowell Mtn Ranch	8	25	167	86.0	485	564	5.0	150.7	1.3
FLW & Redfield	4	43	110	62.0	1270	1147	2.4	164.8	1.0
FLW & Redfield	5	61	92	73.0	1403	1155	2.9	171.8	4.6
FLW & Redfield	7	27	109	62.0	900	1172	2.0	140.0	3.4
FLW & Redfield	8	32	76	54.0	763	1041	2.6	74.0	0.9
Hayden & 74th	4	24	58	36.0	743	1007	4.0	36.5	5.3
Hayden & 74th	5	21	47	32.0	568	913	4.0	22.3	16.9
Hayden & 74th	7	19	63	29.0	675	441	3.0	20.4	5.7
Hayden & 74th	8	24	67	42.0	764	638	3.0	39.5	14.4
Indian Bend & Paradise View	4	28	38	61.0	703	904	7.0	37.3	5.5
Indian Bend & Paradise View	5	31	50	82.0	756	843	8.0	65.6	2.2
Indian Bend & Paradise View	7	15	51	76.0	464	574	4.0	40.2	11.7
Indian Bend & Paradise View	8	22	44	66.0	517	680	4.0	34.8	17.2
Pima & DC Marketplace	4	51	123	41.0	1794	1622	2.0	172.3	2.0
Pima & DC Marketplace	5	45	141	38.0	1710	1305	3.0	161.5	5.0
Pima & DC Marketplace	7	33	102	48.0	1358	1505	2.0	140.2	0.8
Pima & DC Marketplace	8	40	111	44.0	1725	1673	2.0	166.0	6.8
Shea & 118th	4	44	60	83.0	1675	1842	1.0	175.1	5.8
Shea & 118th	5	46	58	91.0	1511	1671	1.0	167.9	8.4
Shea & 118th	7	46	78	76.0	1966	1859	0.5	226.7	15.6
Shea & 118th	8	59	43	63.0	1804	1413	1.0	87.1	6.7
Shea & 120th	4	47	69	64.0	1865	1649	2.0	155.2	5.9
Shea & 120th	5	45	62	73.0	1725	1489	1.0	145.5	8.8
Shea & 120th	7	50	124	48.0	1912	1964	2.0	230.7	8.5
Shea & 120th	8	49	106	60.0	1424	1776	2.0	203.5	13.2

3.4 ROLLING STOP AND MAJOR/MINOR LEFT TURN CONFLICT DATA

As noted in Section 3.3, additional items collected for each minor road left-turning vehicle included whether the vehicle made a 'rolling stop' (i.e. did not come to a complete stop at the stop bar), and whether the minor road left-turning vehicle was involved in a conflict with a major road left-turning vehicle. These items were collected at the request of Scottsdale staff to gain additional insights into LILO operations. A summary of these data are presented in Table 3.3.

With respect to rolling stops, the overall average percentage of minor road left-turning vehicles making rolling stops among all site-hours was 33.7%. It is not clear how this compares with other typical stop-controlled intersections, but comparisons could be made in future research. While rolling stops usually occur when vehicles arrive at the stop bar with no conflicting traffic on the near-side major road, this maneuver could potentially have safety impacts, particularly for pedestrians and bicyclists using sidewalks/crosswalks crossing the minor road.

With respect to conflicts between minor and major road left-turning vehicles, the overall average of this occurrence was 1.5% of all minor road left-turning vehicles. This scenario occurs when a minor road left-turning vehicle starts their crossing of the near-side major road at the same time as a major road left-turning vehicle (which actually has the right-of-way) is starting their turn onto the minor road. Example screen shots of this scenario are shown in Figure 3.1 and Figure 3.2. Although this conflict was a relatively rare occurrence, consideration should be given to ensuring minor road left-turning drivers are aware that they must yield to major road left-turning vehicles. Signage or public awareness campaigns could be considered in this effort. It should be noted that it's unclear how the prevalence of this conflict at LILO sites compares to sites with standard median openings, and future research could explore this comparison.

Figure 3.1: Left Turn Conflict Example at Paradise View and Indian Bend

Figure 3.2: Left Turn Conflict Example at Pima and DC Marketplace

Table 3.3: Summary of Rolling Stop and Major-Minor Left Turn Conflict Data

Site	Hour	Minor Road Left Turn Volume (vph)	No. of Rolling Stops	Percent of Rolling Stops	No. of Maj-Min Left Turn Conflicts	Percent of Maj-Min Left Turn Conflicts
Via De La Sendero & Indian Bend	7-8 AM	104	60	57.9%	0	0.0%
	8-9 AM	94	52	55.5%	1	1.1%
	4-5 PM	68	27	39.8%	0	0.0%
	5-6 PM	70	34	48.5%	1	1.4%
100th & Shea	7-8 AM	23	10	43.3%	0	0.0%
	8-9 AM	25	13	51.8%	0	0.0%
	4-5 PM	36	10	27.7%	0	0.0%
	5-6 PM	28	10	35.8%	0	0.0%
Chaparral & Chaparral Plaza	7-8 AM	8	3	37.6%	0	0.0%
	8-9 AM	15	6	40.5%	0	0.0%
	4-5 PM	32	16	50.4%	2	6.3%
	5-6 PM	33	14	42.7%	1	3.1%
104th & McDowell Mtn Ranch	7-8 AM	86	32	37.3%	0	0.0%
	8-9 AM	144	33	23.0%	3	2.1%
	4-5 PM	84	23	27.2%	0	0.0%
	5-6 PM	115	32	27.8%	0	0.0%
Frank Lloyd Wright & Redfield	7-8 AM	68	13	19.2%	0	0.0%
	8-9 AM	41	8	19.5%	2	4.9%
	4-5 PM	68	14	20.5%	2	2.9%
	5-6 PM	67	8	11.9%	0	0.0%
Hayden & 74th	7-8 AM	18	6	32.8%	0	0.0%
	8-9 AM	28	4	14.2%	0	0.0%
	4-5 PM	21	7	33.5%	0	0.0%
	5-6 PM	15	4	26.6%	0	0.0%
Indian Bend & Paradise View	7-8 AM	39	15	38.7%	0	0.0%
	8-9 AM	29	15	51.7%	1	3.4%
	4-5 PM	23	4	17.3%	1	4.3%
	5-6 PM	41	11	26.8%	1	2.4%
Pima & DC Marketplace	7-8 AM	49	22	44.9%	0	0.0%
	8-9 AM	49	20	41.0%	1	2.0%
	4-5 PM	50	16	31.7%	1	2.0%
	5-6 PM	54	16	29.9%	2	3.7%
Shea & 118th	7-8 AM	59	19	32.1%	4	6.7%
	8-9 AM	27	8	29.5%	0	0.0%
	4-5 PM	50	16	32.1%	2	4.0%
	5-6 PM	53	19	36.0%	1	1.9%
Shea & 120th	7-8 AM	60	17	28.6%	2	3.4%
	8-9 AM	64	19	29.9%	1	1.6%
	4-5 PM	44	14	31.7%	1	2.3%
	5-6 PM	45	9	19.9%	1	2.2%
			Average:	**33.7%**		**1.5%**

4.0 MICROSIMULATION MODEL CREATION AND CALIBRATION

4.1 BASELINE MICROSIMULATION MODEL DEVELOPMENT

After field-observed volume, delay, and queue data were reduced from field-collected videos as described previously, microsimulation models were created for each of the ten study LILO sites using Vissim software. For each site, a roadway network was created based on existing geometry as observed using Bing maps, which is integrated within the Vissim software. This was accomplished by creating roadway links following existing geometry at each LILO site, adding stop signs for the minor road approach, and setting conflict zones (with appropriate priority) where applicable for each site where major or minor road left-turning vehicles cross with major road through traffic and where merge/diverge maneuvers occur. Additionally, vehicle speed ranges were input using the existing speed limits at each site as the 85^{th} percentile speed in the Vissim speed distribution.

Next, vehicle routing/volumes were input for each hour at each site based on the previously described field-collected turning movement volumes for each site-hour. Finally, travel time/delay measurement zones were added to each model such that they matched the delay measurement locations used in the field-collected data described previously in Section 3.3. An example screen shot of the Vissim model for Shea Blvd. and 120th St. is shown in Figure 4.1. Once the baseline models were created, observations of the running models with Vissim default driver behavioral values were made, and based on these qualitative observations, the vehicles within the models seemed to be behaving as expected and similar to vehicles in the field-collected videos. However, quantitative model calibration is required to confirm that the microsimulation models are reliably representing field-observed conditions, particularly with respect to minor road left-turning vehicle delay in this study. As such, a comprehensive calibration process was undertaken for each site-hour using field-observed delay, queue lengths and vehicles served, and that process is described subsequently in Section 4.2. It should be noted that based on existing guidance (CODOT, 2023; ODOT, 2023; WSDOT, 2021), during the calibration process and sensitivity analysis, each Vissim model is run with a 15-minute startup period and each hour is run ten times with ten different random seeds. Reported output values for each hour (e.g. delay) are then averaged across the ten different runs with different random seeds.

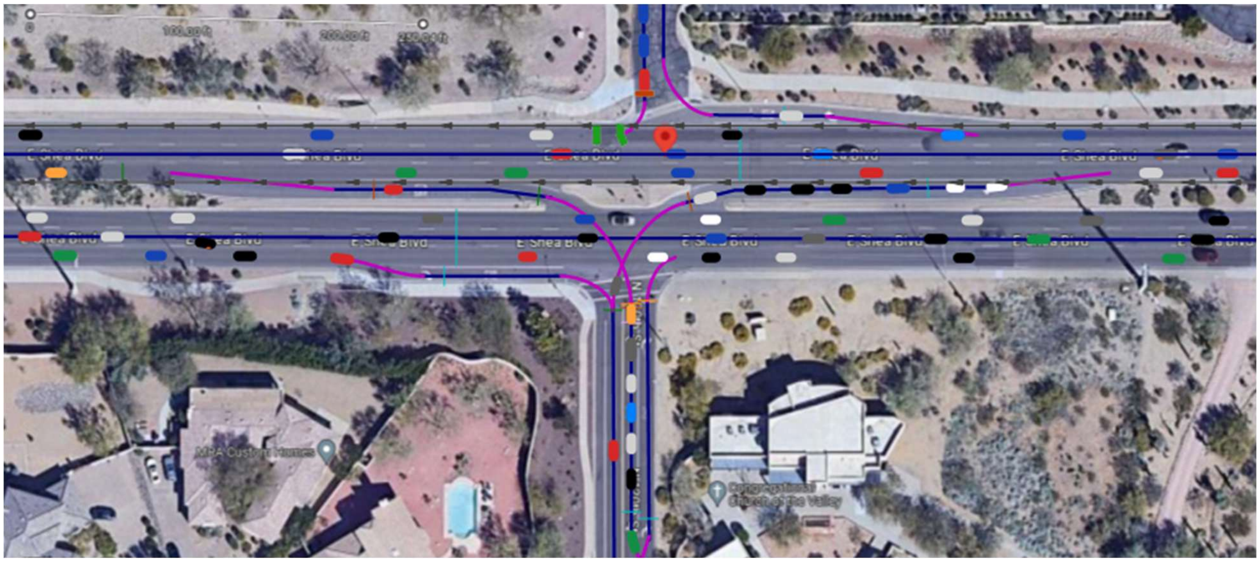

Figure 4.1: Example Vissim model for Shea Blvd. and 120th St.

4.2 MICROSIMULATION MODEL CALIBRATION

After baseline microsimulation models were developed using existing geometries and hourly volumes as described in Section 4.1, a calibration process was undertaken to ensure that the microsimulation models were accurately representing existing real-world conditions. Based on existing practices and past work in this area (ODOT, 2023; Russo et al., 2022), three parameters were used to assess model calibration with a focus on minor road left-turning vehicles:

- Percent difference between field-observed and model-reported delay
- Average queue length
- Vehicles served (i.e. all vehicles input into the model are able to be served within the specified model time frame).

Baseline models for each hour at each site were assessed with respect to all three parameters above with a primary focus on the delay comparison. In each Vissim model, the primary parameters that were adjusted for left-turning vehicles to closer match field-observed conditions were: Front Gap (FrontGapDef), Rear Gap (RearGapDef), the Safety Distance Factor (SafDistFactDef), and occasionally the Additional Stopping Distance (AddStopDist). These parameters are essentially related to the critical gap acceptance behavior for left-turning vehicles.

A comprehensive iterative process was completed for each site-hour of simulation to arrive at the closest possible match to field-observed conditions. The results of the calibration process are shown in Table 4.1. With respect to vehicles served, there were no errors indicating vehicles were not served in any of the hourly simulations, indicating all vehicles input into each model traveled through the intersection as expected. With respect to queue length, the difference between the field observed and model-predicted queue lengths ranged from 0.02ft to 17.7ft, with an average difference of 2.7 ft. According to the American Association of State Highway and Transportation Official's (AASHTO) Policy on Geometric Design of Highways and Streets, the assumed length of passenger vehicles is 19ft (AASHTO, 2011), so all queue differences are less than one vehicle. This is an acceptable difference for queue lengths for calibrated microsimulation models.

With respect to the differences in field-observed and model-predicted delay, 36 out of 40 site-hours had percent differences of less than 15% (with most under 10%) which is considered acceptable for microsimulation model calibration (shown with green shading in Table 4.1). In fact, the average percent difference for these 36 site-hours was 4.1% (or an absolute average difference of 1.1sec). The three site hours shown with yellow shading in Table 4.1 had a percent difference between field-observed and model-predicted delay of greater than 15%, however, the differences were less than 10sec (which is the difference in ranges of LOS values for TWSC intersections), and therefore were retained in the analysis. The site-hour shown with red shading in Table 4.1 (8-9am at Frank Lloyd Wright & Redfield) had a difference of greater than 15% and greater than 10sec, and therefore was excluded from the analysis. Ultimately, the calibrated Vissim models for each hour were then used to conduct the sensitivity analysis described subsequently in Chapter 5.0.

Table 4.1: Microsimulation Model Calibration Results

Site	Hour	Delay [s]			Queue Length [ft]			All Veh. Served ?
		Field-Observed	Vissim	Percent Difference	Average Queue Length [ft] (field-observed)	Average Queue Length [ft] (Vissim)	Difference [ft]	
Via De La Sendero & Indian Bend	7-8 AM	18	16.4	-8.89%	5.25	2.05	3.20	Yes
	8-9 AM	20	18.92	-5.40%	6.57	2.17	4.40	Yes
	4-5 PM	27	26.36	-2.37%	7.54	1.66	5.88	Yes
	5-6 PM	31	27.72	-10.58%	9.24	2.77	6.47	Yes
100th & Shea	7-8 AM	22	20.87	-5.14%	0.95	0.48	0.47	Yes
	8-9 AM	29	29.89	3.07%	4.56	0.85	3.71	Yes
	4-5 PM	32	29.85	-6.72%	3.39	1.59	1.80	Yes
	5-6 PM	23	22.15	-3.70%	0.90	0.88	0.02	Yes
Chaparral & Chaparral Plaza	7-8 AM	20	20.59	2.95%	0.95	0.66	0.29	Yes
	8-9 AM	18	18.48	2.67%	4.56	1.34	3.22	Yes
	4-5 PM	19	19.40	2.11%	3.39	2.91	0.48	Yes
	5-6 PM	17	17.5	2.94%	0.90	3.22	-2.32	Yes
104th & McDowell Mtn Ranch	7-8 AM	17	14.76	-13.18%	5.34	1.50	3.84	Yes
	8-9 AM	25	16.34	-34.64%	16.87	4.82	12.05	Yes
	4-5 PM	18	17.8	-1.11%	5.70	2.19	3.51	Yes
	5-6 PM	28	20.73	-25.96%	14.38	4.83	9.55	Yes
Frank Lloyd Wright & Redfield	7-8 AM	27	26.79	-0.78%	5.45	3.65	1.80	Yes
	8-9 AM†	32	21.77	-31.97%	2.21	0.82	1.39	Yes
	4-5 PM	43	44.16	2.70%	11.71	10.26	1.45	Yes
	5-6 PM	61	61.33	0.54%	17.16	17.65	-0.49	Yes
Hayden & 74th	7-8 AM	19	17.31	-8.89%	1.19	0.22	0.97	Yes
	8-9 AM	24	22.22	-7.42%	2.95	0.44	2.51	Yes
	4-5 PM	24	25.17	4.88%	4.07	0.27	3.80	Yes

	5-6 PM	21	20.29	-3.38%	1.27	0.20	1.07	Yes
Indian Bend & Paradise View	7-8 AM	15	14.07	-6.20%	2.00	0.67	1.33	Yes
	8-9 AM	22	17.42	-20.82%	5.05	0.67	4.38	Yes
	4-5 PM	28	25.71	-8.18%	0.83	0.67	0.16	Yes
	5-6 PM	31	28.79	-7.13%	6.82	2.26	4.56	Yes
Pima & DC Marketplace	7-8 AM	33	32.57	-1.30%	5.78	0.77	5.01	Yes
	8-9 AM	40	38.4	-4.00%	8.39	1.30	7.09	Yes
	4-5 PM	51	53.91	5.71%	15.60	1.29	14.31	Yes
	5-6 PM	45	46.77	3.93%	6.74	1.29	5.45	Yes
Shea & 118th	7-8 AM	46	45.5	-1.09%	5.87	4.24	1.63	Yes
	8-9 AM	59	57.82	-2.00%	8.82	2.86	5.96	Yes
	4-5 PM	44	44.5	1.14%	8.53	1.58	6.95	Yes
	5-6 PM	46	44.64	-2.96%	13.19	4.54	8.65	Yes
Shea & 120th	7-8 AM	50	51.08	2.16%	16.29	4.98	11.31	Yes
	8-9 AM	49	48.87	-0.27%	10.93	7.85	3.08	Yes
	4-5 PM	47	46.72	-0.60%	6.85	2.02	4.83	Yes
	5-6 PM	45	45.62	1.38%	10.38	2.20	8.18	Yes

† Hour excluded from analysis

Green highlighted cells = percent difference between field-observed and model reported delay <15%

Yellow highlighted cells = difference between field-observed and model reported delay >15% but less than 10s

Red highlighted cells = difference between field-observed and model reported delay unacceptable and excluded from analysis

5.0 SENSITIVITY ANALYSIS

To examine the minor road left-turning vehicle delay across different ranges of minor and major road volumes at LILO sites, a sensitivity analysis was conducted using the calibrated microsimulation models described in Section 4.2. To conduct the sensitivity analysis, for each site hour (excluding the 8-9am hour at Frank Lloyd Wright & Redfield as mentioned previously), the following process was conducted:

1) Starting with the field observed volumes for each site-hour, the minor approach volume was decreased by 25vph and the major road volumes (both near side and far side) were decreased each by 100vph (keeping left turn percentages constant). For each change in volumes, the microsimulation model was run (with a 15 min startup and taking the average of 10 runs with different random seeds as mentioned previously) and the resultant delay for minor road left-turning vehicles was recorded. This process was continued incrementally until the resulting delay was less than 10sec (i.e. LOS A for TWSC intersections) or vehicle volumes could not be reduced further.
2) Starting with field observed volumes, the minor approach volume was increased by 25vph and the major road volumes (both near side and far side) were increased each by 100vph (keeping left turn percentages constant). For each change in volumes, the microsimulation model was run (with a 15 min startup and taking the average of 10 runs

with different random seeds as mentioned previously) and the resultant delay for minor road left-turning vehicles was recorded. This process was continued incrementally until the resulting delay was greater than 50 sec (i.e. LOS F for TWSC intersections).

This process resulted in a total of 264 total simulation runs across all site-hours with 10 simulations (with different random seeds) per run, for a total of 2,640 simulation hours. The results of the sensitivity analysis are presented in Appendix A. Figure 5.1 shows a scatterplot of the relationship between minor road left-turn total delay and total major road volume, Figure 5.2 shows a scatterplot of the relationship between minor road left-turn total delay and minor road approach volume and Figure 5.3 shows a scatterplot of the relationship between minor road left-turn total delay and the cross-product of minor road left-turn volume and major road volume (in 1000's). All three of these figures are based on the results of the sensitivity analyses. , Ultimately, this dataset was then used to estimate linear regression predictive delay models presented in Chapter 6.0.

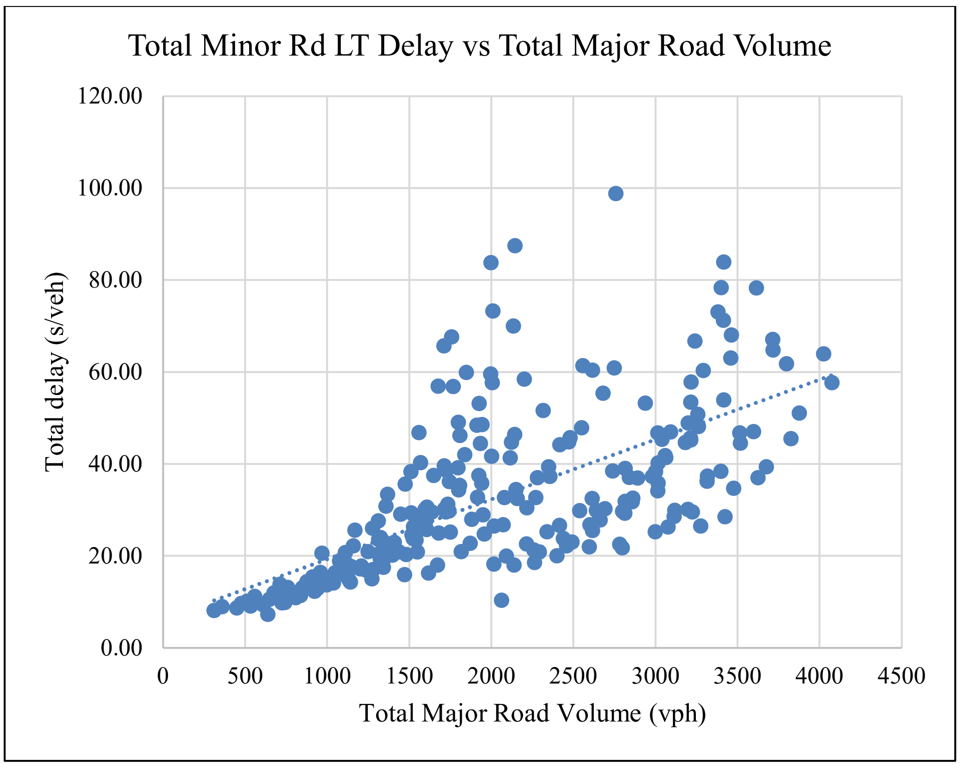

Figure 5.1: Scatterplot of minor road LT delay vs. total major road volume

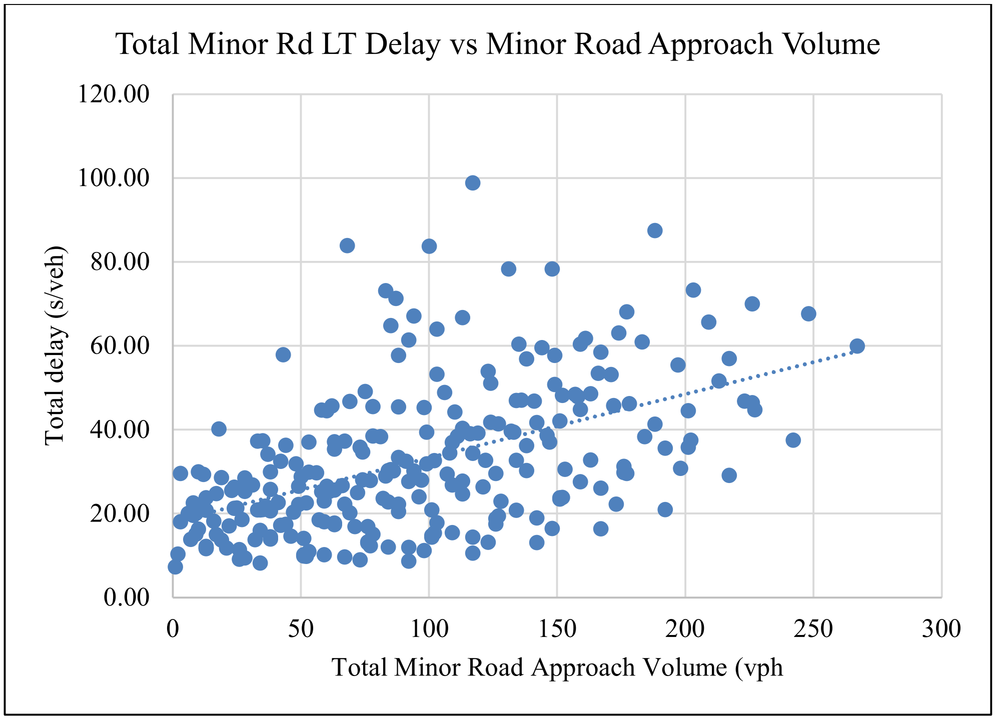

Figure 5.2: Scatterplot of minor road LT delay vs. minor road approach volume

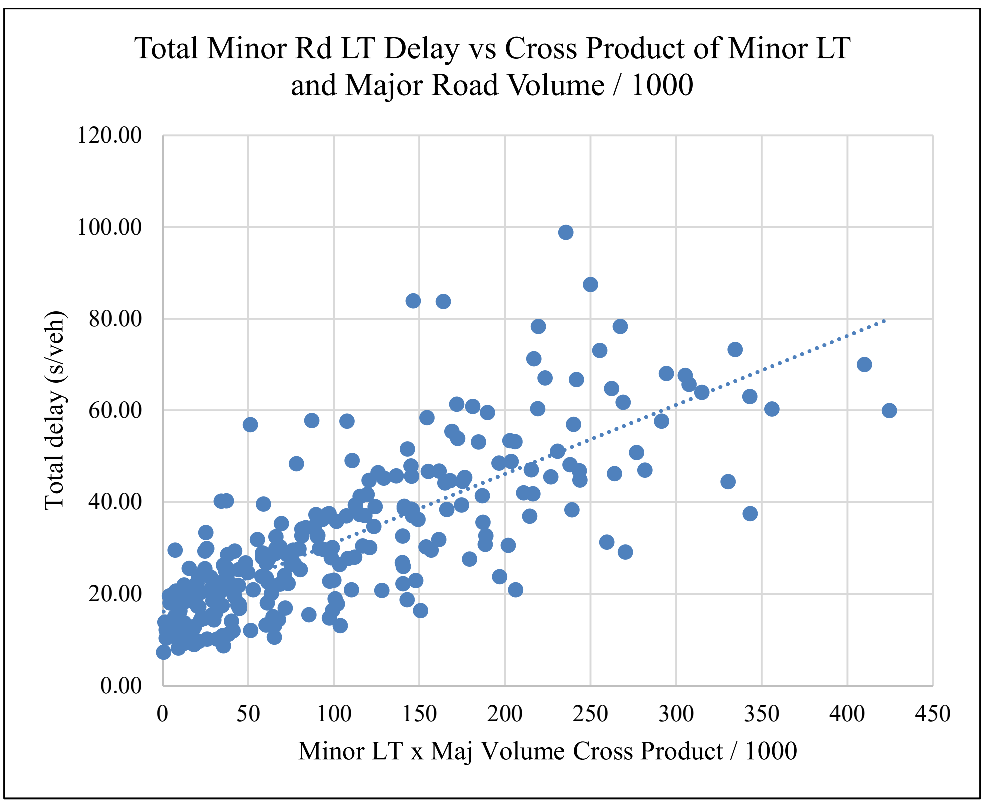

Figure 5.3: Scatterplot of minor road LT delay vs. cross product of minor road LT volume and total major road volume (in 1000's)

6.0 DEVELOPMENT OF PREDICTIVE DELAY MODELS

To predict delay as a function of different combinations of minor left turn and major road volumes, a series of linear regression models were estimated. This modeling framework is appropriate given the continuous nature of the dependent variable (delay in seconds). Linear regression is widely used to model relationships between variables, and the model outputs are relatively easy to interpret and to use to develop predictions (Washington et al., 2011). The linear regression model takes the following form (Washington et al., 2011):

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_i X_i + \varepsilon_i \tag{1}$$

where: Y_i is the delay (in sec/veh) for minor road left-turning vehicle i; X is a vector of volume and site characteristics (i.e. different minor and major road volume characteristics); β's are vectors of model-estimated parameters; and ε's are disturbance terms. Ultimately, the results of each model can be used to predict delay as a function of different minor and major road volume inputs. Additionally, the R^2 goodness of fit parameter is estimated for each model. This parameter represents the proportion of variability accounted for by the independent variables (e.g. X_i) in each model (Washington et al., 2011). The R^2 value ranges from 0 to 1.0, with values closer to 1.0 representing a better model fit.

Two primary sets of linear regression models were estimated: models predicting total delay (from back of queue (BoQ) arrival to merging with traffic after completion of left turn – presented in Section 6.1) and delay from BoQ arrival to arrival in the median acceleration area (presented in Section 6.2). Since the LILO treatment is relatively unique given there is an acceleration length of several hundred feet (this distance varies site to site) when completing left turns, these delays were modeled separately to allow for examination of delay both including and excluding the merging maneuver that does not occur near the midpoint of the intersection. Additionally, a model was estimated which includes site characteristics (e.g. acceleration length, etc.) along with the volume parameters, and that model and discussion is presented in Section 6.3.

6.1 TOTAL DELAY MODELS

Table 6.1 shows the results of the linear regression models for minor road left-turn total delay (BoQ to merging completion). Four different models are presented with various major and minor road volume parameter combinations. Model 1 is identified as the preferred model given that it has the highest R^2 value (0.684) indicating the best model fit of the four models presented, and all parameters in Model 1 are statistically significant at the 95% confidence level (i.e., p-value is less than 0.05). Model 1 inputs include minor road approach volume (vph), left turn percentage (in %) of minor road volume, near-side major road volume (vph), far-side major road volume (vph), and left turn percentage (in %) of far-side major road volume. These volume parameters can be used as inputs to determine the predicted delay using the Model 1 results.

Model 2 uses minor road approach volume, minor road left-turn percentage, far-side major road volume, and near-side major road volume as inputs. Model 3 uses minor road left-turn volume, far-side major road volume, and near-side major road volume as inputs. While Models 2 and 3 can be used to predict delay, the R^2 values are less than that of Model 1, indicating Model 1 is the preferred choice if all the volume input parameters are available. Additionally, based on the results of Model 1, the left-turn percentage of the far-side major road volume does significantly impact minor road left-turn delay (expected as minor road left-turning vehicles need to yield to major road left-turning vehicles), so it's important to consider this parameter.

Model 4 is presented as the most simplified model with only one input parameter: the cross product of the minor road left turn volume multiplied by the total major road volume (far side + near side) and divided by 1000. While the R^2 value of Model 4 (0.587) is less than Model 1, a potential advantage is that this model requires less volume input parameters, and it could be simpler to estimate hourly volumes (using AADT, for example) for potential future LILO sites where existing volumes are not available. Ultimately, all else being equal, Model 1 should be used when the volume input parameters are available, but other models can be considered when these input parameters are not available or need to be estimated at a high level.

Table 6.1: Total Delay Linear Regression Models

Parameter	Estimate	Std. Error	P-Value
Model 1			
Constant	-17.244	4.072	<.001***
Minor Approach Volume (vph)	0.133	0.012	<.001***
Minor Approach Left Turn (LT) Percent (%)	0.104	0.036	0.004***
Near-Side Major Approach Volume (vph)	0.021	0.003	<.001***
Far-Side Major Approach Volume (vph)	0.007	0.003	0.025**
Far-Side Major Approach Left Turn Percent (%)	0.699	0.309	0.025**
R-squared value	0.684		
Model 2			
Constant	3.487	2.478	0.161
Minor Approach Volume (vph)	0.218	0.017	<.001***
Minor Approach Left Turn Percent (%)	-0.167	0.037	<.001***
Near-Side Major Approach Volume (vph)	0.019	0.003	<.001***
Far-Side Major Approach Volume (vph)	0.007	0.003	0.027**
R-squared value	0.663		
Model 3			
Constant	-4.051	1.896	0.034**
Minor Approach Left Turn Volume (vph)	0.181	0.016	<.001***
Near-Side Major Approach Volume (vph)	0.021	0.003	<.001***
Far-Side Major Approach Volume (vph)	0.006	0.003	0.082*
R-squared value	0.636		
Model 4			
Constant	16.081	1.136	<.001***
Cross-Project Minor LT Volume (vph) x Total Major Volume (vph) in thousands	0.151	0.008	<.001***
R-squared value	0.587		

Note: *, **, and *** denotes variable is significant at 90%, 95%, and 99% confidence level, respectively

6.2 BACK-OF-QUEUE TO MEDIAN DELAY MODELS

As mentioned previously, it may be desirable to predict delay for left-turning vehicles delay from BoQ arrival to arrival in the median acceleration area (i.e. potentially a close comparison to traditional median openings). Therefore, a series of models (Models 5-8) were estimated to predict the BoQ-median delay, with the results are presented in Table 6.2. Similar to the results of the total delay models presented in Table 6.1, Model 5, which includes minor road approach volume (vph), left turn percentage (in %) of minor road volume, near-side major road volume (vph), far-side major road volume (vph), and left turn percentage (in %) of far-side major road volume, is the preferred model as it has the highest R^2 value (0.649) of the four models presented in Table 6.2. It should be noted that the far-side major approach volume is not statistically significant in Model 5, an expected result given that the far-side major volume does not significantly affect left-turning minor road vehicles completing the maneuver to arrive in the median acceleration area. Additionally, although not statistically significant, the parameter estimate for the far-side major approach volume in Model 5 is essentially negligible (i.e. a 0.1 sec change in delay per 100vph).

Table 6.2: Back-of-Queue to Median Delay Linear Regression Models

Parameter	Estimate	Std. Error	P-Value
Model 5			
Constant	-21.629	3.846	<.001***
Minor Approach Volume (vph)	0.099	0.011	<.001***
Minor Approach Left Turn (LT) Percent (%)	0.166	0.034	<.001***
Near-Side Major Approach Volume (vph)	0.026	0.003	<.001***
Far-Side Major Approach Volume (vph)	-0.001	0.003	0.770
Far-Side Major Approach Left Turn Percent (%)	0.861	0.292	0.003***
R-squared value	0.649		
Model 6			
Constant	-12.904	2.499	<.001***
Minor Approach Volume (vph)	0.111	0.01	<.001***
Minor Approach Left Turn Percent (%)	0.119	0.03	<.001***
Near-Side Major Approach Volume (vph)	0.025	0.003	<.001***
Far-Side Major Approach Volume (vph)	-0.003	0.003	0.276
R-squared value	0.637		
Model 7			
Constant	-5.224	1.721	0.003***
Minor Approach Left Turn Volume (vph)	0.158	0.014	<.001***
Near-Side Major Approach Volume (vph)	0.025	0.003	<.001***
Far-Side Major Approach Volume (vph)	-0.002	0.003	0.425
R-squared value	0.626		
Model 8			
Constant	12.6	1.061	<.001***
Cross-Project Minor LT Volume (vph) x Total Major Volume (vph) in thousands	0.131	0.007	<.001***
R-squared value	0.552		

Note: *, **, and *** denotes variable is significant at 90%, 95%, and 99% confidence level, respectively

6.3 TOTAL DELAY MODEL WITH ADDITIONAL SITE CHARACTERISTICS

Along with determining the effect of different minor and major road volumes on minor road left-turn delay, a secondary objective of this study was to examine the potential impacts of site characteristics on this delay. As such, an additional model for total delay was estimated which incorporates site characteristics along with the volume characteristics described previously in Models 1 and 5. The results of this model, which incorporates site characteristics, are presented in Table 6.3.

The site characteristics incorporated in this model include center treatment/median width, a binary indicator variable for speed limit of 45-50 mph (compared with 30-40 mph), acceleration length, and a binary indicator for the presence of LILO signage. Based on the model results, the higher speed limit indicator variable (45-50mph), the acceleration length, and the LILO sign presence indicator variable were not statistically significantly associated total delay (all p-values >0.10). The center treatment/median width variable was statistically significant with a negative parameter estimate, indicating lower expected delay at sites with wider medians. It's unclear whether this result is associated with driver gap acceptance behavior at sites with different median widths or some other unobserved effect. It should be noted that the sample of ten study sites does not provide a large sample of different sites characteristics when conducting this type of modeling, so future research could expand the sample to further understand the potential impacts of LILO site characteristics on delay. Ultimately, the previously presented Models 1 and 5 are the recommended models for use in delay prediction, but the model with site characteristics provides some insights into the potential impacts of LILO site characteristics on delay.

Table 6.3: Total Delay Model with Site Characteristics

Parameter	Estimate	Std. Error	P-Value
Constant	0.493	6.75	0.942
Minor Approach Volume (vph)	0.15	0.012	<.001***
Minor Approach Left Turn (LT) Percent (%)	0.122	0.049	0.013**
Near-Side Major Approach Volume (vph)	0.024	0.003	<.001***
Far-Side Major Approach Volume (vph)	0.003	0.003	0.407
Far-Side Major Approach Left Turn Percent (%)	0.064	0.518	0.902
Center Treatment/Median Width (ft)	-0.840	0.200	<.001***
Speed Limit 45-50 mph (0 or 1)	5.589	4.025	0.166
Acceleration Length (ft)	-0.029	0.018	0.115
LILO Signs Present (0 or 1)	1.614	1.941	0.406
R-squared value	0.718		

Note: *, **, and *** denotes variable is significant at 90%, 95%, and 99% confidence level, respectively

7.0 CONCLUSIONS AND RECOMMENDATIONS

This study presented an analysis of the operational impacts of the LILO median opening treatment in Scottsdale, Arizona. The overall objective was to use microsimulation modeling calibrated with field data to determine the effects of different major and minor road volumes (and select LILO design features) on the operational performance of LILO sites. To achieve this objective, field-recorded videos were collected at ten typical LILO intersections in Scottsdale, and delay, queue length, and volume information were extracted for AM peak hours (7-8am) and PM peak hours (4-6pm). Using the existing geometry and volumes, baseline Vissim microsimulation models were developed and then calibrated using delay, queue lengths, and vehicles served. The calibrated microsimulation models were used to perform a sensitivity analysis with the goal of developing predictive delay models which can be used in determining when operational performance at LILO sites is expected to become unacceptable. Ultimately, a series of predictive delay models for both total delay and BoQ-median delay were estimated using linear regression recommended models were identified. To the authors' knowledge, this study presents the first formal analysis of the potential operational impacts of the LILO treatment.

The recommended predictive delay models can be used to assess minor road left-turn delay for either existing volumes or future predicted volumes or ranges of volumes. The formulas for each recommended model are presented below, and major and minor road volumes and left-turn percentages are the inputs to the models, with the output being predicted delay in sec/veh:

- **Total Delay (sec/veh)** = -17.224 + 0.133(Min approach vph) + 0.104(Min approach LT%) + 0.021(Maj near vph) + 0.007(Maj far vph) + 0.699(Maj far LT%)

- **BoQ-Median Delay (sec/veh)** = -21.629 + 0.099(Min approach vph) + 0.166(Min approach LT%) + 0.026(Maj near vph) - 0.001(Maj far vph) + 0.861(Maj far LT%)

The choice on which model to use requires engineering judgement from the practitioner and may depend on the type of analysis being conducted (e.g. predicting existing delay or comparing future delay for different design alternatives). Additionally, the determination on whether the predicted delay is acceptable requires engineering judgement. Typically, LOS D is considered acceptable during peak hours, and the threshold delay values for when operations degrade to LOS E (e.g. potentially unacceptable) are 35 sec/veh for typical TWSC intersections and 55 sec/veh for signalized intersections per the HCM (Transportation Research Board, 2016). Predicted delay values at LILO intersections can be compared with these thresholds to estimate whether operations are expected to be acceptable. Additionally, predicted minor road left-turn delay at LILO sites using the models presented above can be compared with predicted minor road left-turn delay at typical TWSC intersections and signalized intersections (assuming the same volume characteristics) using methods for these other intersection types presented in the HCM (Transportation Research Board, 2016).

In addition to the recommended delay models presented above, a model which incorporated LILO site characteristics was estimated, and while larger median widths were found to be associated with slight delay reduction (other site characteristics were not statistically significant), these results were based on a relatively small sample of different site characteristics (ten study sites).

7.1 LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

While this study presents the first known specific operational analysis of the LILO median treatment, there were some limitations which can also be considered directions for future research in this area. First, this study only analyzed operations at ten LILO study sites. Ideally, control sites (typical TWSC intersections with standard median openings) could be incorporated to compare with the results at LILO sites (including rates of rolling stops and minor-major left turn conflicts), however that was beyond the scope of this project. Future studies could expand both the number of LILO sites and incorporate control sites to provide additional insights. Relatedly, the results of the analysis which incorporated LILO site characteristics was somewhat limited by the overall sample of only ten study sites, and future analyses with an expanded sample could yield additional insights with respect to the potential impact of different LILO site characteristics. Finally, field collected vehicle speeds could be incorporated into future analyses to assess the potential impact of vehicle speeds on the calibration process and operations. That being said, the predictive delay models presented in Sections 6.1 and 6.2 still provide important information that can be used to assess operations at LILO sites.

8.0 REFERENCES

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APPENDIX A: SENSITIVITY ANALYSIS RESULTS

Site	Hour of Day (4=4pm, 5=5pm, 7=7am, 8=8am)	Field-Observed Delay (sec/veh)	Minor Approach Volume (vph)	Minor LT Percent (%)	Major Volume (Near) (vph)	Major Volume (Far) (vph)	Percent Far Side Major LT (%)	BOQ-MEDIAN DELAY (sec/veh)	TOTAL DELAY (sec/veh)
100th & Shea	4	N/A	3	68	1128	1011	1.5	16.28	17.99
100th & Shea	4	N/A	28	68	1228	1111	1.5	21.15	25.25
100th & Shea	4	32	53	68	1328	1211	1.5	25.80	29.85
100th & Shea	4	N/A	78	68	1428	1311	1.5	32.30	38.44
100th & Shea	4	N/A	103	68	1528	1411	1.5	46.32	53.21
100th & Shea	5	N/A	24	57	1275	984	1.9	18.32	21.25
100th & Shea	5	23	49	57	1375	1084	1.9	18.86	22.15
100th & Shea	5	N/A	74	57	1475	1184	1.9	24.53	27.98
100th & Shea	5	N/A	99	57	1575	1284	1.9	27.55	31.80
100th & Shea	5	N/A	124	57	1675	1384	1.9	36.85	41.78
100th & Shea	5	N/A	149	57	1775	1484	1.9	45.53	50.78
100th & Shea	5	N/A	174	57	1875	1584	1.9	56.97	63.06
100th & Shea	7	N/A	9	68	976	1116	0.9	15.43	19.97
100th & Shea	7	22	34	68	1076	1216	0.9	16.68	20.87
100th & Shea	7	N/A	59	68	1176	1316	0.9	18.99	22.98
100th & Shea	7	N/A	84	68	1276	1416	0.9	25.29	30.21
100th & Shea	7	N/A	109	68	1376	1516	0.9	31.34	36.92
100th & Shea	7	N/A	134	68	1476	1616	0.9	40.25	46.98
100th & Shea	7	N/A	159	68	1576	1716	0.9	52.56	60.34
100th & Shea	8	N/A	13	66	1131	1309	0.8	20.52	23.76
100th & Shea	8	29	38	66	1231	1409	0.8	25.59	29.89
100th & Shea	8	N/A	63	66	1331	1509	0.8	32.72	37.10
100th & Shea	8	N/A	88	66	1431	1609	0.8	39.82	45.38
100th & Shea	8	N/A	113	66	1531	1709	0.8	60.45	66.74
Chaparral & Chaparral Plaza	4	N/A	52	25	313	411	12	7.53	9.79
Chaparral & Chaparral Plaza	4	N/A	77	25	413	511	12	8.87	12.28
Chaparral & Chaparral Plaza	4	N/A	102	25	513	611	12	10.91	15.36
Chaparral & Chaparral Plaza	4	19	127	25	613	711	12	12.62	19.40
Chaparral & Chaparral Plaza	4	N/A	152	25	713	811	12	16.86	23.80
Chaparral & Chaparral Plaza	4	N/A	177	25	813	911	12	19.74	29.56
Chaparral & Chaparral Plaza	4	N/A	202	25	913	1011	12	23.91	37.46

Chaparral & Chaparral Plaza	4	N/A	227	25	1013	1111	12	30.53	44.74
Chaparral & Chaparral Plaza	5	N/A	51	26	341	401	10	8.15	9.86
Chaparral & Chaparral Plaza	5	N/A	76	26	441	501	10	10.86	12.94
Chaparral & Chaparral Plaza	5	N/A	101	26	541	601	10	11.56	14.31
Chaparral & Chaparral Plaza	5	17	126	26	641	701	10	14.37	17.50
Chaparral & Chaparral Plaza	5	N/A	151	26	741	801	10	19.33	23.43
Chaparral & Chaparral Plaza	5	N/A	176	26	841	901	10	24.69	29.78
Chaparral & Chaparral Plaza	5	N/A	201	26	941	1001	10	29.72	35.82
Chaparral & Chaparral Plaza	5	N/A	226	26	1041	1101	10	39.71	46.41
Chaparral & Chaparral Plaza	7	N/A	13	21	482	287	6	10.58	12.13
Chaparral & Chaparral Plaza	7	20	38	21	582	387	6	17.80	20.59
Chaparral & Chaparral Plaza	7	N/A	63	21	682	487	6	22.21	25.56
Chaparral & Chaparral Plaza	7	N/A	88	21	782	587	6	27.90	33.37
Chaparral & Chaparral Plaza	7	N/A	113	21	882	687	6	35.21	40.28
Chaparral & Chaparral Plaza	7	N/A	138	21	982	787	6	49.91	56.87
Chaparral & Chaparral Plaza	8	N/A	7	26	495	218	11	12.41	13.80
Chaparral & Chaparral Plaza	8	N/A	32	26	595	318	11	11.39	13.75
Chaparral & Chaparral Plaza	8	18	57	26	695	418	11	16.04	18.48
Chaparral & Chaparral Plaza	8	N/A	82	26	795	518	11	19.92	23.59
Chaparral & Chaparral Plaza	8	N/A	107	26	895	618	11	24.64	29.35
Chaparral & Chaparral Plaza	8	N/A	132	26	995	718	11	33.21	39.60
Chaparral & Chaparral Plaza	8	N/A	157	26	1095	818	11	40.81	48.40
FLW & Redfield	4	N/A	10	62	870	747	2.4	14.13	16.25
FLW & Redfield	4	N/A	35	62	970	847	2.4	18.43	20.89
FLW & Redfield	4	N/A	60	62	1070	947	2.4	23.77	26.49
FLW & Redfield	4	N/A	85	62	1170	1047	2.4	27.31	30.46
FLW & Redfield	4	43	110	62	1270	1147	2.4	40.88	44.16
FLW & Redfield	4	N/A	135	62	1370	1247	2.4	56.47	60.35
FLW & Redfield	5	N/A	17	73	1103	855	2.9	22.74	24.73
FLW & Redfield	5	N/A	42	73	1203	955	2.9	29.22	32.47
FLW & Redfield	5	N/A	67	73	1303	1055	2.9	33.99	37.25
FLW & Redfield	5	61	92	73	1403	1155	2.9	57.65	61.33
FLW & Redfield	5	N/A	117	73	1503	1255	2.9	94.41	98.80
FLW & Redfield	7	N/A	9	62	500	772	2	12.62	15.01

FLW & Redfield	7	N/A	34	62	600	872	2	13.49	15.92
FLW & Redfield	7	N/A	59	62	700	972	2	15.12	18.00
FLW & Redfield	7	N/A	84	62	800	1072	2	19.54	22.75
FLW & Redfield	7	27	109	62	900	1172	2	23.32	26.79
FLW & Redfield	7	N/A	134	62	1000	1272	2	28.50	32.70
FLW & Redfield	7	N/A	159	62	1100	1372	2	40.56	44.81
Hayden & 74th	4	N/A	8	36	543	807	4	11.06	19.57
Hayden & 74th	4	N/A	33	36	643	907	4	13.16	20.84
Hayden & 74th	4	24	58	36	743	1007	4	14.47	25.17
Hayden & 74th	4	N/A	83	36	843	1107	4	18.11	28.94
Hayden & 74th	4	N/A	108	36	943	1207	4	20.55	34.43
Hayden & 74th	4	N/A	133	36	1043	1307	4	22.89	39.37
Hayden & 74th	4	N/A	158	36	1143	1407	4	26.78	47.88
Hayden & 74th	4	N/A	183	36	1243	1507	4	33.55	60.90
Hayden & 74th	5	N/A	22	32	468	813	4	9.90	17.03
Hayden & 74th	5	21	47	32	568	913	4	12.18	20.29
Hayden & 74th	5	N/A	72	32	668	1013	4	15.48	24.96
Hayden & 74th	5	N/A	97	32	768	1113	4	16.32	27.92
Hayden & 74th	5	N/A	122	32	868	1213	4	17.99	32.69
Hayden & 74th	5	N/A	147	32	968	1313	4	19.72	37.01
Hayden & 74th	5	N/A	172	32	1068	1413	4	23.90	45.69
Hayden & 74th	5	N/A	197	32	1168	1513	4	31.26	55.39
Hayden & 74th	7	N/A	13	29	475	241	3	10.03	11.60
Hayden & 74th	7	N/A	38	29	575	341	3	12.41	13.90
Hayden & 74th	7	19	63	29	675	441	3	14.33	17.31
Hayden & 74th	7	N/A	88	29	775	541	3	16.72	20.43
Hayden & 74th	7	N/A	113	29	875	641	3	19.36	24.63
Hayden & 74th	7	N/A	138	29	975	741	3	23.64	30.19
Hayden & 74th	7	N/A	163	29	1075	841	3	25.08	32.74
Hayden & 74th	7	N/A	188	29	1175	941	3	30.21	41.29
Hayden & 74th	7	N/A	213	29	1275	1041	3	38.87	51.60
Hayden & 74th	8	N/A	17	42	564	438	3	12.37	14.95
Hayden & 74th	8	N/A	42	42	664	538	3	13.39	17.16
Hayden & 74th	8	24	67	42	764	638	3	17.11	22.22
Hayden & 74th	8	N/A	92	42	864	738	3	21.18	27.64
Hayden & 74th	8	N/A	117	42	964	838	3	25.68	34.34
Hayden & 74th	8	N/A	142	42	1064	938	3	31.84	41.64
Hayden & 74th	8	N/A	167	42	1164	1038	3	46.37	58.43
Indian Bend & Paradise View	4	N/A	13	61	603	804	7	14.94	20.79
Indian Bend & Paradise View	4	28	38	61	703	904	7	20.70	25.71
Indian Bend & Paradise View	4	N/A	63	61	803	1004	7	29.19	35.36

Indian Bend & Paradise View	4	N/A	88	61	903	1104	7	50.23	57.68
Indian Bend & Paradise View	5	N/A	25	82	656	743	8	17.82	21.29
Indian Bend & Paradise View	5	31	50	82	756	843	8	23.49	28.79
Indian Bend & Paradise View	5	N/A	75	82	856	943	8	42.51	49.04
Indian Bend & Paradise View	5	N/A	100	82	956	1043	8	76.47	83.75
Indian Bend & Paradise View	7	N/A	1	76	264	374	4	7.01	7.27
Indian Bend & Paradise View	7	N/A	26	76	364	474	4	9.24	11.36
Indian Bend & Paradise View	7	15	51	76	464	574	4	11.57	14.07
Indian Bend & Paradise View	7	N/A	76	76	564	674	4	14.00	16.88
Indian Bend & Paradise View	7	N/A	101	76	664	774	4	16.84	20.86
Indian Bend & Paradise View	7	N/A	126	76	764	874	4	24.93	29.56
Indian Bend & Paradise View	7	N/A	151	76	864	974	4	36.57	42.03
Indian Bend & Paradise View	8	N/A	19	66	417	580	4	10.25	13.70
Indian Bend & Paradise View	8	22	44	66	517	680	4	13.91	17.42
Indian Bend & Paradise View	8	N/A	69	66	617	780	4	15.62	20.13
Indian Bend & Paradise View	8	N/A	94	66	717	880	4	23.71	30.12
Indian Bend & Paradise View	8	N/A	119	66	817	980	4	31.57	39.12
Indian Bend & Paradise View	8	N/A	144	66	917	1080	4	51.41	59.54
McDowell Mtn Ranch & 104th	4	N/A	28	82	423	186	3	8.84	9.40
McDowell Mtn Ranch & 104th	4	N/A	53	82	523	286	3	9.96	10.93
McDowell Mtn Ranch & 104th	4	N/A	78	82	623	386	3	13.18	15.05
McDowell Mtn Ranch & 104th	4	18	103	82	723	486	3	15.00	17.80
McDowell Mtn Ranch & 104th	4	N/A	128	82	823	586	3	19.21	22.91
McDowell Mtn Ranch & 104th	4	N/A	153	82	923	686	3	26.25	30.56
McDowell Mtn Ranch & 104th	4	N/A	178	82	1023	786	3	39.57	46.18
McDowell Mtn Ranch & 104th	4	N/A	203	82	1123	886	3	64.28	73.28
McDowell Mtn Ranch & 104th	5	N/A	34	86	268	43	4	7.97	8.15
McDowell Mtn Ranch & 104th	5	N/A	59	86	368	143	4	9.56	10.16
McDowell Mtn Ranch & 104th	5	N/A	84	86	468	243	4	10.96	11.98
McDowell Mtn Ranch & 104th	5	N/A	109	86	568	343	4	13.88	15.42

McDowell Mtn Ranch & 104th	5	28	134	86	668	443	4	18.45	20.74
McDowell Mtn Ranch & 104th	5	N/A	159	86	768	543	4	24.02	27.58
McDowell Mtn Ranch & 104th	5	N/A	184	86	868	643	4	33.76	38.34
McDowell Mtn Ranch & 104th	5	N/A	209	86	968	743	4	59.39	65.67
McDowell Mtn Ranch & 104th	7	N/A	26	85	84	450	3	6.82	9.11
McDowell Mtn Ranch & 104th	7	N/A	51	85	184	550	3	7.36	10.15
McDowell Mtn Ranch & 104th	7	N/A	76	85	284	650	3	9.04	13.19
McDowell Mtn Ranch & 104th	7	17	101	85	384	750	3	9.83	14.76
McDowell Mtn Ranch & 104th	7	N/A	126	85	484	850	3	11.95	18.74
McDowell Mtn Ranch & 104th	7	N/A	151	85	584	950	3	14.86	23.75
McDowell Mtn Ranch & 104th	7	N/A	176	85	684	1050	3	19.85	31.25
McDowell Mtn Ranch & 104th	7	N/A	201	85	784	1150	3	27.50	44.47
McDowell Mtn Ranch & 104th	7	N/A	226	85	884	1250	3	47.40	70.02
McDowell Mtn Ranch & 104th	8	N/A	92	86	185	264	5	7.69	8.66
McDowell Mtn Ranch & 104th	8	N/A	117	86	285	364	5	8.87	10.53
McDowell Mtn Ranch & 104th	8	N/A	142	86	385	464	5	10.47	13.07
McDowell Mtn Ranch & 104th	8	25	167	86	485	564	5	12.90	16.34
McDowell Mtn Ranch & 104th	8	N/A	192	86	585	664	5	16.05	20.89
McDowell Mtn Ranch & 104th	8	N/A	217	86	685	764	5	23.24	29.09
McDowell Mtn Ranch & 104th	8	N/A	242	86	785	864	5	29.24	37.49
McDowell Mtn Ranch & 104th	8	N/A	267	86	885	964	5	48.32	59.93
Pima & DC Marketplace	4	N/A	23	41	1394	1222	2	19.30	25.50
Pima & DC Marketplace	4	N/A	48	41	1494	1322	2	23.83	31.85
Pima & DC Marketplace	4	N/A	73	41	1594	1422	2	27.07	35.83
Pima & DC Marketplace	4	N/A	98	41	1694	1522	2	33.82	45.24
Pima & DC Marketplace	4	51	123	41	1794	1622	2	42.69	53.91
Pima & DC Marketplace	4	N/A	148	41	1894	1722	2	63.12	78.28
Pima & DC Marketplace	5	N/A	16	38	1210	805	3	15.12	18.18
Pima & DC Marketplace	5	N/A	41	38	1310	905	3	18.50	22.56
Pima & DC Marketplace	5	N/A	66	38	1410	1005	3	22.22	26.63

Pima & DC Marketplace	5	N/A	91	38	1510	1105	3	27.00	32.45
Pima & DC Marketplace	5	N/A	116	38	1610	1205	3	32.19	38.99
Pima & DC Marketplace	5	45	141	38	1710	1305	3	39.11	46.77
Pima & DC Marketplace	5	N/A	166	38	1810	1405	3	44.22	53.40
Pima & DC Marketplace	7	N/A	2	48	958	1105	2	8.08	10.33
Pima & DC Marketplace	7	N/A	27	48	1058	1205	2	14.17	18.54
Pima & DC Marketplace	7	N/A	52	48	1158	1305	2	17.49	22.53
Pima & DC Marketplace	7	N/A	77	48	1258	1405	2	21.77	27.84
Pima & DC Marketplace	7	33	102	48	1358	1505	2	25.12	32.57
Pima & DC Marketplace	7	N/A	127	48	1458	1605	2	33.24	41.38
Pima & DC Marketplace	7	N/A	152	48	1558	1705	2	38.80	48.17
Pima & DC Marketplace	7	N/A	177	48	1658	1805	2	57.33	68.05
Pima & DC Marketplace	8	N/A	11	44	1325	1273	2	20.38	21.95
Pima & DC Marketplace	8	N/A	36	44	1425	1373	2	19.12	21.78
Pima & DC Marketplace	8	N/A	61	44	1525	1473	2	22.55	25.24
Pima & DC Marketplace	8	N/A	86	44	1625	1573	2	26.87	30.11
Pima & DC Marketplace	8	40	111	44	1725	1673	2	34.65	38.40
Pima & DC Marketplace	8	N/A	136	44	1825	1773	2	43.12	47.05
Pima & DC Marketplace	8	N/A	161	44	1925	1873	2	57.16	61.77
Shea & 118th	4	N/A	10	83	1475	1642	1	24.13	29.91
Shea & 118th	4	N/A	35	83	1575	1742	1	30.61	37.32
Shea & 118th	4	44	60	83	1675	1842	1	36.97	44.50
Shea & 118th	4	N/A	85	83	1775	1942	1	55.53	64.78
Shea & 118th	5	N/A	8	91	1311	1471	1	17.49	22.51
Shea & 118th	5	N/A	33	91	1411	1571	1	31.89	37.27
Shea & 118th	5	46	58	91	1511	1671	1	38.03	44.64
Shea & 118th	5	N/A	83	91	1611	1771	1	66.36	73.09
Shea & 118th	7	N/A	3	76	1666	1559	0.5	25.44	29.55
Shea & 118th	7	N/A	28	76	1766	1659	0.5	25.14	28.49
Shea & 118th	7	N/A	53	76	1866	1759	0.5	32.40	37.01
Shea & 118th	7	46	78	76	1966	1859	0.5	41.05	45.50
Shea & 118th	7	N/A	103	76	2066	1959	0.5	59.01	63.92
Shea & 118th	8	N/A	18	63	1704	1313	1	36.47	40.18
Shea & 118th	8	59	43	63	1804	1413	1	53.15	57.82
Shea & 118th	8	N/A	68	63	1904	1513	1	78.61	83.91

Shea & 120th	4	N/A	19	64	1665	1449	2	23.62	28.56
Shea & 120th	4	N/A	44	64	1765	1549	2	31.01	36.24
Shea & 120th	4	47	69	64	1865	1649	2	40.75	46.72
Shea & 120th	4	N/A	94	64	1965	1749	2	59.63	67.07
Shea & 120th	5	N/A	12	73	1525	1289	1	24.84	29.31
Shea & 120th	5	N/A	37	73	1625	1389	1	29.58	34.12
Shea & 120th	5	45	62	73	1725	1489	1	39.73	45.62
Shea & 120th	5	N/A	87	73	1825	1589	1	64.85	71.26
Shea & 120th	7	N/A	24	48	1512	1564	2	21.64	26.28
Shea & 120th	7	N/A	49	48	1612	1664	2	21.93	26.47
Shea & 120th	7	N/A	74	48	1712	1764	2	29.61	34.69
Shea & 120th	7	N/A	99	48	1812	1864	2	33.53	39.39
Shea & 120th	7	50	124	48	1912	1964	2	44.70	51.08
Shea & 120th	7	N/A	149	48	2012	2064	2	49.63	57.69
Shea & 120th	8	N/A	6	60	1024	1376	2	14.67	20.00
Shea & 120th	8	N/A	31	60	1124	1476	2	21.89	26.76
Shea & 120th	8	N/A	56	60	1224	1576	2	23.97	29.67
Shea & 120th	8	N/A	81	60	1324	1676	2	31.64	38.29
Shea & 120th	8	49	106	60	1424	1776	2	40.73	48.87
Shea & 120th	8	N/A	131	60	1524	1876	2	69.07	78.33
Via De La Sendero & Indian Bend	4	N/A	21	56	498	228	9	10.90	11.78
Via De La Sendero & Indian Bend	4	N/A	46	56	598	328	9	13.15	14.60
Via De La Sendero & Indian Bend	4	N/A	71	56	698	428	9	14.54	16.85
Via De La Sendero & Indian Bend	4	N/A	96	56	798	528	9	20.90	23.98
Via De La Sendero & Indian Bend	4	27	121	56	898	628	9	22.28	26.36
Via De La Sendero & Indian Bend	4	N/A	146	56	998	728	9	33.67	38.58
Via De La Sendero & Indian Bend	4	N/A	171	56	1098	828	9	47.23	53.12
Via De La Sendero & Indian Bend	5	N/A	13	62	446	298	8	9.90	11.77
Via De La Sendero & Indian Bend	5	N/A	38	62	546	398	8	12.43	14.40
Via De La Sendero & Indian Bend	5	N/A	63	62	646	498	8	15.37	17.75
Via De La Sendero & Indian Bend	5	N/A	88	62	746	598	8	18.61	22.24
Via De La Sendero & Indian Bend	5	31	113	62	846	698	8	23.34	27.72
Via De La Sendero & Indian Bend	5	N/A	138	62	946	798	8	30.67	36.20
Via De La Sendero & Indian Bend	5	N/A	163	62	1046	898	8	41.29	48.53
Via De La Sendero & Indian Bend	5	N/A	188	62	1146	998	8	77.81	87.44
Via De La Sendero & Indian Bend	7	N/A	73	70	204	155	5	8.13	8.93

Via De La Sendero & Indian Bend	7	N/A	98	70	304	255	5	9.79	11.17
Via De La Sendero & Indian Bend	7	N/A	123	70	404	355	5	11.38	13.12
Via De La Sendero & Indian Bend	7	18	148	70	504	455	5	13.92	16.40
Via De La Sendero & Indian Bend	7	N/A	173	70	604	555	5	18.42	22.18
Via De La Sendero & Indian Bend	7	N/A	198	70	704	655	5	25.91	30.77
Via De La Sendero & Indian Bend	7	N/A	223	70	804	755	5	40.40	46.82
Via De La Sendero & Indian Bend	7	N/A	248	70	904	855	5	60.22	67.65
Via De La Sendero & Indian Bend	8	N/A	67	66	261	215	9	8.77	9.62
Via De La Sendero & Indian Bend	8	N/A	92	66	361	315	9	10.64	11.94
Via De La Sendero & Indian Bend	8	N/A	117	66	461	415	9	12.36	14.37
Via De La Sendero & Indian Bend	8	20	142	66	561	515	9	16.17	18.92
Via De La Sendero & Indian Bend	8	N/A	167	66	661	615	9	21.96	26.00
Via De La Sendero & Indian Bend	8	N/A	192	66	761	715	9	30.90	35.58
Via De La Sendero & Indian Bend	8	N/A	217	66	861	815	9	50.99	56.93