Data Analytics for Traffic Signal Optimization

Final Report

By

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Signal optimization and coordination is a cost-effective way to mitigate congestion while keeping smooth traffic flow. Pima County Department of Transportation (PCDOT), as one of the leading public transportation agencies in the State of Arizona, is utilizing new smart sensors and innovative approaches to retime and coordinate multiple corridors on its jurisdiction. For this project, PCDOT teamed up with the University of Arizona (UA) to evaluate and understand the effectiveness of multiple signal retiming software (Synchro® Studio and TranSync suite) for the purpose of signal retiming. In order to provide a deep and comprehensive understanding of each software, a before-and-after study design was set up for two major corridors in Pima County: Ina Road, and Orange Grove Road. Three types of data: 1) Video-based data that provides both real-time and historical signal performance metrics, 2) Vehicle probe-based (INRIX) data, and 3) Vehicle trajectory-based data were collected.</td></tr>
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EXECUTIVE SUMMARY

Signal optimization and coordination is a cost-effective way to mitigate congestion while keeping smooth traffic flow (Scheneider, 2011, Srinivasa Sunkari, 2004). Pima County Department of Transportation (PCDOT), as one of the leading public transportation agencies in the State of Arizona, is utilizing new smart sensors and innovative approaches to retime and coordinate multiple corridors on its jurisdiction. For this project, PCDOT teamed up with the University of Arizona (UA) to evaluate and understand the effectiveness of multiple signal retiming software (Synchro® Studio and TranSync Suite) for the purpose of signal retiming. Synchro® Studio (henceforth referred to as Synchro) is one of the most common software used by different agencies for conducting traffic analysis and optimization. TranSync Suite (henceforth referred to as TranSync) is the first mobile tool for systematic management, optimization, and performance evaluation of traffic signal timing plans. The findings of this study will further help PCDOT to incorporate and utilize more effective and cost-beneficial strategies and software for conducting future signal retiming.

In order to provide a deep and comprehensive understanding of each software, a before-and-after study design was set up for two major corridors in Pima County: Ina Road, and Orange Grove Road. Three types of data: 1) Video-based data that provides both real-time and historical signal performance metrics, 2) Vehicle probe-based (INRIX) data, and 3) Vehicle trajectory-based data were collected. To explore the above and beyond of each signal retiming software (Synchro and TranSync), traffic data was collected at three time periods at these two study corridors:

1) Baseline data collection: before signal retiming using Synchro studio (Feb. 2020)
2) Data collection after signal retiming using Synchro (April 2020, Oct. 2020, and Nov. 2020, and Feb. 2021)-Due to covid extra analyses were conducted
3) Data collection after TranSync offset optimization (March 2021, April 2021, June 2021, and July 2021)

Initially, the UA team developed the Synchro models for AM and PM Peaks based on the updated turning movement counts collected from the intersections on the study corridors. Then, using the updated Synchro models, all splits and offsets were optimized, and new signal timing plans were sent to PCDOT; In March 2020, Pima County technicians implemented the updated signal timing. However, due to Covid-19 Pandemic, the project team faced some challenges in evaluating the intersection performance and corridor progression. Therefore, based on the mutual agreement with the PCDOT project manager, the project was halted for a limited amount of time. In 2021, the project restarted and the UA team collected the required after-period data. Then, the UA team provided the next round of optimized offsets to PCDOT using the TranSync model; In June 2021, Pima County technicians implemented the new optimized offsets. For evaluating the TranSync model, a final set of data were collected after implementing the TranSync model, during March and April 2021. The results of Synchro and TranSync model evaluation are provided below:

1- Based on the corridor-based level data collected from Miovision smart sensors before and after signal retiming using the Syncro model, the average corridor's travel time and speed improved significantly; the reduction in average travel time and enhancement in average speed was statistically significant (alpha=0.05).
2- Based on the intersection-based level data collected from Miovision smart sensors before and after signal retiming using the Syncro model, the average delay on most of the corridors' intersections was reduced significantly; the average delay reduction was statistically significant (alpha=0.05).
3- Based on the vehicle trajectory-based data collected using TranSync-M before and after offset optimization using TranSync suite, it was observed that for Ina Road (west of State Route 77 to Interstate 10) corridor performance (travel time, speed and stop time) improved. While, for Orange Grove Road corridor performance (travel time, speed and stop time) deteriorated; it is worth mentioning that since the number of vehicle trajectories was limited, these results could be biased.
4- Based on the vehicle probe-based data (INRIX) collected before and after offset optimization using the TranSync suite, it was observed that average travel time and speed were improved for both directions on the study corridors.

5- Based on the side street delay analysis, it was found that after signal retiming using Synchro, the average delay on side streets were also reduced. Further, offset optimization using TranSync did not have any negative impact on the side streets' average delay; for most cases, the side streets' delays were decreased. In this report, the side street evaluation results for two sample intersections are provided.
6- Based on benefit/cost analysis it was found that both signal retiming software (Synchro and TranSync) can provide extreme benefit in terms of delay saving. For instance, after signal retiming using Synchro, on a selected intersection (W Ina Rd. @ N Shannon Rd. (EB Thru)), up to $468,726 can be saved annually only during AM and PM peaks. In addition, after optimizing the offsets using TranSync, an additional $105,621 can be saved only during AM and PM peaks; it is worth mentioning that certain costs, such as collecting turning movement count, model development, signal timing implementation, and field fine-tuning are not included.
7- The UA team developed an innovative methodology for fine-tuning signal splits by only using the signal performance measures collected from the Miovision platform. This innovative approach, 1) enables transportation agencies to identify the TOD breakpoint intervals based on both intersection and corridor-based measures, 2) provides a simple fine-tuning procedure for frequently fine-tuning the signal timing parameters, rather than retiming the whole corridor every three to five years; in other words adjusting the signal parameters without replacing the whole signal timing as a way around retiming, and 3) predicts the future of the intersection mobility performance prior to the field implementation of the revised timing plan.

The project team provided the following recommendations to further help PCDOT to incorporate and utilize more effective strategies and software for conducting future signal retiming.

1- Synchro is a great tool for signal retiming; Synchro will allow PCDOT to optimize different traffic signal timing parameters, such as splits, cycle length, and offsets. However, in order to build up the Synchro model, turning movement count (TMC) data is required.

2- TranSync is a great tool for real-time diagnosis and evaluation of traffic signal timing plans. Using this tool transportation engineers at PCDOT could easily diagnose the current timing plan and identify any common issues with actuated coordinated signals, such as phase early return transition, and clock drifting.

3- PCDOT can use the TranSync suite as an effective tool for optimizing offsets. However, TranSync requires an initial signal timing plan. Therefore, Synchro could be used as the main signal retiming application, and TranSync could be used as a diagnosing tool and also for offset optimization.

4- During the project, the UA team found out that many of the intersections are experiencing a high amount of clock drifting. The UA team recommends PCDOT to work more closely with Miovision to sync all the intersections clock multiple times per day, rather than once per day.

5- Future studies could target the use of other third-party data for potential network screening, intersection ranking, and developing a real-time application alerting PCDOT of any necessary signal retiming or parameter modification on the county signal network.

6- Based on the positive results from the benefit/cost analysis, and operational performance improvement of both study corridors, PCDOT could use a similar approach and retime other corridors in Pima County.

7- The current study evaluated the effectiveness of utilizing both Synchro and TranSync for signal retiming. Future studies could target the possibility of conducting signal retiming only using on TranSync software.

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1. INTRODUCTION

1.1 Project Background

Signal optimization and coordination is a cost-effective way to mitigate congestion while keeping a smooth traffic flow. With the implementation of efficient signal optimization, costly infrastructure improvements and roadway construction can be avoided. Traffic signal optimization can significantly reduce the amount of delay experienced by travelers on the roadway. Optimized traffic signals can also significantly reduce the travel time and stops experienced by the drivers, thus resulting in reduction of fuel consumption. There are also numerous safety enhancements provided by effective signal timing optimization. Some of these include optimizing the all-red times and yellow times in order to reduce the frequency of red-light runners, which in turn, reduces the risk of fatal pedestrians and vehicular accidents.

Pima County Department of Transportation (PCDOT), as one of the leading public transportation agencies in the State of Arizona, is utilizing new smart sensors and innovative approaches to retime and coordinate multiple corridors. The findings of this study will further help PCDOT to incorporate and utilize more effective and cost-beneficial strategies and software for conducting future signal retiming.

1.2 Project Objective

For this project, PCDOT teamed up with the University of Arizona (UA) to evaluate and understand the effectiveness of multiple signal retiming software (Synchro® Studio and TranSync suite) for the purpose of signal retiming. Synchro® Studio (henceforth referred to as Synchro) is one of the most common software used by different agencies for conducting traffic analysis and optimization. TranSync suite (henceforth referred to as TranSync) is the first mobile tool for systematic management, optimization, and performance evaluation of traffic signal timing plans. In order to provide a deep and comprehensive understanding of each software, two major corridors on Pima County, 1) Ina Road, and 2) Orange Grove Road were selected as the study corridors. A detailed explanation of each study corridor is provided in Chapter 3.

After selecting the study corridors, four steps as illustrated in Figure 1.1 were undertaken. Initially, AM and PM peaks Synchro models for the study corridors were developed. Then, splits and offsets were optimized, and new signal timing plans were provided to PCDOT for field implementation. The third step was developing the TranSync model, and finally, after optimizing all the intersections offsets in TranSync, PCDOT implemented the new offsets. As it can be seen from Figure 1.1, before each step, multiple types of data sources (such as vehicle probe-based, sensor-based, and vehicle trajectory-base data) were collected; points A, B, and C in Figure 1.1.

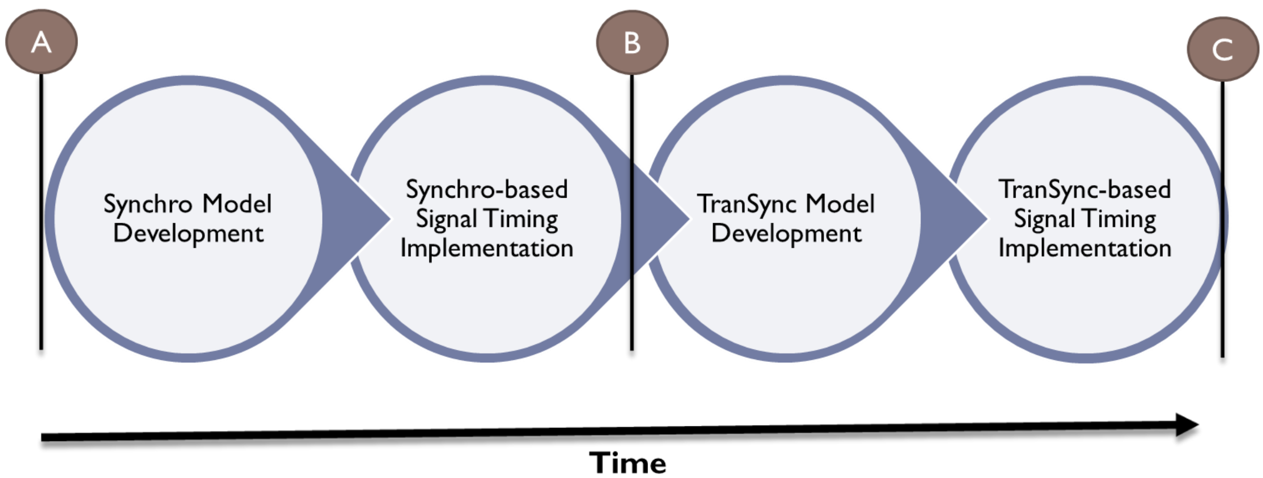


Figure 1.1 Project Overview

2. LITERATURE REVIEW

Arterial and collectors are the main roadways providing accessibility to urban neighborhoods, that play an important role in the regional economy and residents' quality of life. Traffic signals are one of the most cost-effective tools that ensure efficient mobility and operation on the arterial network (Park et al., 2004). Traffic signals distribute the right of way among pedestrians, cyclists, passenger vehicles, and transit vehicles at a signalized intersection. Signal optimization and coordination is a cost-effective way to mitigate congestion and smooth traffic flow without any costly infrastructure improvement or construction.

2.1 Signal Retiming Benefits

Traffic signal retiming and corridor coordination will result in direct and indirect benefits such as reduction in the delay and travel time as direct benefits, and reduction in fuel consumption, air pollution, pavement wear and tear (Scheneider, 2011, Srinivasa Sunkari, 2004) as indirect benefits. A study in Maryland showed a 13% reduction in vehicle delay, a 10% reduction in the total number of vehicle stops, and a 2% reduction in vehicle fuel consumption was achieved by correctly implementing and retiming 215 traffic signals. According to the traffic signal timing manual, transportation agencies are required to review and retime their existing signal timing plans every three to five years (Koonce and Rodegerdts, 2008).

2.2 Signal Control Strategies

The control strategies of traffic signals are broadly categorized into adaptive and non-adaptive control strategies (Jin et al., 2017). In adaptive signal control, the traffic signal phasing plans and splits are adjusted in real-time using network-wide sensors. However, due to the costly implementation and maintenance of roadway sensors and adaptive signal controllers, agencies are decades behind in implementing a network-wide adaptive control strategy (Yin, 2008). Therefore, still, transportation agencies are favoring non-adaptive signal control strategies. Due to the time-varying trip departure times and intrinsic fluctuation of traffic demand over time, transportation agencies are required to schedule several signal timing plans for a day (Park et al., 2004, Urbanik et al., 2015). This approach is known as the time-of-day (TOD) signal control strategy (Park et al., 2003).

2.3 Time-of-Day Signal Control Strategy

TOD signal control is the most widely used interval-based approach in the US cities (Lu et al., 2019, Abbas and Sharma, 2005, Skabardonis and Gomes, 2010, Wan et al., 2019) that divides a day into several breakpoint intervals and schedule separate timing plans for each interval (Chen et al., 2019). TOD strategy is highly responsive to traffic demand and traffic pattern change. Therefore, it reduces more delays relative to the fixed time signal control strategy. In practice, the first step for designing a TOD signal control plan is to collect turning movement counts (TMC) to identify the number of timing plans required for a day; this process is also referred to as TOD breakpoints identification. Then, developing a signal timing plan for each interval by using optimization tools such as Synchro (Mulandi et al., 2010, Tarnoff and Ordonez, 2004). Finally, the developed plans are implemented in the field for evaluation. Usually, the whole process of data collection, signal timing plan development, and implementation is a costly and labor-intensive process and needs to be repeated periodically to keep up with the change in the traffic pattern and travel demand.

Traditionally, to determine the correct TOD breakpoints a simple traffic flow pattern over the course of a day was developed. Then, based on observational judgment, the time intervals were determined (Smith et al., 2002). Although this approach is straightforward and effortless, engineers and researchers have argued regarding the validity of this process (Guo and Zhang, 2014). Using observational judgment by inexperienced engineers might result in misidentification. Recently, heuristic approaches, such as Genetic algorithms, non-dominated sorting genetic algorithm (NSGAII), neural network, and clustering approaches, such as K-means and hierarchical clustering are being used as alternative approaches to assist in identifying TOD breakpoint intervals (Park et al., 2004, Abbas and Sharma, 2005, Park and Lee, 2008, Hua and Faghri, 1993). Heuristic approaches tend to optimize the time-of-day intervals using an empirical search, while the clustering approach uses traffic pattern recognition algorithms to identify similar traffic patterns. The recent advancements in data collection techniques made it easier to use a wider range of traffic data such as GPS and probe-based data for determining the TOD breakpoints (Wan et al., 2019, Bie et al., 2015). Because of high coverage and short sampling intervals of probe-based data, such data are favorable compared with traditional traffic volume-based TOD identification. Bie et al. (2015) developed an algorithm to partition bus operating hours into TOD breakpoints using GPS data collected from buses (Bie et al., 2015). In another recent study, Wan et al. (2019) used vehicle trajectory probe-based data at an isolated intersection to determine the TOD breakpoints. The authors used K-means clustering to group the speeds of queueing shockwaves (Wan et al., 2019).

2.3. Signal Retiming Procedure

According to the traffic signal timing manual, transportation agencies are required to review and retime their existing signal timing plans every three to five years (Koonce and Rodegerdts, 2008). Retiming the existing signal timing plan on a corridor requires extensive turning movement count data collection, and traffic pattern interpretation (Mulandi et al., 2010, Tarnoff and Ordonez, 2004). This process is challenging due to many factors, including cost, availability of resources, and data availability. However, technological advances in the last decade have allowed cities to gather large amounts of high-resolution signal controller event-based data at intersections. Using this type of data, researchers and transportation agencies developed metrics known as Signal Performance Measures (SPMs) to evaluate the performance of their intersections. SPMs can provide valuable information to take proactive steps toward the safety, operation, and management of every individual intersection (Dabiri et al., 2018, Liu et al., 2009, Zheng et al., 2013). The emergence of SPMs provides a unique opportunity for transportation agencies to take advantage of SPMs to frequently fine-tune their existing signal timing parameters. For example, in one study, Day et al. used Purdue Coordination Diagram for adjusting the offset of a corridor (Day et al., 2010). In another effort, researchers from the University of Minnesota used SPMs and high-resolution data to develop a systematic approach to monitor the intersection queue in real-time (Liu et al., 2009). Dabiri et al. (2018) also proposed a cost-effective approach based on SPMs to improve arterial traffic performance by fine-tuning the green split (Dabiri et al., 2018).

2.4. Summary

Determining the TOD breakpoint intervals and retiming each interval plan is followed by several complications: 1) Most of the corridors have more than one critical intersection, with various traffic patterns in their side streets, therefore, the TOD breakpoints should represent both intersection and corridor characteristics, 2) For retiming TOD signal plans, agencies need to collect extensive turning movement count and traffic-related information, which the data is not always readily available, 3) The field implementation of the new retimed plans are costly, time-consuming and labor extensive, and 4) The future mobility performance of the revised signal timing is unknown until after field implementation.

3. STUDY SITES AND DATA DESCRIPTION

3.1 Study Corridors

In order to provide a deep and comprehensive understanding of each software, two major corridors on Pima County, 1) Ina Road, and 2) Orange Grove Road were selected as the study corridors.

3.1.1 Ina Road Corridor

Ina Road corridor in Pima County, Arizona is a west-east corridor connecting the east side of Tucson to Interstate 10, with a speed limit of 45 mi/hr (Figure 3.1). This corridor is a multimodal arterial with high volumes of passenger cars, transit, and pedestrian activity. All the intersections on this corridor are equipped with Miovision's SmartView 360 video-based sensors. This corridor follows actuated-coordinated timing, with the major approaches in coordination (Phases 2 & 6) while the minor approaches are actuated (Phases 4 & 8) only during peak periods.

Figure 3.1 Study Corridor: Ina Road; Source PCDOT

Most of the intersections on Ina Road are operated by PCDOT. However, several of these intersections are operated by other jurisdictions, such as the Town of Marana. A complete list of intersections on Ina Road that are included in this study and their corresponding jurisdiction are provided in Table 3.1.

Table 3.1 List of Intersections on Ina Road Corridor

Site ID	Intersections	Major Directions	Coordination Direction	Jurisdiction
1	W Ina Rd. @ Camino De Las Capas	W Ina Rd.	EB/WB	Town of Marana
2	W Ina Rd. @ Old Father Dr.	W Ina Rd.	EB/WB	Town of Marana
3	W Ina Rd. @ Thornydale Rd.	Balanced	Balanced	Town of Marana
4	W Ina Rd. @ Meredith Blvd	W Ina Rd.	EB/WB	Pima County
5	W Ina Rd. @ N Camino de la Tierra	W Ina Rd.	EB/WB	Pima County
6	W Ina Rd. @ N Shannon Rd.	W Ina Rd.	EB/WB	Pima County
7	W Ina Rd. @ N Mona Lisa Rd..	W Ina Rd.	EB/WB	Pima County
8	W Ina Rd. @ N La Cholla Bl.	W Ina Rd.	EB/WB	Pima County
9	W Ina Rd. @ N La Canada Dr.	W Ina Rd.	EB/WB	Pima County
10	W Ina Rd. @ N Westward Look Dr.	W Ina Rd.	EB/WB	Pima County
11	E Ina Rd.@ N 1st Ave. @ N Christie Dr.	E Ina Rd	EB/WB	Pima County
12	E Ina Rd. @ E Skyline Dr. @ N Pima Canyon Dr.	E Ina Rd	EB/WB	Pima County

3.1.2 Orange Grove Road Corridor

Orange Grove Road corridor in Pima County, Arizona is a west-east corridor connecting the east side of Tucson to Interstate 10, with a speed limit of 45 mi/hr (Figure 3.2). This corridor is a multimodal arterial with high volumes of passenger cars, transit, and pedestrian activity. Similar to Ina Road, all the intersections on this corridor are equipped with Miovision's SmartView 360 video-based sensors.

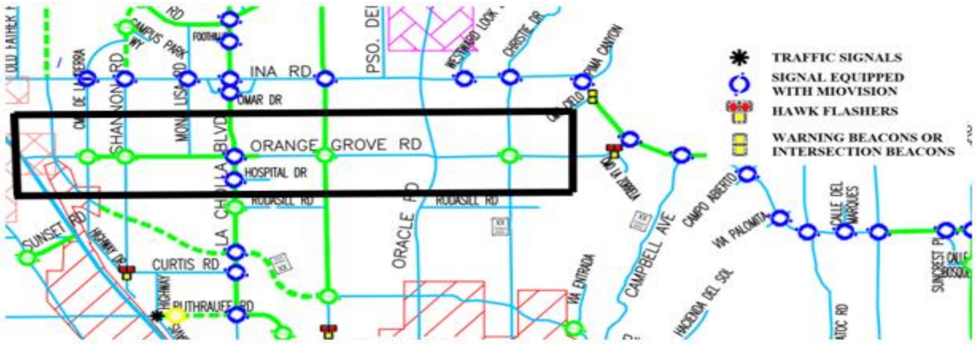


Figure 3.2 Study Corridor: Orange Grove Road; Source PCDOT

Most of the intersections on Orange Grove Road are operated by PCDOT. However, several of these intersections are operated by other jurisdictions, such as the Town of Marana. A complete list of intersections on Orange Grove Road that are included in this study and their corresponding jurisdiction is provided in Table 3.2.

Table 3.2 List of Intersections on Orange Grove Road Corridor

Site ID	Intersections	Major Directions	Coordination Direction	Jursdiction
1	W Orange Grove Rd. @ Thornydale Rd.	NB/SB	NB/SB	Town of Marana
2	W Orange Grove Rd. @ N Camino de la Tierra	W Orange Grove Rd	EB/WB	Pima County
6	W Orange Grove Rd. @ N Shannon Rd.	W Orange Grove Rd	EB/WB	Pima County
7	W Orange Grove Rd. @ N La Cholla Bl.	W Orange Grove Rd	EB/WB	Pima County
8	W Orange Grove Rd. @ N La Canada Dr.	W Orange Grove Rd	EB/WB	Pima County

3.2 Data Collection

To evaluate intersection and corridor levels performance after Synchro and TranSync signal optimization, several data sources were collected. Below outlines the detailed information of each data source used in this project.

3.2.1 Miovision Sensor-based Data

All the intersections on both study corridors are equipped with Miovision's SmartView 360 video-based sensors. Miovision data could be collected via two platforms: 1) TrafficLink (provides signal performance measures), and 2) DataLink (provides turning movement counts). TrafficLink is the

Miovision Graphical User Interface (GUI) that allows users to selected specific intersections and access their corresponding signal performance measures. Figure 3.3 shows all the intersections in Pima County that are equipped with Miovision's SmartView 360.

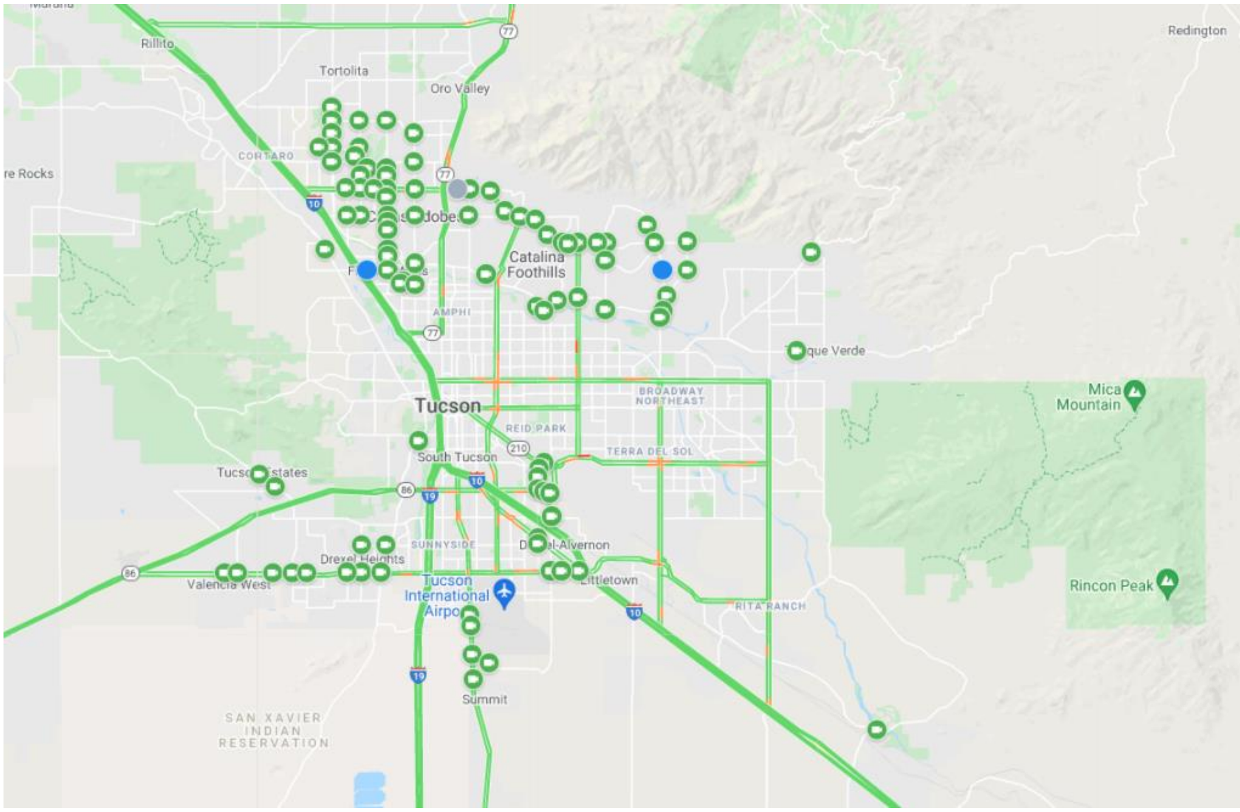


Figure 3.3 TrafficLink Platform for Miovision

Figure 3.4 illustrates all the signal performance measures available in the Miovision TrafficLink platform; Approach Volume, Arrivals on Red, Green Allocation, Occupancy Ratio, Pedestrian Simple Delay, Pedestrian Compliance, Red-light Runner, Phase Interval, Purdue Coordination Diagram, Simple Delay, Split Failure, Split Trends, and Turning Movement Count.

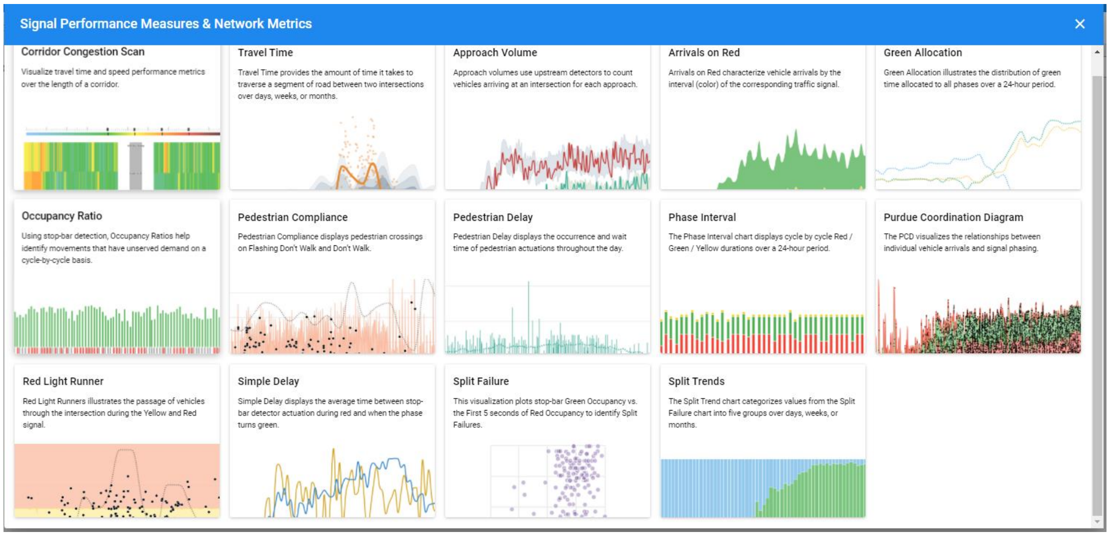


Figure 3.4 Signal Performance Measures available in Miovision TraffikLink

3.2.2 Vehicle Probe-based Data (INRIX)

Beginning in July 2017, The U.S. Federal Highway Administration selected INRIX as the national traffic data set for monitoring travel reliability, congestion, and emission. INRIX provides the most comprehensive coverage with the most accurate information using fusion technologies. INRIX data is mainly aggregated using vehicles equipped with GPS devices. INRIX data provides travel time rates at every one-minute interval.

The servers located at the UA archive both historical data (up to 2017) and real-time INRIX data. The UA team has developed the Statewide Mobility Analytics in Real-Time (SMART)[1] Tool that is consists of different data analytic modules. Figure 3.5 shows a screenshot of the SMART Tool. For this project, segment-based speed and travel time were collected from the SMART Tool. This tool is the result of a collaboration between the Arizona Department of Transportation (ADOT) Transportation Systems Management and Operations (TSMO) division and the University of Arizona Smart Transportation Lab.

[1] https://adot.ua-star.org/

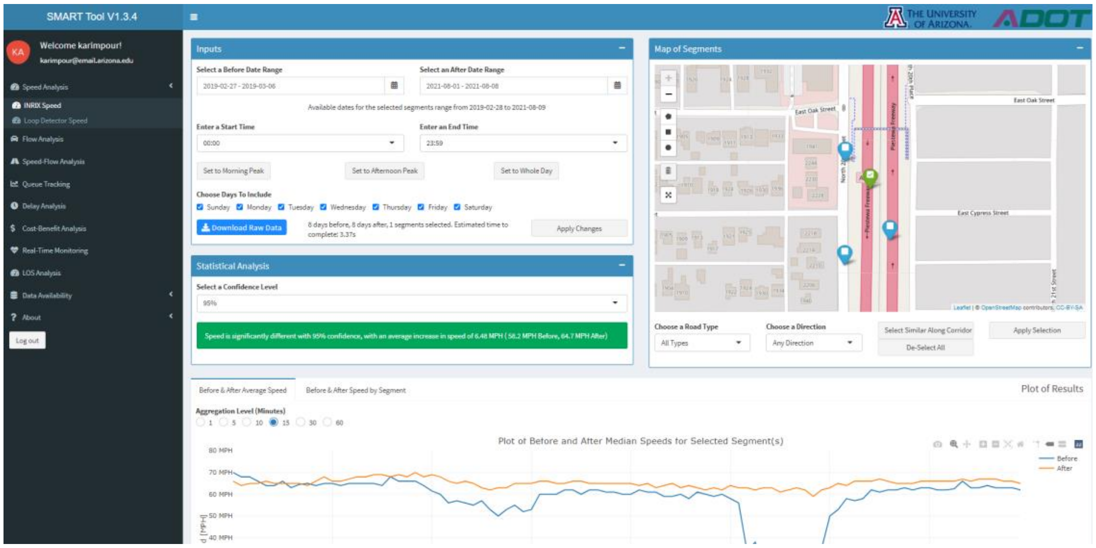


Figure 3.5 SMART Tool Platform

3.2.3 Vehicle Trajectory-Based Data

Vehicle trajectory-based data for this study consist of the GPS data collected using TranSync-M. For each data collection, several students were sent to the field and GPS data were collected. The collected data contains the latitude, longitude, speed, and heading information for each vehicle that runs as they traverse.

4. SIGNAL RETIMING SOFTWARE

Studies have widely shown that signal retiming is one of the most cost-effective tasks that transportation agencies can perform in order to improve their roadway traffic conditions. The conventional traffic signal retiming procedure consists of several approaches:

1. Organizing existing information
2. Collecting new traffic data, such as turning movement counts either in the field or using the implemented sensors
3. Modeling traffic network in a simulation tool (such as Synchro, Vissim, and TranSync)
4. Developing updated signal timing plan by optimizing offsets, cycle length, and offsets
5. Implementing the updated signal timing plan and field fine-tuning

In this chapter, detailed descriptions of the two software used in this study for developing updated signal timing plans are explored.

4.1 Synchro Studio

Synchro consists of three separated modules, 1) Synchro, 2) SimTraffic, and 3) 3D viewer (Trafficware, 2017). Synchro is a macroscopic analysis and optimization software application, SimTraffic has mostly used for simulation and 3D viewer model the reality in 3D modules. For this project, only the Synchro module was used.

Synchro supports the Highway Capacity Manual’s (HCM) 6th Edition, 2010 and 2000 for signalized intersections, unsignalized intersections, and roundabouts (Trafficware, 2017). Synchro provides users with an interface to build the traffic network, input appropriate geometric, and signal timing information and optimize the whole network. Since Synchro has a user-friendly environment, it has been widely adopted by many transportation agencies around the US. The latest version of Synchro (Synchro 11) also includes a Bing map to facilitate network development. Figure 4.1 shows the main interface of Synchro 11.

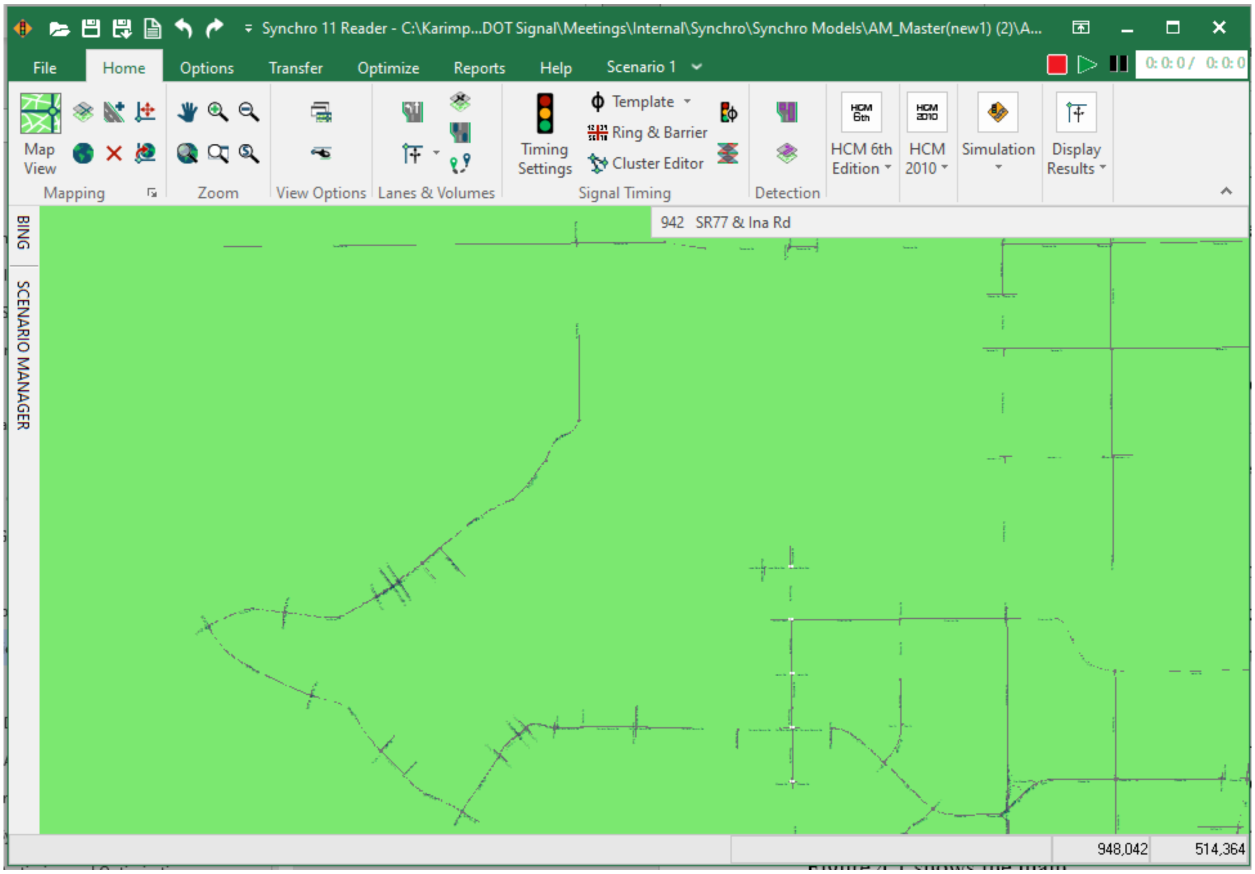


Figure 4.1 Synchro 11 Interface

4.1.1 Turning Movement Count

While retiming the signal timings, it is crucial to use the most up-to-date turning movement counts. For this study, turning movement counts (TMC) were collected from the Miovision DataLink platform. DataLink provides traffic count at a 15-minute aggregation level. In order to find the TMC for each intersection, initially, the data were aggregated into one-hour bins. Then, based on the peak period provided by PCDOT the TMC for each intersection's approaches were calculated and imported to the Synchro model. It is worth mentioning that for this project, the UA team was tasked to only develop AM and PM peaks signal timing plans. Figure 4.2 illustrates a sample TMC for one of an intersection on the Ina Road corridor.

	EB			WB			NB			SB		
AM Peak	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right
	1356	4	514	1043	89	63	42	415	77	21	23	93
PHF	0.84613	0.5	0.862416	0.932469	0.790179	0.801282	0.677419	0.901087	0.939024	0.552632	0.605263	0.762295

	EB			WB			NB			SB		
PM Peak	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right
	1285	7	453	1491	80	82	48	595	77	29	18	77
PHF	0.954681	0.7	0.946653	0.931563	0.784314	0.848958	0.631579	0.915385	0.708333	0.763158	0.972222	0.780612

Figure 4.2 TMC for 1st Street and Ina Road

4.1.2. Final Synchro Model

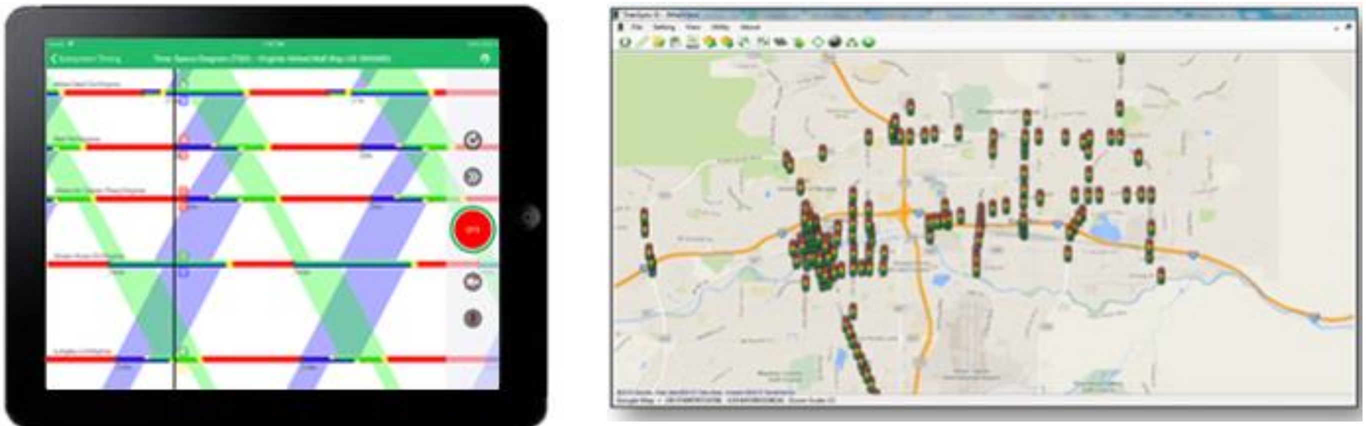
The UA team updated and developed the final Synchro model base on the collected TMC counts. Figure 4.3 illustrates the Synchro model for the two study corridors.

Figure 4.3 Final Synchro Model of the Study Corridors

After developing the final models, the cycle length for all the intersections was set to 150 seconds (this cycle length was proposed by PCDOT). Further, the splits and offsets were optimized on EB/WB coordination plan. The updated signal timing sheets then were sent to PCDOT for implementation.

4.2 TranSync Suite

TranSync provides two applications, one for smartphones (TranSync-M) and one for Desktop computers (TranSync-D). The platform of TranSync-M and TranSync-D are illustrated in Figure 4.4.



(a) (b)

Figure 4.4 TranSync Overview; a)TranSync-M, and b)TranSync-D-Figure source: http://trans-intelligence.com/

TranSync-M is a real-time signal diagnosis tool that can be installed on smartphones. This tool will enable traffic engineers to develop virtual signal controllers on their mobile devices, and easily diagnose common issues with actuated coordinated signals, such as phase early return transition, clock drifting, and erroneous offset inputs. TranSync-D is the windows-based version of TranSync that allows the users to build up their traffic network, input their existing signal timing plans, optimize the cycle lengths and offsets, and develop a time-space diagram. Similar to Synchro, the user needs to create the intersections in TranSync-D and update the signal timing parameters in the application. It is worth mentioning that, unlike Synchro, TranSync does not require TMC data for optimization. However, the existing signal timing plans need to be imported into the model.

TranSync-D provides a time-space diagram for every selected subsystem (i.e., in TranSync a subsystem could be created by selecting multiple intersections). The time-space diagram provides invaluable information regarding the overall corridor progression and illustrates the corridor green bandwidth. Figure 4.5 illustrates a sample time-space diagram for Ina Road.

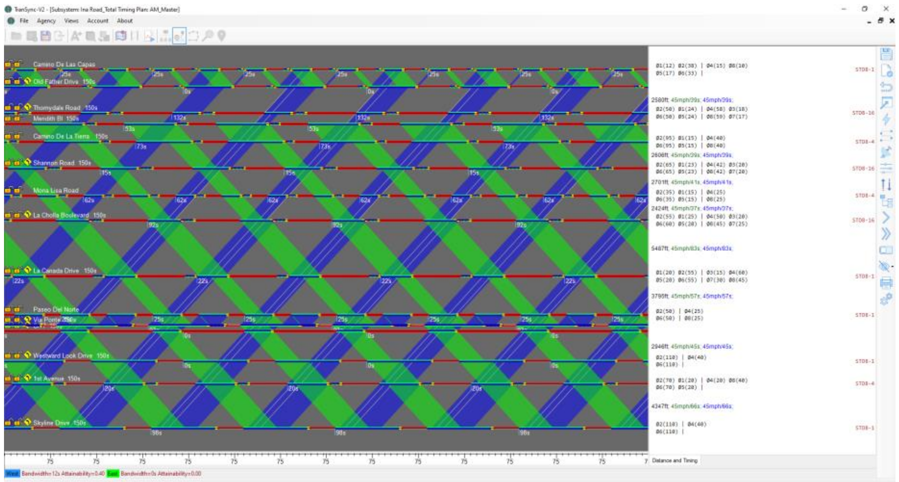


Figure 4.5 Time-space Diagram for Ina Road

4.2.1 Final TranSync Model

Figure 4.6 illustrates the two study corridors selected for this project developed in TranSync-D. The first step in developing the TranSync model is creating the intersections. For this study, due to limitation and restriction of the study intersections (several of the intersections on the study corridors are operated by other jurisdictions), several of the intersections such as Ina Road @ SR77, Orange Grove Road @ SR77, Ina Road @ I-10/Frontage Road, Ina Road @ Via Ponte were eliminated from the study corridors. The input parameters for each intersection are from the existing signal timing information which was obtained from the developed Synchro model. Next, the intersections on the same corridor are grouped and three subsystems as illustrated in Figure 4.6 were created:

- Subsystem 1: Ina_West_SR77 (Between Interstate 10 and State Route 77)
- Subsystem 2: Ina_East_SR77 (East of State Route 77)
- Subsystem 3: Orange Grove Road (Between Interstate 10 and State Route 77)

Figure 4.6 TranSync Model for the Study Corridors

4.2.2 TranSync Offset optimization

TranSync models for AM and PM peaks were developed and using TranSync-D the offsets were optimized. TranSync-D allows users to optimize offsets and sequences based on the direction of preference. Figure 4.7 illustrates a screenshot from the optimization tool in TranSync-D.

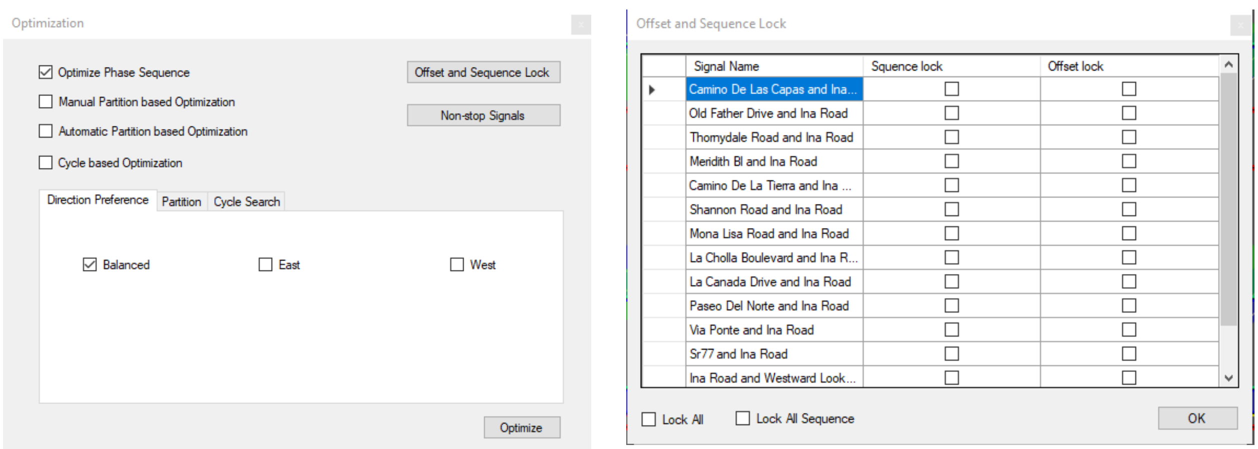


Figure 4.7 TranSync Offset Optimization; a) Optimization UI, and b) Offsets and Sequence Lock

Based on Figure 4.7, it can be seen that users can lock both the initial imputed offsets and sequences for every individual intersection. It is worth mentioning that TranSync is only able to optimize offsets for full and half-cycle lengths.

5. COMPREHENSIVE DATA ANALYSIS

The results section of this report consists of several parts. Since this project was influenced by the Covid-19 Pandemic, initially pandemic data analysis and its results are provided. Next, the results of the network performance after signal retiming using Synchro are outlined. Then, the results of network performance under the updated signal timing plan using TranSync are provided. Finally, an innovative methodology is discussed for signal timing parameters fine-tuning using only signal performance measures.

5.1 Pandemic Data Analysis

As discussed in the previous chapters, after implementing the new signal timing plans developed by Synchro in the study corridors (during March 2020), the Covid-19 pandemic started. Therefore, the UA team initially conducted a traffic volume evaluation. This evaluation is performed to understand the impact of pandemics on traffic demand and patterns. To this end, sensor-based data were collected at four time periods as below:

1) Before Pandemic, under the old signal timing plan (Feb. Data Collection)
    a. *During 2/18/2020-2/20/2020 and 2/25/2020-2/27/2020*
2) During Pandemic, under old signal timing plan (March Data Collection)
    a. *During 3/17/2020-3/19/2020 and 3/24/2020-3/26/2020*
3) During pandemic under retimed signal timing plan using Synchro model (April Data Collection)
    a. *During 4/14/2020-4/16/2020 and 4/21/2020-4/223/2020*
4) During new-normal (most offices reopened for business), under newly retimed signal timing plan using Synchro (May Data Collection)
    a. *During 5/12/2020-5/14/2020 and 5/19/2020-5/21/2020*

Initially, the total daily volume at the different intersections was compared. Figure 5.1 illustrates the total daily volume for eastbound movement at Ina Road @ La Canada Dr for the four data collection periods.

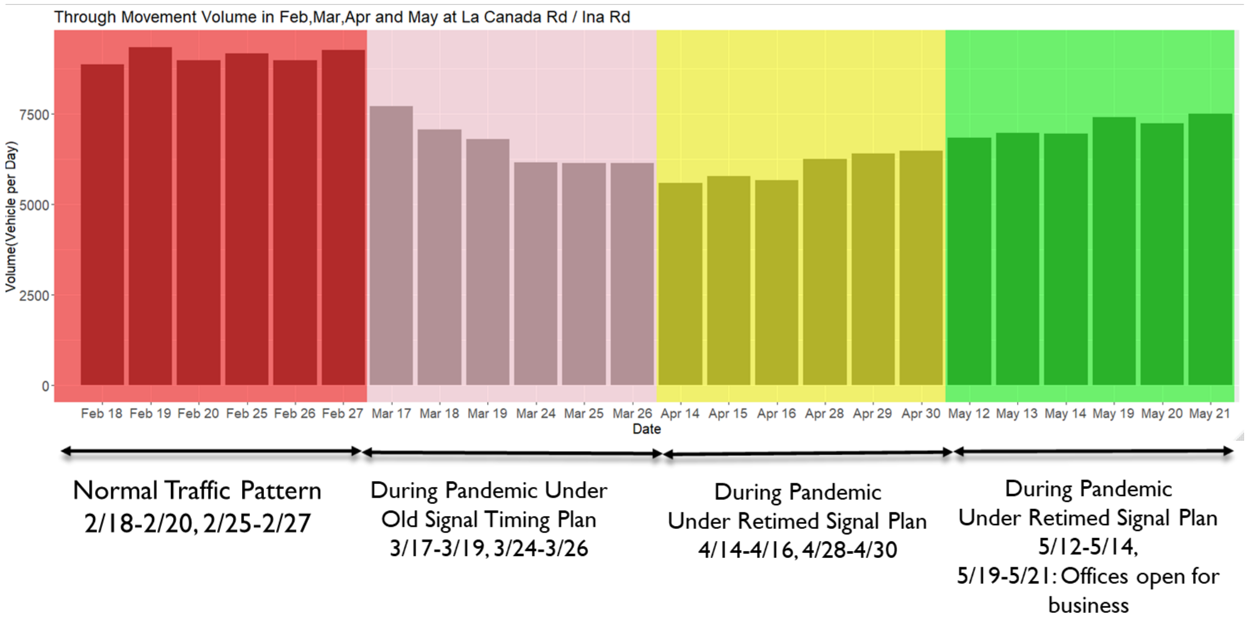


Figure 5.1 Total Eastbound Daily Volume for Ina Road @ La Canada Dr. for Different Data Collection Periods

Figure 5.1 shows that during March 2020, traffic volume decreased significantly compared to Feb. 2020, and it gradually increased during May 2020. Similar results were also observed for other intersections on the study corridors. For instance, Figures 5.2 and 5.3 illustrate the total eastbound daily volume for Ina Road @ Mona Lisa Road and Orange Grove Road @ Camino de la Tierra Road, respectively.

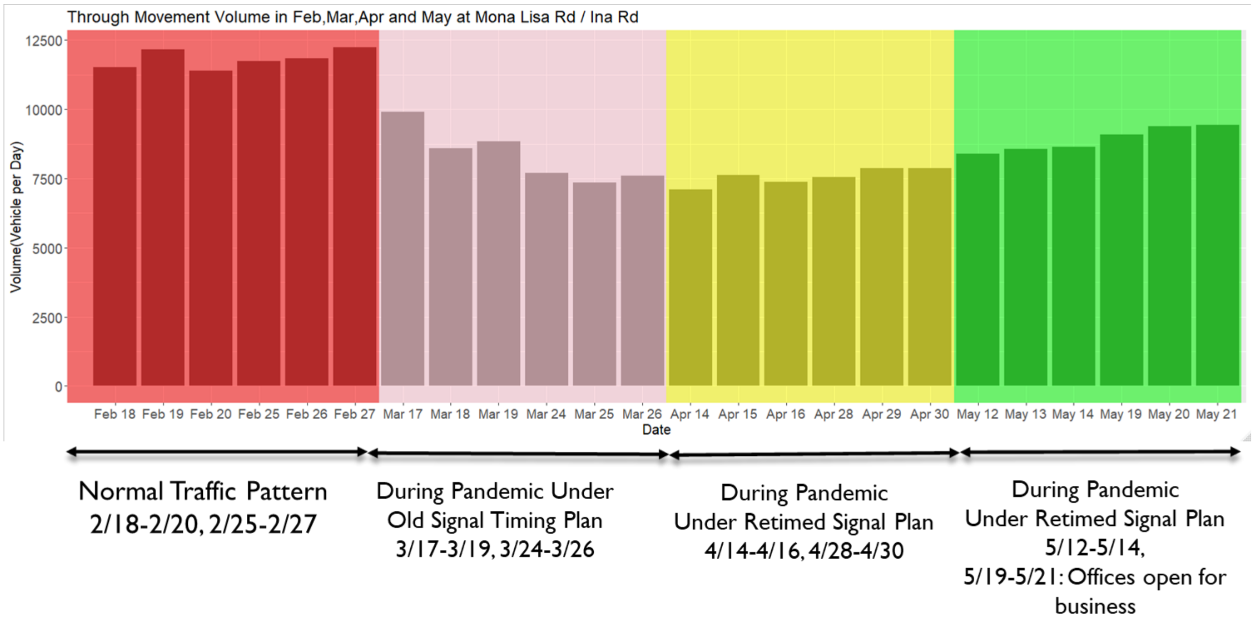


Figure 5.2 Total Eastbound Daily Volume for Ina Road @ Mona Lisa Road for Different Data Collection Periods

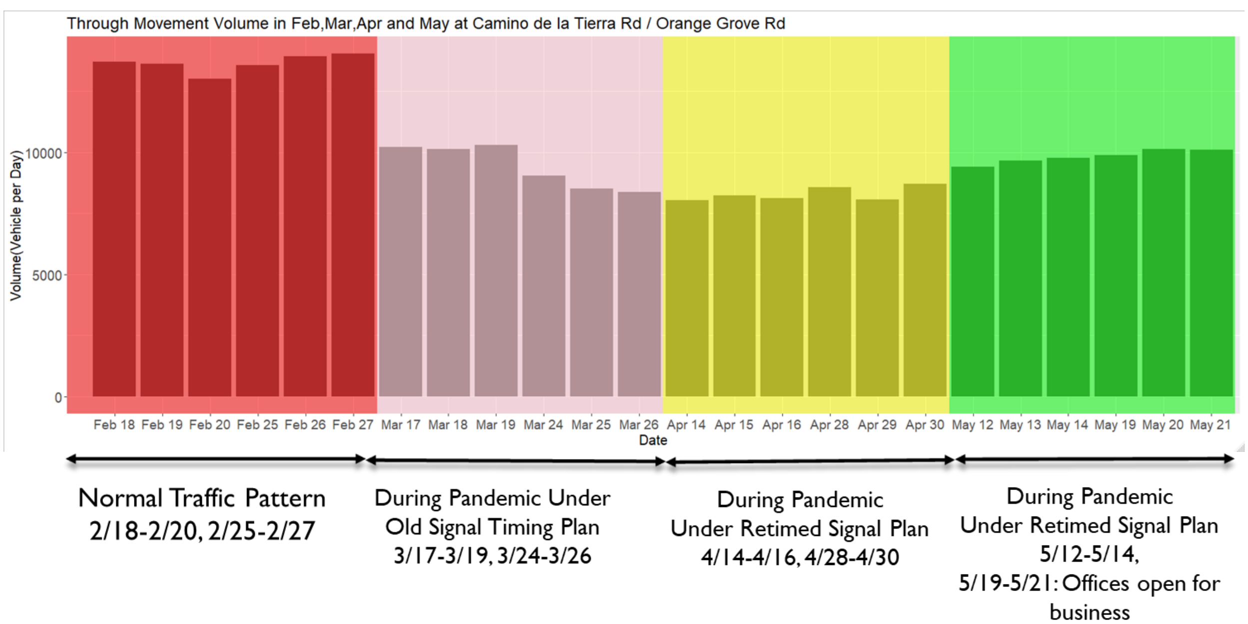


Figure 5.3 Total Eastbound Daily Volume for Orange Grove Road @ Camino de la Tierra Road for Different Data Collection Periods

To understand how traffic volume changes during this four-month of data collection, three sets of tests were developed; data was divided into three-time scenarios, AM, PM, and Off Peaks. Each test was repeated for each time scenarios independently. Table 5.1 illustrates the sample volume for one intersection (Ina Road @ La Cholla) on the study corridor. Considering Feb. 2020 as the baseline data collection, it can be observed that traffic drops during March and April data collection.

Table 5.1 Total Traffic Volume for Ina Road@La Cholla

Traffic Volume (Pc/Hr)				
	Feb 2020	**Mar. 2020**	**Apr. 2020**	**May 2020**
AM Peak	612	407	352	444
Off Peak	658	446	428	512
PM Peak	594	337	326	403

The first test compares the average traffic volume between Feb. 2020 and March 2020; the null and alternative hypotheses for this test are as below:

$$H_0: Volume_{Feb.} = Volume_{March}$$

$$H_a: Volume_{Feb.} \neq Volume_{March}$$

The sample results of this t-test for a sample intersection (Ina Road @ La Cholla) showed a p-value lower than 0.05. Meaning that the difference between the average volume of Feb and March is statistically significant at the $\alpha = 0.05$ level. Detailed information on the p-value for different time scenarios is provided in Table 5.2.

Table 5.2 T-test: Between Feb. 2020 and March 2020

	t value	**P value**	**H0 (Alpha=0.05)**
AM Peak	5.610	<0.001	Rejected
Off Peak	17.926	<0.001	Rejected
PM Peak	5.210	<0.001	Rejected

The second test compared the average traffic volume between March 2020 and April 2020; the null and alternative hypotheses for this test are as below:

$H_0: Volume_{March} = Volume_{April}$

$H_a: Volume_{March} \neq Volume_{April}$

The sample results of this t-test for a sample intersection (Ina Road @ La Cholla) showed a p-value higher than 0.05. Meaning that not enough evidence exists to reject the null hypothesis. That is, the difference between the average volume of March and April is not statistically significant at the α = 0.05 level. Detailed information on the p-value for different time scenarios is provided in Table 5.3.

Table 5.3 T-test: Between March 2020 and April 2020

	t value	P value	H0 (Alpha=0.05)
AM Peak	1.578	0.122	Not Rejected
Off Peak	1.580	0.121	Not Rejected
PM Peak	0.034	0.973	Not Rejected

The third test compared the average traffic volume between April 2020 and May 2020; the null and alternative hypotheses for this test are as below:

$H_0: Volume_{Apr.} = Volume_{May}$

$H_a: Volume_{Apr.} \neq Volume_{May}$

The sample results of this t-test for a sample intersection (Ina Road @ La Cholla) showed a p-value lower than 0.05. Meaning that the difference between the average volume of April and May is statistically significant at the α = 0.05 level. Detailed information on the p-value for different time scenarios is provided in Table 5.4.

The sample results of this t-test for a sample intersection (Ina Road @ La Cholla) showed a p-value lower than 0.05. Meaning that the difference between the average volume of Feb and

March is statistically significant at the α = 0.05 level. Detailed information on the p-value for different time scenarios is provided in Table 5.4.

Table 5.4 T-test: Between April 2020 and May 2020

	t value	P value	H0 (Alpha=0.05)
AM Peak	-3.022	0.004	Rejected
Off Peak	-9.001	<0.001	Rejected
PM Peak	-2.423	0.018	Rejected

A similar analysis was conducted for the average delay during the four data collection periods. The results of the t-test are as below:

1- The difference between average delay during Feb. and March was statistically significant at the α = 0.05 level. Average delay reduced which could be due to the reduction in total volume.
2- The difference between average delay during March and April was statistically significant for all times of the day. Average delay reduced, however, since total volume difference was not statistically different, this improvement could be due to signal retiming.
3- The difference between average delay during April and May was statistically significant for all times of the day. The average delay increased, however, since total volume also increased hugely, this deterioration might be due to the results of traffic demand change

To further elaborate on the impact of the Covid-19 pandemic on corridor mobility, corridor travel time density was plotted for the four months of data collection. Figure 5.4 illustrates this density plot. Figure 5.4 is developed for eastbound direction on Ina Road (Start: Ina Road @ Camino de la Tierra; End: Ina Road @ Pima Canyon/Skyline Road).

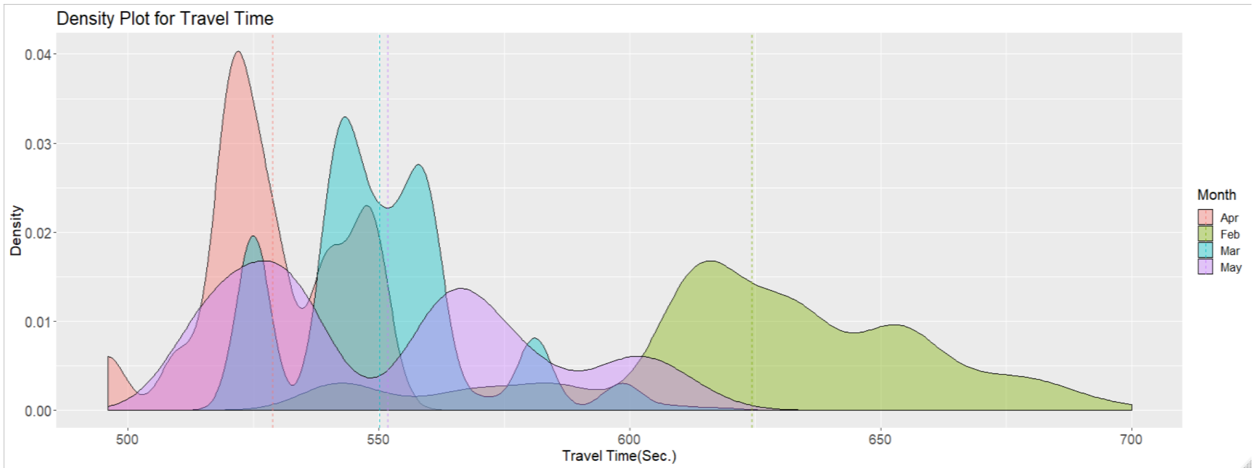


Figure 5.4 Ina Road Corridor: Travel Time Density

Based on Figure 5.4 following points are observed:

1- February vs. March: Travel time decreased, potentially due to the decrease in daily volume
2- March vs. April: Travel time decreased, potential due to implementing the new signal timing plan from Synchro
3- April vs. May: Travel time increased (longer than that in March), potentially due to the significant increase in daily volume

5.2 Synchro Effectiveness Evaluation

To evaluate the effectiveness of Synchro, a new set of data during October and November 2020 was collected. In order to evaluate the performance of the study corridors after implementing the timing plan obtained from the Synchro model, two types of analyses were conducted: 1) travel time analysis, and 2) delay analysis. However, in order to compare the traffic volume during October and November with our baseline condition (before pandemic during Feb. 2020), initially, traffic volume between data collection period were compared. Tables 5.4 show the total volume of major intersections on Ina Road and Orange Grove Road.

Table 5.5 Volume Comparison between before Pandemic and During New-Normal

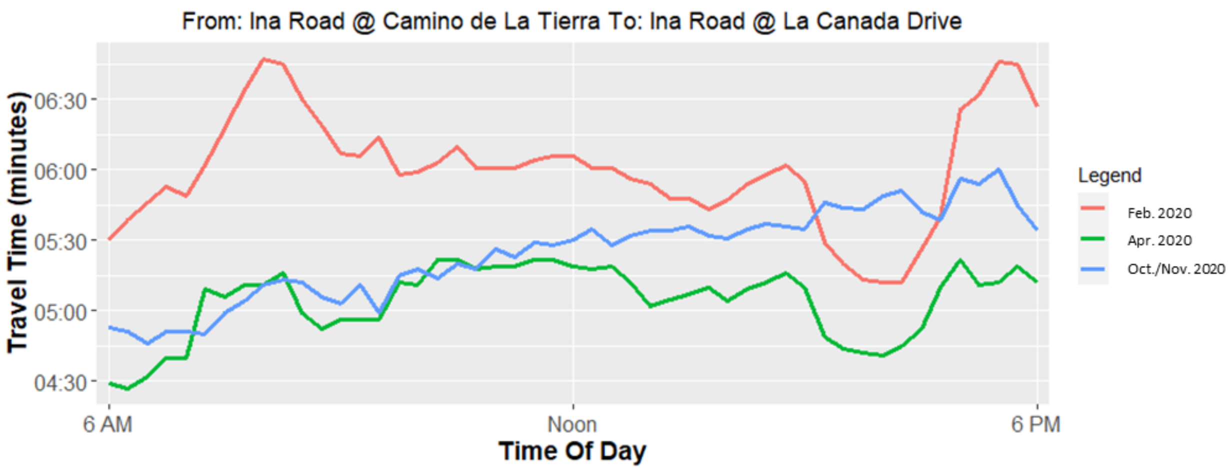
Intersection Name	Baseline (February 2020)	October-November 2020	Significant Difference (Feb. & Oct.-Nov.)	P-Value
	Total Volume			
Ina Road @ Camino de La Tierra	36,103	34,512	✗	0.82
Ina Road @ Shannon Road	44,764	38,442	✗	0.47
Ina Road @ Mona Lisa Road	34,633	32,337	✗	0.74
Ina Road @ La Cholla Boulevard	57,995	48,965	✗	0.43
Ina Road @ La Canada Drive	57,665	48,024	✗	0.39
Orange Grove Road @ Camino de La Tierra	33,363	33,098	✗	0.96
Orange Grove Road @ La Cholla Boulevard	50,375	42,638	✗	0.44
Orange Grove Road @ La Canada Drive	45,688	37,633	✗	0.39

Based on Table 5.5 it can be observed that although traffic dropped going from our baseline data collection in February 2020 to Oct./Nov. 2020, however, this reduction was not statistically significant. Knowing this, we can compare the effectiveness of the Synchro timing plan.

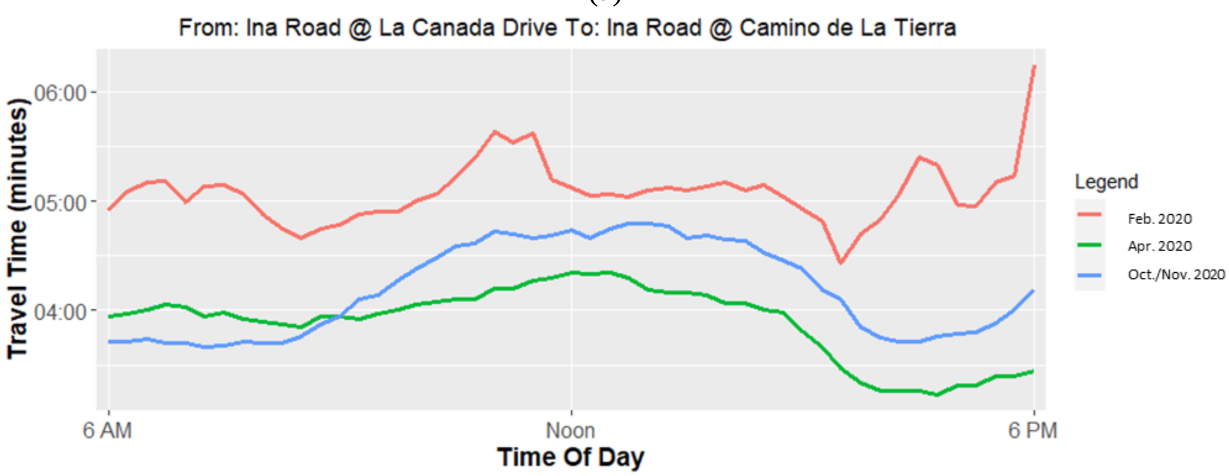
5.2.1 Travel Time Analysis

In order to evaluate the performance of the study corridors after implementing the signal timing plan obtained from the Synchro model, a before-and-after study framework was developed. Sensor-based data were collected for baseline data collection (During Feb. 2020), and after signal retiming data collection (during Oct./Nov. 2020). In addition to these two time periods, a third data collection was also conducted during April 2020 (between before and after). Then, travel time for both study corridors was plotted for all the above-mentioned periods. Figures 5.5-a and 5.5-b show the travel time for the Ina Road for eastbound and westbound directions, respectively. Figure 5.6-

a and 5.6-b show the travel time for the Orange Grove Road for eastbound and westbound directions, respectively.



(a)



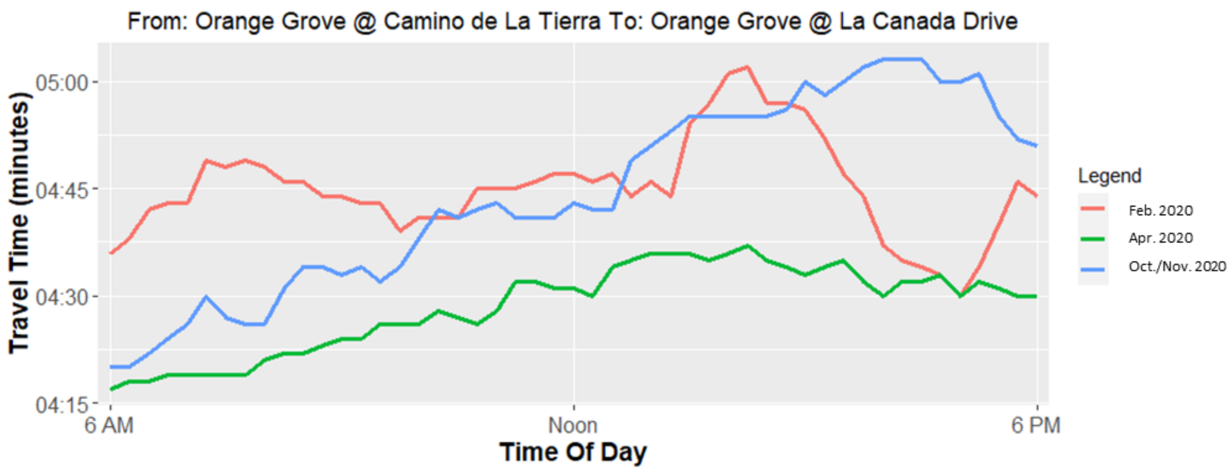
(b)

Figure 5.5 Ina Road Corridor Travel Time

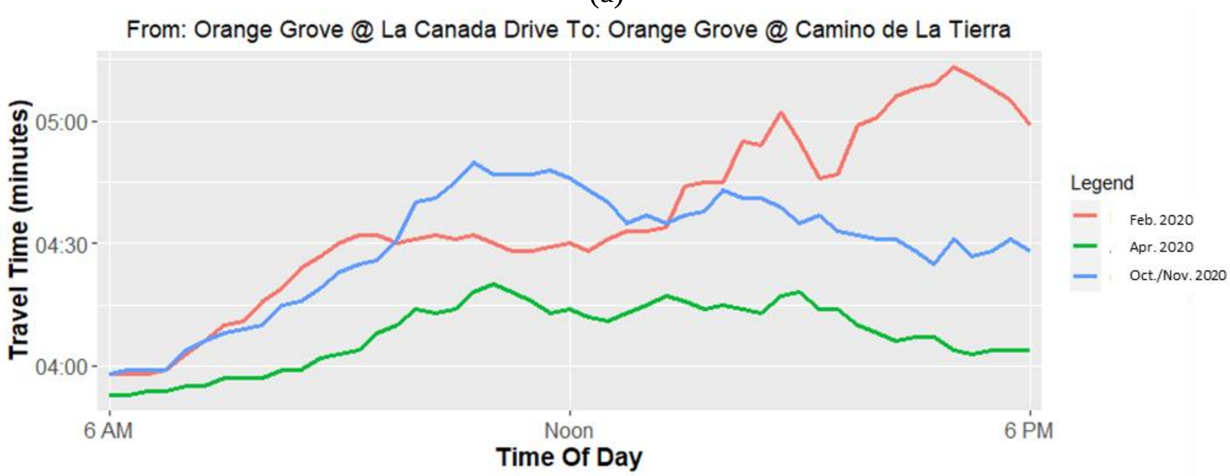
Based on Figure 5.5, it can be observed that:

1- Average corridor travel time reduced during April 2020, compared to the baseline data collection in Feb. 2020. This reduction is likely due to the Covid-19 Pandemic (was discussed in the previous section),

2- Average corridor travel time reduced during Oct./Nov. 2020 compared to the baseline data collection in Feb. 2020. Meaning that the new signal timing plan developed by Synchro was able to effectively improve the whole corridor progression; it is worth mentioning that this improvement was statistically significant.



(a)



(b)

Figure 5.6 Orange Grove Road Corridor Travel Time

Based on Figure 5.6, the following points can be observed:

1- Average corridor travel time reduced during April 2020 compared to the baseline data collection in Feb. 2020. This reduction is likely due to the Covid-19 Pandemic (was discussed in the previous section),

2- Average travel time reduced during Oct./Nov. 2020 compared to the baseline data collection in Feb.2020. Meaning that the new signal timing plan provided by Synchro was able to effectively improve the whole corridor progression; it is worth mentioning that this improvement is statistically significant.

5.2.2 Mainline Delay Analysis

To conduct the intersection level performance evaluation, simple delay data was collected from all intersections on the study corridors. The same data collection periods as previous sections were used. Table 5.6 shows the results of delay comparison for a sample study intersection (Ina Road @ Shannon Road). Based on this table it can be observed that

- Average delay reduced during April 2020 compared to the baseline data collection in Feb. 2020, which is likely due to the Covid-19 pandemic (was discussed in the previous section)
- On both westbound and eastbound directions, intersection delay significantly reduced during Oct./Nov. 2020. Meaning that the new signal timing plan provided by Synchro was able to effectively improve intersection delay.

Table 5.6 Delay Comparison Results; Ina Road @ Shannon Road

Direction	Average	Average Delay (Seconds per 15 Minutes)	
		AM	PM
Westbound Direction	**February 2020**	34.88	54.41
	April 2020	19.24	26.36
	October-November 2020	27.84	47.73
Eastbound Direction	**February 2020**	36.66	52.23
	April 2020	22.39	24.59
	October-November 2020	30.35	44.49

5.3. TranSync Effectiveness Evaluation

In the project, TranSync was mainly utilized to further optimize intersections offsets after implementing the Synchro timing plan. Offsets are the main parameters in signal timing that impact coordination and corridor progression. In our study, both corridors are anticipated to have balanced coordination between eastbound and westbound directions. After optimizing the offsets using the developed TranSync model (please refer to section 4.2.1), PCDOT implemented the new offsets. To evaluate the effectiveness of TranSync, corridor progression was evaluated before and after offset optimization using TranSync. To conduct the evaluation, two types of data, Trajectory-based data (collected using vehicle runs with TranSync-M), and vehicle probe-based data (INRIX) were used. Similar to previous analyses, a before-and-after framework was set up

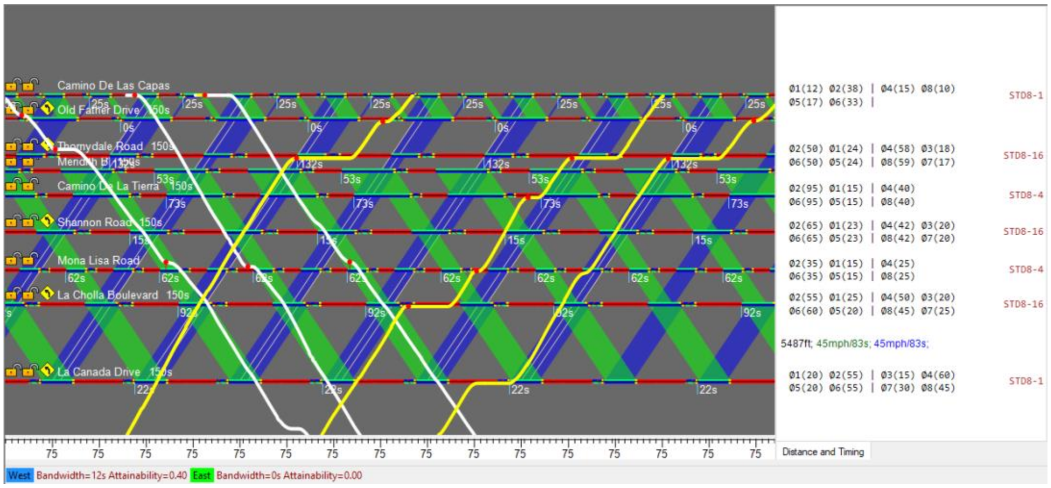
1- INRIX and trajectory-based data were collected during Feb. 2021 (before TranSync implementation)
2- INRIX and trajectory-based data were collected during June 2021 and July 2021 (after TranSync implementation)

5.3.1 Evaluation Results Using the Vehicle Trajectory-based Data

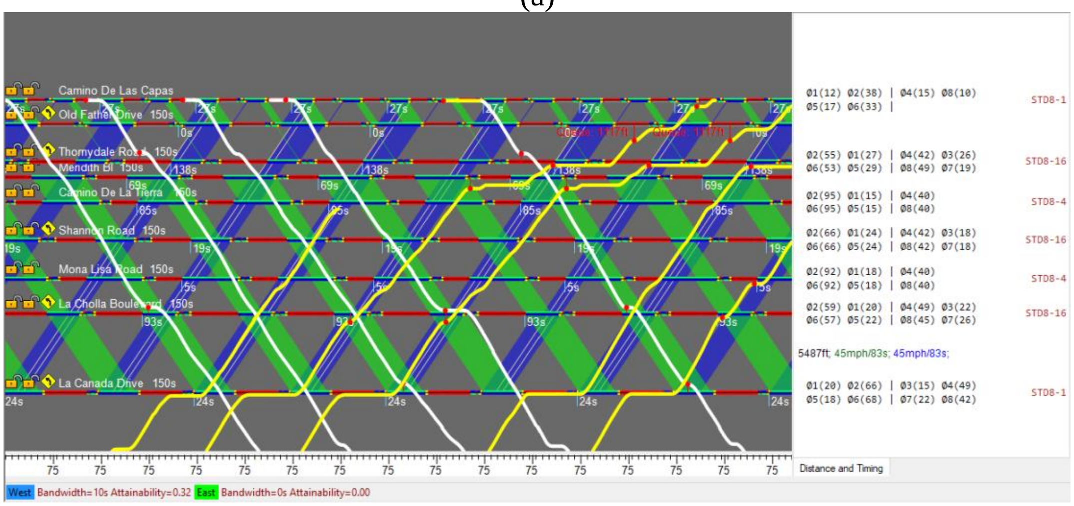
TranSync-M allows users to collect GPS data while using the time-space diagram (please refer to section 4.2) in their smartphones. In order to evaluate the effectiveness of the TranSync offset optimization, initially, subsystems (as discussed in section 4.2.1) need to be developed. For this study, as discussed in section 4.2.1, three subsystems were used:

- Subsystem 1: Ina_West_SR77-Between Interstate 10 and State Route 77
- Subsystem 2: Ina_East_SR77-East of State Route 77
- Subsystem 4: Orange Grove Road- Between Interstate 10 and State Route 77

After developing the subsystems, two sets of vehicle runs were performed. For the initial set, before period, several students drove along with both directions on the study corridors. For the second set, a similar approach was followed but after offsets were optimized using TranSync. For each set of data, two students were sent to the field, and they performed two rounds of data collection for each corridor. Then, the recorded trajectory data was used in TranSync-D to evaluate the corridor performance. A sample view of the trajectory data collected for after period for AM and PM peaks on Ina Road (Subsystem 1: Ina_West_SR77) is illustrated in Figure 5.7.



(a)



(b)

Figure 5.7 Sample Vehicle Trajectory-based data for Subsystem 1

The white lines in Figure 5.7 illustrate the vehicle trajectory-based data collected by UA students on the Ina Road corridor. Based on Figure 5.7-b, it can be seen that in total ten trajectory samples are available for eastbound (white line) and westbound directions (yellow line). It is worth mentioning that the green and blue bandwidths on this figure are the green bandwidth for each direction. TranSync-D was used to develop a similar time-space diagram for other subsystems as well.

Using the collected trajectory data, TranSync-D provides several performance measures, such as average travel time, stop time, delay time, speed score, and stop score for evaluating the quality of signals. Based on these measures, TranSync-D will provide a final quality score, A+ being the best performance and F- being the worse performance. The results of the corridor performance evaluation using vehicle trajectory-based data for each of the subsystems are summarized in Tables 5.7 and 5.8 for AM and PM peaks, respectively.

Table 5.7 Corridor performance using Vehicle Trajectory-based Data for AM Peak

Subsystems		Avg. Travel Time (s)		Avg. Stop Time (s)		Avg. Delay Time (s)		Avg. Speed Score		Avg. Stop Score		Avg. Score		Quality of Signal Timing	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
(1) Ina_West_SR77	***W***	*420*	435	*67*	109	112	127	*85*	81	*90*	88	*89*	86	***B***$^{+}$	***A (↑)***
	E	*498*	367	*100*	30	190	59	*74*	92	*83*	99	*80*	97	***B***$^{-}$	***B (↑)***
(2) Ina_East_SR77	***W***	*100*	83	*7*	0	10	0	*96*	100	*95*	100	*94*	99	***A***	***A***
	E	*108*	127	*0*	20	8	28	*100*	89	*100*	84	*99*	85	***A***	***B (↓)***
(3) Orange Grove	***W***	*305*	339	*49*	96	53	88	*88*	81	*87*	76	*86*	77	***B***	***C***$^{+}$ ***(↓)***
	E	*323*	360	*45*	91	66	103	*85*	76	*85*	59	*84*	63	***B***	***D(↓)***

Table 5.8 Corridor performance using Vehicle Trajectory-based Data for PM Peak

Subsystems		Avg. Travel Time (s)		Avg. Stop Time (s)		Avg. Delay Time (s)		Avg. Speed Score		Avg. Stop Score		Avg. Score		Quality of Signal Timing	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
(1)Ina_West_SR77	***W***	*584*	494	*157*	120	276	203	*65*	72	*71*	77	*68*	74	***D***$^{+}$	***C (↑)***
	E	*568*	345	*169*	22	260	37	*65*	97	*68*	99	*66*	97	***D***	***A (↑)***
(2)Ina_East_SR77	***W***	*181*	123	*55*	22	81	30	*86*	87	*91*	80	*89*	81	***B***$^{+}$	***B***$^{-}$***(↓)***
	E	*122*	116	*19*	6	24	16	*90*	94	*86*	100	*86*	97	***B***	***A (↑)***
(3) Orange Grove	***W***	*427*	417	*130*	141	169	159	*67*	69	*59*	53	*61*	58	***D***$^{-}$	***F (↓)***
	E	*383*	408	*77*	134	126	150	*73*	69	*71*	51	*72*	56	***C***$^{-}$	***F (↓)***

Based on Tables 5.7 and 5.8 the following conclusions could be made:

1- For subsystem (1), Ina Road-West SR77, corridor progression improved after offset optimization using TranSync, for both directions and periods
2- For subsystem (2), Ina Road-East_SR77, corridor progression improved after offset optimization using TranSync for only eastbound direction during PM Peak
3- For subsystem (2), Ina Road-East_SR77, corridor progression decorated after offset optimization using TranSync for both eastbound and westbound directions during PM peak
4- For subsystem (3), Orange Grove, corridor progression decorated after offset optimization using TranSync for both eastbound direction and westbound directions, during both AM and PM peaks

Please note that the results provided using vehicle trajectory-based data are biased since a limited number of samples were collected. In addition, since only two drivers conducted the vehicle runs, driver behavior will add additional bias to the results. To eliminate the bias issue, a second data source of data, vehicle probe-based data, with more sample sizes were used to further investigate the corridor performance evaluation after TranSync offset optimization.

5.3.2 Evaluation Results Using Vehicle Probe-based Data

INRIX data was collected for the before and after periods as discussed in section 5.3. In order to evaluate the corridor progression, the average speed was plotted versus the time of the day for the developed subsystems for both directions. Figures 5.8 and 5.9 and show the average speed during AM and PM peaks for subsystems 1, Ina_West_SR77, before and after offset optimization using TranSync.

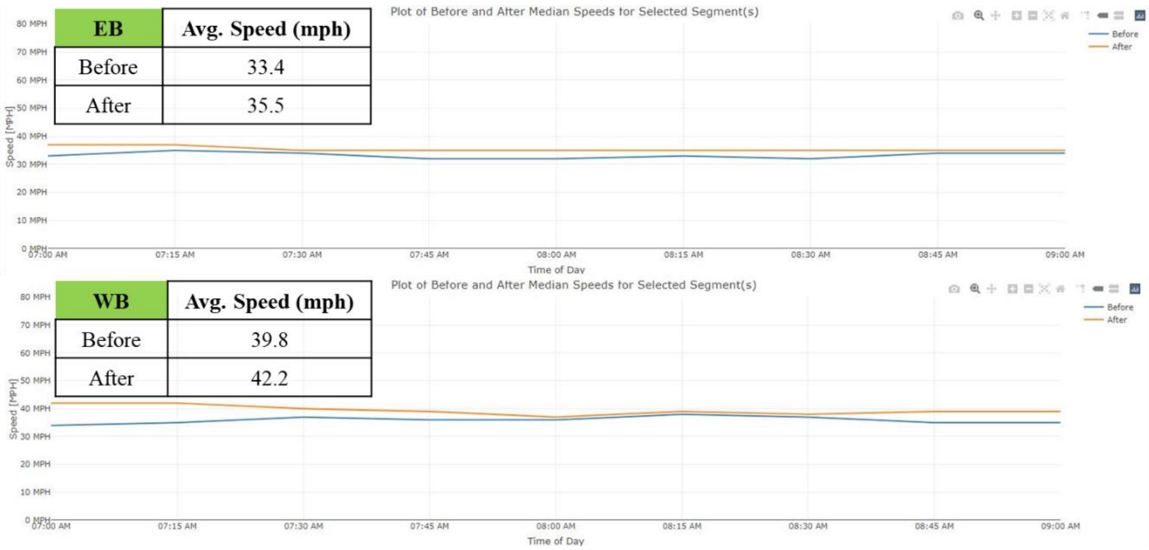


Figure 5.8 Average Speed for Subsystems 1 (AM Peak)

Based on Figure 5.8 it can be observed that after offset optimization using TranSync optimization using TranSync, corridor average speed improved by 1.1 MPH and 2.4 on the eastbound and westbound direction, respectively; this improvement was statistically significant.

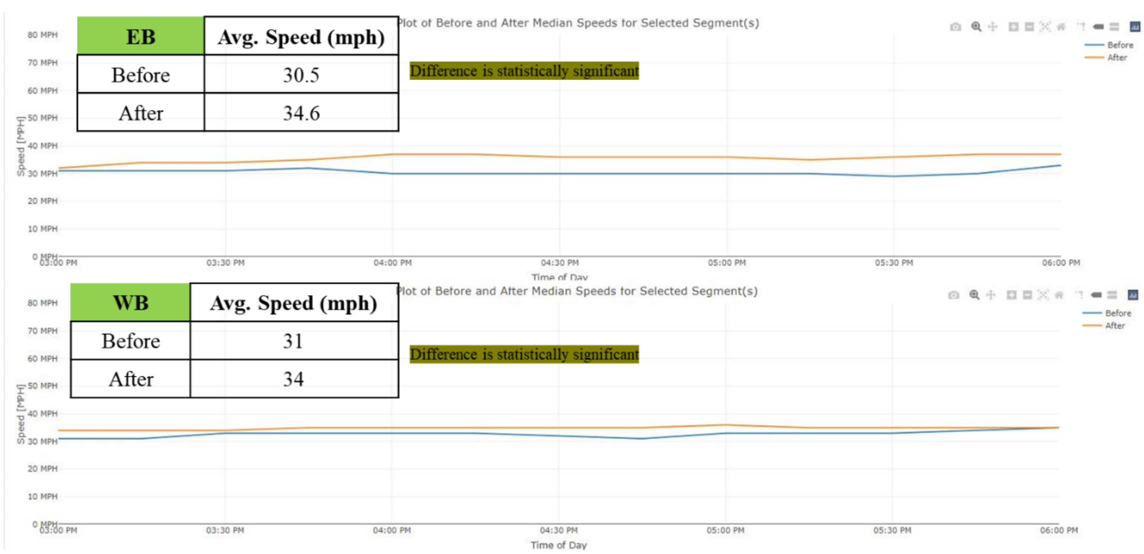


Figure 5.9 Average Speed for Subsystems 1 (PM Peak)

Similarly, for PM peak, the corridor average speed improved by 4.1 mph and 3 mph on the eastbound and westbound directions, respectively; this improvement was statistically significant.

A similar plot was also developed for subsystem 3 in Figures 5.10 and 5.11 for before and after offset optimization using TranSync.

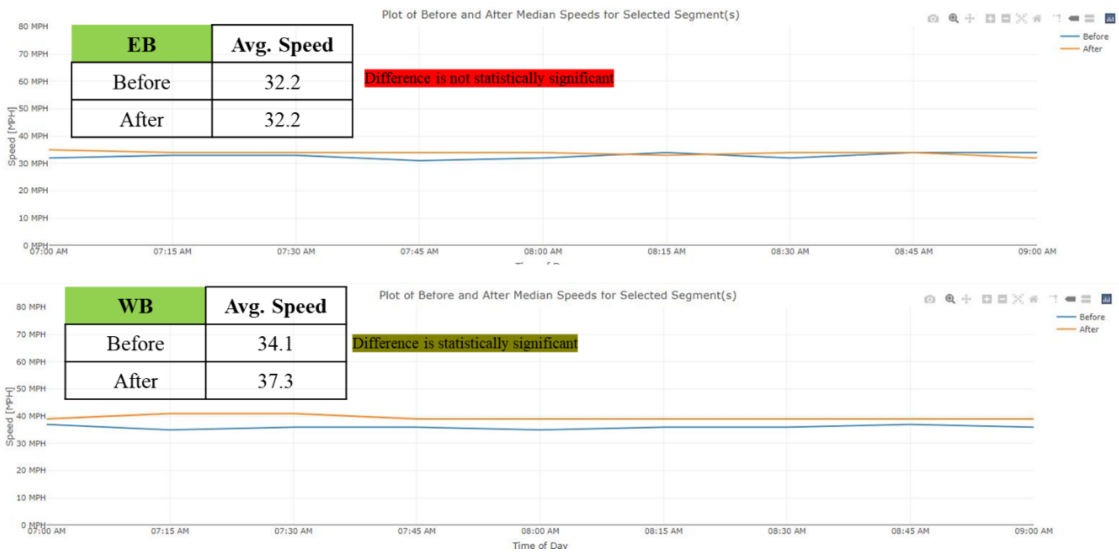


Figure 5.10 Average Speed for Subsystems 3 (AM Peak)

Figure 5.11 Average Speed for Subsystems 3 (PM Peak)

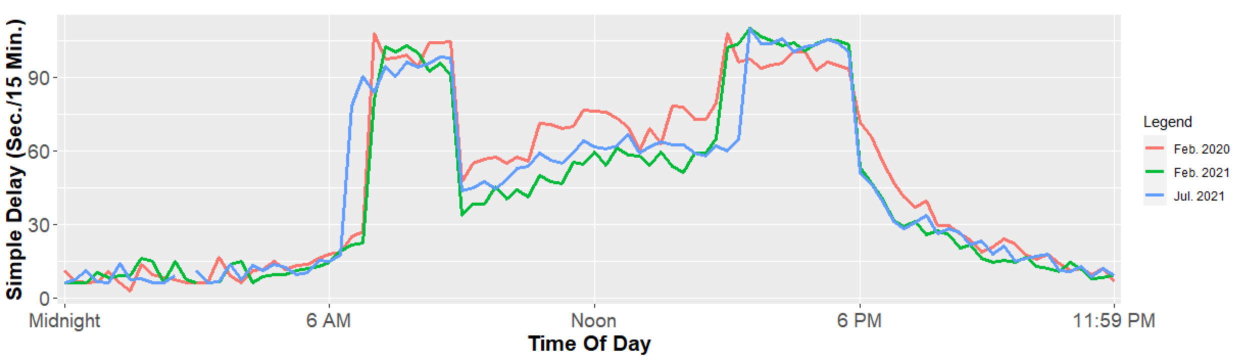
Based on Figure 5.10 it can be observed that after offset optimization using TranSync, Orange Grove corridor average speed improved by 3.2 MPH during AM Peak in the westbound direction; this improvement was statistically significant. Similarly, based on Figure 5.11 it can be observed that after optimizing the offsets using TranSync, Orange Grove corridor average speed improved by 3.6 MPH and 3.7 MPH during PM peak on the eastbound and westbound directions, respectively.

5.4 Side Street Delay Analysis

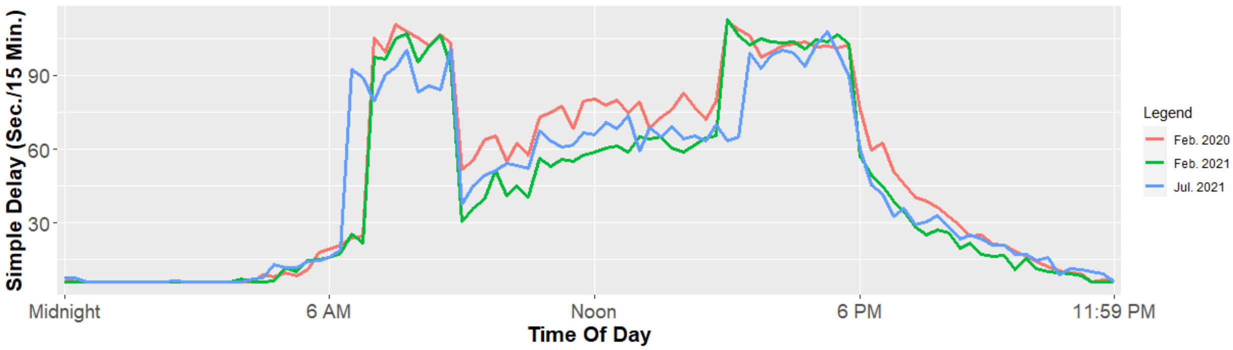
The main objective of this project was to improve the performance of the coordinated phases on our study corridors; Eastbound and Westbound directions for both Ina and Orange Grove roads. However, it is also critical to understand how this might impact the side streets' performance (Northbound and Southbound directions). In order to evaluate the impact of signal retiming on side streets (minor streets), delay analysis was conducted on side streets. Simple delay data was collected from all intersections on the study corridors. The same data collection periods as previous sections:

1- Before Pandemic, under the old signal timing plan (Feb. 2020)
2- During new-normal, under newly retimed signal timing plan using Synchro (Feb. 2021)
3- During new-normal, under optimized offsets using TranSync (July. 2021)

In this report, delay analysis was conducted on one sample intersection on Ina Road (W Ina Rd. @ N Shannon Rd.) and one sample intersection on Orange Grove Road (Orange Grove @ La Canada Dr). Figure 5.12 (a) and (b) illustrate the average delay on northbound and southbound of W Ina Rd. @ N Shannon Rd., respectively.



(a)

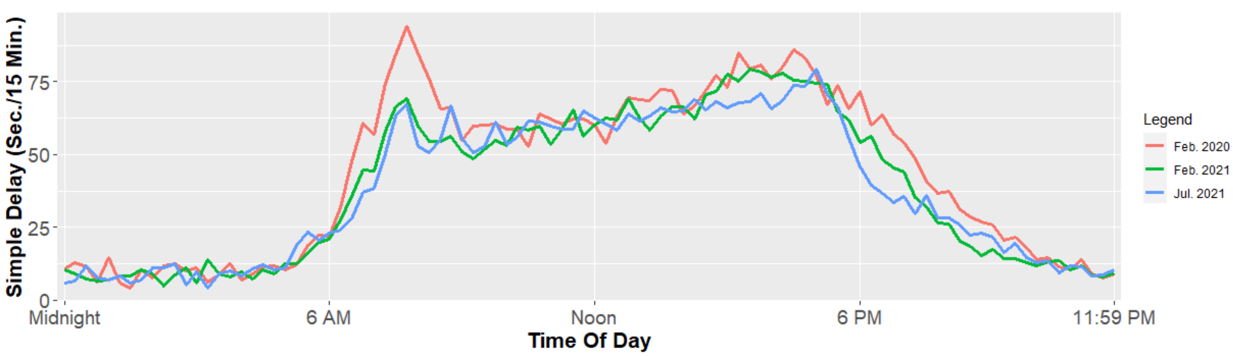


(b)

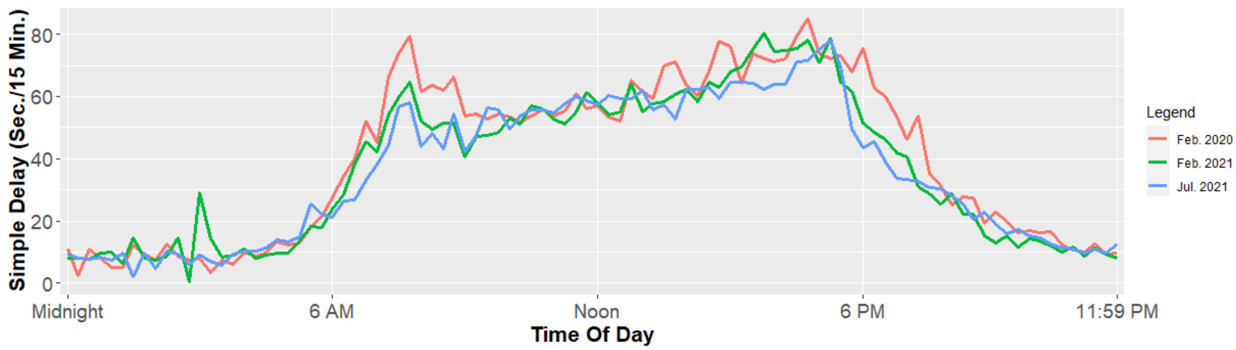
Figure 5.12 Average Delay on W Ina Rd. @ N Shannon Rd.; (a) Northbound Direction and (b) Southbound Direction

Based on the delay distribution for the side streets illustrated in Figure 5.12, it can be observed that for northbound direction, during AM Peak, the average delay decreased after signal retiming using the Synchro model. However, during PM peaks, the average delay increased slightly after signal retiming. However, for the southbound direction, for both AM and PM peaks, the average delay decreased after signal retiming using the Synchro model. Comparing delay before and after offset optimization using the TranSync model, it can be seen that after offset optimization, for northbound direction average delay increased, and for southbound direction, average delay decreased.

Figure 5.13 (a) and (b) illustrate the average delay on northbound and southbound of Orange Grove @ La Canada Dr., respectively.



(a)



(b)

Figure 5.13 Average delay on Orange Grove @ La Canada Dr.; (a) Northbound Direction, and (b) Southbound Direction

Based on Figure 5.13, it can be observed that for both directions and both peak periods, average delay decreased after signal retiming using Synchro and offset optimization using TranSync. Table 5.9 tabulates the average delay on both sample intersections during the data collection period. Based on this table, it can be observed that after retiming the signal timing plans using Synchro, the average delay was also decreased on side streets.

Table 5.9 Average Delay on Side Streets

Intersections	Average Delay (Seconds per 15 Minutes)					
	AM Peak			PM Peak		
	Feb. 2020	Feb. 2021	Jully 2021	Feb. 2020	Feb. 2021	Jully 2021
W Ina Rd. @ N Shannon Rd. (NB Thru)	82.60	76.60	87.60	93.80	100.1	99.19
W Ina Rd. @ N Shannon Rd. (SB Thru)	85.50	80.07	85.16	99.53	99.36	94.76
W Orange Grove Rd. @ N La Canada Dr. (NB Thru)	69.54	54.06	51.32	76.47	72.05	67.1
W Orange Grove Rd. @ N La Canada Dr. (SB Thru)	60.33	50.00	44.45	74.20	71.4	64.77

Feb. 2020: Before Pandemic, under the old signal timing plan
Feb. 2021: During new-normal, under newly retimed signal timing plan using Synchro
July. 2021: During new-normal, under optimized offsets using TranSync

5.5 Benefit/Cost Analysis

This section outline the benefit of using Synchro and TranSync in dollar value. In order to obtain the dollar value benefit of using Synchro and TranSync, the amount of saved time (reduction in delay) at each intersection was multiplied by $24.70 per hour, the mean hourly wage in Tucson, Arizona[1]. It is worth mentioning that, the cost of purchasing a Synchro license (Synchro plus Sim Traffic 11) for 2-4 machines, with three years of support is $3,989[2]. Further, the cost of purchasing one standard license (1 TranSync-D + 1 TranSync-M) is $6,875 for standard support (free maintenance for year 1 and year 2 and after annual Maintenance Fee will apply- $700)[3].

The benefit of using Synchro and TranSync is determined based on intersection delay. Initially, to determine the dollar value benefit of signal retiming using Synchro Studio, for each intersection, average delay during Feb. 2020 (before signal retiming using Synchro models) was compared with the average delay in Feb. 2021 (after signal retiming using Synchro models). Further, to determine the dollar value benefit of offset optimization using TranSync suit, for each intersection the delay during Feb. 2021 (before offset optimization using TranSync) was compared with the average delay in July 2021 (after offset optimization using TranSync). Next, the following formula was used to determine the annual benefits during AM (6:30 am – 9 am) and PM (3:30 pm-6 pm) peaks:

Annual Benefit= Avg. Traffic Flow (Veh./Hr.) * Avg. Simple Delay (Sec. / Veh.) *1/3600 (Hr. /Sec.) * Hourly Wage ($ / Hr.) * Annual Hour (Hr. / Year) **(Eq.1)**

Note that the "Annual Hour" in Equation 1, is the total hours of AM/PM peaks (2.5 hours for each peak period) for all the weekdays in a year (261 weekdays); the reason behind selecting only peaks and weekdays is that PCDOT only operate on TOD signal timing plan during peak periods on weekdays. The "Avg. Traffic Flow" in Equation 1, is the average traffic flow during

[1] Occupational Employment and Wages in Tucson — May 2020 : Western Information Office : U.S. Bureau of Labor Statistics (bls.gov)
[2] https://online.trafficware.com/tw_orderkit/orderkit.asp
[3] http://trans-intelligence.com/files/Transync%20Price%20List.pdf

July 2021 and Feb. 2020. Table 5.10 illustrate the annual dollar value benefits of using Synchro and TranSync at two sample intersections on our study corridors.

Table 5.10 benefit of Using Syncro; Two Sample Intersections

	Annual Benefit ($)			Annual Benefit ($)**		
Intersections	**AM Peak**	**PM Peak**	**Total (AM & PM Peaks)**	**AM Peak**	**PM Peak**	**Total (AM & PM Peaks)**
	Synchro Studio			**TranSync Suite**		
W Ina Rd. @ N Shannon Rd. (EB Thru)	$130,029	$381,845	$468,726	-*	$185,589	$105,621
W Ina Rd. @ N Shannon Rd. (WB Thru)	$105,611	$385,137	$439,060	-	$93,247	$7,761
W Orange Grove Rd. @ N La Canada Dr. (EB Thru)	$77,046	$139,208	$218,389	-	$133,382	$73,055
W Orange Grove Rd. @ N La Canada Dr. (WB Thru)	$103,048	$161,977	$267,277	-	$155,926	$113,165

* No benefit was observed; ** Annual Benefit provided by TranSync is an additional benefit after Syhcnro implementation

Taking "W Ina Rd. @ N Shannon Rd. (EB Thru)" as an example, during PM Peak on weekdays, after signal retiming using Synchro model, up to $468,726 can be saved annually. In addition, after optimizing the offsets using TranSync, an additional $105,621 can be saved. It is worth mentioning that, the total column in Table 5.9 represents the average traffic volume during AM and PM peaks and the total hours of AM and PM peaks (for this specific case study, 5 hours). Please note that the manpower cost of the signal retiming procedure (collecting turning movement count, model development, signal timing implementation, and field fine-tuning) are not considered in this study.

5.6 Signal Timing Software Evaluation Summary

The effectiveness of Synchro signal timing was evaluated at two levels, corridor and intersection levels. The corridor-based results indicated that after signal retiming, corridor progressions improved in terms of average travel time and speed; this improvement was observed for both eastbound and westbound direction, during AM and PM peaks. The intersection-based results also indicated that simple delay was statistically reduced for the majority of the study intersections both for AM and PM peaks.

The effectiveness of TranSync offset optimization was evaluated using two data sources: Vehicle Trajectory-based data, and vehicle probe-based data. The results from vehicle trajectory-based data showed that during both AM and PM peaks, corridor performance (average travel time, stop time, delay time, speed score, and stop score) improved only on the Ina Road corridor after offset optimization. However, extra attention needs to be taken to these results since the trajectory sample size was limited. The results from vehicle probe-based data showed that during both AM and PM peaks, corridor performance (average speed and travel time) improved for both study corridors after offset optimization.

Based on the side street delay analysis, it was found that after signal retiming using Synchro, the average delay on side streets were also reduced. In this report, the side street evaluation results for two sample intersections are provided. Based on cost/benefit analysis it was found both signal retiming software (Synchro and TranSync) will provide extreme benefit in terms of delay saving. For instance, after signal retiming using Synchro, on a selected intersection (W Ina Rd. @ N Shannon Rd. (EB Thru)), up to $468,726 can be saved in delay during AM and PM Peaks. In addition, after optimizing the offsets using TranSync, an additional $105,621 can be saved; it is worth mentioning that certain costs, such as collecting turning movement count, model development, signal timing implementation, and field fine-tuning were not included.

5.7 Fine-Tuning Signal Timing Plan Parameters using Miovision Data

The UA team developed an innovative approach for fine-tuning signal splits by only using the performance measures (SPMs) obtained Miovison platform. This innovative approach will 1) enable transportation agencies to identify the TOD breakpoint intervals based on both intersection and corridor-based measures, 2) provide a simple fine-tuning procedure for frequently fine-tuning the signal timing parameters, rather than retiming the whole corridor every three to five years; in other words adjusting the signal parameters without replacing the whole signal timing as a way around retiming, and 3) can predict the future of the intersection mobility performance prior to the field implementation of the revised timing plan. The proposed approach consists of three main steps: in the first step, a clustering approach is proposed to identify the TOD breakpoint intervals. The clustering approach will fuse SPMs at both intersection and corridor levels to group time intervals of the day with a similar traffic pattern. In the second step, an empirical method is proposed to fine-tune the signal timing parameters by adjusting the green splits on both minor and major streets. Next, a fuzzy-logic model is developed in this step to predict the intersection mobility performance. The fuzzy-logic model will be used to predict the intersection mobility performance prior to the field implementation. The application of this method was applied to two intersections on one of the study corridors:

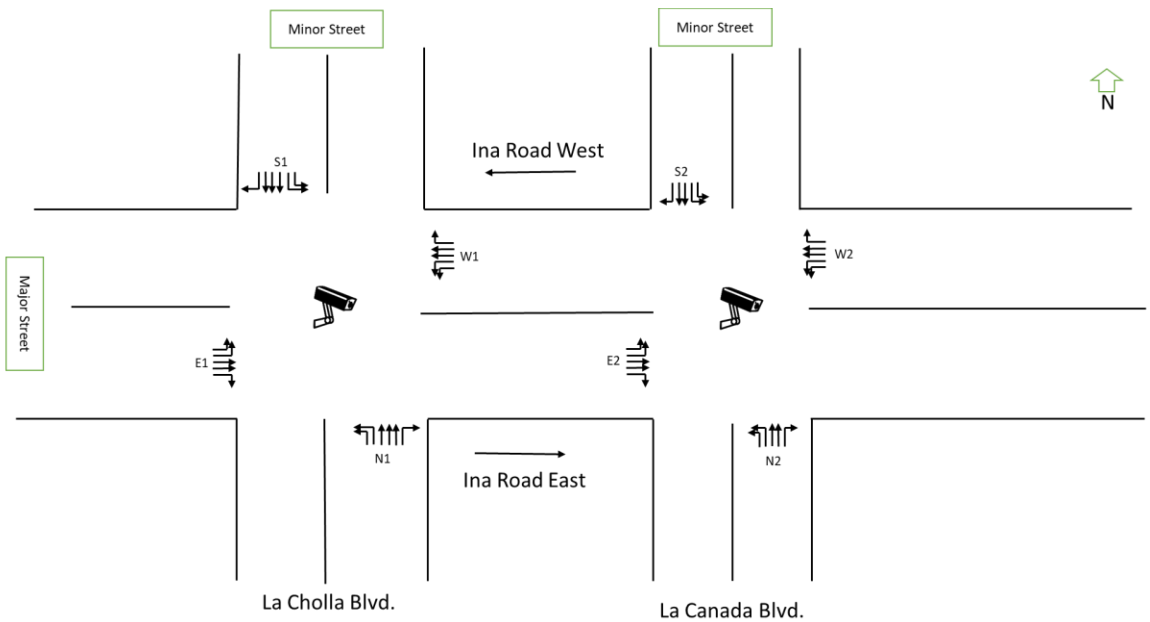


Figure 5.14 Layout of case study intersections

For the selected intersections, the eastbound and westbound approaches are the major streets, and the northbound and southbound approaches are the minor streets. The detailed description of each approach of these two intersections are described as below:

E1, W1: Eastbound and westbound on La Cholla Blvd. @ Ina Road, respectively.

E2, W2: Eastbound and westbound on La Canada Dr. @ Ina Road, respectively.

N1, S1: Northbound and southbound on La Cholla Blvd. @ Ina Road, respectively.

N2, S2: Northbound and southbound on La Canada Dr. @ Ina Road, respectively.

For the entire corridor, event-based data was collected via smart sensors at the intersection level and probe-based data was collected at the corridor level.

The results of this section are divided into two parts, identifying the appropriate TOD signal timing breakpoints and determining the impact of fine-tuning traffic signals on side street performance.

5.7.1 Identifying TOD Breakpoint Intervals

A K-mean clustering method is utilized to identify the TOD breakpoints. K-means clustering partition data using their closeness to each other according to Euclidean distance. In this algorithm, the data are partitioned into *N* clusters, with a representative point that summarizes the information of the *n*th cluster.

The output of the K-mean clustering algorithm is presented in Figure 5.15. For the 15-min aggregation level, cluster #4 represents traffic conditions with the highest traffic volume (810 vehicles/hour) and the steadiest traffic turbulence (lowest standard deviation of speed: 2.76 mph). Cluster # 3 represents a large range of traffic volume (130 vehicles/hour to 596 vehicles/hour) with the highest traffic turbulence (highest standard deviation of speed: 3.57 mph), and clusters #1 and #2 both represent the lowest traffic volume (8 vehicles/hour to 130 vehicle/hour). Similarly, for the one-hour aggregation level clusters #3 and #4 represent the highest traffic volume and the steadiest traffic turbulence, cluster # 2 represents a large range of traffic flow with the highest traffic turbulence, and cluster #1 represents the lowest traffic volume.

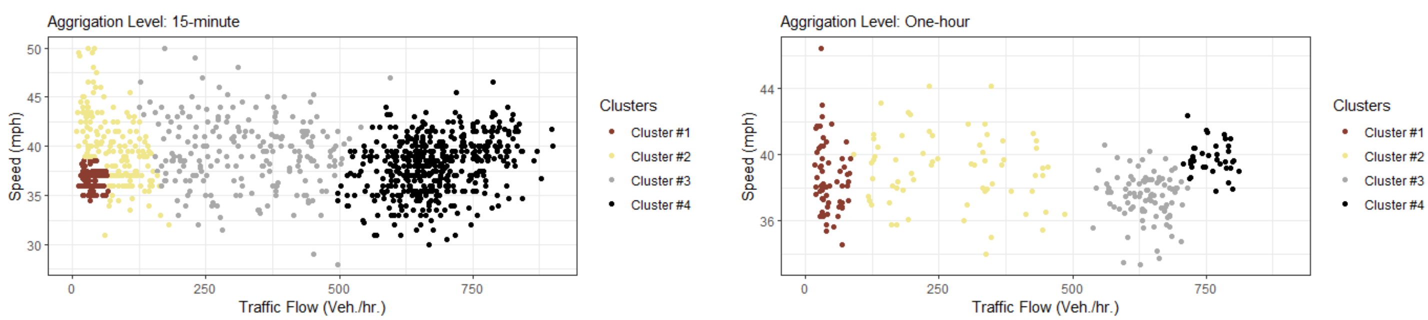


Figure 5.15 Clustering Analysis

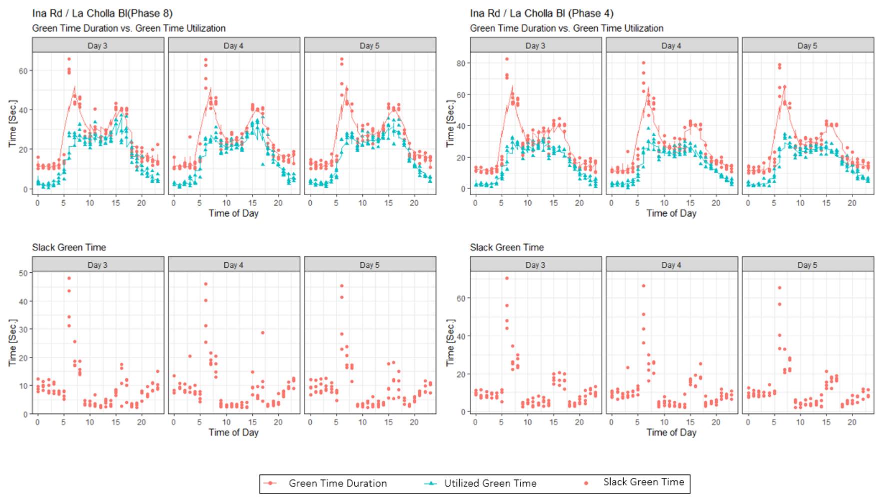
Next, the identified clusters are mapped to their corresponding time intervals of the day. The clusters with the highest traffic volume and the steadiest traffic turbulence represent the peak hours during the day: 7 AM-6:45 PM for a 15-min aggregation level and 7:00 AM -7:00 PM for a one-hour aggregation level. The clusters with the largest range of traffic volume and the highest traffic turbulence represent the transition time between peak and off-peak hours: 5:15 AM - 7 AM and 6:45 PM-9:30 PM for 15-min aggregation level and 5:00 AM – 7:00 AM and 7:00 PM-10:00 PM for one-hour aggregation level. The cluster with the lowest traffic volume represents the off-peak hour: 9:30 PM-5:15 AM for a 15-min aggregation level and 9:30 PM-5:00 AM for a one-hour aggregation level.

Based on the results from the clustering section, three breakpoints for the TOD signal timing plan were proposed: Peak-hour (7:00 AM -7:00 PM), the transition between peak and off-peak hours (5:00 AM – 7:00 AM and 7:00 PM-10:00 PM), and off-peak hour (10:00 PM-5:00 AM).

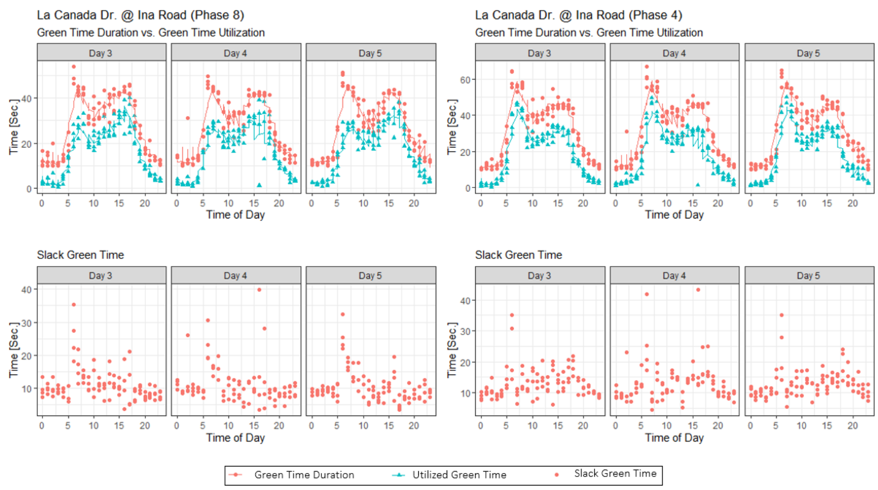
5.7.2. Fine-Tuning Green Splits

To adjust signal timing parameters; green splits, for the minor and major phases, are considered in this study. Initially, three weekdays, Tuesday, Sept. 3rd, Wednesday, Sept. 4th, and Thursday, Sept. 5th were selected, and the amount of green time utilization and slack green (The Slack green time is calculated by subtracting utilized green duration from green split) for the minor streets were estimated.

Figure 5.16 illustrates green duration against utilized green time and the amount of slack green time for La Cholla Bl @ Ina Road and La Canada Dr. @ Ina Road. From Figure 5.16, it can be seen that at both intersections, on the minor streets green time duration exceeds the green time utilization. Meaning, an extra amount of un-utilized green exists throughout the day.



(a)



(b)

Figure 5.16 Green time duration, utilized green time and slack green time; a) La cholla Bl @ Ina road, b) La Canada Dr. @ Ina road

To identify the amount of slack green that can be transferred from minor streets to major streets, descriptive statistics of the slack green at each approach along with the approach delay is presented in Table 5.11.

Table 5.11 Descriptive Information of the Slack Green and Delay

		Phase 8 (NB)	Phase 4 (SB)	Phase 8 (NB)	Phase 4 (SB)
		Slack Green (sec.) / Time of Day		Delay (Sec.) / Time of Day	
La Cholla Bl @ Ina Road	*Day 3*				
	Min	1.89 (12:15 PM)	1.93 (9:45 AM)	0.75 (1:45 AM)	0.2 (1:00 AM)
	Max	50.11 (6:00 AM)	73.61 (6:00 AM)	116.81 (2:00 PM)	117.02 (2:00 PM)
	Average	7.89	10.82	59.43	62.57
	Day 4				
	Min	1.9 (2:00 PM)	1.89 (2:15 PM)	0.6 (2:30 AM)	0.91 (1:30 AM)
	Max	49.09 (6:00 AM)	64.83 (6:00 AM)	112.27 (1:15 PM)	119.64 (2:00 PM)
	Average	8.23	10.49	62.45	62.68
	Day 5				
	Min	2.04 (1:30 PM)	1.89 (9:00 AM)	0.5 (1:15 AM)	1.04 (1:45 AM)
	Max	43.62 (6:00 AM)	65.29 (6:00 AM)	110.91 (2:30 PM)	110.94 (12: 45 PM)
	Average	7.61	10.54	62.23	61.64
La Canada Dr. @ Ina Road	*Day 3*				
	Min	1.29 (5:00 PM)	4.35 (11:45 AM)	3.23 (1:15 AM)	0.5 (12: 45 AM)
	Max	33.3 (6:00 AM)	39.48 (6:00 AM)	101.13 (3:15 PM)	97.7 (2:45 PM)
	Average	9.82	12.09	51.94	52.35
	Day 4				
	Min	1.76 (4:15 PM)	4.37 (1:00 PM)	4.11 (3:30 AM)	0.3 (12:30 AM)
	Max	39.83 (4:45 PM)	45.39 (6:00 AM)	105 (5:00 PM)	94.6 (4:15 PM)
	Average	9.55	11.87	57.64	52.36
	Day 5				
	Min	1.19 (5:30 PM)	3.94 (12:00 PM)	0.9 (4:00 AM)	0.1 (1:00 AM)
	Max	33.37 (6:00 AM)	37.59 (6: 00 AM)	104.88 (2:15 PM)	97.59 (3:00 PM)
	Average	9.16	11.83	53.45	50.77

Based on the information provided in Table 5.11, the amount of 10 seconds from the minor streets' green split can be transferred to the major streets' green split. After this adjustment, using the proposed method the average predicted delay and the percentage of change in delay on the major streets are provided in Table 5.12.

Table 5.12 Predicted Performance Measures

	Average Delay Before Cycle Length Modification (Sec.)	Average Delay After Cycle Length Modification (Sec.)	Percent Change in Delay (%)
La Cholla Blvd. @ Ina Road	Day 3		
	66.92	63.06	5.7
	Day 4		
	69.76	64.2	7.97
	Day 5		
	71.29	68.27	4.24
La Canada Dr. @ Ina Road	Day 3		
	48.81	42.58	12.76
	Day 4		
	53.57	45.95	14.22
	Day 5		
	54.08	45.08	16.64

Based on the results provided in Table 5.12, the average delay was improved at both intersections after the implementation new TOD plan with adjusted signal timing parameters. The amount of improvement was more in La Canada Dr. @ Ina Road intersections, which could be due to better green utilization of the intersections.

5.7.3 Fine-Tuning Methodology Summary

The results of the systematic approach proposed in this study show how taking advantage of this approach can help transportation agencies to frequently adjust their signal timing parameters, rather than retiming the whole corridor every three to five years. Moreover, understanding and predicting the posterior mobility performance of the fine-tuned signal timing parameters will assist agencies to save money and labor before conducting any field implementation.

The application of the proposed systematic approach could benefit transportation agencies to identify the TOD breakpoint intervals based on both intersection and corridor-based measures, provide them with a simple fine-tuning procedure to frequently fine-tune the TOD signal timing parameters, rather than retiming the whole corridor every three to five years, and predict the future of the intersection mobility performance prior to the field implementation of the revised timing plan.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Signal optimization and coordination is a cost-effective way to mitigate congestion while keeping a smooth traffic flow. With the implementation of efficient signal optimization, costly infrastructure improvements and roadway construction can be avoided. Traffic signal optimization can significantly reduce the amount of delay experienced by travelers on the roadway. The objective of this project was to evaluate and understand the effectiveness of multiple signal retiming software (Synchro and TranSync) for signal retiming and corridor coordination. Synchro is one of the most common software used by different agencies for conducting traffic analysis and optimization. TranSync is the first mobile tool for systematic management, optimization, and performance evaluation of traffic signal timing plans.

In order to provide a deep and comprehensive understanding of each application, a before-and-after study design was set up for two major corridors in Pima County: Ina Road, and Orange Grove. Three different types of data were collected:

- Sensor-based data from Miovision smart sensors: All the intersections on these two corridors are equipped with Miovision's SmartView 360 video-based sensors. These video-based sensors provide both real-time and historical signal performance metrics.
- Vehicle probe-based data (INRIX): INRIX provides the most comprehensive coverage with the most accurate information using fusion technologies. INRIX data is mainly aggregated using vehicles equipped with GPS devices. INRIX data provides travel time rates at every one-minute interval.
- Vehicle trajectory-based data: Vehicle trajectory-based data for this study consist of the GPS data collected using TranSync-M.

The following bullet points summarize the overall evaluation results for both Synchro and TranSync effectiveness.

1- Based on the corridor-based level data collected from Miovision smart sensors before and after signal retiming using the Syncro model, it was found that the average corridor's travel time and speed improved significantly; the reduction in average travel time and enhancement in average speed was statistically significant (alpha=0.05).

2- Based on the intersection-based level data collected from Miovision smart sensors before and after signal retiming using the Syncro model, it was found that the average delay on most of the corridors' intersections was reduced significantly; the average delay reduction was statistically significant (alpha=0.05).
3- Based on the vehicle trajectory-based data collected using TranSync-M before and after offset optimization using TranSync suite, it was observed that for Ina Road (west of State Route 77 to Interstate 10) corridor performance (travel time, speed and stop time) improved. While, for Orange Grove Road corridor performance (travel time, speed and stop time) deteriorated; it is worth mentioning that since the number of vehicle trajectories was limited, these results could be biased.
4- Based on the vehicle probe-based data (INRIX) collected before and after offset optimization using the TranSync suite, it was observed that average travel time and speed were improved for both directions on the study corridors.
5- Based on the side street delay analysis, it was found that after signal retiming using Synchro, the average delay on side streets were also reduced. In this report, the side street evaluation results for two sample intersections are provided.
6- Based on benefit/cost analysis it was found that both signal retiming software (Synchro and TranSync) can provide extreme benefit in terms of delay saving. For instance, after signal retiming using Synchro, on a selected intersection (W Ina Rd. @ N Shannon Rd. (EB Thru)), up to $468,726 can be saved annually only during AM and PM peaks. In addition, after optimizing the offsets using TranSync, an additional $105,621 can be saved only during AM and PM peaks; it is worth mentioning that certain costs, such as collecting turning movement count, model development, signal timing implementation, and field fine-tuning are not included.
7- The UA team developed an innovative methodology for fine-tuning signal splits by only using the signal performance measures collected from the Miovision platform. This innovative approach, 1) enables transportation agencies to identify the TOD breakpoint

intervals based on both intersection and corridor-based measures, 2) provides a simple fine-tuning procedure for frequently fine-tuning the signal timing parameters, rather than retiming the whole corridor every three to five years; in other words adjusting the signal parameters without replacing the whole signal timing as a way around retiming, and 3) predicts the future of the intersection mobility performance prior to the field implementation of the revised timing plan.

6.2 Recommendation

The project team provided the following recommendations to further help PCDOT to incorporate and utilize more effective strategies and software for conducting future signal retiming.

1- Synchro studio could be used as a great tool for signal retiming; Syncro will allow PCDOT to optimize different traffic signal timing parameters, such as splits, cycle length, and offsets. However, in order to build up the Synchro model, TMC data is required.
2- TranSync suite could be used as a great tool for real-time diagnosis and evaluation of traffic signal timing plans. Using this tool transportation engineers at PCDOT could easily diagnose the current timing plan and identify any common issues with actuated coordinated signals, such as phase early return transition, and clock drifting.
3- PCDOT can use the TranSync suite as an effective tool for optimizing offsets. However, TranSync requires an initial signal timing plan. Therefore, Synchro could be used as the main signal retiming application, and TranSync could be used as a diagnosing tool and also for offset optimization.
4- During the project, the UA team found out that many of the intersections are experiencing a high amount of clock drifting. The UA team recommends PCDOT to work more closely with Miovision to sync all the intersections clock multiple times per day, rather than once per day.
5- Future studies could target the use of other third-party data for potential network screening, intersection ranking, and developing a real-time application alerting PCDOT of any necessary signal retiming or parameter modification on the county signal network.

6- Based on the positive results from the benefit/cost analysis, and operational performance improvement of both study corridors, PCDOT could potentially use a similar approach and retime other corridors in Pima County.
7- The current study evaluated the effectiveness of utilizing both Synchro and TranSync for signal retiming. Future studies could target the possibility of conducting signal retiming only using on TranSync.

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