THE IMPACT OF PEDESTRIAN ACTIVITIES IN ADAPTIVE TRAFFIC SIGNAL CONTROL SYSTEM OPERATIONS

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This research has explored how the presence of pedestrians can influence Adaptive signal Control Technology (ASCT) system performance. The research focused on an example case: the SURTRAC (Scalable Urban Traffic Control) system, an ASCT system developed by Carnegie Mellon University, which is currently operating a 9-intersection grid road network in the East Liberty section of Pittsburgh, Pennsylvania.

The Trafficware program Synchro was used to simulate the operations of the system under four scenarios by inputting traffic volume collected and timing plans utilized in real-time by SURTRAC. Adaptive traffic control selected timings and operations with pedestrian actuations were compared to conditions without pedestrian actuation. Also the performance of the conventional time-of-day timing plans, prior to installation of SURTRAC, with and without pedestrian intervals was compared.

The purpose of this research was to determine the impact of pedestrian calls on ASCT systems and to provide potential guidelines for the appropriate level of pedestrian activity that can be accommodated during the planning phase of ASCT project development. It could also be used as a tool to determine how pedestrian activity may impact system performance. The research results will help traffic and system developers to develop better optimization methods for ASCT systems to consider pedestrian delays.

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1.0 INTRODUCTION

This chapter introduces the background, hypothesis, objectives and methodology of this research.

1.1 BACKGROUND

Adaptive Signal Control Technology (ASCT) is a new Intelligent Traffic System (ITS) technology developed to optimize cycle lengths, green times or phasing sequences for traffic signals based on the changing traffic volumes collected from advanced detectors, in order to reduce traffic congestion and improve safety. The emergence of ASCT gives traffic engineers an alternative to traditional Time-of-Day (TOD) timing plans. TOD timing plans is a set of signal-timing plans that run on a specified schedule for multiple hour time periods during specific days of the week. Because the predetermined TOD timing plans cannot accommodate variable and unpredictable traffic demands within those time periods, the control delay of traffic signals may generally increase along with time until maintainers retime those outdated signal timing plans; while ASCT help traffic signals frequently adjust timing and phasing scenarios to accommodate changing traffic patterns and thus improve the traffic signal operations.

The algorithm of the adaptive traffic control systems not only considers the needs of vehicles, but also considers the needs of pedestrians. For some traffic signal operations, pedestrians are required to push buttons to activate pedestrian crossing phases when they intend to walk across intersections in the systems. It is appropriate when pedestrian actuations are frequent enough that they must be assumed to be present every cycle or most cycles. Although adaptive signal control technologies (ASCTs) have been implemented in dozens of states, the effects of the pedestrian calls on the overall effectiveness of the systems are unknown.

Different algorithms to optimize and set timings are used for different ASCT systems, however, conflicts between optimized green times and pedestrian interval requirements seem certain in some situations when pedestrian activity is present for all the existing ASCT systems. In optimization of signal timing patterns, spilt or green time is subject to configured minimum green times, pedestrian interval requirements (optionally) and maximum green times. When a pedestrian phase is called at an intersection, the adaptive traffic control systems will select the required pedestrian crossing time as the spilt time, of the pedestrian interval requirement and not the optimized green time, ensuring that pedestrians can have sufficient time to walk across the intersection. Sometimes the time required for pedestrian crossing is more than the optimized green time. For example, if vehicle volumes are low in off-peak hours the pedestrian actuation will force up the split time to increase at some intersections when pedestrian intervals are actuated. And during the peak traffic hours the optimized split time for the side street is probably less than the time needed for pedestrians to cross the main road. Because of the heavy traffic on the main road it is preferred to have good progression, and then the system most likely will reduce splits for the side street. In either case the use of pedestrian push buttons may cause some additional vehicular delay and counteract the positive effect of the ASCTs by extending splits to accommodate pedestrians rather than vehicular volumes.

At locations with long pedestrian crosswalks or a history of conflicts between turning vehicles and pedestrians, the system operator needs to accommodate advance pedestrian intervals or exclusive pedestrian phases during adaptive operations. If so, a huge amount of vehicular delay may be produced by high levels of pedestrian activities.

Additionally, the adaptive traffic control systems can gather the data (pending pedestrian calls and current queues on the side street) to determine whether to normally initiate a phase for the side street. If no pedestrian is present and the side street traffic is light, the optimizer likely begins the phase for the side street later than its normal starting point within the cycle. In other words, a pedestrian call can prevent ASCTs from achieving the function of maximizing the effectiveness of traffic signal timings.

1.2 HYPOTHESIS

The author hypothesized that frequent pedestrian crossing behaviors can offset a part of the potential benefits brought by the ASCTs. The adaptive traffic control systems theoretically can reduce vehicular travel time, number of stops, delay, vehicular emissions and fuel consumption. Some pedestrian calls, however, disrupt good progression for vehicles and increase their waiting time under the systems. More specifically, ASCTs are not effectively applied to all the dynamic traffic conditions. For those traffic patterns with a certain pedestrian volume and frequency, an adaptive traffic control system may have no advantage over the Time-of-Day (TOD) coordination timing plans.

The impact of pedestrian activities on the adaptive traffic control systems were evaluated in both two types of networks. A segment of the State Route 19 in the North Hills of Pittsburgh Pennsylvania was selected as a test corridor. A grid network located in the City of Pittsburgh Pennsylvania near the Penn Circle area in which land use generates a significant number of pedestrian trips was selected as a second test network location. It was hypothesized that the negative effect of pedestrian activities on the adaptive control systems is more obvious for the grid network than the corridor, as there may be more pedestrian crossing behaviors.

1.3 OBJECTIVES

The objectives of this thesis were to identify how the use of pedestrian actuations affects performance of the adaptive traffic control systems and how these systems affect pedestrian crossing behaviors; to determine what the level of pedestrian activity is suitable for the adaptive traffic control systems and create potential guidelines; and to explore whether the optimization methods used by the ASCTs should incorporate pedestrian delay and whether the optimization methods can be revised for this.

1.4 METHODOLOGY

The Trafficware program Synchro was to be used to simulate the operations of the two ASCTs respectively for a grid and a corridor and calculate control delays, and other measures of performance, for all the intersections during four traffic peak hours (AM peak, Mid-day hour, PM peak and Saturday shopping peak hour). The performance in real time under the adaptive traffic control system was then compared to the same system without pedestrian activity, in the Time-of-Day (TOD) coordination with and without pedestrian activity. The differences between the four scenarios were to be analyzed in order to evaluate the impact of pedestrian activities on the systems. Performance measure of the traffic control operation for each intersection is the control delay, or level of service. Table 1-1 presents a matrix showing the four scenarios and different times of days for the methodology. This table gives a concept that how control delays were compared in different scenarios during the four traffic peak hours.

Table 1-1. The methodology of comparisons in four scenarios during different periods of days

Control Delay (Seconds)	TOD				ASCT			
	WEDNESDAY			SATURDAY	WEDNESDAY			SATURDAY
	AM PEAK	MID-DAY	PM PEAK	SHOPPING PEAK	AM PEAK	MID-DAY	PM PEAK	SHOPPING PEAK
WITH PEDESTRIAN ACTUATIONS								
WITHOUT PEDESTRIAN ACTUATIONS								

2.0 LITERATURE REVIEW

This chapter describes practices and research on ASCTs relevant to this thesis and a recommended method to evaluate performance of traffic operations under the ASCT systems developed based upon these research achievements.

2.1 INTRODUCTION

The adaptive traffic control systems have been implemented in the US and overseas for the past few decades. The Federal Highway Administration (FHWA) gives its full support to research and application of adaptive signal control technologies (ASCTs). Many valuable studies and practices on the measurement of benefits have been conducted by research centers, state departments of transportations (DOTs), and municipal traffic agencies. The literature review detailed the research and practices on particular adaptive traffic signal systems performed by FHWA, academic institutions, DOTs and municipal traffic agencies to develop a method to evaluate the potential benefits brought by the adaptive traffic signal systems.

2.2 FHWA

The Federal Highway Administration has studied adaptive signal control technologies through a coordinated program called The National Cooperative Highway Research Program (NCHRP). In 2010, the research program has published a cooperative research report: *NCHRP SYNTHESIS 403*, which covers the most recent non-vendor specific information on ASCT. Its study methodology was to interview agencies that supervised the installation and operation of adaptive traffic control systems, conduct a literature review from previous studies and do surveys of ASCT vendors and users.

2.2.1 Category

There are two major categories of ASCT: they include (e.g., SCATS and SCOOT) systems that adjust the signal settings while maintaining a common cycle length. The other one is a type of systems based on adaptive control policies (OPAC, PRODYN) that requires a fixed sequence of phases and continually adjusts the timing plans at each intersection based on rolling horizon optimization without necessarily maintaining a common cycle length in the network.

The *NCHRP SYNTHESIS 403* gives detailed descriptions of major adaptive traffic control systems deployed worldwide in 2010. It was reported that ACS Lite and SCATS are suitable for arterial networks, whereas SCOOT and UTOPIA operate best on grid networks. Although the working principles of various ASCTs are distinct, the diverse operational features do not always lead to very different field performances as reported by FHWA.

Different types of ASCTs have different detectors. There are four major types of loop detector locations. Stop-line detectors are commonly seen and often used by SCATS. Near-stop-line detectors, used by BALANCE, can easily calculate queue length, making up the deficiency of stop-line detectors. Upstream (mid-block) detectors are able to estimate long queue lengths. And upstream (far-side) detectors located at the exit point of the upstream intersection are used by SCOOT, UTOPIA, ACS Lite, and optionally by RHODES. The location of detectors is related to the type of reaction of adaptive traffic control systems. The summary of existing adaptive signal control systems with their detector types and locations is provided in Table 2-1. Four types of ASCT systems used loop detectors at or near the stop bar. Three types of ASCT systems adopt fully actuated design. Exit loops are utilized by two types of systems. Only TUC system collects traffic data by using system loops.

Table 2-1. Summary of Existing Adaptive Signal Control Systems with different detections [1]

System	Detection
SCOOT	Exit loops
SCATS	Stop bar loops
OPAC	Exit loops
RHODES	Fully actuated design
BALANCE	Loops near Stop bar
INSYNCE	Loops near Stop bar
ACS Lite	Stop bar loops upstream
ATCS	Fully actuated design
TUC	System loops
UTOPIA	Fully actuated design

2.2.2 Implementation

The survey results indicated that most adaptive traffic control systems are operated by local agencies. The majority of the U.S. ASCT users are located in California and Florida. In order to improve overall operations, 80% of the interviewed, installed their adaptive traffic control systems on a roadway traffic network with speed limits between 30 and 45 mph, and the most predominant application is a corridor. In the synthesis it’s reported that the most significant benefits can be observed when an aged fixed-time, or actuated-isolated, traffic signal system was replaced by an adaptive traffic control system. Nowadays SCOOT and SCATS, the two types are mostly deployed by the interviewed agencies, are used because they are mature technologies and technical support is easily available. The installation of an ASCT is influenced by factors such as interaction, the impact of ongoing projects in a high-growth area, existing infrastructure (detection, hardware, communication) and availability of funding. The length of the installation process is about 18 months on average. It is noted that 70% of the interviewed agencies have expanded their adaptive traffic control systems since the initial deployments.

2.2.3 Cost

The report also provided information on costs of installing and operating adaptive traffic control systems. On average, the costs of installing an ASCT are approximately $65,000 per intersection. When an ASCT is installed, funds will also be needed to maintain the hardware and software of the system. But its maintenance costs are less than the retiming costs of conventional traffic signal systems, even given the its costly maintenance of detectors and communication systems.[2]

2.3 CASE STUDIES

Many DOTs and cities have implemented ASCTs to address the variable traffic demands along the implementation site. The following cases are provided to illustrate how ASCTs are being implemented and the evaluation of their performance.

2.3.1 Powell Boulevard, Portland, Oregon

Oregon Department of Transportation (ODOT) has implemented the SCATS adaptive signal system along 3.7 miles of Powell Boulevard in Portland, Oregon. Kittelson & Associates was engaged to be responsible for planning and evaluation of the project. The firm compared performance of time-of-day (TOD) operations with SCATS operations at this location. Performance measures involved delay and level of service (LOS) of intersections under TOD operations as well as Synchro projected delay change.

However, the report does not evaluate LOS of intersections under SCATS by using Synchro. The study only compared travel times experienced before and after implementation of SCATS. And the results indicate that the overall positive effect of SCATS adaptive signal system is minor and it does not significantly improve through vehicle travel time in the corridor. The results of the analysis reveal that in the early morning traffic volumes are too low to trigger cycle time changes, and during the afternoon peak, traffic volumes pushed cycle times to their preset maximum value so that ASCTS was unable to react to traffic demands in these conditions.[3]

2.3.2 City of Gresham, Oregon

The City of Gresham, Oregon implemented SCATS to reduce the congestion of arterial roadways within the city. The evaluation work on SCATS began in 2005. The project was designed and studied by DKS Associates. The team came up with project goals and objectives and conducted an adaptive signal system evaluation process. According to its benefits report, the project is worthwhile and all the expected goals were met. Field surveys were conducted while the traffic signals along the Burnside Road corridor were operating in two different control modes.

The new system with SCATS improved operational efficiency of the arterial by reducing travel time, number of stops and delay compared with the previous TOD coordinated signal timing plans. The report also recommended that the future benefits analysis should focus on the balance between travel times on main route and side street delay.

For example, the city of Gresham preferred to sacrifice some delay to the side street in favor of providing better progression for the significant volume on the mainline. Moreover, the report discussed the matter of expandability for the rest of region, which was related to jurisdiction of systems and compatibility of hardware. Finally the report revealed that it is a cost effective system. In the first year a benefit-cost ratio of 1.4 was calculated by averaging benefits during peak hours and off-peak hours and when it was in the fifth year the ratio increased to 4.2. Importantly the benefit is only associated with delay and fuel consumptions. [4]

2.3.3 State Route 291, Missouri

The Missouri Department of Transportation (MoDOT) installed the InSync system along the Missouri Route 291 corridor. MoDOT engaged Midwest Research Institute (MRI) to evaluate the system's Performance by a before-after study. MRI installed GPS and software in several vehicles. Four vehicle runs in each direction of travel were conducted during selected time periods. Data was collected by the PC-travel software. In addition to travel time data, delay and number of stops, the measures reported included vehicle emissions and fuel consumption, which was estimated based on travel time and average speed. But the report does not provide a detailed benefit-cost analysis. MRI also manually collected traffic volumes and turning movement counts for comparison because they were concerned that traffic pattern changes would occur. In the end the report gave some recommendations for future use of adaptive traffic signal systems. [5]

2.4 ACADEMIC RESEARCH

In recent years adaptive signal control technology has developed very quickly and there is a significant amount of research recently completed. The most recent research has been reviewed, that is relevant to this research topic, and is summarized as follows.

2.4.1 University of Nevada

A study of the evaluation of the Sydney Coordinated Adaptive Traffic System (SCATS) at a major arterial section in Las Vegas, Nevada was performed by the University of Nevada. The evaluation focused on two typical performance measures: travel time and number of stops. Practitioners collect data for a year before and after installation of SCATS. When compared with the previous optimized TOD coordinated plan operations, no significant improvement were found with SCATS plans for the arterial during normal weekday and weekend peak periods. This experience is very useful in selecting the period when the benefits of ASCT should be measured for comparison to previous technologies. [6]

2.4.2 Illinois Transportation Center

Illinois Center for Transportation made an effort to determine benefit-cost ratios for adaptive traffic control systems by measuring safety benefit (cost of crash reduction) and cost of implementation and maintenance. The study method was to do an online survey. 17 agencies responded with useful information. Volumes, geometry information and crash data were provided for only three intersections. Although data is very limited, it was conducted that the average cost of ASCT is determined by the type of system as well as the type of detection technology. [7]

2.4.3 Park City, Utah

In order to improve traffic efficiency at a network, Park City, Utah installed an adaptive traffic control system using SCATS. The city conducted a field evaluation of the previous time-of-day actuated-coordinated signal timings before SCATS installation. But two additional signals were installed before the post-SCATS field evaluation and some changes were made to the original network. Two years later, Park city conducted an off and on study to reevaluate the SCATS system for comparison to the before-after study. The before-on and off-on studies showed that 62.5% of all performance indicators were the same between before and off evaluations. The improvement in traffic performance was even more distinct in the off-on study. The report concluded that the off-on study is an alternative method to evaluate benefits of those adaptive traffic control systems with many network changes. [8]

2.4.4 Salt Lake City, Utah

A study was conducted to evaluate performance of SCOOT during incidents. The incidents were defined by variables: midblock locations, one-lane closure, and incident durations of 15, 30 and 45 min, and v/c (Volume/Capacity) ratios of six different networks: 0.80, 0.85, 0.90, 0.95, 1.00, and 1.05. The FHWA micro simulator CORSIM was used test a theoretical network and two real-world networks: Salt Lake City Downtown Network and Fort Union Area Network. The results of the simulation indicated that SCOOT could provide additional benefits during incidents and the marginal benefits were quantified. [9]

2.5 EVALUATION OF CURRENT PRACTICE

There is no currently accepted method to identify the benefits for ASCT during the planning and design phase based upon a literature review of current practice and research. In Pennsylvania, the TE-153 (11-12) Pennsylvania Adaptive signal Control System Evaluation form, used by the Pennsylvania Department of Transportation, offers an evaluation of the systems engineering process for adaptive signal systems, but fails to quantify or predict the benefit or operating measures of installation of ASCT.

Much of the current research uses before/after studies to evaluate both performance and safety improvements associated with a particular ASCT system. The author drew upon the relevant literature and developed a recommended practice to measure the expected benefits of systems by using the HCM (Highway Capacity Manual) methodology and traffic simulation software. These are currently the most accepted methodologies to measure traffic signal system performance. Currently in the practice, performance measure of signal operation systems is measured Level of Services (LOSs), and corresponding delay, at intersections and signal system.

2.5.1 Level of Service

Level of Service (LOS) for intersections is a method that uses an A to F rating system to describe performance provided by individual or groups of traffic signals. The value of LOS is result of many factors including quality of progression, cycle length, green time and v/c ratio. Generally traffic engineers analyze LOS in hourly increments for each intersection because they set traffic timing plans according to one-hour traffic volume counts. If the predetermined traffic volumes vary during that one hour analysis period, LOS for a period of time within the one hour period may be significantly different and the possible changes in LOS may be difficult to measure using a one hour analysis period.

However, ASCT's benefits are derived by frequently changing cycle lengths, splits and phasing sequences based on traffic conditions in periods shorter than one hour. In order to predict the benefits of ASCT (improvements in LOS) in the simulation environment, the method measuring LOS does not apply to an ASCT system and must be modified to match with this attribute of ASCT to use the simulation software as an analysis tool. As changes in traffic volume may spur an adaptive traffic control system to adjust optimized timing plans many times within an hour, LOS for intersections should be measured at a shorter time intervals to report benefits.

The HCM recommends that 5-minute, 15-minute and 60-minute intervals be used for traffic data analysis and a 5-minute interval is the shortest time base for practical purpose. So the value of LOS can be calculated by the simulation software based on the collected data every 5 or 15 minutes. The expected benefits can then be reported with statistics when compared with the previous LOSs in hourly periods. [10]

2.5.2 Synchro

The Trafficware program Synchro is a powerful, friendly and widely-used traffic software application, which is designed to simulate traffic signal operations of networks on the basis of the HCM methodology. The application is very suitable for evaluating ASCT because it allows the user to change traffic volumes or signal timings and to simulate while playing without re-seeding the network. Also, the traffic volumes used for the simulation can be imported from an external data file, which documents the 15-minute traffic volumes in a possible network in the CSV (Comma Separated Variable) file format.

2.5.3 Performance Evaluation of Recommended Practice

It is recommended that an evaluation of ASCT should use the Highway Capacity Manual (HCM) methodology. HCM is the U.S. standard for capacity and level of service (LOS) analyses, published by the Transportation Research Board (TRB) of the National Academy of Engineering. Level of service shows service quality provided by a facility or service with a simple A-F system. In the HCM, level of service for intersections is defined in terms of total control delay per vehicle in a lane group, approach, intersection of a system of intersections. As control delay increases, LOS worsens. The control delay is determined (in order of importance) by quality of progression, cycle length, green time and v/c ratio. Control delay is a measure of driver discomfort, frustration, fuel consumption, and increased travel time. [10] Therefore, level of service can be used as a general measure parameter for evaluation of traffic control performance before and after deploying ASCT.

Simulation is a low-cost and time-saving methodology, and a calibrated simulation model can reflect field traffic conditions to a large degree. The Utah Department of Transportation has validated that simulation results of ASCT are accepted by comparing performance measures from simulation to those from a field evaluation. [11] The analyst can input the optimized timing plans created by a type of ASCT based on its volume counts to. By simulating ASCT systems in the model, control delays and their corresponding LOS grades per 15 minutes reported by Synchro can be collected and used to compare with the previous LOSs of test networks.

2.5.4 Safety Benefit

A safety study always focuses on the frequency and type of crashes occurred along the roads. The validity of safety benefits of ASCT systems can be supported by three reasons. At first it has been proved that ASCT can effectively reduce the number of stops. As a result, there may be fewer rear-end crashes which typically make up a high percentage of total crashes at intersections. And if drivers can go through a series of intersections with few stops, they would feel less frustrated and not likely drive with emotions because they do not need to wait for green lights and spend too much time on the roads. So the number of crashes related to aggressive driving will largely decrease. Also, the fewer red lights drivers face, the fewer crashes related to red-light running may occur.

However, it is difficult to evaluate crash reduction by using any existing traffic simulation software. Theoretically the ASCT systems can minimize the number of stops or offer the best quality of progression, which can reduce the risk of accidents to the most degree. But in practice the safety of an ATCS not only depends on the traffic progression provided by ASCT but also relates to extensive field data, like intersection design, sight distance, crash history and many other parameters. It would be expected that the analysis process is quite complicated for computer algorithm to simulate a network model with all parameters.

In the Highway Safety Manual, there is no statement about adaptive signal control technology as it is a very new technology. The Highway Safety Manual explains some measures can be taken to reduce crashes. One of those measures is providing actuated signal control. Its safety benefits have been identified and are similar to that of adaptive traffic control systems. However, their safety benefits of ASCT are not quantified at this time. [12]

2.5.5 Benefits/Costs Ratio

A benefit/cost study is important to the projection of ASCT results. The economic benefits of the systems should be evaluated in terms of fuel savings, crash reductions as well as emissions reduction and time savings. An analysis of the benefits would gather information on installation and maintenance cost for ASCTs and retiming and maintenance cost for TOD operations. A full benefit-cost evaluation should also consider increased delay and number of stops at minor-street approaches, which will contradict some of the benefits experienced on the mainline. In addition, it is noted that benefits of the adaptive signal systems are anticipated to increase after a period, because a great quantity of data will be stored over a long time to optimize signal timing plans. With the long-term benefits, the benefits/costs ratio of the system will also increase.

2.6 SUMMARY

It has been known through studies and practices conducted by FHWA, academic institutions, DOTs and traffic agencies in cities that the new traffic technology ASCT is a promising alternative to improve traffic signal operations. And an appropriate method to evaluate potential benefits of ASCT systems will greatly promote the further development and spread of ASCT. It is recommended that simulation program such as the Trafficware program Synchro should develop a method to replicate the operation of ASCTs which automatically create optimized signal timings based on collection traffic data. However because different ASCT systems use different algorithms for the optimization, this information from the ASCT developers would need be made available. Synchro can obtain the actual timing plans from an operating ASCT system every 15 minutes and calculate the LOSs at intersections in the simulation environment. Changes in LOS can then be recorded statistically into a contrastive analysis of traffic operating performance with and without the implementation of ASCT.

3.0 APPROACH FOR TESTING THE HYPOTHESIS

This chapter elaborates how to test the hypothesis, where the test locations are and how the ASCT systems are operating, what and how the data were collected and the reason why the data were needed.

3.1 PROPOSED METHOD

In order to test the hypothesis, the recommended practice mentioned previously was performed to evaluate level of services for each intersection in the simulation environment. A road network in four scenarios was simulated by the Trafficware program Synchro. In order to clarify the method, Figure 3-1 illustrates the four scenarios and their inputs and Table 3-1 defines the four scenarios.

In scenarios 1&2, traffic signals are controlled by the TOD timing plan coordination. The test network is under the adaptive signal control system in scenarios 3&4. There are no pedestrian actuations in scenarios 1&3. In each scenario, LOS and overall control delay for an intersection with and without implementation of ASCT was calculated by the traffic signal simulation software Synchro. All inputs are discussed in more detail in the data collection of this chapter. The comparisons of the control delays (LOSs) for each intersection in different scenarios are discussed in the next chapter.

Table 3-1. Definitions of the four scenarios in the simulation

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
operation	TOD coordinated timing plans without pedestrian actuations	TOD coordinated timing plans with pedestrian actuations	ASCT system without pedestrian actuations	ASCT system with pedestrian actuations

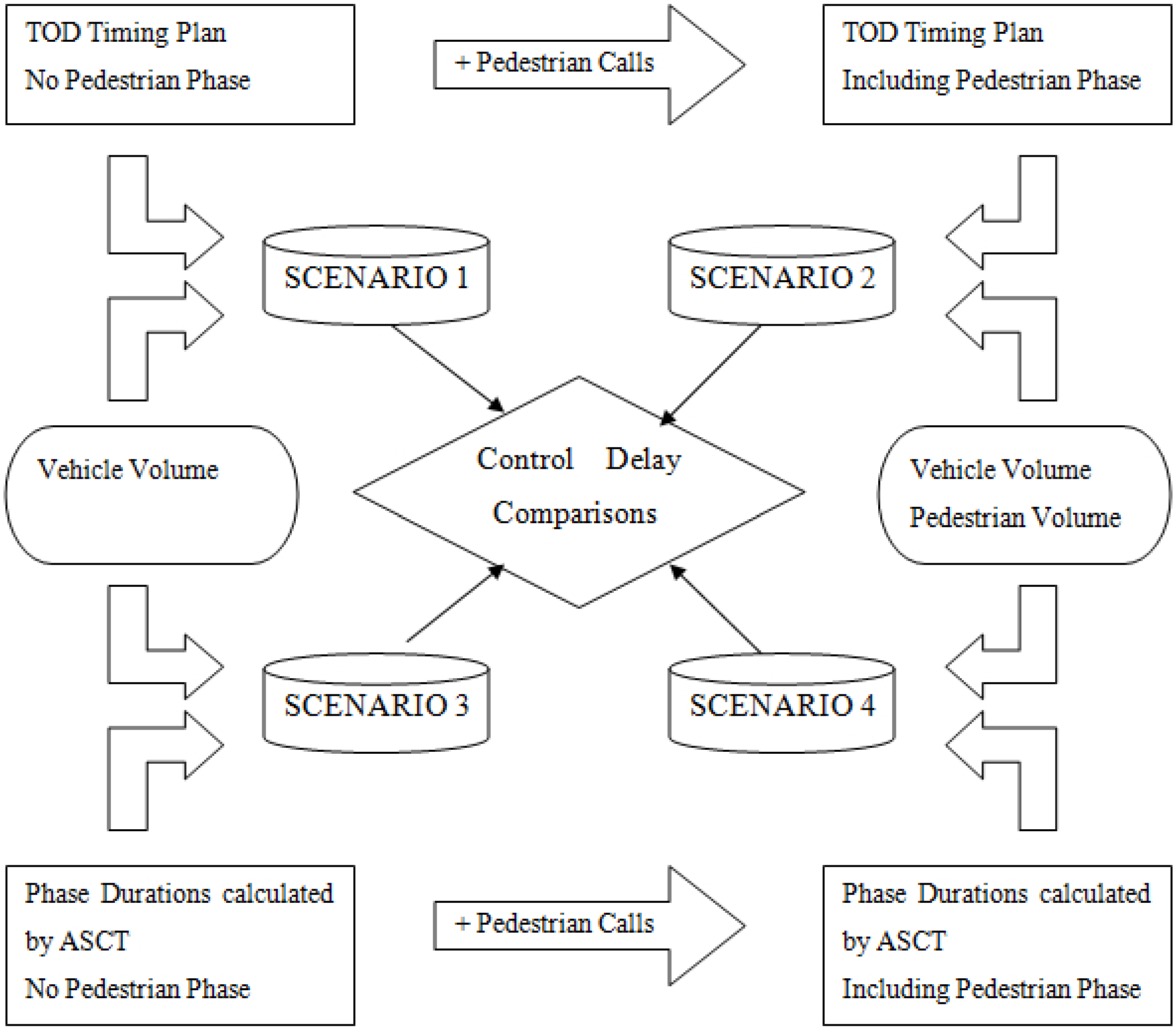

Figure 3-1. Four scenarios and inputs in simulation

3.2 SELECTION OF TEST LOCATIONS

Two sites that currently operating with ASCT systems were selected as the test locations. One site is a segment of State Route 19, Wexford, Pennsylvania where InSync adaptive traffic control is installed along the corridor. The other is the East Liberty section of Pittsburgh, a grid-like traffic network which is operated under SURTRAC (Scalable Urban Traffic Control) system in the area. The researcher originally expected to predict the impacts of pedestrian activities on these two very different types of network, by hypothesis on both sites.

3.2.1 State Route (SR) 19, Wexford

The transportation infrastructures along the segment of SR 19 are highly developed in favor of vehicles, but may be less friendly to pedestrians. Based on its land use context, there are some businesses, a large shopping plaza including many stores and hundreds of parking spaces. No bus stop or any public transportation is nearby. And no obvious destination or reason for pedestrian crossing behaviors can be identified. There are pedestrian push button devices and crosswalks at all the intersections currently operating with ASCT. The pilot corridor network is shown in Figure 3-2.

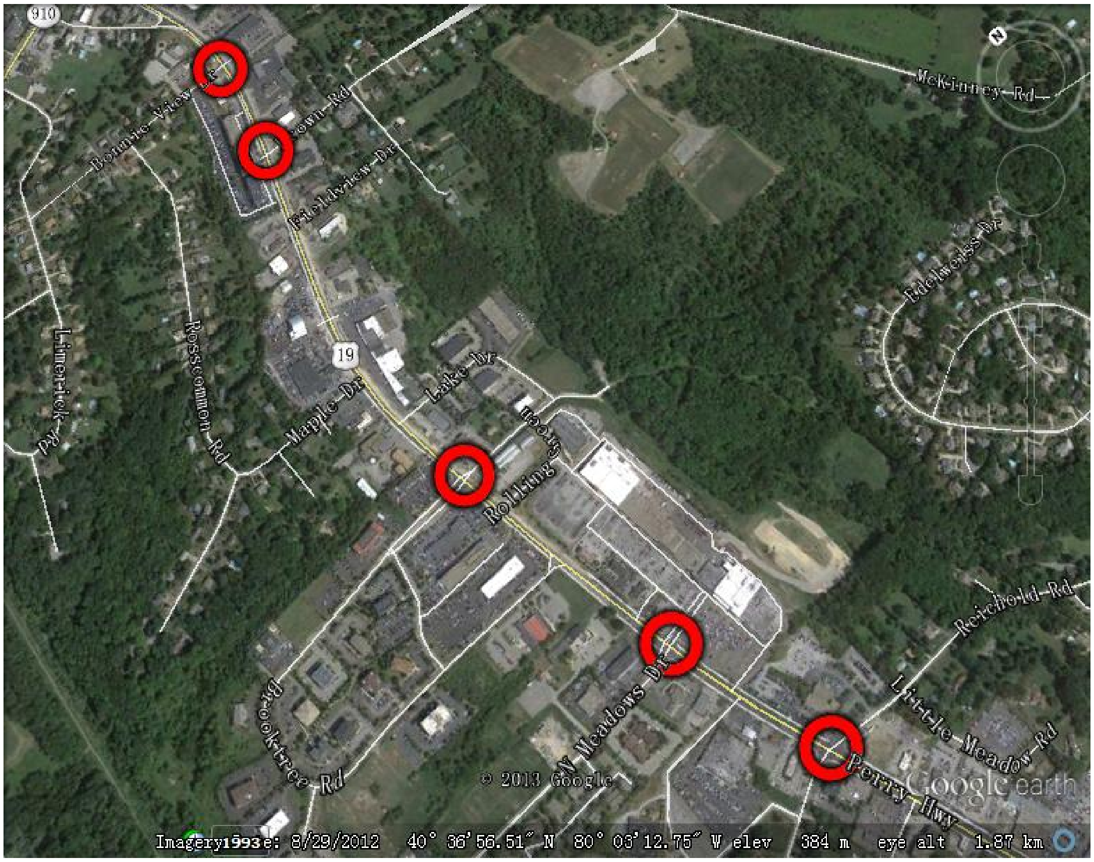

Figure 3-2. SR 19 in the North Hills, Wexford[1]

3.2.2 East Liberty, Pittsburgh

The second test location is a portion of East Liberty that experiences high average daily traffic volumes, because three major roads (Penn Avenue, Penn Circle and Highland Avenue) which cross each other there. A shopping center, supermarket, church, residential area land uses in the area generate a large number of pedestrian trips. Bus stops, garages and parking lots nearby are also looked as potential pedestrian traffic generators. It was expected that a high level of pedestrian activities existed in this test site. As shown in Figure 3-3, a nine-intersection system

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[1] Intersections in the red circle are signalized in the ASCT system.

was installed with ASCT. For all the intersections, no traffic signal operates in an exclusive pedestrian phase. Pedestrian push-button devices are utilized at all intersections except for the intersection of Penn Ave & N Highland Ave.

Figure 3-3. The Penn Avenue/Penn Circle system in East Liberty, Pittsburgh[2]

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[2] It is the same as note 1.

3.3 CURRENT OPERATING SYSTEM PARAMETERS

The following parameters are used in InSync and SURTRAC, the two current operating systems for each of the sites. This thesis gives a capsule description of how pedestrian actuations are factored into the development of traffic signal timing plans for each of the systems. The specific algorithms used to develop the operating systems timing plans are relevant to the scope of the study.

3.3.1 Pedestrian Calls

The InSync system filters pedestrian calls and permits every pedestrian phase at the period that is fit for real-time traffic flows. SURTRAC also offers service times for pedestrian calls after optimization. In the both systems, the critical time and location of each pedestrian actuation can be derived from their operating history databases.

3.3.2 Vehicle Volumes

InSync uses IP digital cameras to collect real-time vehicle movement counts. A group of digital cameras that connect to a local processor in the cabinet collects the data. The InSync processors determine the lengths of green phases and phase sequences through detector cards to serve all currently approaching vehicles and clear out queues.

In SURTRAC system, loops, video and radar systems are used as vehicle sensors. Each sensor collects traffic counts and occupancy time of vehicles and sends real-time data to the local scheduler (or the remote scheduler if the sensor serves for an advance detector of the downstream neighbor intersection).

3.3.3 Configuration Settings

InSync adjusts cycle length, spilt within the minimum/maximum initialization value. The first principle of the system is to guarantee coordinated green waves for the main road. Then, each InSync processor can serve to progress vehicles based on logic and features of the optimization algorithm.

In SURTRAC system, each intersection operates the signals according to its own intelligent scheduling. Based upon this, an intersection is required to communicate with direct neighbors and exchange schedule information. And neighboring intersections are globally coordinated by recalculating schedules.

3.4 DATA COLLECTION

3.4.1 Overview

This section sketches the processes of the data collections in the two test locations and lists a series of data that were obtained from several sources. More information on those data source is given in this chapter.

3.4.1.1 Corridor Network

According to the pedestrian data provided by Rhythm Engineering, which is responsible for the operation of InSync on the segment of SR 19, the frequency of pedestrian calls is very low in the suburban area. Table 3-2 shows the average total number of pedestrian calls on weekday for three major intersections. On average for each intersection, cycles involving pedestrian intervals occupied less than 5% of total number of cycles during peak hours. It was believed that the additional delay caused by such a small number of pedestrian actuations is too little to observe. Therefore the researchers did not perform simulations on this case. It was also assumed that this number of pedestrian actuations would have a minimal impact on overall delay at the intersections and would not yield meaningful results for the research.

Table 3-2. Weekday Average Number of Pedestrian Calls on SR 19

	Brooker Dr & SR 19	N Meadows Dr & SR 19	Richard Rd & SR 19
Weekday Average Number of Pedestrian Calls	8	18	28

3.4.1.2 Grid Network

The research focused on the nine-intersection grid-like network because of the anticipated significant volume of pedestrians and corresponding actuations.

Historical TOD timing plans including pedestrian phase actuations for the intersections in the system were obtained from Carnegie Mellon University (CMU) who designed and developed the ASCT system in the test location. Also historical one-week total vehicle volumes for each intersection from 6:00am to 8:00pm Monday through Saturday were needed to determine the peak weekday AM hour, Mid-day hour, PM hour and Saturday shopping peak hour are provided. Next, during the four peak one-hour periods of two selected days (a Wednesday and a Saturday), pedestrian call data, 15-minute interval vehicle volumes and timing plans with and without pedestrian actuations calculated and used by SURTRAC in real-time for all intersections were retrieved from the database of the ASCT system. Also, one-year historical data on number of pedestrian calls collected by CMU were obtained. In addition, a field data collection work was conducted during the four peak hours. For each intersection, the total number of pedestrians crossing each crosswalk (including pedestrians that crossed illegally) and the total number of conflicting pedestrians by 15 minutes period were recorded.

3.4.2 Establishment of Peak Hours

The researcher established traffic peak hours to test the hypothesis because the impact of pedestrian actuations was expected to be more significant during these peak hours. Based on vehicle volume counts from Monday to Friday, peak hours on a weekday were established for the grid: 8:00-9:00 (AM hour), 12:00-1:00 (Mid-day hour) and 4:00-5:00 (PM hour). Figures 3-4, 3-5, 3-6 show the average vehicle volumes at three major intersections in the system. From 6am vehicle volume increased along the time and reached the first peak at 8am. Later vehicle volume continued to go up and reached the second peak at noon. During 4:00 to 5:00pm, vehicle volume reached the peak level of the day and began to go down.

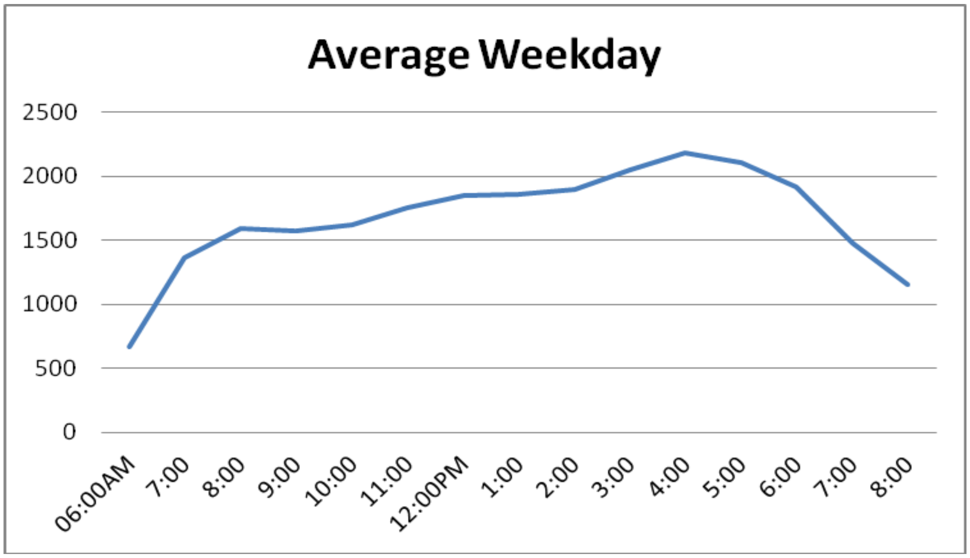

Figure 3-4. Vehicle volumes at Penn Ave- Penn Circle St Intersection on weekday

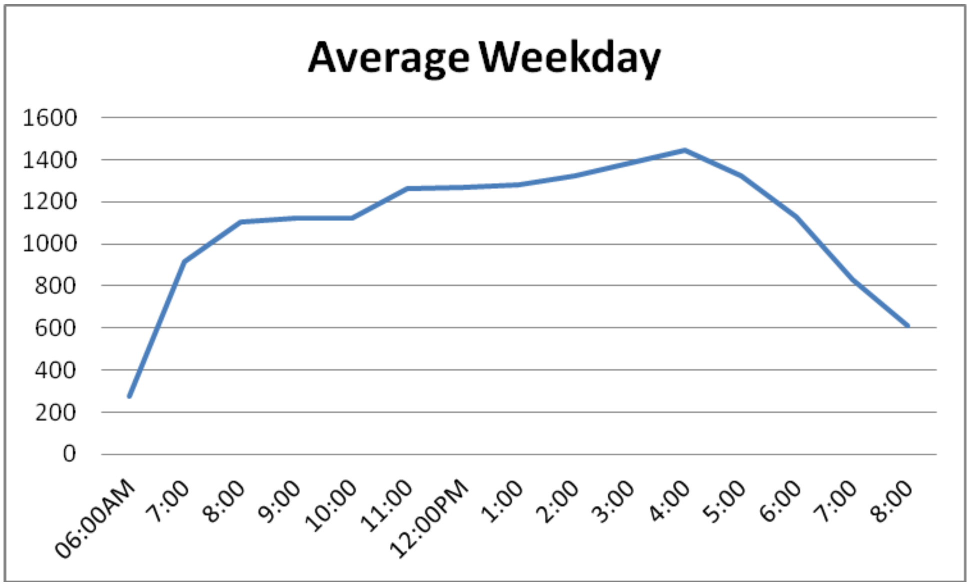

Figure 3-5. Vehicle volumes at Penn Circle St-Highland St Intersection on weekday

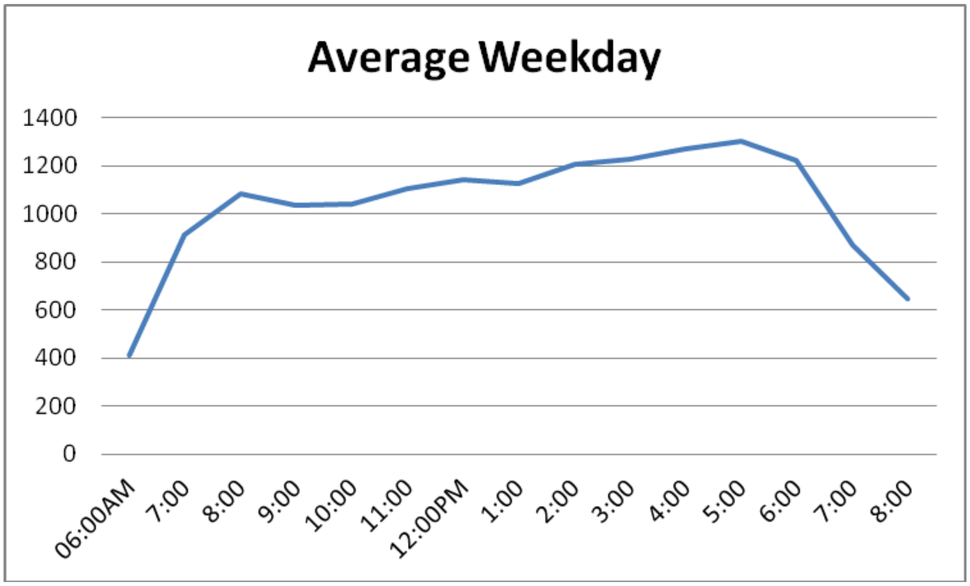

Figure 3-6. Vehicle volumes at Penn Ave-Highland St Intersection on weekday

By comparing vehicle volume counts on Saturday, 3:00-4:00pm was selected as the Saturday shopping peak hour.

3.4.3 Number of Pedestrian Calls

SURTRAC system collected and stored a great amount of pedestrian phase request data for all intersections except for Penn Ave & N Highland St, because there is no pedestrian push button device at this intersection. In order to look everything clearly, the author sorted the pedestrian actuation data provided for each intersection during the four peak hours. Table 3-3 shows pedestrian calls at the intersection of Broad St & Penn Cir E as example. The pedestrian actuation data includes start time and phase which were used in the simulation.

Table 3-3. Pedestrian Calls at Broad St& Penn Cir E

Broad St & Penn Cir E							
Wednesday						Saturday	
8:00-9:00		12:00-13:00		16:00-17:00		15:00-16:00	
Start time	**Phase**	**Start time**	**Phase**	**Start time**	**Phase**	**Start time**	**Phase**
8:09:56	2	12:01:30	8	16:05:12	2	15:11:45	2
8:25:46	2	12:10:32	8	16:08:21	2	15:12:46	8
8:27:49	8	12:24:39	8	16:11:28	8	15:18:00	8
8:33:21	2	12:44:42	2	16:17:12	2	15:22:23	2
8:34:52	2			16:21:56	2	15:24:10	8
8:53:46	2			16:22:37	8	15:52:30	8
8:59:44	8			16:24:42	8	15:53:58	8
				16:25:11	2	15:57:55	2
				16:26:47	2		
				16:27:24	8		
				16:36:34	8		
				16:40:54	2		
				16:42:02	2		
				16:42:21	8		
				16:47:25	8		
				16:49:17	8		
				16:49:44	2		
				16:58:57	8		

The pedestrian data was collected in February. In a cold climate such as Pittsburgh Pennsylvania, there may not be many pedestrians present as compared to an average condition. Because the data was collected in February, the researcher normalized the number of pedestrian calls and took into account the normal data in simulation and analysis. Based on one-year of data on the number of pedestrian calls at Penn Ave & Penn Cir S, the major intersection in the system, the researcher developed adjustment factors by month and the day of the week for pedestrian data in the grid network. Table 3-4 presents the average daily number of pedestrian calls at Penn Ave & Penn Cir S intersection by month and the day of the week. Typically number of pedestrian calls in June, July or August is much more than that in winter months. Table 3-5 presents a group of factors which can be applied to the analysis of pedestrian activities in the ASCT system. This is similar to traffic volume adjustment factor developed for vehicle volumes.

Base upon the month and day of week that the pedestrian data is collected the factor can be applied to determine an average condition.

Table 3-4. Average Daily Number of Pedestrian Calls at Penn Ave & Penn Cir S

13-14	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
January	371	343	358	415	435	388
February	502	510	438	504	515	469
March	446	495	482	480	530	482
April	527	544	515	543	555	494
May	473	540	544	501	560	500
June	569	538	562	543	587	518
July	577	530	557	547	545	480
August	581	506	572	594	595	552
September	422	456	547	541	501	508
October	486	495	458	475	528	449
November	452	425	465	443	467	427
December	421	396	243	396	451	380

Table 3-5. Average Day of Week by Month Factors Compiled for Total Pedestrians[3]

13-14	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
January	0.7521	0.6953	0.7257	0.8413	0.8818	0.8245
February	1.0177	1.0339	0.8879	1.0217	1.0440	0.9966
March	0.9041	1.0035	0.9771	0.9731	1.0744	1.0243
April	1.0684	1.1028	1.0440	1.1008	1.1251	1.0498
May	0.9589	1.0947	1.1028	1.0156	1.1353	1.0625
June	1.1535	1.0907	1.1393	1.1008	1.1900	1.1008
July	1.1697	1.0744	1.1292	1.1089	1.1048	1.0200
August	1.1778	1.0258	1.1596	1.2042	1.2062	1.1730
September	0.8555	0.9244	1.1089	1.0967	1.0156	1.0795
October	0.9852	1.0035	0.9285	0.9629	1.0704	0.9541
November	0.9163	0.8616	0.9427	0.8981	0.9467	0.9074
December	0.8535	0.8028	0.4926	0.8028	0.9143	0.8075

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[3] The researchers collected pedestrian data on a Wednesday and a Saturday in February. The highlighted factors were used to adjust the number of pedestrian calls.

3.4.4 Vehicle Volumes

Vehicle volumes were collected from detectors in the system. The researcher summarized all the vehicle volumes during the four peak hours in a reporting format that was easy for the simulation software to use and read. It was determined that it is unnecessary to normalize the collected vehicle volumes because the thesis primarily studies the relative impact of pedestrian activity on traffic control operations. Therefore any variation in traffic volumes should yield similar results in the difference between the two operations. Table 3-6 displays the 15-minute vehicle volumes at the major intersection of Penn Ave-Penn Cir S during the four hours as example. The input details vehicle movement counts of approaches at each intersection that can be directly used in the simulation software.

Table 3-6. 15-min Vehicle Volumes at Penn Ave & Penn Cir S

	Penn &Penn Cir	Eastbound		Westbound			Southbound		Northbound	
	Time Period	L	T	L	T	R	L	T	T	R
Wednesday	8:00-8:15	7	52	31	60	59	16	57	30	42
	8:15-8:30	14	51	18	59	67	13	63	44	46
	8:30-8:45	9	67	17	62	42	17	38	38	48
	8:45-9:00	15	64	20	71	49	12	54	38	52
	12:00-12:15	15	72	35	78	64	18	49	50	85
	12:15-12:30	15	81	42	84	46	24	51	51	67
	12:30-12:45	14	82	28	66	38	21	49	69	75
	12:45-1:00	17	73	32	78	54	24	43	71	78
	4:00-4:15	20	78	31	93	73	15	51	63	61
	4:15-4:30	10	87	35	71	74	25	48	78	54
	4:30-4:45	23	75	34	65	73	17	44	55	67
	4:45-5:00	19	92	41	86	44	26	47	77	78
Saturday	3:00-3:15	11	51	35	90	85	28	61	59	71
	3:15-3:30	14	64	36	68	45	22	42	36	78
	3:30-3:45	16	61	30	88	54	20	45	45	36
	3:45-4:00	29	61	38	86	77	12	46	37	25

3.4.5 Timing Plans

Two sets of timing plans were needed to simulate the traffic operations for the research.

3.4.5.1 Previous Time-of-Day Timing Plans

Traffic signal plans for the nine intersections provide their cycle lengths, splits and phase sequences at the periods of the day, which can be used for the phase settings in Synchro. This information was provided by Carnegie Mellon University and represents what operations were occurring prior to installation of the ASCT.

3.4.5.2 Phase Durations Calculated by ASCT

For purposes of this research, the ASCT system computed and saved timing plans for the four peak hours based on the real-time traffic flows. This information was requested for the same days and times that pedestrian volume information was collected in the field by the researchers. The data included each phase with its start time and duration from the database of SURTRAC system.

3.4.6 Pedestrian Volume

The field data collection work was conducted on February 12th and 15th 2014, a Wednesday and a Saturday. The purpose of this data collection was to count the number of conflicting pedestrians and the total number of pedestrians crossing each crosswalk (including pedestrians that cross illegally) at each intersection, for the four time periods studies, for the preparation of the simulation software inputs. This is critical for the calculation of delay in the simulation software, because the volumes of pedestrians affect the right turn pedestrian/bike factor and the saturated flow rate for the lane settings. For permitted right turns, conflicting pedestrians are the number of pedestrians that right turning traffic must yield to; for permitted left turns, the total number of pedestrians crossing the link was inputted as conflicting pedestrians. In order to collect data more efficiently, the researchers did full hour counts only at the intersection of Penn Avenue & Penn Circle South and did 15-minute sample counts for the other eight intersections. The value of conflicting pedestrians for the eight intersections at other times within the four peak hours was determined in accordance with ratios of 15-minute counts collected at Penn Ave-Penn Cir S intersection.

3.5 SIMULATION

The researcher performed the analysis using the Trafficware program Synchro software which performed all the simulations. The simulation model was carefully developed. The link distances were set based on the data given by Google Map. At the nine nodes the turn types and lanes are the same as the real conditions. Whether the right turn is allowed on red was also defined for each approach of nodes. All the work has been done to make up a realistic traffic control condition in the simulation software. Figure 3-7 shows the map of simulation model for the grid road network.

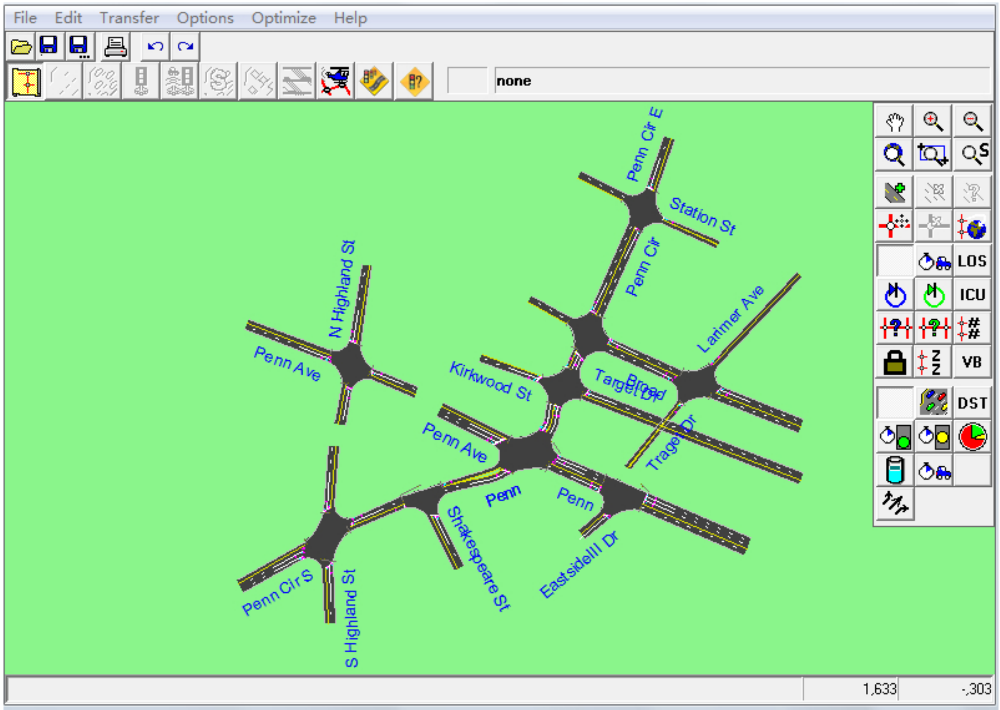

Figure 3-7. The simulation model built in Synchro

The same collected vehicle volumes were used for all of the scenarios with and without pedestrian actuations. Because most vehicles will not change their routes due to pedestrian actuations and most vehicles can run through each segment in fifteen minutes a 15-minute analysis period was used. Pedestrian volumes and the number of pedestrian calls were assumed to be constant in the four scenarios. Although they may vary under different signal operations, the level of pedestrian activity was almost constant on a macro basis.

For each intersection in the two scenarios with TOD timing coordination, timings and phases exactly followed its traffic signal plan in the simulation. LOSs per hour for each intersection, with and without conflicting pedestrians and pedestrian calls, was directly calculated in Synchro.

For each intersection operating with the ASCT system, in the simulation environment, cycle length and green time in a fifteen-minute period used in the software was the average of phase durations during the 15 minute time period to provide more accurate results. For some intersections, the sequence of certain phases was optimized by Synchro. Cycle length and green time for cycles involving pedestrian actuations were also averaged for phase durations of these cycles. This method of averaging timings and phase sequences during the 15-minute period was used so that improvements of ASCT system performances could be clearly measured. It is recognized that with the ASCT operation timings are changed more frequently than every 15 minutes however because this is a limitation of the software this averaging was required, so the same method could be used to calculate LOSs in the ASCT system with pedestrian activities.

3.6 SUMMARY

The proposed method to evaluate performance of ASCT systems was applied to testing the hypothesis of the thesis. The impact of pedestrian activity on ASCT systems can be assessed by measuring LOSs of traffic operations under four scenarios in the simulation software. In order to implement the method, the following tasks were undertaken:

1. A network in East Liberty, Pittsburgh was selected as the test location because there are adequate pedestrian activities for study.
2. SURTRAC, the current ASCT system in the test site, accommodates pedestrian actuations and is compatible with the Trafficware program Synchro.
3. The related field data were collected and filtered to ensure that the simulation can accurately reflect the traffic signal operations and traffic conditions in real-time.
4. The grid network model was established in Synchro and the simulation was conducted by using all the collected data.

4.0 TEST RESULTS

In this chapter the researcher tested the hypothesis by comparing and analyzing the simulation results in different scenarios. The researcher also made conclusions and potential recommended guidelines based on the analysis result.

4.1 CATEGORIZATION

In order to pertinently analyze the different results, the researcher categorized the nine intersections in the road network based on levels of pedestrian activity.

4.1.1 Level of Pedestrian Activity Variations

At the intersection of Penn Ave & N Highland St, there is no pedestrian push button device. So the researchers took out the intersection of the result analysis. All other intersections have pedestrian actuation devices. In order to use intersections for the analysis that have significant amount of pedestrian actuations a standard was established to define high activity pedestrian conditions.

To determine the variation in pedestrian activity and establish the standard the percentage θ was calculated, as shown in Table 4-1. The formula is

$$\theta = \alpha / \beta \cdot 100\%$$

Where α is the number of cycles involving pedestrian intervals during a one-hour study period, β is the total number of cycles at an intersection during the same time.

Table 4-1. Percentages of cycles involving pedestrian intervals at all the intersections

Intersection	AM PEAK	MID-DAY	PM PEAK	SHOPPING PEAK
Broad & Penn Cir	11.1%	5.9%	29.4%	10.0%
Penn & Eastside III	50.0%	93.8%	75.0%	83.3%
Kirkwood & Penn Cir	34.5%	19.4%	33.3%	11.9%
Broad & Larimer	2.7%	6.7%	2.0%	0.0%
Penn & Penn Cir	73.3%	56.7%	75.0%	76.7%
Penn Cir & Highland	42.9%	40.0%	50.0%	83.3%
Penn Cir & Shakespeare	0.0%	5.6%	0.0%	14.3%
Station & Penn Cir	3.2%	0.0%	25.0%	4.0%

It can be seen in Table 4-1, the percentages at two intersections of Penn & Eastside III and Penn & Penn Cir are quiet high. For intersections of Broad & Larimer and Penn Cir & Shakespeare, the percentages are very low. The researcher defined a levels of pedestrian activity to rate the intersections: if the percentage $\theta < 33\%$, the level of pedestrian activity is defined as low; 33% to 66%, the level of pedestrian activity is medium and $\theta > 66\%$, the level of pedestrian activity is high.

4.1.2 Grouping of Intersections Types

According to the standard developed for the research, the researcher also categorized the nine intersections into three groups: central intersections, secondary intersections and pedestrian unfrequented intersections. The purpose of developing this grouping system was to provide an analysis of different types of intersections relative to their pedestrian activity.

The researcher defined the intersection of Penn Avenue and Penn Circle as the central intersection because there are a very high vehicle volume and a high level of pedestrian activities at this intersection. And the researcher further defined that the intersections of Penn Ave & Eastside III Dr, Penn Cir E & Highland St and Kirkwood St & Penn Cir S are the secondary intersections and all the four other intersections as the pedestrian unfrequented intersections. Table 4-2 presents the categorization of the nine intersections in the road network. For each group of intersection(s), the researcher compared and contrasted the LOSs in four different scenarios.

Table 4-2. The categorization of the eight intersections on the network

Central intersection	Level of pedestrian activity
Penn & Penn Cir	High
Secondary intersection	**Level of pedestrian activity**
Penn & Eastside III	High
Penn Cir & Highland	High
Kirkwood & Penn Cir	Medium
Pedestrian unfrequented intersection	**Level of pedestrian activity**
Broad & Penn Cir	Low
Broad & Larimer	Low
Penn Cir & Shakespeare	Low
Station & Penn cir	Low

4.2 ANALYSIS RESULTS COMPARISON

The analysis results reported the impact of the pedestrian activity for the individual intersections, groups of intersections and the complete system. The criteria used for the comparison was overall control delays of the road network in the four scenarios of the system timings.

4.2.1 Central Intersection

Penn Ave & Penn Cir S, the center of the grid road network, is an east-west intersection. It is a skewed-angled intersection with multiple lanes in each of four directions. And it has multiple phases including protected left-turn and right-turn phases. Figure 4-1 shows the TOD timing plan for this intersection. It can be seen that the multiple signal timing phases are complicated at this intersection.

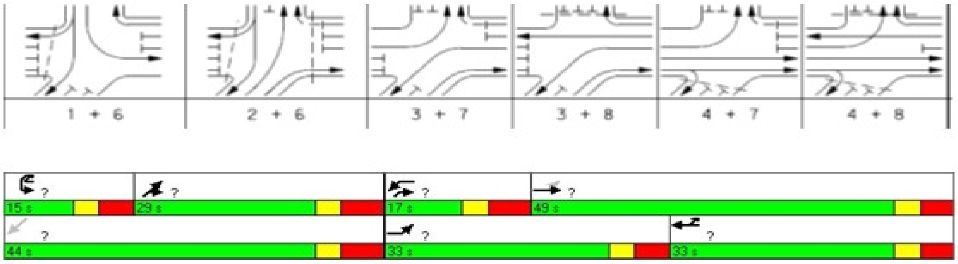

Figure 4-1. Timing phases for the intersection of Penn & Penn Cir

During the AM peak hour, traffic flows mainly come from the north and southwest directions, and meet at the Penn Ave & Penn Cir S intersection, and then flow towards Downtown Pittsburgh and North Oakland. Between twelve and one o’clock in the afternoon, vehicle volume at this intersection was more than the preceding study period. And traffic flows from east and wet were moving towards balance during the time. At PM peak hour, a majority of vehicles went past the central intersection from Downtown and vehicle volume quickly researched peak level of a day. To show differences between simulation results at this intersection, overall control delays of the intersection in four scenarios during the four peak hours is provided in Table 4-3.

Table 4-3. The comparison of simulation results for Penn & Penn Cir

AM Peak Hour 8:00-9:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	38.4	42.5	26.4	29.3
Level of Service	D	D	C	C
Mid-day Hour 12:00-1:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	34.4	38.8	35.8	38.3
Level of Service	C	D	D	D
PM Peak Hour 4:00-5:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	48	49.1	42.5	44.6
Level of Service	D	D	D	D
Saturday Shopping Peak Hour 3:00-4:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	46.3	48.9	38.6	40.7
Level of Service	D	D	D	D

Let S_1 = the control delay in the scenario of TOD W/O Ped.; S_2 = the control delay in the scenario of TOD W/ Ped.; S_3 = the control delay in the scenario of ASCT W/O Ped.; S_4 = the control delay in the scenario of ASCT W/ Ped.. These definitions apply in the research.

AM Peak: $(S_2 - S_1)/S_1 = (42.5 - 38.4)/38.4 = 0.107$

$(S_1 - S_3)/S_1 = (38.4 - 26.4)/38.4 = 0.313$

$(S_4 - S_3)/S_3 = (29.3 - 26.4)/26.4 = 0.110$

Mid-day: $(S_2 - S_1)/S_1 = (38.8 - 34.4)/34.4 = 0.128$

$(S_1 - S_3)/S_1 = (34.4 - 35.8)/34.4 = -0.041$

$(S_4 - S_3)/S_3 = (38.3 - 35.8)/35.8 = 0.070$

PM Peak: $(S_2 - S_1)/S_1 = (49.1 - 48)/48 = 0.023$

$(S_1 - S_3)/S_1 = (48 - 42.5)/48 = 0.115$

$(S_4 - S_3)/S_3 = (44.6 - 42.5)/42.5 = 0.049$

Shopping Peak: $(S_2 - S_1)/S_1 = (48.9 - 46.3)/46.3 = 0.056$

$(S_1 - S_3)/S_1 = (46.3 - 38.6)/46.3 = 0.166$

$(S_4 - S_3)/S_3 = (40.7 - 38.6)/38.6 = 0.054$

As shown in calculations above, pedestrian actuations increased the control delays by 10.7 percent under the TOD timing plans coordination and by 11 percent under the ASCT system at AM traffic peak hour when comparing operations with and without pedestrian actuations. The ASCT system reduced the control delay by 31.3% when compared to the control delay in scenarios without pedestrian actuations during the hour.

From 12 to 1pm, the ASCT system did not effectively improve the traffic signal operation under the TOD timing plans. Meantime, the control delay increased by 12.8% under the TOD timing plans coordination and increased by 7.0% under the ASCT control due to the impact of pedestrian activities.

During the PM peak hour, pedestrian actuations slightly increased the control delay by 2.3% under the TOD timing plans. In the ASCT system the control delay decreased by 11.5 percent when compared to the TOD timing plans, and then increased by 4.9 percent because of pedestrian actuations.

During Saturday shopping peak hour, 16.6 percentage of the control delay was reduced by ASCT when compared to the TOD timing plans. Under the two traffic signal operations, the TOD plan and ASCT, the impact of pedestrian activities respectively increased 5.6 percent and 5.4 percent the control delay.

4.2.2 Secondary Intersections

The intersections of Penn Ave & Eastside III Dr, Penn Cir E & Highland St and Kirkwood St & Penn Cir S are the secondary intersections of the road network. There are high vehicle volumes at the Penn-Eastside III and Penn Cir-Highland intersections. The vehicle volume at the Kirkwood-Penn Cir intersection is less than those at the two other intersections. To visually reflect delay characters of these intersections, in Tables 4-4, 4-5 and 4-7 simulation results for the three secondary intersections are presented.

Table 4-4. The comparison of simulation results for Penn & Eastside III

AM Peak Hour 8:00-9:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	9.5	9.5	1.3	3.6
Level of Service	A	A	A	A
Mid-day Hour 12:00-1:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	5.4	5.4	3.2	5.3
Level of Service	A	A	A	A
PM Peak Hour 4:00-5:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	7	7.5	1.4	5.4
Level of Service	A	A	A	A
Saturday Shopping Peak Hour 3:00-4:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	6.4	7	1.9	4
Level of Service	A	A	A	A

The Penn-Eastside III intersection is a ‘T’ intersection adjacent to the intersection of Penn & Penn Cir. Because of a construction project, the southbound approach of the intersection was closed. East-west traffic volume was huge and transient north-south phases completely served only pedestrians. All north-south phases were actuated by pedestrian calls under the ASCT system, as a result that the impact of pedestrian activities may be expanded in this situation. The research did not use the data because it is abnormal.

Table 4-5. The comparison of simulation results for Penn Cir & Highland

AM Peak Hour 8:00-9:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	16.7	16.7	12.5	14.6
Level of Service	B	B	B	B
Mid-day Hour 12:00-1:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	17.8	17.8	13.3	15
Level of Service	B	B	B	B
PM Peak Hour 4:00-5:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	22	22.2	15.7	16.8
Level of Service	C	C	B	B
Saturday Shopping Peak Hour 3:00-4:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	21.4	21.6	16.3	17.3
Level of Service	C	C	B	B

Penn Cir & Highland is a major intersection in this road network. Pedestrian intervals were automatically actuated in the east-west direction at every cycle. Pedestrians use the push buttons when they want to cross Penn Circle East at Highland Street. Table 4-6 shows analysis calculation results for this intersection

Table 4-6. The analysis calculation results for Penn Cir & Highland

Period	$(S_2 - S_1)/S_1$	$(S_1 - S_3)/S_1$	$(S_4 - S_3)/S_3$
AM Peak	0	0.251	0.168
Mid-day	0	0.253	0.128
PM Peak	0.009	0.286	0.070
Shopping Peak	0.009	0.238	0.061

As shown in Table 4-6, there was little difference between the control delays under the TOD timing plans coordination with and without pedestrian actuations. The ASCT system improved the control delays in range from 23.8% to 28.6% in scenarios without pedestrian activities when compared to those under the TOD timing plans coordination. Under the ASCT control pedestrian actuations increased delays by 16.8%, 12.8%, 7.0% and 6.1% respectively during the four peak hours.

Table 4-7. The comparison of simulation results for Kirkwood & Penn Cir

AM Peak Hour 8:00-9:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	8.8	9.2	9.1	9.9
Level of Service	A	A	A	A
Mid-day Hour 12:00-1:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	13	14.5	12.3	12.8
Level of Service	B	B	B	B
PM Peak Hour 4:00-5:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	22.4	23.4	20.3	21.1
Level of Service	C	C	C	C
Saturday Shopping Peak Hour 3:00-4:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	19.3	20	13	13.1
Level of Service	B	C	B	B

Kirkwood & Penn Cir intersection is very close to Penn & Penn Cir. The north-south intersection is an end of the Kirkwood St, which is a one-way street. The westbound approach of the intersection was the entrance/exit of a parking lot.

Table 4-8. The analysis calculation results for Kirkwood & Penn Cir

Period	$(S_2 - S_1)/S_1$	$(S_1 - S_3)/S_1$	$(S_4 - S_3)/S_3$
AM Peak	0.045	0.034	0.088
Mid-day	0.115	0.054	0.041
PM Peak	0.045	0.094	0.039
Shopping Peak	0.036	0.326	0.008

The ASCT improved the control delay less than 10 percent during peak hours on weekday and 32.6 percent on Saturday shopping peak hour when compared to TOD plans without pedestrian actuations. The impacts of pedestrian activities cause a few additional control delays for cases for both the TOD and ASCT plans.

4.2.3 Pedestrian Unfrequented Intersections

At these intersections pedestrians were only present at several cycles each hour. For some periods no pedestrian phase was called at certain intersections, therefore the negative effect on their LOSs was negligible because there were often few conflicting pedestrians as well at the same time. Table 4-9, 4-10, 4-11 and 4-12 are the comparisons of simulation results for these four pedestrian unfrequented intersections. Table 4-13 provides their analysis calculation results.

Table 4-9. The comparison of simulation results for Broad & Penn Cir

AM Peak Hour 8:00-9:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	17.6	17.6	10.4	11.2
Level of Service	B	B	B	B
Mid-day Hour 12:00-1:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	15.1	15.3	12.8	13.2
Level of Service	B	B	B	B
PM Peak Hour 4:00-5:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	21.5	21.5	19.6	22.1
Level of Service	C	C	B	C
Saturday Shopping Peak Hour 3:00-4:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	21.2	21.2	12	12.4
Level of Service	C	C	B	B

Table 4-10. The comparison of simulation results for Broad & Larimer

AM Peak Hour 8:00-9:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	10.2	10.2	7.2	7.3
Level of Service	B	B	A	A
Mid-day Hour 12:00-1:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	12	12.8	7.4	7.7
Level of Service	B	B	A	A
PM Peak Hour 4:00-5:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	17	17.6	10.3	10.3
Level of Service	B	B	B	B
Saturday Shopping Peak Hour 3:00-4:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	16.8	17.5	10.1	No actuation
Level of Service	B	B	B	

Table 4-11. The comparison of simulation results for Penn Cir & Shakespeare

AM Peak Hour 8:00-9:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	4	4.3	9.1	No actuation
Level of Service	A	A	A	
Mid-day Hour 12:00-1:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	13	13	7.8	8.2
Level of Service	A	A	A	A
PM Peak Hour 4:00-5:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	3.6	4.5	12.5	No actuation
Level of Service	A	A	B	
Saturday Shopping Peak Hour 3:00-4:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	3.3	4	13	13
Level of Service	A	A	B	B

Table 4-12. The comparison of simulation results for Station & Penn Cir

AM Peak Hour 8:00-9:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	6	6	3.3	3.4
Level of Service	A	A	A	A
Mid-day Hour 12:00-1:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	2.5	2.8	2.6	No actuation
Level of Service	A	A	A	
PM Peak Hour 4:00-5:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	3.1	4.9	3.3	3.9
Level of Service	A	A	A	A
Saturday Shopping Peak Hour 3:00-4:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	2.6	3.7	3.9	3.9
Level of Service	A	A	A	A

Table 4-13. The analysis calculation results for Kirkwood & Penn Cir

Period	Intersection	$(S_2 - S_1)/S_1$	$(S_1 - S_3)/S_1$	$(S_4 - S_3)/S_3$
AM Peak	Broad & Penn Cir	0	0.409	0.077
	Broad & Larimer	0	0.294	0.014
	Penn Cir & Shakespeare	0.075	-1.275	
	Station & Penn Cir	0	0.450	0.030
Mid-day	Broad & Penn Cir	0.013	0.152	0.031
	Broad & Larimer	0.067	0.383	0.041
	Penn Cir & Shakespeare	0	0.400	0.051
	Station & Penn Cir	0.120	-0.040	
PM Peak	Broad & Penn Cir	0	0.088	0.128
	Broad & Larimer	0.035	0.394	0
	Penn Cir & Shakespeare	0.250	-2.472	
	Station & Penn Cir	0.580	-0.065	0.182
Shopping Peak	Broad & Penn Cir	0	0.434	0.033
	Broad & Larimer	0.042	0.399	
	Penn Cir & Shakespeare	0.212	-2.939	0
	Station & Penn Cir	0.423	-0.500	0

There was almost little difference in the control delay between the ASCT system with and without pedestrian activities. Pedestrian actuations only produced larger than 10 percent additional control delays for Broad & Penn Cir and Station & Penn Cir intersections during the PM peak hour. For the TOD plans, pedestrian actuations only significantly affect the delay at Penn Cir & Shakespeare and Station & Penn Cir intersections during PM peak hour and shopping peak hour, ranged from 21.2% to 58%. At other times, the impact of pedestrian activities on conventional TOD timing coordination was also very low.

4.2.4 The Complete Coordinated Network

Penn & Highland was not included in the coordinated network analysis, because there is no pedestrian push button device at the intersection and it is an isolated intersection with individual cycle length both under the TOD timing operation and the ASCT system.

A review of the results showed a common result for traffic signal operations of the road network, that is the overall control delay generally was increased by the impact of pedestrian activities under the TOD coordinated timing plans. For ASCT plans, the control delay was successfully reduced by the ASCT system, when compared to the TOD plan without pedestrian actuation, and increased by pedestrian actuations during the four selected hours. Table 4-14 shows the simulation results for the complete coordinated network which also followed the common regulation.

Table 4-14. The comparison of simulation results for the complete network

AM Peak Hour 8:00-9:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	111.2	116	79.3	88.4
Mid-day Hour 12:00-1:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	113.2	120.4	95.2	103.1
PM Peak Hour 4:00-5:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	144.6	150.7	125.6	136.7
Saturday Shopping Peak Hour 3:00-4:00				
Scenario	TOD W/O Ped.	TOD W/ Ped.	ASCT W/O Ped.	ASCT W/ Ped.
Control Delay (s)	137.3	143.9	108.8	114.5

4.3 TEST RESULTS ANALYSIS AND CONCLUSIONS

This report section provides an analysis of the test results and compares these results to the hypothesis of the thesis. The following section provides the analysis for the complete network and individual intersections.

4.3.1 Analysis on a Network-wide Basis

According to the comparisons of simulation results, it is noted that ASCT improves the overall operation in the system 28.7%, 15.9%, 13.1% and 20.8% respectively during the four traffic peak hours when compared to the operations for TOD plans without pedestrian actuation. But pedestrian activities counteract some of the positive change and increase the control delay in most cases. In Figure 4-2, the use of pedestrian push button increases the control delay of the complete road network and the increased control delays are not negligible, which are 11.5%, 8.3%, 8.8% and 5.2% respectively, which shows a rate of increase during all the traffic peak hours. It can be concluded that pedestrian activities can increase the control delay and offset some of the anticipated benefits on delay brought by ASCT in this case study.

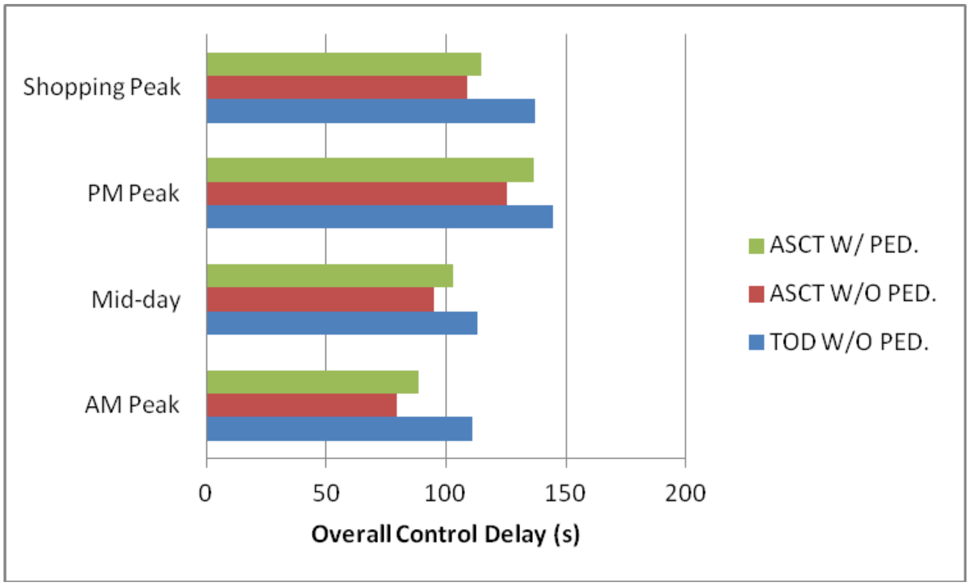

Figure 4-2. Overall control delays of network in different scenarios during the four peak hours

As shown in Figure 4-3, control delays increased by pedestrian actuations for ASCT plans are more than those for TOD plans during the traffic peak hours on weekday. But pedestrian activities increased more control delay under the TOD timing plans than in the ASCT system at Saturday shopping peak hour.

The defined the percentage of control delays increased by pedestrian activities for TOD plan is $\frac{S_2 - S_1}{S_1}$, for ASCT plan is $\frac{S_4 - S_3}{S_3}$. Figure 4-4 illustrates that the impact of pedestrian activities on the ASCT system is more significant. During the four peak hours percentages of control delays increased by pedestrian activities under the ASCT system were higher when compared to their scenarios without pedestrian activities. Both of the two factors are considered, it seems that on the traffic operation under the control of TOD timing coordination, the influence of pedestrian actuations is less than on the ASCT system. It may be explained that optimized green time for the side street were often below pedestrian minimum intervals during the peak hours in the ASCT system. While in the TOD timing plans of the road network, green time was usually more than the required pedestrian intervals in the test case.

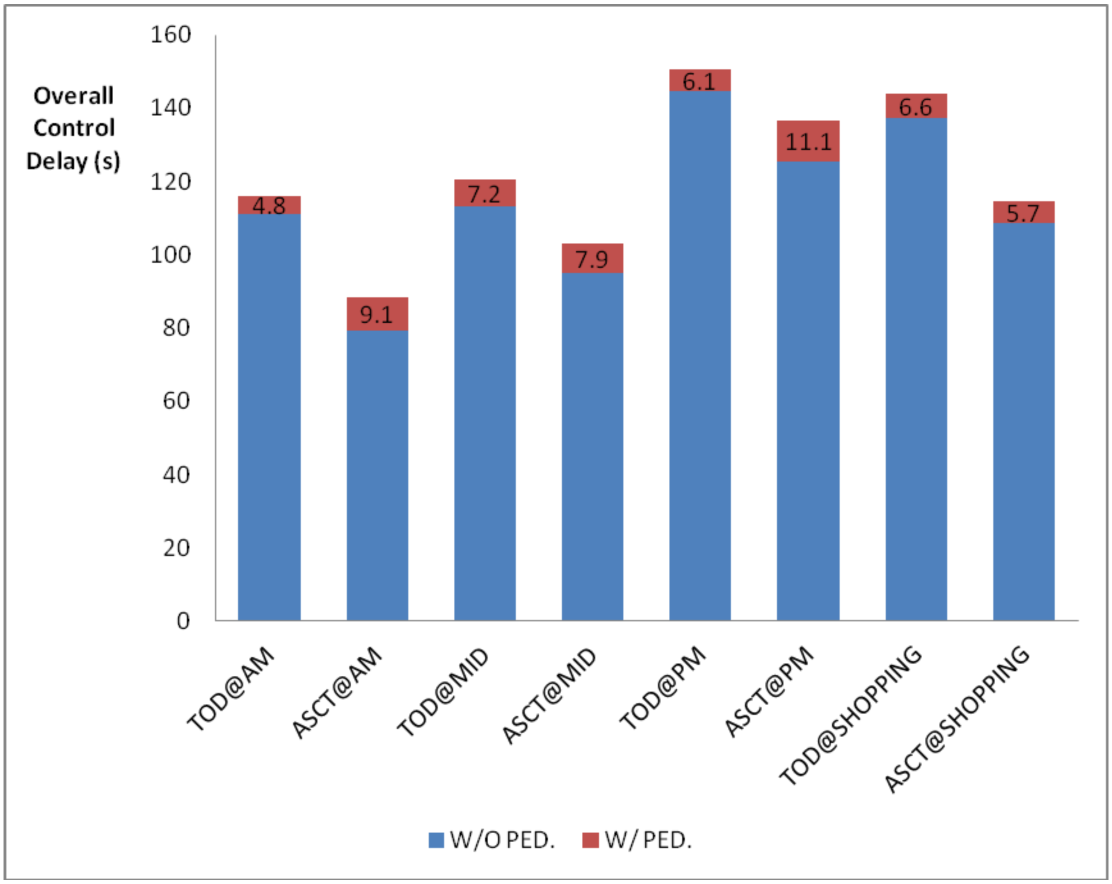

Figure 4-3. Additional control delays caused by pedestrian actuations

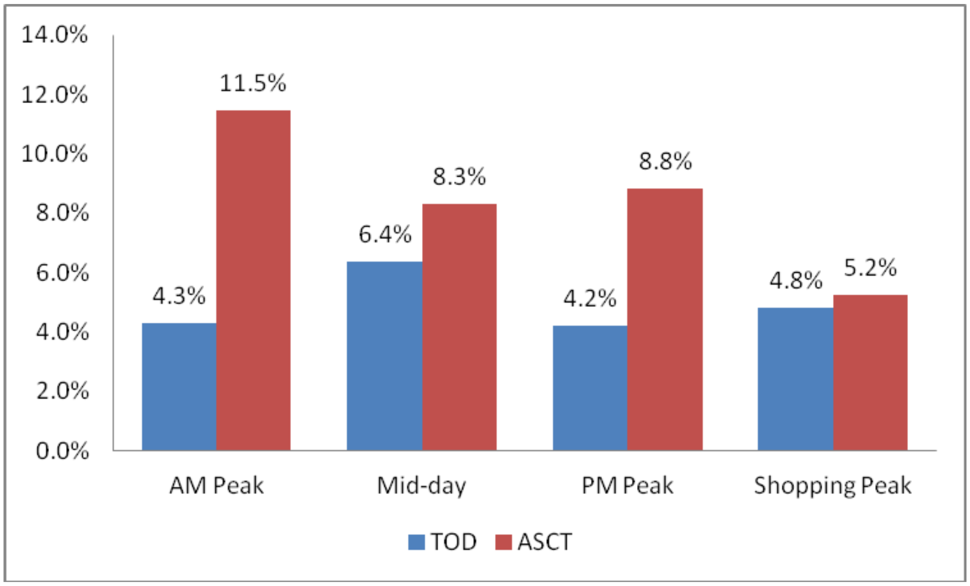

Figure 4-4. Percentages of control delays increased by pedestrian activities

4.3.2 Analysis at a Single Intersection

The research plotted a scatter diagram (Figure 4-5) to show the impact of pedestrian activities of the three groups of intersection types under the ASCT system during the four selected hours. The percentage of cycles with pedestrian intervals to total cycles from 0 to 100 percent is plotted along the X axis. The pedestrian control delay ratio is plotted along the Y axis.

Pedestrian control delay ratio is defined as $\lambda = \frac{S_4 - S_3}{S_4}$, which expresses the ratio of the control delay increased by pedestrian actuations to the real-time total control delay under the ASCT system control.

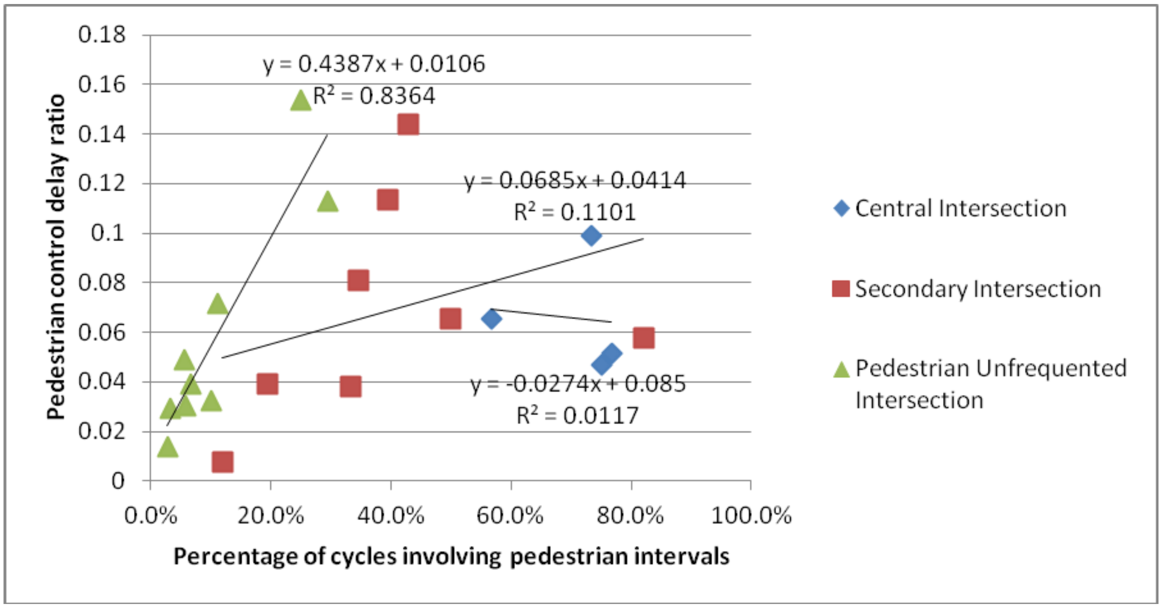

Figure 4-5. The scatter diagram for impact of pedestrian activities of groups of intersections

In Figure 4-5, the larger pedestrian control delay ratio is a point which corresponds to, the more negative effect of pedestrian activities on the ASCT system it indicates. As shown in this figure, all points distribute below the line of $\lambda = 0.16$. It means additional control delays caused by pedestrian activities are less than 16 percent of the total real-time control delays in all cases under the ASCT system. When the percentage of cycles with pedestrian intervals is below 20%, each additional control delay occupied less than 8 percent of its total control delay. When the percentage of cycles with pedestrian intervals is not more than 10 %, each additional control delay occupied less than 5 percent.

The effects of pedestrian activities at the three groups of intersections are different. For pedestrian unfrequented intersections, there is a positive linear relationship between impact and frequency of pedestrian actuations in the ASCT system. The confidence of the fit value for is expressed by $R^2 = 0.8364$. R-squared for each of the three groups, which is the percentage of the response variable variation that is explained by a linear model, has been shown in Figure 4-5.

The relationship may be linear for those secondary intersections. The impact of pedestrian activities is not directly proportional to the rate at which the frequency of pedestrian calls is increasing at the central intersection.

It is worth noting that when the percentage of cycles involving pedestrian intervals exceeds approximately 50%, the pedestrian control delay ratio no longer increases linearly for the secondary intersections. The same pattern was found at the central intersection. There are two possible reasons contributing to the phenomenon. With high vehicle volumes in two or four directions and multiple traffic signal phases exist at an intersection, there are quite a few cycles at which the optimized green time are larger than the pedestrian interval requirements when the percentage of cycles involving pedestrian intervals is more than 50 percent. And the overall control delays for the two groups of intersections are far more than pedestrian unfrequented intersections, which dilutes the extent of the negative impact of pedestrian actuations.

Based on the analysis above, it is believed that the most negative impact of pedestrian activities on the ASCT system is likely to occur when the percentage of cycles involving pedestrian intervals ranges from 20% to 50% during an hour.

4.4 RECOMMENDED GUIDELINES

Based upon the analysis of the test results above, the researcher made several conclusions that can be used for the development of recommended guidelines about the impact of pedestrian activities in ASCT systems. In the development of future ASCT projects on urban road networks, the control delays caused by pedestrian activities should be considered during the planning and design phase. Because pedestrian actuations can increase the control delay under the ASCT system and the total amount of the increased control delay for the complete network is generally more than that amount under the TOD coordinated timing plans. The control delay estimation work on the impact of pedestrian activities is recommended to focus on intersections with from 20 to 50 percent of cycles involving pedestrian actuated intervals when compared to the total number of cycles during the traffic peak hours. Large intersections with high vehicle volumes in four directions and multiple signal phases can be suitable for the ASCT plan, even though they may have very high levels of pedestrian activities. In normal cases, an additional control delay caused by pedestrian activities is less than 20% of the total control delay either at a single intersection or on a network-wide basis.

5.0 SUMMARY AND CONCLUSIONS

This chapter summaries the results, determines whether the results match the hypothesis, and gives the author’s opinions on future research.

5.1 SUMMARY OF RESULTS

5.1.1 Review of Tests Performed

In order to test the hypothesis, a grid ASCT system was selected as the test locations. The grid-like road network in a section of East Liberty, Pittsburgh Pennsylvania includes nine intersections which are currently operating an ASCT, called SURTRAC. Traffic signal operations of the nine intersections in four scenarios TOD timing plans with and without pedestrian activities, ASCT system with and without pedestrian activates were simulated in Synchro during the four peak hours of 8-9am, 12-1pm, and 4-5pm on weekday and 3-4pm on Saturday.

5.1.2 Control Delays

Synchro calculated the control delay of each intersection in different peak hour traffic conditions. The difference, or increase, between the overall control delay with and without pedestrian activities under TOD timing plan coordination is smaller than that under the ASCT system control for the complete network during the peak hours on a weekday. The impact of pedestrian activities on the ASCT plan is more significant, which results in greater delays, than the TOD plan on this test road network. This may be because the incident of the green time that is used by SURTRAC is less than pedestrian interval requirement that more frequently occurred in the ASCT system. ASCT improved traffic operations by largely reducing control delays, especially at AM traffic peak hour when compared to the previous TOD plans without pedestrian actuations. Pedestrian activities increased overall control delays, 11.5%, 8.3%, 8.8% and 5.2% during each of the four selected hours when comparing ASCT operation with and without pedestrian actuations.

The pedestrian control delay ratio, or increase, was the largest at a pedestrian unfrequented intersection, 15.4% of the control delay increase was caused by pedestrian activities. Control delays for pedestrian unfrequented intersections are larger with the increase of the percentage of cycles involving pedestrian intervals. The linear relationship between impact and frequency of pedestrian actuations is not apparent at central intersection and secondary intersections.

5.2 CONCLUSIONS

The hypothesis that pedestrian activities can counteract a portion of the positive effect of the ASCTs is confirmed by the test results. For the grid road network, the increased control delay resulting from pedestrian activities offset some of the benefit on delays brought by the ASCT when compared to the previous TOD coordination plan during all the selected peak hours. In the evaluation process of an ASCT system installed on an urban network, the impact of pedestrian activities is recommended to be incorporated in to expected performance improvements, and in particular for intersections with the percentage of cycles involving pedestrian intervals is expected to be in the range of 20% to 50% during a one-hour period.

5.3 RECOMMENDATIONS FOR FUTURE RESEARCH

This section provides the author's advice on future study of ASCTs.

5.3.1 Pedestrian Delay

Pedestrian delay is recommended to be considered by the developers of the ASCT operating systems at intersections with frequent pedestrian crossings. Walking is an important transportation mode especially in an urban area. Traffic signal operations including ASCT plans should serve pedestrians friendly by reducing pedestrian delay and improve pedestrian safety. One of difficulties in incorporating pedestrian delay into the optimization of the ASCTs is to detect pedestrian volume on each crosswalk by directions at an intersection. The pedestrian push button device can only reflect rough pedestrian frequency. Future research on ASCT optimization method can explore this field.

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