ABSTRACT

IMPACTS ON VEHICULAR TRAFFIC FLOW DUE TO CHANGES IN PEDESTRIAN WALKING SPEED

By

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In January 2012, California adopted federal law requiring city's traffic engineers to decrease the pedestrian walking speeds at signalized intersections from 4fps to 3.5fps. Ten signalized intersections along Atlantic Avenue between Spring Street to Carson Street were selected to evaluate impacts due to pedestrian walking speed changes. One hour peak evening volumes were collected and entered into Synchro by Trafficware to compare intersections and approach delays on 75 and 100 seconds cycle lengths with combination of coordinated and uncoordinated systems. Volume growth rate effects, surveyed pedestrian walking speed, and various observed characteristics at signalized intersection crossing were evaluated. Converting pedestrian walking speed from 4-fps to 3.5fps caused the cycle length to increase from 75 seconds to 90 seconds for coordination purposes. The Synchro results, overall, showed more intersection/approach delay, vehicular growth rates data showed a small effect on the major intersections delay when comparing the two walking speeds, and sampled pedestrian walking speeds indicated that the 15th percentile of pedestrians walked at a faster speed than 3.5fps.

IMPACTS ON VEHICULAR TRAFFIC FLOW DUE TO CHANGES IN PEDESTRIAN WALKING SPEED

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CHAPTER 1

INTRODUCTION

1.1 Background

Prior to California adopting the new pedestrian walking speed agreement between the Federal Highway Administration (FHWA) and American with Disabilities Act (ADA), the City of Long Beach existing pedestrian walking speed was 4 feet per second (fps) for pedestrians to travel from one side of the street to the approaching side. The FHWA believes the pedestrian walking speed should remain 4fps; however the ADA community disputed that the walking speed was too fast and it should be 3fps. To compromise, they took the average of 4fps and 3fps, which resulted in a new pedestrian walking speed of 3.5fps.

1.2 Problem Statement

Currently in the City of Long Beach, traffic signal cycle length on major corridors range from as low as 75 seconds on Atlantic Avenue and 100 seconds for Willow Street, Lakewood Boulevard, and other arterials. The city's philosophy in regard to traffic signal timing is compromising the green band to reduce delays in all directions. When incorporating the new requirements, cycle lengths in the City of Long Beach increased by 20 to 30 seconds. This is actually 30 seconds of added delay for non-sync phase vehicles waiting at the stop bar. The delay may even be greater if a non-sync phase vehicle approaches a signalized intersection just after the last call from the side street is sent to the controller.

The Bitrans 233 timing firmware was implemented in the City of Long Beach in the early 90s. The firmware allowed the city to run low cycle lengths ranging from 75 seconds to 100 seconds during coordination. These cycle lengths were rather low compared to the geometry of the intersection; which ideally demanded a higher cycle length. The scenario, in regards to running a lower cycle length with the Bitrans 233 firmware while maintaining an approximate upstream and downstream coordination was due to the characteristics of the city's inconsistent pattern of pedestrian calls to the controller per a specific leg of the intersection during a given cycle. To illustrate, an intersection with a 120 seconds cycle length, which requires all crosswalk legs of the intersection to give 35 seconds of walk plus clearance time to pedestrians, with lead/lag protective left-turn phasing in north-south direction, protective left-turn phasing in the east-west direction, will require 5 phases. Given the speed limit is 30 mph in all directions, the yellow plus all red-time will require 4.2 seconds for 3 phases and 4 seconds for 2 phases for a total of 21 seconds of yellow plus all red time. Given each leg of the intersection is 100 feet and it is known that the pedestrian timing is based on a 3.5fps walking speed, the pedestrian clearance time requirement will be 29 seconds. Based on the stated phase sequencing and pedestrian timing, starting with the main street through and left-turns (first barrier phases 1-2 & 5-6), the total time required to complete pedestrian walk/flashing don't walk (FDW) and yellow plus all red timing is 85 seconds of the 120 seconds cycle length or 70% of cycle length. The breakdown of the 85 seconds consisted a total of 7 seconds walk time plus 29 seconds FDW for combination of timing for left turn overlapped with pedestrian timing (phases splits 1-6 and 2-6). For north-south and north through and left turn (phases split 2-6 and 2-5) a total of 7 seconds plus 29 seconds was used as well to incorporate the pedestrian walk and FDW requirement for the 100 feet cross walk. The yellow and all-red total stated above, was added for the left-turn side barrier for a total of 85 seconds. On the second side of the barrier, east and westbound left turns along with the east and westbound through movement (phases splits 3-7 & 4-8), total time required is 50 seconds. Given the 2 splits 3 and 7 & 4 and 8, 10 seconds of green was assumed for phases 3 and 7. For phases 4 and 8, 7 seconds of walk time plus 29 seconds of FDW was considered to satisfy the pedestrian requirement. Between the two phases, the yellow and all-red total is 9 seconds.

With the break down of all sequences, phases/splits, and green time requirements; if one was to consider this particular intersection maxing out, it will require a cycle length of 135 seconds. However, since pedestrian calls are usually low and signal is semi-actuated, the City of Long Beach developed timing plans based on the fact that one of the non-sync phases will gap out during coordination to allow more timing for the next movement.

1.3 Purpose

Using prior traffic signal timing, a comparative study is done to determine the effects on vehicular traffic flow due to changing the pedestrian walking speed from 4.0fps to 3.5fps. Data used to evaluate the effects, are vehicular count data to input into Synchro traffic simulation project, 30%, 60%, 90% growth rate, and sampled pedestrian walking speeds at various signalized intersections. The corridor of Atlantic Avenue between Spring Street and Carson Street is used as the study area due to having the greatest corridor cycle length change when timing was converted to 3.5fps, different business attractions for pedestrians at various signalized intersections, various volume approaches, and various phasing combination.

1.4 Organization of Report

In regards to the organization of this thesis, it consists of six chapters. The first chapter is the introduction, which defines the topic of this thesis. The second chapter is the literature review. Various research was compiled together discussing pedestrian walking paces and how it relates to traffic signal timing. Chapter 3 is the technical background; various calculations and technical timing concepts are explained in this chapter. Chapter 4 is the methodology and data collection; which consists of the data collection method that will be used to identify the effects on vehicular traffic flow to pedestrian speed differences. The data section show all the existing phasing and volumes to evaluate the topic of discussion. Chapter 5 focuses on analysis from data collected to discuss the effect on traffic signal timing, evaluating the two walking speeds without changing the 75 second cycle length and with changing the cycle length from 75 to 100 seconds. Growth rate effects will be evaluated; it evaluates the delay condition when the volumes are increased by 30%, 60%, and 90%. Lastly in chapter 5, collected pedestrian walking speed by evaluating different area that will attract certain type of pedestrians will be discussed. The last chapter, chapter 6 is the conclusion; which will highlight some of the findings and discuss any future technology that will improve efficiency.

CHAPTER 2

LITERATURE REVIEW

This study on the Impacts on vehicular traffic flow due to change in pedestrian speed from 4-fps to 3.5-fps is a new topic which to the knowledge of the author has not been addressed in the past. The 2012 California Manual of Unified Traffic Control Devices (MUTCD) (*California Department of Transportation*) mandate of 3.5fps pedestrian walking speed increases pedestrian clearance time. A paper by Gates et al. (2006) focuses on a collection of data to determine which should be the preferred walking speed for the average pedestrian based on age, disability, sex, group, and the intersection characteristic. The data was collected along 10 intersections in Madison, Wisconsin. Their research results showed that pedestrians over 65 years of age were the slowest walkers with a pace of 3.02fps. The 15^{th} percentile speed was 3.81fps. Based on the data Gates et al. determined that 3.8fps should be the pace used to calculate pedestrian FDW time. However, they determined if there are 40% senior or slower walkers present, the walking speed on average of 3.4fps should be considered and if the proportion is greater, a walking speed of 2.9fps should be used (Gates et al. 2006).

An article written by John Laplante and Thomas Kaeser (2004) regarding pedestrian walking speed, expressed the development of the MUTCD starting with the 1948 edition. The 1948 edition did not specify a specific pedestrian walking speed; however it was based on actual time needed abased on the characteristics of the intersection to safety provide time for pedestrians to cross. In the 1961 MUTCD, it specified that pedestrian clearance should be based on a pedestrian traveling from the curb to the center of the last opposing travel lane with a walking speed of 4fps. The 2000 MUTCD added that at locations with pedestrians who walk slower than 4fps, slower walking pace shall be considered while incorporating new timing. The 2003 MUTCD changed the specified crossing requirement to "pedestrians shall cross from one curb side to the other curb side," rather than to the far side middle lane (LaPlante and Kaesar 2004).

` John Laplante and Thomas Kaeser (2004) also conducted research and it was determined that 4fps was determined to be the average walking speed for pedestrians; however, the 15^{th} percentile walked at 3.5fps. For elderly, it was determined their walking pace was 3.5fps and the 15^{th} percentile of elderly, has a walking pace of 3fps (LaPlante and Kaesar 2004).

In regards to the elderly, Jarmin Yeh (2010) wrote a paper on population aging and how people are living longer as a result are needing more assistance with various public infrastructures to independently get from one place to another. From information from the United States Administration on Aging, statistics show that the number of people above 65 years of age is increasing at an exponential pace. In the early 1900s there were 3.1 million people living in the US above 65 years of age; in the year of 2060, it is expected to be over 92 million Americans living above the age of 65. It is a known fact that as humans get older, they tend to slow down. The author conducted a survey of elderly adults from two sites. One has hosted 37 and the other 36 elderly adults. The survey asked questions such as: "Where do you regularly walk?" and "What makes walking difficult?" As related to the thesis topic, more than 50% of the total stated "no crosswalk" or "not enough crossing time" made it difficult for them to cross the street (Yeh 2010).

In an article written by Abbas et al. (2008), they conducted a comparative analysis on a Single Point Urban Interchange (SPUI) to a Tight Diamond Interchange (TDI) to measure the efficiency and pedestrian impacts when comparing the two walking speeds of 4fps to 3.5fps. The study used three different traffic volumes as follows: light (4000 vph), medium (5500 vph), and heavy (7000 vph). Based on the author's evaluation of data, it was determined that the SPUI was more efficient than the TDI system given the ability with the SPUI allowing free-flow right turns. In regard to the pedestrian walking speed decrease from 4fps to 3.5fps, the SPUI showed less of a delay impact compared to the TDI (Abbas et al. 2008).

In an article by Tian et al. (2001), he introduces different scenarios in regards to split phasing and its impacts on pedestrian crossing time. Signals under protected left-turn allow for pedestrians to cross safely without having to encounter left turning vehicle. Under permissive left-turns, vehicles have to make sure that pedestrians are not in the crosswalk before proceeding. This puts pedestrians under higher probability that they could be hit. It was also identified that pedestrians timing in split phasing use a large amount of the cycle length due to timing being repeated twice to cross the same roadway segment (Tian et al. 2001).

CHAPTER 3

TECHNICAL BACKGROUND

The technical background chapter introduces the phasing and timing calculations for the studied segment. Figure 1 shows the typical signal phasing sequence at a signalized intersection. Assuming phase 2 is northbound, 6 is southbound and other directions so forward. For the Atlantic Avenue segment between Spring Street and Carson Street, all of the signalized left-turns are protective/permissive. The right-turns are displayed below; however are not signalized for the studied segment. The pedestrian movements are consistent with the phasing sequence shown on the figure.

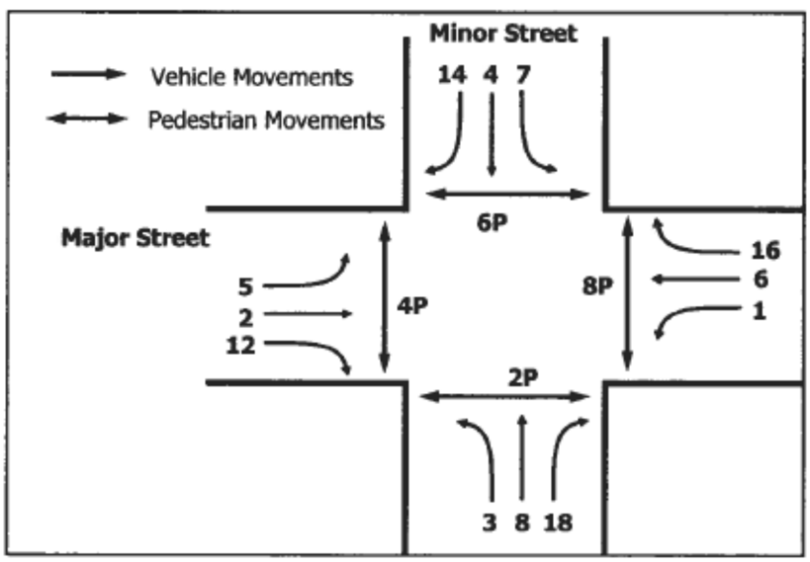

FIGURE 1. Typical signal intersection phasing sequence HCM 2010.

Timing calculations are determined based on pedestrian, vehicles, and bicycle demand in relation to intersection geometry. In this section, various timing calculations are demonstrated to show how green, yellow and red intervals, pedestrian, and cycle length are determined. The intersection of Carson Street and Atlantic Avenue was used to demonstrate these timing calculations.

The cycle length is dependent on vehicle demand and mainly pedestrian crossing distance. In most cases, pedestrian timing needs are the main component that determines what the cycle length is due to the fact that pedestrians consume the most time crossing an intersection. The Webster formula for cycle length (C) is determined is:

$C = [(1.5L + 5)/ (1 - \Sigma Y_i)]$

L = unusable time per cycle (sec) = $nl + R$
Y_i = critical lane vol. (vph)/ saturation flow rate (vph)
n = number of phases
l = average lost time per phase, sec.
R = total all-red time per cycle, sec.

FIGURE 2. Cycle length calculation Webster's formula.

For the intersection of Carson Street and Atlantic Avenue the variables are defined based on 100 second cycle as shown in Figure 3.

L = 16.2 sec
$Y_{NB/SB}$ = 837 vph/ 1900 vph = 0.44
$Y_{EB/WB}$ = 271 vph/ 1900 vph = 0.14
Y_{WBLT} = 158 vph/ 1900 vph = 0.08
Y_{Total} = 0.66
n = 3 phases (split)
l = 2 sec
R = 3 sec

FIGURE 3. Variable data for Webster's cycle length calculation.

Based on the calculations, the optimum cycle length was determined to be 87 seconds. The value of the yellow time is determined based on the approach speed divided by half the deceleration rate (a). For this thesis, the deceleration rate used was 10 feet per second square (fps^2). The 85^{th} percentile speed (V) for the Atlantic Avenue is 35 mph and the perception-reaction time (t) is 1 second. Given all of the variables, the computed yellow time is 3.56 seconds. In regard to state law, based on the MUTCD, the yellow time for a signalized direction with a 35 mph speed limit is 3.6 seconds. Figure 4 shows the yellow time equation.

$$Y = t + (V/2a)$$

Y = yellow interval, sec
t = perception-reaction time, sec
V = Speed fps
a = deceleration, fps^2

FIGURE 4. Yellow time calculation.

The computation for the all-red time, is based on the width of intersection (W), length of vehicle (L), and the 85^{th} percentile approach speed. There are three different phases/splits occurring at the intersection of Atlantic Avenue and Carson Street. For the north/south direction (phases 2 and 6), the width of the intersection is 87 feet and the east/west (phases 4 and 8) is 86 feet. The computed interval for phases 2 & 6 is 2 seconds and for phases 4 & 8 is 2 seconds. Per the MUTCD, the all-red time requirement at this intersection is 1 second per phase. This is typically universal. Figure 5 shows the all-red interval equation.

$$Ar = (W + L) / (V)$$

Ar = All red time, sec
W = Width of intersection, ft
L = Length of vehicle, ft

FIGURE 5. All red-time calculation.

In regards the intersection of Atlantic Avenue and Carson Street, the walk time per the 2012 MUTCD requires a 7 second minimum plus clearance interval without studies; when there is a pedestrian interval study that has taken place, the walk time can go as low as 4 seconds plus clearance. The formula in Figure 6 shows the pedestrian walk time equation per the 2010 Highway Capacity Manual (Transportation Research Board). For this calculation, the side street was used. The calculated pedestrian effective walk time for the intersection of Atlantic Avenue and Carson Street is 28 seconds.

$$G_W = D - Y - R$$

G_W = Pedestrian Effective Walk Time (sec.)
D = Duration of phase serving minor street
Y = Yellow change interval serving minor street
R = Red clearance interval serving minor street

FIGURE 6. Pedestrian effective walk time HCM 2010.

D = 32 seconds
Y = 3.2 seconds
R = 1 second

$G_W = D – Y - R = 32 – 3.2 – 1 = 28$ seconds

FIGURE 7. Variable data for pedestrian effective walk time HCM 2010.

Another computation in regards to pedestrian timing, is pedestrian service time. The difference between “effective walk time” versus “pedestrian service time” is the “effective walk time” is based on allocated green time from the side/main street and the that “pedestrian service time” is based on characteristics of the crosswalk. The formula is shown in Figure 8. The computed effective available crosswalk time for the intersection of Atlantic Avenue and Carson Street is 31 seconds; shown in Figure 9.

Based on the data calculated above, the 31 seconds fit within the required pedestrian timing. The 3.2 seconds is considered the walk; however, per the 2012 MUTCD, the initial walk time cannot be less than 4 seconds. This the calculated data case, given the 10 pedestrian data, the walk time went over the minimum state requirement of 4 seconds.

In relation to appropriating a cycle length that is less than the actual needed to accommodate every travel mode movement at a signalized intersection, the result based on demand could cause the signal to go into transition mode. Transition mode is the effect of a traffic signal increasing or decreasing its cycle length due to the fact that one or more of the signal phases allocated time does not meet minimum timing allocation

t_P = 3.2 + (L/S) + 0.27 (N)

t_P = effective available crosswalk time-space, ft^2-s
L = length of Crosswalk, ft
S = pedestrian walking pace, fps
N = Number of pedestrians, assume 10-peds
W = Width of crosswalk, 10-ft

FIGURE 8. Effective available crosswalk time space HCM 2010.

L = 86 feet
S = 3.5 fps
N = Number of pedestrians, assume 10-peds
W = Width of crosswalk (10-ft)

t_P = 3.2 + (86/3.5) + 0.27 (10) = 31 seconds

FIGURE 9. Variable data for effective available crosswalk time space HCM 2010.

requirements to gap-out or terminate at its appropriate point. An example was given in the introduction in regards to a five phase/split signalized intersection with 100 feet crossing in all directions. The in-place cycle length specified was 120 seconds. A calculated cycle length of 135 seconds was determined to prevent transition mode. In most cases, during the morning or late afternoon peak hour, the signal goes into a 1 to 15 second different transition period. This causes the intersection to go out of synchronization and lose coordination. In most cases the reason the signal goes into a transition mode is due to a pedestrian call. Pedestrians use most of the traffic signal timing at an intersection. In the Webster cycle length calculation, it is purely based on vehicular flow rate; which results in a smaller cycle length. This cycle length must be adjusted to accommodate pedestrian needs.

There is an advantage in regards to running lower cycle lengths that are less than the intersection's ideal requirement. With the firmware BiTrans 233, there a designated flag that allows for pedestrian adjustment by a specified number of seconds. This feature is used when a cycle at a given intersection is below the minimum requirement and the intersection experienced no "gapped" timing. Given the intersection maxed out and did not experience any gapped timing, it will enter into transition mode due to the cycle count not terminating at the appropriate point for the synchronization phase to begin. Given the additional time needed for the cycle to synchronize to other cycles along the corridors, the BiTrans 233 firmware syncing method is able to re-synchronize the cycle without much of a notice of mal-synchronization. For example, if a signalized intersection goes out of sync for 10 seconds on a 100 second cycle length, the BiTrans 233 firmware would re-synchronize the intersection over 3 to 4 cycles to reduce the impact of the intersection being out of synchronization. Therefore, the intersection would synchronize at 102 seconds to 103 seconds cycle length. The majority of drivers would not notice, because the change is just a few seconds.

During the implementation of Adaptive Traffic Control System (ATCS) in Douglas Park (Long Beach) in 2010, the transferring of timing from BiTran 233 to ATCS had it challenges. Given the city's green-time allocation was below minimum green requirement to serve all modes, it was required that the splits be rearranged to current demand or if that was not feasible, the cycle length would have to be increased. This adaptive system was implemented during the time in which the pedestrian walking speed was still at 4fps. Corridors such as Willow Street, Lakewood Boulevard, and others. were corridors that the cycle length had to be adjusted to stay in synchronization. After California adopted the new pedestrian walking speed from 4fps to 3.5fps, more increases to the cycle lengths occurred. Atlantic Avenue was changed from mostly 75 seconds to 90 seconds. A short period later it was increased to 100 seconds to consider the cross traffic along major corridors it intersected.

Lastly considering timing that is below minimum thresholds and the effects that it has on a signalized intersection, one must consider the safety. It has been stated several times through this paper that pedestrians determine what the cycle length will be along a signalized corridor. In regard to safety, when a pedestrian walk time occurs and the interval duration is not on track with the current cycle split, it causes the pedestrian timing to extend pass its cut-off point. Typically after pedestrian timing ends, the left turn phase follows. If allocated pedestrian timing extends pass its cut off point and the extension extends pass the allocated left-turn allocate timing, the left-turn will not be served. This occurrence presents a safety dilemma due to the fact that the left-turning vehicles are not able to clear the intersection during the given cycle. This causes some drivers to run the red light. After several cycles, ATCS will send the intersection into transition mode, which will raise the cycle length to allow for the skipped phases to be served. This results in the signal being out of coordination.

CHAPTER 4

METHODOLOGY AND DATA COLLECTION

4.1 Methodology

The corridor contains ten intersections with pedestrian signals, as shown in Figure 10. It comprises of a mix of low volume and high volume intersections with a variety of local neighborhood businesses to high recognition businesses that bring more activity attraction to the area. Vehicular and pedestrian data are collected to support vehicle delay and pedestrian walking speed analysis.

FIGURE 10. Atlantic Avenue corridor between Spring Street to Carson Street.

The first collection of data was a vehicular peak evening hour count based on a five minute interval along the Atlantic Avenue corridor. The vehicular volume counts are used to compare the effects of changing the pedestrian walking speed from 4fps to 3.5fps on traffic signal timing. The program used is Synchro by Trafficware. Synchro enables inputting of data to calculate delays with regards to intersection/ vehicular movements and calculate the actual cycle length based on volumes received from the field. Volume growth rates are applied to determine how and long-term effects of pedestrian walking speed on vehicular traffic flow.

The FHWA and ADA compromised that the new pedestrian walking speed shall be 3.5fps. The 3.5fps was imposed on the entire United States. It is known that different communities have different necessities when it comes to physical ability. Different communities across the US will walk slower compared to other communities. For example, it is know that pedestrians in New York City may walk faster than pedestrians in the City of Long Beach, California. The whole ideal in traffic signal timing is to maximize efficiency for all users.

A proposed study in Long Beach is conducted to determine actual pedestrian walking speed. Various types of scenarios have been selected to capture different types of pedestrian end point. These areas consist of residential communities, urban entertainment, shopping, and downtown working community.

4.2 Data Collection

Data used on Atlantic Avenue between Spring Street and Carson Street is presented in this section. Atlantic Avenue is a four-lane arterial with left-turn storage bays at each intersection. The speed limit is 35-MPH from Spring Street to Wardlow Road and 30-MPH from Wardlow Road to Carson Street. Table 1 summarizes the peak-hour volumes collected between 4PM and 5PM on a weekday at the ten intersections along the corridor. The Jammar turning movement count device was used to collect vehicular turning volume data. These volumes are used to perform signal timing analysis using Synchro. Intersection phasing are shown on Figure 11.

TABLE 1. Vehicle Volume for Study Area

Intersections	Northbound (vph)			Southbound (vph)			Eastbound (vph)			Westbound (vph)		
	LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
Spring Street	32	793	129	159	690	125	192	631	21	32	7	129
31st Street	65	650	26		650	24	24			12		12
33rd Street	24	650	192	36	650	24	60		60	144		96
Wardlow Road	134	838	41	76	675	137	153	415	61	57	275	38
36th Street	36	650	24	72	650	24	72		96	12		12
37th Street	48	650	24	36	650	12	24		24	12		48
Bixby Road	37	942	31	25	762	31	62	73	37	32	67	29
Roosevelt Road	132	650	36	12	650	48	120		84	24		36
Marshall Place		650	60	12	650					36		
Carson Street	78	837	168	108	651	25	33	271	59	158	202	115

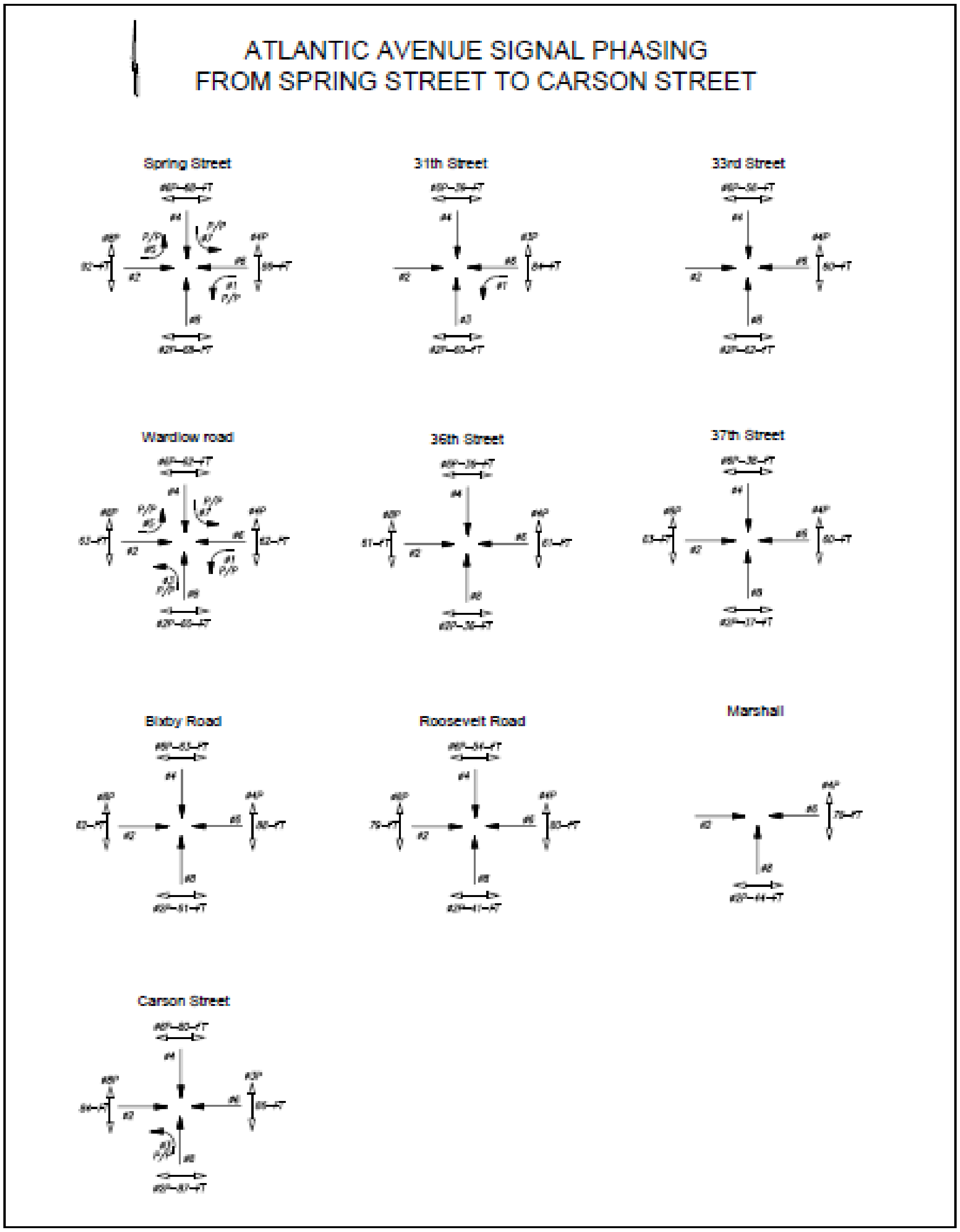

FIGURE 11. Phasing diagram for signals on Atlantic Avenue corridor.

Six intersections along the corridor are two-phase intersections. The remaining intersections have protective-permissive indication in certain directions. All of the intersections along the corridor are semi-actuated with the synchronization movement being Atlantic Avenue.

Table 2 below is a tabulation of the sum of minimum of green, yellow, and all-red intervals to keep intersection from going out of synchronization. The last column shows the minimum cycle length needed to satisfy this condition. Based on a cycle length of 75 seconds, three intersections will not satisfy the minimum when the pedestrian walking speed is converted to 3.5fps. These are the intersections of Atlantic Avenue and Spring Street, 31st Street, and Carson Street. Based on these data, the study includes three scenario analyses: a 75 seconds cycle on a coordinated system comparing 4fps to 3.5fps; a 75 seconds cycle on a coordinated system at 4fps to a 75 seconds cycle on a uncoordinated system at 3.5fps; and a 75 seconds cycle at 4fps to a 100 seconds cycle to 3.5fps all coordinated.

TABLE 2. Timing Allocation for Signals to Meet Cycle Length Requirements

Intersections (3.5fps)	Phases 1 & 5 (seconds)	Phases 2 & 6 (seconds)	Phases 3 & 7 (seconds)	Phases 4 & 8 (seconds)	Min. Cycle Needed
Spring Street	17	26	17	33	93
31st Street	21	24	31	13	89
33rd Street		25		24	49
Wardlow Road	12	25	12	25	74
36th Street		18		25	43
37th Street		18		25	43
Bixby Road		25		32	57
Roosevelt Road		23		30	53
Marshall Place		20		30	50
Carson Street		32	17	32	81

Lastly, fifty samples at each intersection of pedestrian walking speed were collected at various intersections along the studied corridor and not on the studied corridor. The intersection selected were Pine Avenue and Shoreline Drive, Ocean Boulevard and Magnolia Avenue, 2nd Street and Granada, and Atlantic Avenue and Wardlow Road. These intersections were selected based on having unique pedestrian attraction characteristics. Some attract most pedestrians to work, restaurants, sport activities, and local community businesses. Pedestrian walking speed data results can be found in Appendix B.

CHAPTER 5

ANALYSIS AND DISCUSSION

5.1 Effects on Main-Street Due to New Pedestrian Timing Requirements

In traffic signal timing, when new state legislature is imposed on local government that affects coordination, traffic engineers ideally try to implement these new requirements without changing the cycle length. In this chapter, discussing will consist of the effect the main-street absorbs and the pedestrian walking speed is reduced. In addition, the change in cycle length will discuss to show the effects on the main street. In examining the initial timing at a 4fps walking speed, Atlantic Avenue and 31st Street intersection is the only intersection that has a cumulative minimum timing that does not meet minimum cycle length need based on geometry. With the existing cycle length of 75 seconds compared to what the actual should be, it is off by 9 seconds. However, given the signal at 31st Street is semi-actuated; certain phases may gap-out. As mentioned in the technical background, a phase gapping out occurs when a specific phase does not use all of its green time due to no vehicle being present and the phase terminating early. The lack of meeting the minimum requirements for existing intersection geometry, the intersection operation makes up for it in saved timing from other phases. That is the art of green-time management.

Following the new standard, in examining the effects of changing the pedestrian walking speed to 3.5fps along the Atlantic Avenue corridor between Spring Street and

Carson Street without increasing the cycle length, it was determined that two additional intersections were affected. Based on calculated output, Atlantic Avenue at Spring Street, and Atlantic Avenue at Carson Street were affected with addition to 31st Street. The overage in cycle timing ranged from 3 to 6 seconds. Ideally, given gap timing on a semi-actuated signal, the intersection won't be affected; however, 3 to 6 seconds is significant at major intersections that have frequent pedestrian demand and tend to use most of its allocated green-time.

Given the fact that the cycle length was not changed, and the pedestrian timing was increased, one must consider the impacts to existing conditions. Theoretically, the green-time is allocated for pedestrians crossing the main street. In result, this creates a longer wait periods and subsequent delay for the vehicles along the main street. Synchro traffic simulation software was used to evaluate coordinated vehicle approaches and intersection delays of coordinated/coordinated (C/C) or uncoordinated/coordinated (U/C) timing. The initial base timing was coordinated with a pedestrian walking speed of 4-fps and then converted to a walking speed of 3.5fps due to new state mandate.

When the walking speed is reduced from 4fps to 3.5fps on a 75 seconds cycle length C/C signal, the conversion to a 3.5fps walking speed resulted in 7 out 10 intersections showing more intersection delays as shown on Table 3. The intersections of Atlantic Avenue and Carson Street, 36th Street and Roosevelt Road were the three intersections that experience less intersection delay when 4fps pedestrian walking speed was converted to 3.5fps. However, Roosevelt Road, 33rd Street Avenue, and Carson Street intersection delays were 0.6 seconds or less. This is identified as negligible due the minor difference in intersection delay seconds. All intersections were expected to have more delay; however, data could have varied due to approach volumes. See Appendix A for increases and decreasing in pedestrian walking speeds.

TABLE 3. Intersection Delay Comparison for 75 Seconds Cycle Length Coordinated/ Coordinated System 4fps and 3.5fps Walking Speed

Intersection	75 Seconds - Cycle @ 4fps		75 Seconds - Cycle @ 3.5fps		Delta Change Int. Delay (seconds)
	Intersection Delay (seconds)	Intersection LOS (seconds)	Intersection Delay (seconds)	LOS	
Spring Street	24.1	C	31.7	C	7.6
31th Street	7.9	A	12.5	B	4.6
33rd Street	10.3	B	10.5	B	0.2
Wardlow Road	19.2	B	20.4	C	1.2
36th Street	9.7	A	6.3	A	-3.4
37th Street	4.1	A	6.5	A	2.4
Bixby Road	11.8	B	13	B	1.2
Roosevelt Road	9.3	B	9	A	-0.3
Marshall Place	2.8	A	6.3	A	3.5
Carson Street	15.4	B	14.8	B	-0.6

In regards to not making changes to the cycle length and adjusting the pedestrian walk/ clearance interval, one must consider the impact on the main-street flow. When more green-time allocation is provided on the side street to allow for pedestrians to cross the main street, this typically causes more delay on the main-street. Based on the Synchro calculations, when comparing the northbound and southbound approach delays with coordinated/coordinated system based on a 75 seconds cycle length, 7 of 10 intersections northbound and southbound approach delays increased when the pedestrian walking speed was decreased to 3.5fps. As shown on Table 4, intersection on Atlantic Avenue at 36th Street, Bixby Road, and Roosevelt Road decreased. See table 4 for northbound and southbound approach delays data. Carson Street showed a half of a second difference, which is considered to be negligible. The highest approach delay from is used to calculate the change in delay due to both northbound and southbound green – times starting and terminating at the same time.

TABLE 4. Northbound/Southbound Approach Delay Comparison for 75 Seconds Cycle Length Coordinated/Coordinated 4fps and 3.5fps Walking Speed

Intersection	Approach Delays 75 Seconds - Cycle @ 4fps		Approach Delays 75 Seconds - Cycle @ 3.5fps		Delta Change Approach (seconds)
	NB Approach (seconds)	SB Approach (seconds)	NB Approach (seconds)	SB Approach (seconds)	
Spring Street	23.1	12.5	29.6	21.8	6.5
31th Street	7.8	7.8	12.8	12.8	5
33rd Street	7.1	6.5	8.2	8	1.1
Wardlow Road	16.1	15.2	21.2	17.3	5.1
36th Street	10.8	7	3.3	3.9	-6.9
37th Street	0.9	5.7	3.5	8.8	3.1
Bixby Road	9.7	21	8.3	15.3	-5.7
Roosevelt Road	10	6.7	5.6	8.7	-1.3
Marshall Place	2.4	1.9	7.5	20.5	18.1
Carson Street	11.1	9.5	10.6	12.4	0.5

When comparing the delays with coordinated versus uncoordinated signal system based on a 75 second cycle length at a 3.5fps walking speed, Atlantic Avenue and Spring Street showed a significant decrease in intersection delay on uncoordinated system, from 31.7 to 13.1 seconds; as shown in Table 5. Atlantic Avenue at 31st Street, 36th Street, Roosevelt Road, and Carson Street showed an increase in intersection delay. There was a decrease in delay at Atlantic Avenue at 33rd Street, Wardlow Road, Bixby Road, and

Marshall Place was negligible with 0.4 second or less delay. In regards to these results, the comparison is between a coordinated system versus an uncoordinated system. Vehicle Volumes and pedestrian timing played a part in nine intersections showing more delay or being negligible.

TABLE 5. Intersection Delay Comparison for 75 Seconds Cycle Length Coordinated/ Uncoordinated Systems 3.5fps Walking Speed

Intersection	75 seconds - Cycle @ 3.5fps (coordinated)		75 seconds - Cycle @ 3.5fps (un-coordinated)		Delta Change Intersection Delay
	Intersection Delay (seconds)	Intersection LOS	Intersection Delay (seconds)	Intersection LOS	
Spring Street	31.7	C	13.1	B	-18.6
31st Street	12.5	B	16.3	B	3.8
33rd Street	10.5	B	10.1	B	-0.4
Wardlow Road	20.4	C	20	B	-0.4
36th Street	6.3	A	9.2	A	2.9
37th Street	6.5	A	6.9	A	0.4
Bixby Road	13	B	12.8	B	-0.2
Roosevelt Road	9	A	10.7	B	1.7
Marshall Place	6.3	A	6.2	A	-0.1
Carson Street	14.8	B	16.7	B	1.9

When evaluating the northbound and southbound approach for the coordinated system versus the uncoordinated system, the results were similar to the comparison of the intersection delay of the two systems in the discussion above. Spring Street showed a significant decrease in approach delay; as shown in Table 6. Wardlow Road, 37th Street, Bixby Road, and Marshall Place showed a decrease in approach delay as well. The intersections at 31st Street, 36th Street, and Carson Street showed an increase in delay; while Roosevelt was negligible with a difference of 0.5 second. The variation again identifies two different distinct operations. For example, in a coordinated system, the operation is gauged toward moving a platoon down a corridor; given appropriate vehicle volume compared to cycle length. In an uncoordinated signal timing operations could be "running free."

TABLE 6. Northbound/Southbound Approach Delay Comparison for 75 Seconds Cycle Length Coordinated/Uncoordinated System 3.5fps Walking Speed

Intersection	Approach Delay 75 second - Cycle @ 3.5fps (coordinated)		Approach Delay 75 second - Cycle @ 3.5fps (uncoordinated)		Delta Change Intersection Delay (seconds)
	NB Approach (seconds)	SB Approach (seconds)	NB Approach (seconds)	SB Approach (seconds)	
Spring St.	29.6	21.8	2.1	3	-26.6
31th St.	12.8	12.8	16.7	16.7	3.9
33rd St.	8.2	8	8.2	8.2	No Change
Wardlow Rd.	21.2	17.3	20.2	19.9	-1
36th St.	3.3	3.9	8.9	8.9	5
37th St.	3.5	8.8	6.7	6.7	-2.1
Bixby	8.3	15.3	9.1	8.3	-6.2
Roosevelt	5.6	8.7	9.2	9.2	0.5
Marshall	7.5	20.5	5.6	5.4	-14.9
Carson St.	10.6	12.4	15.8	13.2	3.4

It is known that in order for a corridor to be coordinated, all of the intersection along the corridor must have the same cycle length. As well as the uncoordinated intersections should experience the same or less delay than the coordinated. The outlier data points at 31st Street, 36th Street, and Carson Street did not correlate with these findings. This could have been due to the significant overage in cycle length causing the transition mode to increase the cycle to resynchronize back its specified cycle length. When considering a 75 seconds cycle signal that is "uncoordinated," this signal is typically running free or running a coordinated cycle separate from the arterial. For an uncoordinated signal to go into transition mode, it's actually a positive gain, given the focus is only on that intersection. The transition mode acts as an artificial adaptive system to filter more vehicles through the intersection. For example, in the City of Los Angeles when a sporting event is over, detector occupancy readings from the adaptive system alerts the controller that timing is under served and needs to be increased. This is the same thing that happens when a lesser cycle length is used at an intersection that is supposed to have a higher cycle length. On the other hand, with a coordinated system, the whole corridor is taken into account. The signals have to simultaneously work together to drive progression. Without the help of an adaptive system, the cycle length, green-splits, nor offsets can be adjusted to accommodate progression needs.

The previous paragraphs in this section discuss the effects on the main street when the cycle length is not change; however, one must discuss the effects when the cycle length is changed. Evaluation of intersection and approach delay on the northbound and southbound approach was evaluated. In the simulation software, it was determined that 7 intersections had an decreased or approximately the same change in delay and 3 intersections had increased in delay; however it was not significant. When the cycle length is increased, an increase in delay is expected due to each phase having additional time extensions resulting in a later start to the next phase. During a 75 seconds cycle length, an intersection can cycle 48 times; and during a 100 second cycle length, an intersection can cycle 36 times. The difference is 12 more cycle on a 75 seconds cycle length. However, the 100 second cycle length can filter more vehicles through the intersection per phase. On a typical residential side street, volumes are not very high and 75 seconds is sufficient for vehicles. A higher cycle is not favorable on the side street.

TABLE 7. Intersection Delay Comparison for 75 to 100 Seconds Cycle Length Coordinated 4fps to 3.5fps

Intersection	75 second - Cycle @ 4-fps (Coordinated)		100 second - Cycle @ 3.5-fps (Coordinated)		Delta Change Int. Delay (seconds)
	Intersection Delay (seconds)	Intersection LOS	Intersection Delay (seconds)	Intersection LOS	
Spring Street	24.1	C	22.2	C	-1.9
31st Street	7.9	A	8.9	A	1
33rd Street	10.3	B	11.8	B	1.5
Wardlow Road	19.2	B	25.7	C	6.5
36th Street	9.7	A	10.7	B	1
37th Street	4.1	A	6.1	A	2
Bixby Road	11.8	B	9.9	A	-1.9
Roosevelt Road	9.3	B	9.4	A	0.1
Marshall Place	2.8	A	2.7	A	-0.1
Carson Street	15.4	B	18.3	B	2.9

TABLE 8. Northbound/Southbound Approach Delay Comparison for 75 to 100 Seconds Cycle Length Coordinated 4fps to 3.5fps

Intersection	Approach Delay 75 second - Cycle @ 4fps (Coordinated)		Approach Delay 100 second - Cycle @ 3.5fps (Coordinated)		Delta Change Approach Delay (seconds)
	NB Approach Delay (seconds)	SB Approach Delay (seconds)	NB Approach Delay (seconds)	SB Approach Delay (seconds)	
Spring Street	17.7	9.4	15.4	15.6	-2.1
31st Street	5.7	7.5	9.5	7.2	1.7
33rd Street	7.1	6.2	7.7	5	0.6
Wardlow Road	15.9	18.1	14.9	19.2	1.1
36th Street	10.9	5.6	5.9	4.8	-5
37th Street	.9	5.8	7	2.6	-2
Bixby Road	9.9	9.9	6.2	5.7	-3.7
Roosevelt Road	8.5	3.9	6.4	3.8	-2.1
Marshall Place	2.4	1.9	1.6	1.9	-0.5
Carson Street	10.6	11.5	7.5	9.4	-2.1

The approach delays for the northbound and southbound traffic was evaluated when comparing cycle length change; as shown on Table 8. 7 out of 10 intersections showed a decrease in delay. It was anticipated that given an increase in the cycle length, the main-street will have a decrease in delay given that when the side street approach gap out, the main-street will acquire additional green-time. However, since Synchro is a linear traffic simulation software, it assumes that the same green time appropriation happens every time.

5.2 Effect on Side-Street Due to New Pedestrian Timing Requirements

In the previous section, the effect on timing was discussed in regards to changes with in the current cycle length utilized. In this section, the discussion is expanded to the changes in traffic signal timing along the Atlantic corridor due to the increases in the cycle length. The increase in the cycle length from 75 seconds to 100 seconds was determined purely based on pedestrian and cross-coordination needs. The corridor can run on a 90 second cycle length given proper semi-actuated gapping at 31st Street. However, it is important to consider cross-coordination as well when considering major crossing at Spring Street, Wardlow Road, and Carson Street, that all run 100 seconds cycle lengths east and west. The impacts of changing from a 75 seconds coordinated cycle length at 4fps to a 100 second coordinated cycle length at 3.5fps were compared.

When the cycle length was raised from 75 to 100 seconds, the approach delays were evaluated on the side streets; the results are shown on Table 9. From the Synchro data, all 10 intersections approach delays increased due to the 25 seconds increase in the cycle length. Some approaches may have had decreased slightly; however, given the both approaches are given greens simultaneously, the approach with higher delay is considered when comparing delays.

TABLE 9. Eastbound/Westbound Approach Delay Comparison for 75 to 100 Seconds Cycle Length Coordinated 4fps to 3.5fps

Intersection	Approach Delay 75 seconds - Cycle @ 4fps (Coordinated)		Approach Delay 100 seconds - Cycle @ 3.5fps (Coordinated)		Delta Change Approach Delay (seconds)
	EB Approach Delay (seconds)	WB Approach Delay (seconds)	EB Approach Delay (seconds)	WB Approach Delay (seconds)	
Spring Street	39.1	43	37.4	44.9	1.9
31st Street	29.5	0.8	43.6	1.4	14.1
33rd Street	11.5	33.4	15.3	46.2	12.8
Wardlow Road	26.5	25.5	38.8	40.6	14.1
36th Street	19.7	14.2	49.8	21.4	30.1
37th Street	17.5	17.5	28.5	18.8	11
Bixby Road	21	21	44.8	34.2	23.8
Roosevelt Road	28	11.8	45.2	11.8	17.2
Marshall Place		28.7		41	12.3
Carson Street	25.7	18.5	39.3	21.9	13.6

Lastly, the variations of increases and decreases of intersection/approach delays are also dependent on the volumes that the main-street and side street experience. From the data, although some intersections are almost identical geometrically, intersections may experience opposing minor increases/ decreases in delay due to the volume variations. Synchro offers linear output data. Actual volume proportions from the side street are minimal and are not critical to determining the cycle length.

In traffic signal timing, when coordinating vehicles along a signalized corridor, a time-space diagram is the most important component. A time-space diagram consists of a X-Y coordinate graph that represents time on the X-axis and space, distance between intersections, along the Y-axis. There are 2 sets of double parallel lines in which the double line headed north-east is for phase 2 (northbound) and the double lines headed south-west is for phase 6 (southbound) window. Given Synchro is a linear modeling software, it does not maximize the coordinating benefit of a semi-actuated coordination. For example, in the case of the Atlantic Avenue corridor, the timing of some of the intersection side streets gives access to purely residential communities from 36th Street north. Traditionally when it comes to traffic signal timing in relations to residential side-streets, most of the cycle length is spent on the main-street due to low volumes and variations of vehicle arrivals throughout the day. It is very common during any given non-peak or peak hour, all of its cycle length goes to the main-street. The inputs in Synchro assume this is experienced every cycle.

When the time-space diagram is considered, the main street green-band mainly varies based on cycle length and pedestrian walking speed. The higher the cycle length and faster the pedestrian walking speed, the wider the green-band. The wider the green-band, the more green-time is spent on the main-street. For example, The intersection of Atlantic Avenue and Carson Street shows 37 seconds eastbound and 48 seconds westbound of green band with a cycle length of 75 seconds with a 4fps pedestrian walking speed; however, when the pedestrian walking speed is reduced to 3.5fps, the green band is 19 seconds eastbound and 35 seconds westbound. This is another example of how pedestrian can significantly reduce the main-street green time allocation. Lastly, when the cycle length is increased to 100 seconds while maintaining a walking speed of 3.5fps, the green allocation for eastbound is 70 seconds and 59 seconds for westbound. See figures 12 to 14 for pictorial reference of the corridor comparison.

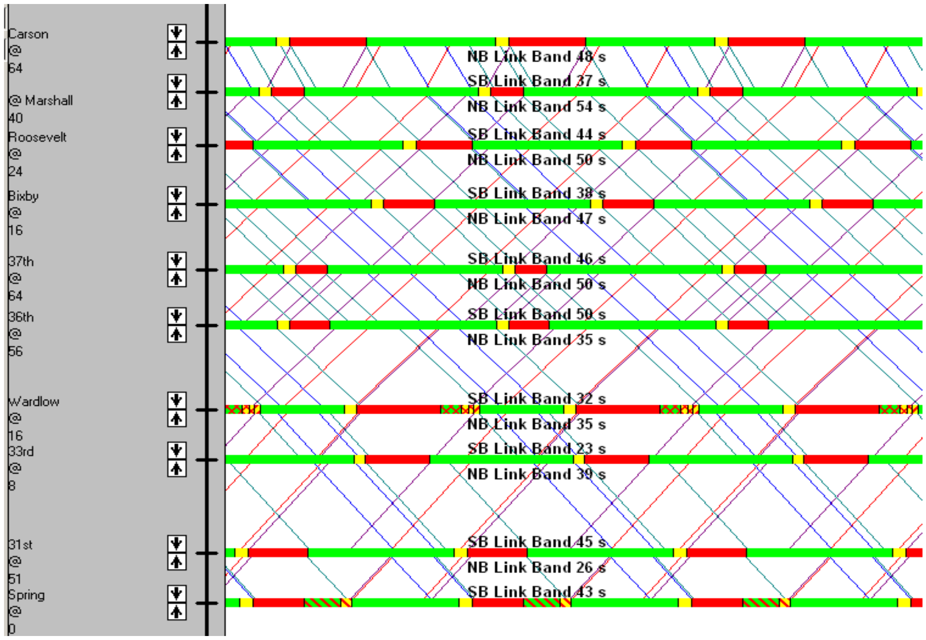

FIGURE 12. Time space diagram for 75 seconds cycle length @ 4fps.

In regards to the increasing the cycle length from 75 to 100 seconds due the pedestrian changing requirements, negative impact is solely passed on to the vehicles on the side-street as shown in Table 9 on page 33. In a semi-actuated coordinated system, if a vehicle from the side street or vehicle in a non-sync phase lane approach misses a call for a green light, it has to wait until the next cycle. The allocated timing for that phase is passed on to the sync phases. In result as the cycle length increases, the green band increases. Typically, the non-sync phase vehicle will notice the change in the cycle length. The benefit in widening the green band, is it makes it easier to coordinate in both directions and push more volume through the corridor. However, when vehicles are out of coordination, due to the longer cycle length, it takes a longer time to get back in coordination.

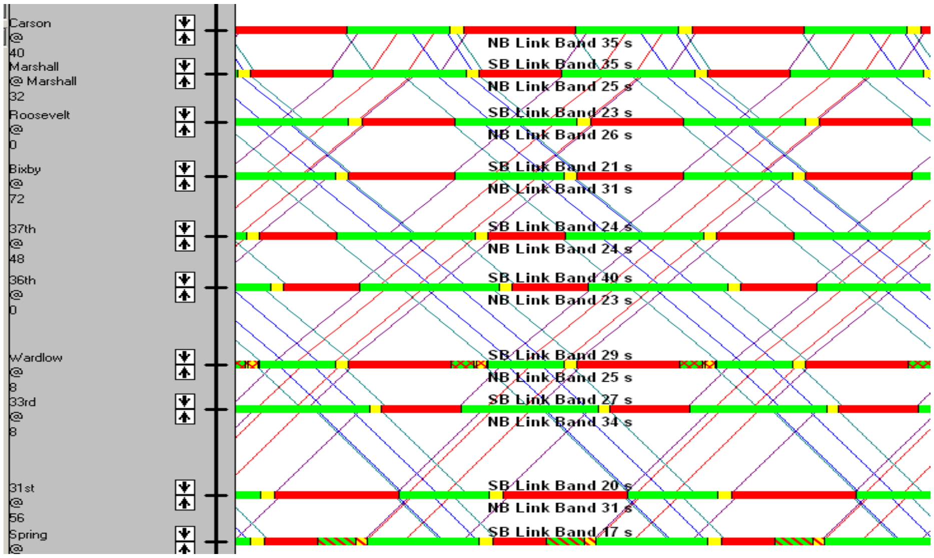

FIGURE 13. Time space diagram for 75 seconds cycle length @ 3.5fps.

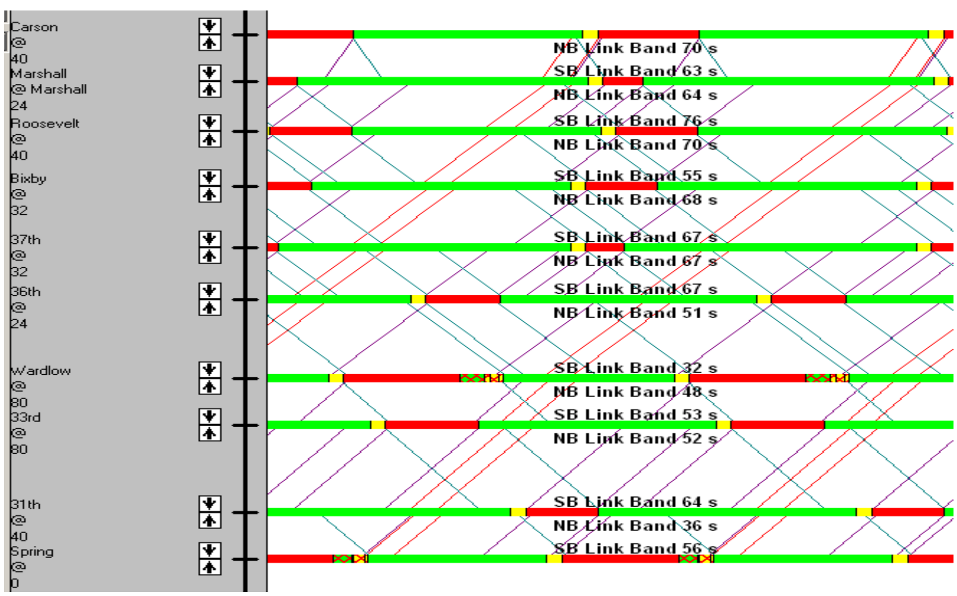

FIGURE 14. Time Space Diagram for 100 seconds cycle length @ 3.5fps.

5.3 Growth Rate Comparison in Volume vs. Delay

In previous section, the change in pedestrian walking speeds was evaluated based on adjustments within the cycle and adjustments by extending the cycle length. Various results determined that the impact to changing the pedestrian walking pace from 4fps to 3.5fps resulted in either delay from the main-street in regards to not changing the cycle length or delays to the side street due to increasing the cycle length. In this chapter, a comparison is discussed based on a 0%,30%,60%, and 90% growth rates.

Spring Street, 31st Street, Wardlow Road, and Carson Street are four intersections on the corridor that are used to evaluate the growth effect when comparing the different evaluated pedestrian walking paces. These intersections were selected because these are the first to experience the most delay over a growth period. Each intersection was compared based on graphical model of the 75 and 100-seconds cycle length.

TABLE 10. Growth Rate for Walking Speed Comparison at 75 Seconds Cycle Length

	Delay, sec @ 3.5-fps				Delay, sec @ 4-fps			
Intersections	G=0%	G=30%	G=60%	G=90%	G=0%	G=30%	G=60%	G=90%
Spring Street	35.7	71.5	154	244	34.5	70.4	152.1	242.9
31st Street	11.3	13.1	15	21	6.8	7.5	10.2	12.4
Wardlow Road	21.4	30.8	85.5	155	20.1	29.8	85	154.2
Carson Street	14.9	31.5	55	113.3	15.5	30.5	53.5	67.9

At the intersection of Atlantic Avenue and Spring Street and Atlantic Avenue and Wardlow Road, the growth rate comparisons were very similar. When comparing the growth rates of 75 seconds at 4fps to 3.5fps, the trend lines were approximately the same.

TABLE 11. Growth Rate for Walking Speed Comparison at a 100 Seconds Cycle Length

	Delay, sec @ 3.5-fps				Delay, sec @ 4-fps			
Intersections	G=0%	G=30%	G=60%	G=90%	G=0%	G=30%	G=60%	G=90%
Spring Street	23.5	31.8	77.8	101	22.3	30.7	76.4	100.6
31th Street	20.2	22.4	25.5	35	8.3	9.4	10.8	13.5
Wardlow Road	24.3	34	45.1	108.4	23.7	30.7	47.6	108.4
Carson Street	18.3	41.1	70.2	116.3	19.3	32.8	70.6	117

However, it is clear the 3.5fps graphical line was constantly higher than the 4fps graphical line; which proves that the 3.5fps does cause more intersection delay. At Wardlow Road, between 0% to 30%, growth rate, the 100 seconds cycle length showed a slightly larger intersection delay gap between the pedestrian walking speed. However, by the time the graphical line reaches 60%, the gap is negligible. These results encountered are due to volume variation and extra allocation of green-time left based on minimum calculations need to maintain coordination with a 3.5fps pedestrian walking speed. Based on the calculations at Spring Street, there was 7 seconds of extra green time and Wardlow Road has 26 seconds extra green time. Given the growth rates are significantly increased, the separation in intersection delay will eventually start to become greater.

In regards to Atlantic Avenue and Carson Street, the trend lines characteristic similar to the Atlantic at Spring Street and Atlantic Avenue at Wardlow Road. Carson Street at 100 seconds cycle length had a slight separation up to 60% growth rate with the 3.5fps walking speed above the 4fps walking speed. Following the 60% growth rate, the trendine started to become more approximate. This is due to volume growth and the cycle length adjustment to extra time just following 3.5fps walking speed for the intersection. When looking at the 75-seconds cycle length, the intersection delay trends are similar up to 60% growth rate. However, as the growth rates approach 90%, the

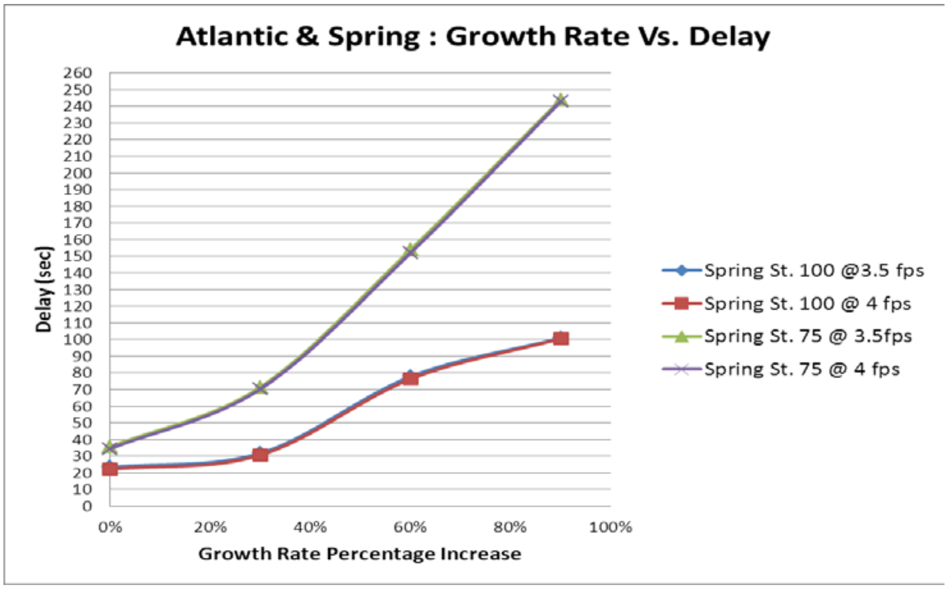

FIGURE 15. Atlantic Avenue and Spring Street growth rate graph.

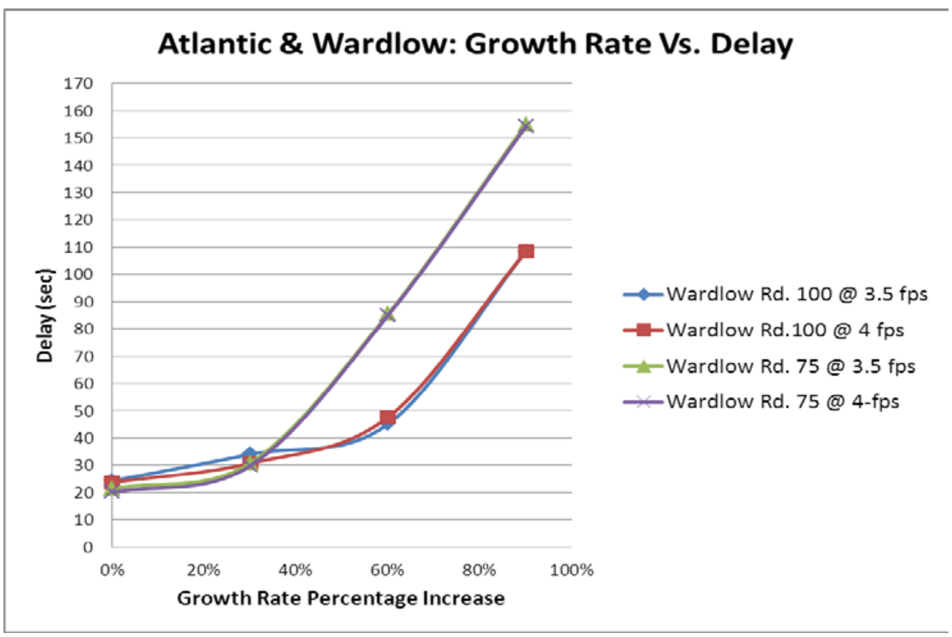

FIGURE 16. Atlantic Avenue and Wardlow Road growth rate graph.

separation between the 3.5fps and the 4fps starts to be larger. At this point, data is showing that the intersection delays start to rapidly increase as intersection volumes increase higher. For all the intersections, this will eventually occur at a certain growth rate.

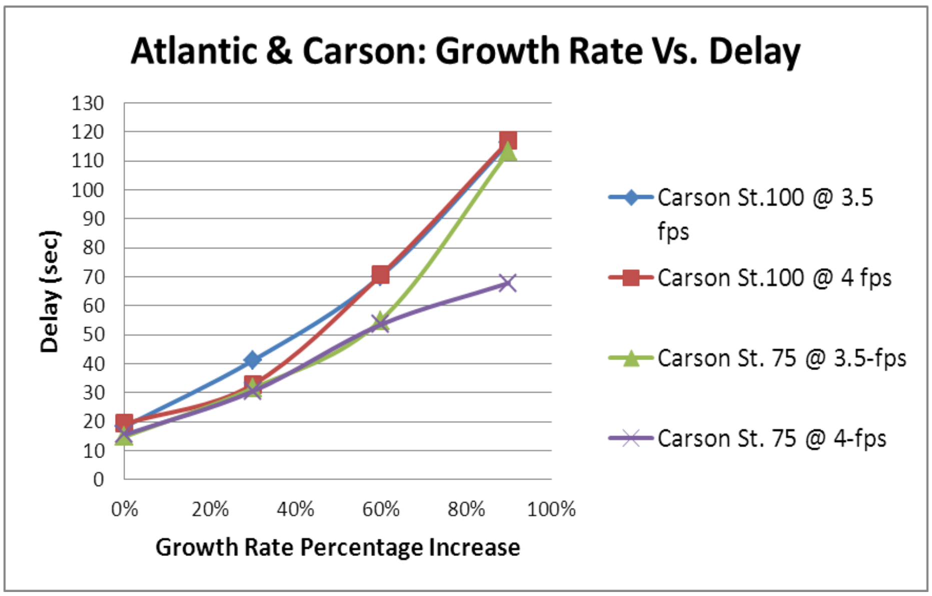

FIGURE 17. Atlantic Avenue and Carson Street growth rate graph.

From the discussion in "Effect on Main Street Due to New Pedestrian Requirements", it was stated that Atlantic Avenue and 31st Street was the most critical intersection due to not meeting minimum green time requirement based on both analyzed pedestrian walking speed. The growth rate output data showed clear separation from the start. For the 75 seconds cycle length, the difference in intersection delay when at 0% was 4.5 seconds and for the 100 seconds cycle it was 11.9 seconds of intersection delay. Once the growth rate reaches 90%, for the 75 seconds cycle length, the intersection delay reaches 8.6 seconds and 21.5 seconds for the 100 second cycle length. The 100 seconds cycle length at 90% almost tripled the difference in intersection delay of the 75 seconds cycle at the 90%. These results were more so expected due to this intersection from the start not meeting its minimum theoretical green-time allocation.

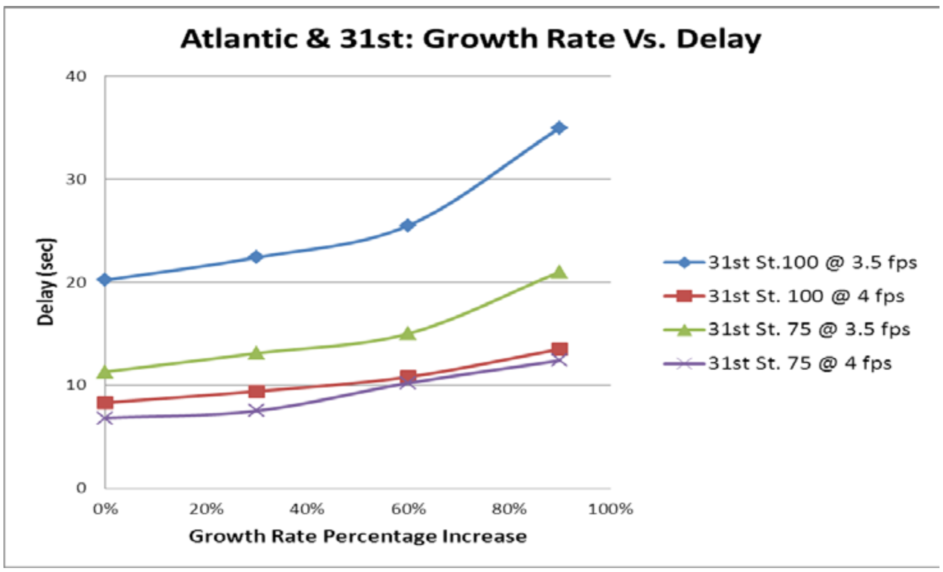

FIGURE 18. Atlantic and 31st Street growth rate graph.

5.4 Pedestrian Walking Speed

When we consider pedestrian walking speed, one must consider location type. Depending on location characteristics, pedestrian walking speeds may vary. They can vary based on business attractions, perception of pedestrian signal equipment, and density of pedestrian groups. From an attraction perception, pedestrians walking through a downtown entertainment attraction are most likely younger compared to pedestrians near a senior center. The difference in attractions will result in different walking speeds. Pedestrian speeds were observed at four different locations. It was determined that some pedestrian gets a sense of safety and ability to meter the speed to cross the street due the pedestrian countdown timer being in place. For example, if a pedestrian has 10 seconds to clear the intersection and he or she has 20 feet remaining to clear the intersection, he or she can walk at 2fps and arrive to the corner approach on time. In reality, the pedestrian walking speed by law is 3.5fps; however, pedestrians can walk at a slower speed than the minimum criteria.

Fifty pedestrian speed samples were taken at each of the four types of locations based on location characteristics. These locations serve different type walking speeds of pedestrians from entertainment, shopping, residential, and downtown business. The reason for selecting these different locations is to serve as a guideline to determine what walking paces should be based on location attraction and if the 3.5fps criteria by law is needed. The intersections that were selected are as followed: Shoreline Drive and Pine Avenue, Atlantic Avenue and Wardlow Road, 2nd Street and Granada Avenue, Ocean Boulevard and Magnolia Avenue.

The first intersection evaluated is Shoreline Drive and Pine Avenue. This intersection is an attraction for tourist to access boat riding, restaurants, viewing water fronts, various entertainment spots. It is typically for families, and younger individual to use this intersection in their leisure time. A sample of 50 pedestrians walking paces were taken at this intersection. Out of 50, there were 7 that walked at a pace between 2.8fps and 3.9fps. Out of this crowd, these were all able body people that have the ability to walk faster. However, since they were in their leisure time and engaged with other individuals crossing the intersection or on their cell phone, they walked lower. The remaining 43 pedestrians walked at a speed between 4fps and 7.4fps. Best on observations, it was apparent that the pedestrians who were walking faster, were on their way to work. That's the differences between leisure and non-leisure pedestrians. The average pedestrian walked at 4.66fps, the 15th percentile walked at 4fps, and the 85th percentile walked at 5.2fps.

At the intersection of 2nd St. and Granada Avenue, the collected data showed 18 out of 50 pedestrians walked between 3fps to 3.8fps and the remaining walked between 4fps and 6.2fps. This intersection is also identified as a leisure intersection. Along 2nd Street in Long Beach are shopping areas and many restaurants to attend. It is also more pedestrian friendly. All of the crosswalks crossing the side street is very short. Most people who are down in the area is walking or talking with someone as they cross the street. As stated above best on observations, engagement in conversation while crossing the street will cause for most pedestrians to walk at a slower speed. The average walking speed was 4.19fps, the 15th percentile was 3.52fps, and the 85th percentile was 4.89fps.

The next intersection evaluated was Atlantic Avenue and Wardlow Road. This intersection is surrounded by businesses and is highly used by the residents who live in the community. Located at the intersection corners are a car wash, gas station, and other local businesses, and bus transit stop. The pedestrian walking pace data collected indicated 3 out of 50 pedestrians walked at 3.5, 3.6, and 3.7fps. The remaining walking paces were between 4.2fps to 9.6fps. The average was 5.05fps and the 15th percentile was 4.35fps and the 85th percentile was 5.75fps. It is expected that the walking pace at this intersection compared to other more entertainment intersections is greater. This intersection is closer to a non-leisure intersection. There are no attractions.

The last intersection evaluated for pedestrian walking speed assessment was Ocean Boulevard and Magnolia Avenue. This intersection is identified as a downtown intersection with many white-collar professionals, young residents, and individual accessing the gym. The pedestrian average walking speed calculated is 4.77fps, the 85th percentile walking speed is 5.34fps, and the 15th percentile walking speed is 4.16fps. There were 4 pedestrians that walked at a walking speed between 3.6fps and 3.9fps. However, now that walked with a speed of 3.5fps or less.

Based on the cumulative data, given 2nd Street and Granada Avenue was the only intersection to produce a 15th percentile walking speed of 3.52fps. This data indicates that the pedestrian timing should incorporate a 3.5fps walking speed. The data does not indicate that pedestrians are walking slower due to their inability to walk faster. It is a combination of intersection characteristics that make these pedestrians walk slower. Short crossing allow pedestrians to feel more safe and relaxed, and to engage socially while crossing the street. The other three intersections evaluated showed a 15th percentile walking speed greater than 4fps is an indication to the most pedestrians are not walking at a less than 4fps walking speed.

CHAPTER 6

CONCLUSION

6.1 Summary

From the findings and discussion within this paper, the findings have identified various impacts to vehicle traffic-flow due to maintaining the cycle length and reducing the pedestrian walking speed from 4fps to 3.5fps, increasing the cycle length with a 3.5fps walking speed, and growth rate impacts. From the various analysis, it was determined that intersection delay increases when the cycle length is increased and the pedestrian walking speed is reduced to 3.5fps. However, the increases are not significant. When regards to growth-rate, as the lane volumes increase, an increasing gap will continuously develop.

6. 2 Recommendations

It was determined that the main effect when changing the pedestrian walking speed from 4fps to 3.5fps, was a transition mode effect can occur when signalized approached are maxed out and Spring Street, 31st Street, and Carson Street go out of synchronization. This was the underlining cause of the intersection cycle length being increased from 75 seconds cycle length to 100 seconds cycle length.

When running a lower cycle length than required, it is recommended that a turning movement count be done during peak hour to determine how the cycle length can be best utilized to prevent a signalized intersection from going into transition mode. Otherwise, the minimum required cycle length based on field conditions should be used.

6.3 Future Research

Concepts in adaptive pedestrian signal timing are under consideration through "connected vehicles" research, which the United States Department of Transportation is leading. These concepts include vehicle to vehicle, vehicle to infrastructure, vehicle to pedestrian, and pedestrian to infrastructure communication. Development of new adaptive pedestrian signal timing software for traffic signal controllers can be the future answer to minimize delay among all modes of transportation by terminating pedestrian timing interval when allocated timing is no longer needed.

APPENDICES

APPENDIX A

PEDESTRIAN WALK PLUS CLEARANCE CHANGE

	Spring St.				31th				33rd.				Wardlow Rd.			
	phase				phase				phase				phase			
	2	4	6	8	2	4	6		2		6	8	2	4	6	8
Walk Time Before	6				6				6				6			
Walk Time After	7				7				7				7			
FDW Before	17	21	17	21	14	18	10		13		13	13	13	13	13	14
FDW After	16	23	16	23	14	21	8		15		15	15	15	15	15	15
Diffemce(+/-/o)	(-)	(+)	(-)	(+)	(o)	(+)	(-)		(+)		(+)	(+)	(+)	(+)	(+)	(+)
Total (+) =	13															
Total (-) =	16															
Total (o) =	7															

	36th				37th				Bixby				Roosevelt				Marshall				Carson St.			
	phase				phase				phase				phase				phase				phase			
	2	4	6	8	2	4	6	8	2	4	6	8	2	4	6	8	2			8	2	4	6	8
Walk Time Before	10	6	10	6	10	6	10	6	6	10	6	10	6				10			6	6			
Walk Time After	10	7	10	7	10	7	10	7	7	10	7	10	7				10			7	7			
FDW Before	10	18	10	18	10	18	10	18	15	28	15	28	15	21	15	21	10			17	20	19	17	19
FDW After	8	14	8	14	7	14	7	14	15	24	15	25	14	19	14	19	10			18	25	19	22	19
Diffemce(+/-/o)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(o)	(-)	(o)	(o)	(-)	(-)	(-)	(-)	(o)			(+)	(+)	(o)	(+)	(o)

APPENDIX B

PEDESTRIAN WALKING SPEED STUDIES DATA

Type of Location	Downtown Food/ Entertainment	
Intersection	Pine/ Shoreline	
1	4.6	4.2
2	5.2	4.5
3	5.2	4.8
4	4.5	4.6
5	4	3.7
6	4.6	5
7	4.5	4.3
8	3.7	4.8
9	4.3	5.2
10	4	4
11	3.6	3.9
12	6.3	3.9
13	2.8	4.2
14	5.7	4.6
15	4.2	4.2
16	4.6	5.2
17	4	4.6
18	4.6	3.8
19	5	5
20	5	5.7
21	4.2	4.8
22	7.4	4.6
23	4.5	4.8
24	5.4	5.9
25	6.6	4
Average	**4.66**	
85th	**5.2**	
15th	**4**	

Type of Location	Community Business Stops	
Intersection	**Atlantic/ Wardlow Road**	
1	4.7	5.8
2	6.6	4.5
3	5.2	4.9
4	4.7	5.1
5	4.7	7.1
6	4.9	6.5
7	4.8	4.5
8	5.9	4.7
9	7.0	5.3
10	5.2	4.3
11	4.5	4.6
12	3.6	4.3
13	4.6	5.1
14	4.8	4.3
15	5.2	4.6
16	4.8	5.0
17	4.2	5.1
18	5.6	5.3
19	4.2	4.9
20	9.6	3.5
21	3.7	5.1
22	4.7	4.6
23	4.7	4.6
24	6.3	5.0
25	5.3	4.7
Average	**5.05**	
85th	**5.753**	
15th	**4.353**	

Type of Location	Shopping/ Dining	
Intersection	**2nd & Granada**	
1	4.5	4.1
2	4.7	3.8
3	4.3	5.1
4	4.4	3.5
5	3.4	5.2
6	3.3	4.0
7	4.8	4.6
8	4.9	3.8
9	5.2	5.1
10	4.0	4.6
11	4.9	4.0
12	3.5	3.8
13	3.8	4.7
14	4.8	3.5
15	5.5	4.0
16	4.5	3.5
17	3.8	4.2
18	4.3	6.2
19	4.0	3.7
20	4.0	3.8
21	3.1	3.6
22	4.2	4.0
23	4.3	3.7
24	4.1	4.4
25	3.0	3.4
Average	**4.19**	
85th	**4.8985**	
15th	**3.5235**	

Type of Location	Downtown Business	
Intersection	**Magnolia/ Ocean**	
1	4.9	5.3
2	4.2	4.2
3	5.5	4.1
4	5.3	5.6
5	4.6	4.7
6	6.4	4.8
7	4.4	3.6
8	5.3	4.3
9	4.5	5.8
10	4.4	4.8
11	5.1	5.7
12	5.3	4.7
13	4.6	4.8
14	4.8	5.6
15	4.5	5.1
16	4.8	4.6
17	4.3	5.0
18	4.1	4.1
19	5.4	3.9
20	4.9	4.7
21	5.0	5.1
22	4.9	4.8
23	5.1	4.1
24	5.4	3.7
25	4.3	3.8
Average	**4.77**	
85th	**5.3423**	
15th	**4.16035**	

APPENDIX C

DEFINITIONS

DEFINITIONS

1. Gapped Out – A phase is given an allocation of green-time. During the onset of
green, when vehicles stop passing over the detection area and there is extra time left, the phase will terminate and the remaining time is given to the major street.

2. Synchronization – When traffic signals are connected/timed to each other for continuous flow of vehicles based on distance and speed. The synchronization movement is typically the main street through directions.

3. Split Phase– at a signalized intersection, each one side of the street is given the right of way one-at-a-time rather than sides being given green together.

4. Time Space Diagram– is used to determine offsets to synchronize traffic signals.

5. Offset- time difference in onset of green in reference to other green along a signalized corridor.

6. Transition Mode- Occurs when the provided cycle length is less than actual cycle length needs and all phases max out.

7. Protected/ permissive left-turn – allows for drivers in the left-turn pocket to make a left-turn with an arrow if three or more vehicles are in the pocket. Otherwise they will just get the green signal indication.

8. Semi-actuated – vehicle detection is installed and operational in the left-turn pockets and the side streets only.

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REFERENCES

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