2015

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Citation Details

Kothuri, Sirisha Murthy; Koonce, Peter; Monsere, Christopher M.; and Reynolds, Titus, "Exploring Thresholds for Timing Strategies on a Pedestrian Active Corridor" (2015). *Civil and Environmental Engineering Faculty Publications and Presentations*. 320.
https://pdxscholar.library.pdx.edu/cengin_fac/320

Exploring Thresholds for Timing Strategies on a Pedestrian Active Corridor

Paper # 15-3025

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Submitted for presentation and publication to the 94th Annual Meeting of the Transportation Research Board January 11-15, 2015

November 2014

7,740 words [4,990+ 9 figures x 250 + 2 tables x 250]

ABSTRACT

Traditional signal timing policies have typically prioritized vehicles over pedestrians at intersections, leading to undesirable consequences such as large delays and risky crossing behaviors. The objective of this paper is to explore signal timing control strategies to reduce pedestrian delay at signalized intersections. The impacts of change in signal controller mode of operation (coordinated vs. free) at intersections were studied using the micro-simulation software VISSIM. A base model was developed and calibrated for an existing pedestrian active corridor. A hypothetical network of three intersections was used to explore the effects of mode of operation and measures of delay for pedestrians and all users. From a pedestrian perspective, free operation was found to be more beneficial due to lower delays. However, from a system wide (all user) perspective, coordinated operation showed the greatest benefits with lowest system delay under heavy traffic conditions ($v/c > 0.7$). In the off-peak conditions when traffic volumes are lower, free operation resulted in lowest system delay ($v/c < 0.7$). During coordination, lower cycle lengths were beneficial for pedestrians, due to smaller delays. The results revealed that volume to capacity (v/c) ratios for the major street volumes coupled with pedestrian actuation frequency for the side street phases, could be used to determine the signal controller mode of operation that produces the lowest system delay. The results were used to create a guidance matrix for controller mode based on pedestrian and vehicle volumes. To demonstrate application, the matrix is applied to another corridor in a case study approach.

INTRODUCTION

Walking is a critical component in the development of healthy and sustainable communities. An estimated 42.5 billion walking trips were undertaken nationwide in 2009, accounting for 10.9% of all trips (*1*). Many of these walking trips occur in urban areas which may require mid-block or intersection street crossings. Signal timing objectives and practices have generally prioritized vehicle movements at intersections- even in places with significant pedestrian activity, which can impose unnecessary delays for pedestrians.

Though intersections are generally viewed as the preferred place to cross the street for safety reasons, they can be a deterrent for walking if their design and operation heavily favor motor vehicles. Unnecessary delays to pedestrians may result in signal non-compliance and negative safety implications. There is emerging interest within cities to promote multimodal transportation, and to design and operate streets and intersections for all users. However, currently there is very limited research on accommodating and/or prioritizing pedestrians at signalized intersections in the North American context. Pedestrians are often considered as a deterrent to efficient traffic flow, due to reductions in saturation flow rate for turning vehicles that occur when vehicle movements are interrupted (*2*). Therefore active efforts to include them in operational decisions at intersections have been lagging.

The objectives of this research were to explore pedestrian responsive signal timing strategies in the context of user delay. In this paper, pedestrian delay is defined as the difference between the time when a pedestrian activates the push button and the time when the pedestrian phase is served. The micro-simulation software VISSIM was used to study the impacts on average delay per user resulting from changes in signal controller mode of operation (coordinated vs. free) with varying pedestrian and vehicular volumes in a hypothetical network. Coordination refers to synchronization of multiple intersections to prioritize certain movements, whereas during free operation, the intersections operate in isolation without a background cycle length (*3*). The results show that free operation resulted in statistically significant lower pedestrian delay irrespective of the vehicular volumes. However, when the entire network is considered, free operation results in statistically significant lower system delays for low v/c ratios ($v/c < 0.7$). Coordination results in lower system delay at higher v/c ratios (> 0.7). These results provide guidance to practitioners to improve system operations and efficiency by changing signal controller mode of operation based on pedestrian and vehicular data that can be easily collected in the field.

The remainder of this paper is organized in the following manner. Related work is reviewed in the background section, followed by descriptions of the methodology, results, conclusions and implications.

BACKGROUND

While vehicular delays have been well researched and quantified (e.g. the Highway Capacity Manual); research on reducing pedestrian delay is minimal. Both analytical and simulation modeling techniques have been adopted to optimize network delays. Bhattacharya et al. used the signal timing optimization software Synchro to study the changes in vehicle delay resulting from changes in coordination plans and offsets (*4*). They found that offsets that produce lowest vehicle and pedestrian delays are not necessarily the same, when pedestrian value of time is considered (*4*). Through a simple analytical model, Noland analyzed the travel delay costs of pedestrians and showed that ignoring pedestrian delay and focusing on vehicular flows may not be the most cost effective solution from an economic perspective, as the travel time costs of delay to pedestrians may be significant (*5*). Ishaque and Noland used micro simulation to understand pedestrian delay and studied the trade-offs between pedestrian and vehicle delays in a hypothetical network (*6, 7*). They found that low cycle lengths benefit pedestrians. A matrix identifying the optimal pedestrian phase based on proportion of pedestrians and vehicles was developed. While the type of pedestrian crossing was varied, they did not study the effects of changing the mode of operation or signal timing parameters on pedestrian delay.

Research conducted in New Zealand evaluated strategies such as phasing changes, signal timing optimization and cycle length reduction to reduce pedestrian delay, using micro-simulation modeling in three cities (*8*). Per person optimization of time was proposed instead of per vehicle to allow for equitable consideration of all users. Although this study evaluated the impacts of certain pedestrian control strategies on delay, it did not evaluate the effects of mode of signal controller operation on delay and the associated feasibility regimes. Roshandeh et al. proposed simultaneous minimization of vehicle and pedestrian delays by adjusting green splits during the peak periods and timing plans during other time periods in a day, without changing cycle lengths and signal coordination (*9*). While signal timing optimization reduced delays within the coordinated framework; delays resulting from uncoordinated operation were not considered.

Tian evaluated different forms of split phasing and pedestrian timing alternatives and their impacts on coordinated systems (*10*). However, pedestrian delay was not explicitly included in the analysis. Wang et al. proposed a pedestrian delay model with a two stage crossing design for unconventional pedestrian crossings (*11*). While the proposed model provides a method to estimate average pedestrian delay at two stage crossings, it does not propose any strategies to reduce delay at single crossings.

METHODOLOGY

In this research, VISSIM micro simulation software was used to model the impacts of changing the signal controller mode of operation from coordinated to free on an urban street network, and to assess the feasibility of traffic regimes for each mode of operation.

First, a base model was first constructed, calibrated and validated. All the data required for simulation and validation were gathered via field observations, either manually or extracted from video. Results from the base model were analyzed (but are not reported here in detail). Using the base model as a starting point, a hypothetical network was then constructed. Pedestrian and vehicle volumes were synthesized in high, medium and low categories. Simulation models for each combination of these scenarios were run and analyzed. The following describes these steps.

Base Model Development and Calibration

Three signalized intersections were chosen for simulation: NE 11th Avenue, NE 13th Avenue and NE 15th Avenue along NE Multnomah Street. These intersections were chosen based on criteria such as heavy pedestrian activity, coordinated operations, presence of pedestrian push buttons and Type 2070 signal controllers (for data logging). A protected cycle track was added along NE Multnomah St in late 2012 by reconfiguring the corridor from five lanes to three lanes. Figure 1 shows the Multnomah Street network that was used for simulation.

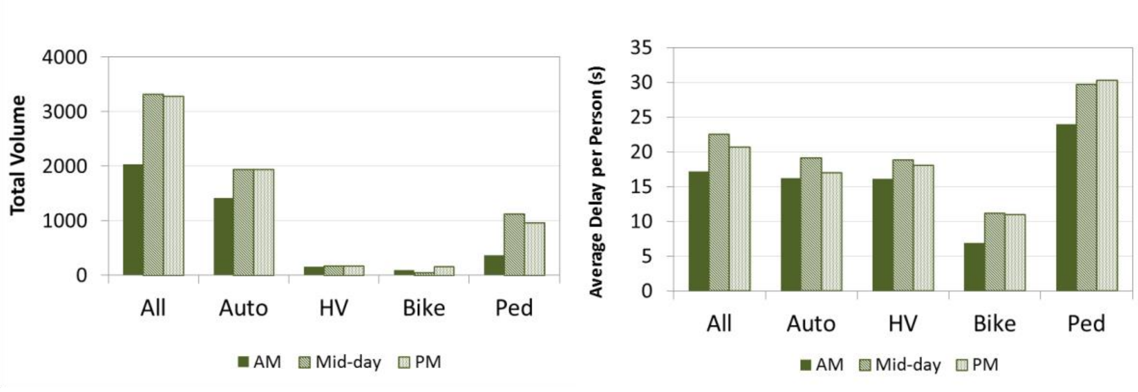
FIGURE 1 Multnomah Street Simulation Network

Vehicle and bicycle volumes were collected using pneumatic tube counters and pedestrian volumes were collected manually for each crosswalk in the network. The total bicycle and vehicle volumes were then allocated to each approach based on manual turning movement counts. The time periods chosen for data collection were 7-8 AM, and 4-6 PM to correspond with the typical AM and PM vehicular peak periods, as well as 11AM – 1 PM which represented a time period with high pedestrian activity and low vehicle volume. Signal timing for each intersection was obtained from TransSuite®, the central ATMS software for the City of Portland, Oregon. The east and westbound movements along Multnomah St. were coordinated during all time periods. The cycle length at the three intersections varied between 70 and 80 sec, with the higher cycle length in operation during the day.

The network was created in VISSIM, a micro-simulation software that provides the ability to model the interactions between various users. Road geometry for network development was partly obtained from Google Maps® Satellite images. Road widths and speeds were obtained from City of Portland's records if available and were assumed otherwise. Vehicle composition was obtained from the pneumatic tube counts. Once the network was developed, it was calibrated. Calibration is the process used to obtain a reliable model by specifying certain parameter values so that the model replicates local traffic conditions as accurately as possible (*12*). During calibration, modeled volumes and travel times from the simulation were compared to the observed values to assess how closely they matched. These parameters including queue lengths were accepted as matched based on prior set guidelines (*12*). Detailed descriptions on the simulation setup and calibration process can be found elsewhere (*13*).

Three time of day models were run in VISSIM using the appropriate volumes and signal timing parameters. The signals were in coordination during all three time periods. The main street pedestrian phase was placed in recall and rest in walk setting was also enabled to mimic the operation in the field. The rest in walk feature allows the pedestrian walk phase to expand during the coordinated movement green until a conflicting call on the side street is received. Side street pedestrian phases at Multnomah and 11th and Multnomah and 15th were also placed on pedestrian recall and side street phase at Multnomah and 15th was placed on maximum recall to replicate the field settings.

Performance metrics were extracted from the simulation. The results presented here represent an average of 10 simulation runs. Figure 2a shows the network volume by mode for each of the analyzed time periods.



a) Network Volume by Mode b) Average Delay per User by Mode

FIGURE 2 Performance Metrics from Base Model

It is apparent from Figure 2a, that Multnomah corridor is busier during the mid-day and PM peak periods compared to the AM period. The highest percentage of pedestrians is observed during mid-day. Average network delays and per mode are shown in Figure 2b. The average delays for auto users were below 20s during all the analyzed time periods, with the delays during AM and PM peaks slightly lower than mid-day. For pedestrians, the delay is lowest during AM peak and increases during mid-day and PM peak and approaches the 30s threshold. Compared to all the users in the network, pedestrians faced the largest delays. Bicycle delays are lowest, because only the through bicycle movements on Multnomah Street are simulated in this research and as such they benefit from the green band and progression during coordination.

Hypothetical Network Development

A hypothetical network was constructed based on the validated Multnomah Street network and was used to study the impacts on delay resulting from change in signal controller mode of operation from coordinated to free. Scenarios pertaining to coordinated and free operation were tested with varying vehicular and pedestrian demands to determine the traffic regimes for which each mode of operation would be best suited. The metric for determining feasibility of mode of operation (coordinated or free) was minimization of overall network delay.

While the majority of the Multnomah network features were carried over to the hypothetical network, a few changes were made. All Multnomah pedestrian movements are placed on recall and rest-in-walk enabled for coordinated operation, which was unchanged from the existing network. All side street vehicular and pedestrian movements were actuated in the hypothetical network, while previously in the Multnomah St. network some of these movements did not have detection and were placed on recall. The vehicle, bicycle and pedestrian flows were varied in three ranges of high, medium and low demand. Hypothetical vehicle, bicycle and pedestrian volumes for the high scenario are shown in Figure 3. The bolded figures represent the bicycle volumes. The medium and low volumes were assumed to be 60% and 30% of the high volume respectively.

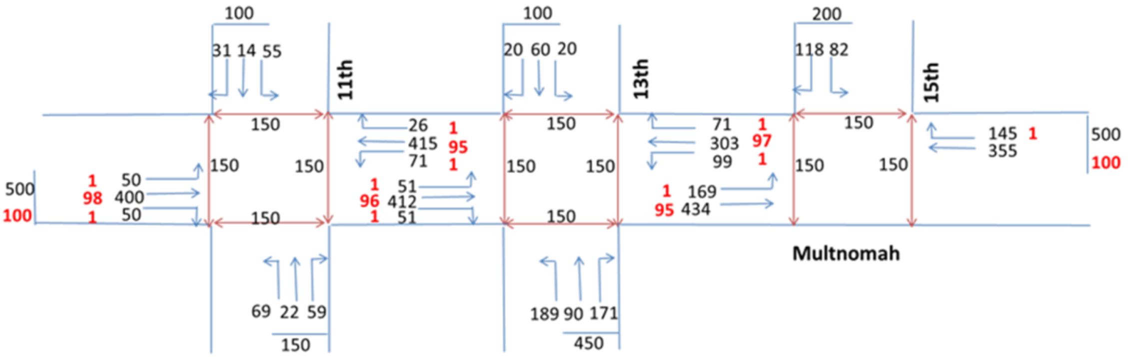


FIGURE 3 Hypothetical Vehicle, Bicycle and Pedestrian Volumes (High Scenario)

In order to determine the high auto volumes, the capacity for each lane group was estimated using HCM methodology (2). The volumes for each lane group for the high volume scenario were assumed such that a v/c ratio of 0.7 or greater was achieved for the coordinated movements (through movements). The exception to that rule was at Multnomah and 15th, where the v/c ratio for high scenario was 0.5 – 0.6, due to only two phases being operational at the intersection, which in turn resulted in more green time for the coordinated movement. The v/c ratios for the coordinated movements for high, medium and low volume scenarios at the three intersections are shown in Table 1.

Pedestrian volumes were also divided into three ranges of high, medium and low. Based on the input volume provided by the user, VISSIM loads the pedestrians onto crosswalks using the Poisson distribution. These volumes were assumed based on the frequency of pedestrian phases in an hour. In the high scenario, the demand was assumed such that a pedestrian phase would come up every cycle. The pedestrian volume was obtained by observing multiple simulation runs with varying pedestrian volumes and determining the number of cycles during which the pedestrian phase was served. For example, the maximum number of cycles in one hour with an 80 sec cycle length is 45 (3600/80). Assuming a pedestrian volume of 150 per crosswalk, the number of pedestrian phases served in one hour based on observation of multiple VISSIM runs is 45. This implies that the pedestrian phase is served every cycle and the frequency is 100%. In the medium and low scenarios, the pedestrian phase was designed to be served during approximately 60% and 30% of the number of cycles in one hour. Table 1 also shows the varying pedestrian flows for the high, medium and low scenarios.

TABLE 1 Assumed Inputs for Different Scenarios

Intersection	***High***		***Medium***		***Low***	
	EB	***WB***	***EB***	***WB***	***EB***	***WB***
v/c, Multnomah and 11th	0.73	0.71	0.43	0.44	0.24	0.22
v/c, Multnomah and 13th	0.96	0.77	0.57	0.47	0.29	0.23
v/c, Multnomah and 15th	0.60	0.50	0.36	0.30	0.18	0.15
Ped Volume/Cross-Walk		150		50		10
# of Cycles (80 s Cycle Length)		45		45		45
# of Observed Ped Phases		45		29		10
Ped Phase Frequency (# Ped Phases/# Cycles)		100%		64%		22%

RESULTS

Based on the varying combinations of auto and pedestrian volumes, a total of 18 simulation models were constructed; 9 for each mode of operation. For each combination of auto and pedestrian volume, 10 runs were carried out. The number of runs was selected based on the recommendation in ODOT's VISSIM protocol guide (*13*). Using a random number generator, a starting random seed was generated and a total of 180 simulation runs were created. Each run was approximately 75 minutes long and the data from the first 15 minutes was discarded for analysis purposes as the network was still being populated during this time. The simulation resolution was set to 10 time steps/s similar to the calibrated Multnomah St. network.

The resulting simulation outputs were analyzed and performance metrics were extracted similar to original Multnomah Street network. Percent change in average delay resulting from each mode of operation was the metric used for comparison and is calculated using the equation below:

$$\%\ \text{Difference in Delay} = \frac{(\text{Free Delay} - \text{Coordinated Delay}) * 100}{\text{Coordinated Delay}} \quad 1$$

Three sets of comparisons between delays resulting from coordinated and free operation were made. First, existing signal timing including cycle lengths, splits and offsets from the field were used for coordinated operation. In addition, to make a fair comparison between average delays resulting from the two modes of operation, the signal timing optimization software VISTRO was used to optimize the signal timing in two ways. First, the splits and offsets for each scenario were optimized, while keeping cycle length constant (80 sec). Next, the cycle length was also optimized in addition to the splits and offsets. During cycle length optimization, a cycle length of 70s was chosen by VISTRO for low vehicle volume scenarios and 90s was chosen for high volume scenarios. The resulting pedestrian and overall average delays were compared and the percent change in average delays for coordinated and free operation using existing as well as optimized timing are shown in Figure 4 and Figure 5. The x-axis shows the different scenarios with varying auto and pedestrian volumes. For example, low-low refers to low auto - low pedestrian scenario.

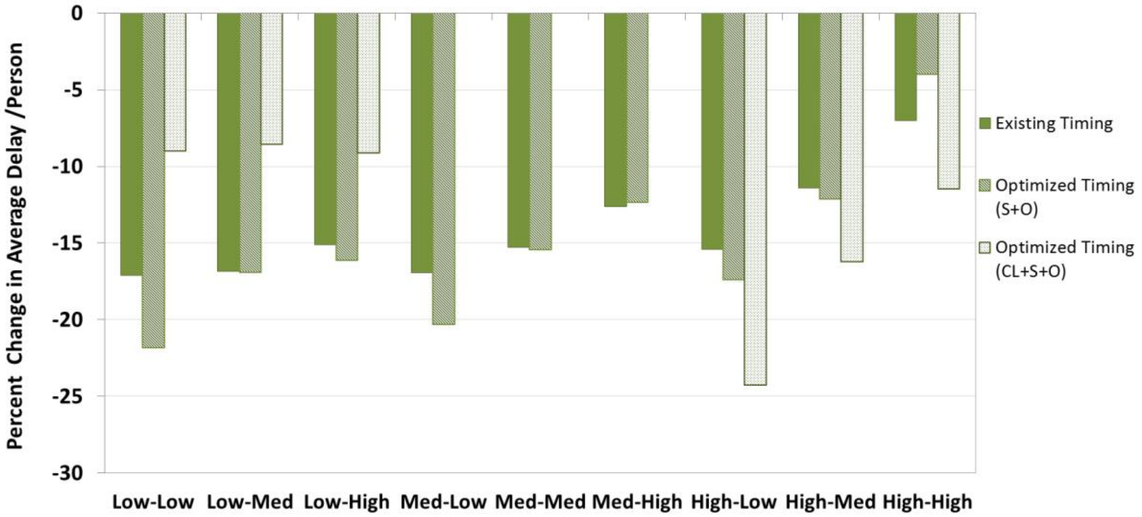


FIGURE 4 Percent Difference in Average Pedestrian Delay

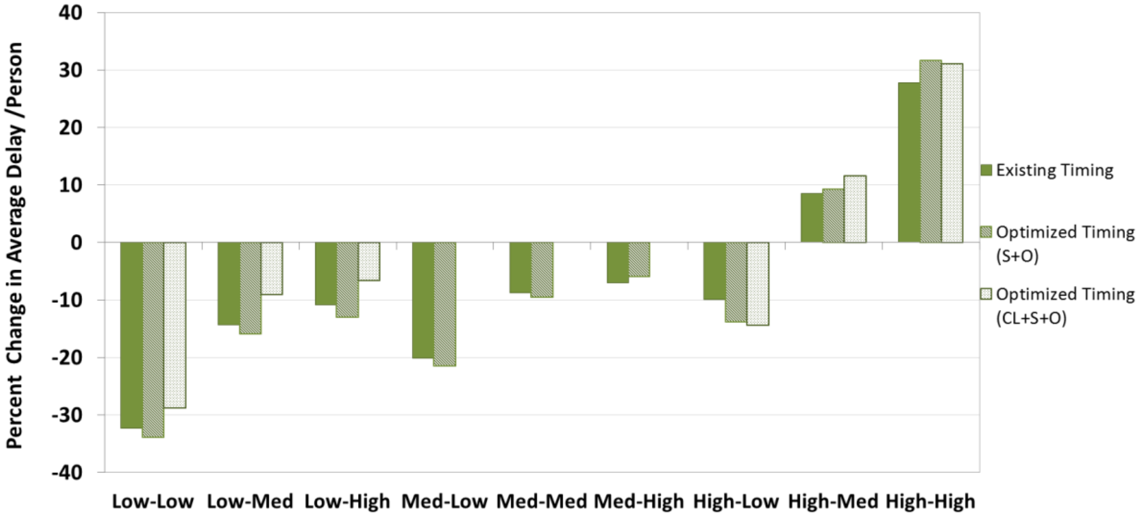


FIGURE 5 Percent Difference in Overall Average Delay

In the analysis presented above, for every tested scenario, pedestrian delay is always lower during free operation irrespective of the auto volumes as seen in Figure 4. However from an overall delay minimization perspective, when all users are considered, the trends in Figure 5 clearly indicate that free operation produces lower system delays for low and medium vehicle volumes (v/c ratios for mainline through movements < 0.7). Coordinated operation is beneficial when auto volumes are nearing capacity (v/c > 0.7).

Delays for coordinated operation were compared to the delays resulting from free operation using Welch's two sample T-Test with unequal variances. For all the nine scenarios, overall average delay per user was significantly different between coordinated (existing or optimized) and free operation at 95% confidence ($\alpha = 0.05$). The average delays for each scenario and each mode of operation as well as the resulting p-values are shown in Table 2.

TABLE 2 Overall Average Delays for Different Scenarios

Scenario *Auto-Ped*	*Coord Delay (s) (Existing)*	*Coord Delay (s) (Optimized)*	*Free Delay (s)*	*p-value (Existing)*	*p-value (Optimized)*
Low – Low	12.79	13.08	8.65	3.49E-14	2.53E-13
Low – Med	16.57	16.88	14.19	1.72E-08	4.09E-13
Low – High	19.97	20.47	17.80	1.13E-09	2.44E-13
Med – Low	13.74	13.97	10.97	6.23E-13	1.56E-13
Med – Med	16.49	16.62	15.04	2.88E-06	9.63E-07
Med – High	19.99	19.76	18.58	1.32E-08	3.16E-08
High – Low	16.37	17.09	14.74	1.01E-06	5.09E-09
High - Med	19.58	19.45	21.25	0.02	0.01
High - High	22.01	21.37	28.12	0.00	0.00

DISCUSSION

This research has demonstrated empirically, the various traffic regimes that are best suited for strategies that benefit pedestrians from an efficiency perspective. Under the conditions assumed in the simulation, the results demonstrate that free operation is beneficial for pedestrians leading to reduced delay as compared to coordinated operation. Free operation also shows network benefits under low and medium volumes (v/c for main line through movements < 0.7). Coordinated operation was beneficial when traffic volumes are high (v/c > 0.7). While in coordination, lower cycle lengths generally benefit pedestrians.

System operators and signal timing engineers face tradeoffs each day while operating the signals at various intersections. The primary tradeoff is balancing safety vs. efficiency. Secondary tradeoffs include balancing delay between modes such that no mode is unduly penalized. Although traditional signal timing policies have favored motor vehicles, this policy needs to be reconsidered if cities want to develop livable communities that promote walking and bicycling. Therefore, with the aim of providing guidance to system operators, a concept graphic based on the results obtained in this research has been developed, that seeks to consolidate the findings with the objective of informing signal timing decisions based on policy. Figure 6 shows the graphic with recommendations for operational decision strategies at the intersection level.

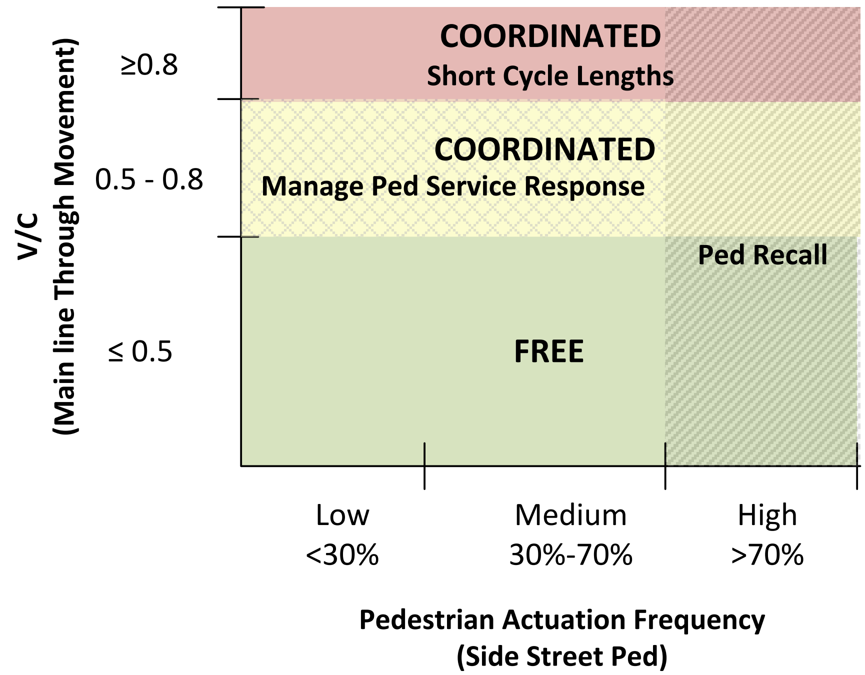


FIGURE 6 Strategy for Change in Signal Controller Mode of Operation

Although the results showed that free operation provides benefits when v/c is less than 0.7 for the main line through movements, this graphic takes a conservative approach by recommending free operation when v/c is less than 0.5. Coordination with the ability to manage the type of pedestrian response is recommended for the middle regime where v/c is between 0.5 and 0.8 and the pedestrian actuation frequency is low or medium. The type of response for pedestrian service will depend on the policies adopted by agencies and the priority hierarchy assigned for each mode. Pedestrian friendly strategies such as temporary removal of a signal from coordination by increasing permissive length or providing pedestrian priority service could be employed, if agencies want to prioritize pedestrians (*14*). Permissive length refers to the period of time during the coordinated cycle during which a call received on a non-coordinated phase results in transition from the coordinated to the non-coordinated phase (3). Prior research by Kothuri et al. has shown that increase in permissive length can produce significant reductions in pedestrian delay (*14*). For v/c ratios greater than 0.8, coordination is recommended with short cycle lengths, so that pedestrians are not faced with large delays. It is recommended that pedestrian signals be actuated with pushbuttons when the actuation frequency is less than 70% of the number of cycles during the design time period. Higher actuation frequencies dictate the need for pedestrian recall. Placing the pedestrian movements on recall during periods of low actuation has the potential to impose unwarranted delays on the main street movements leading to larger delay overall and lower system efficiency.

However, switching the pedestrian detection from actuated to recall based on time of day could be confusing for pedestrians given the existing detection technology limitations at intersections. In the future, this could be mitigated with advances in automated detection technology that could respond efficiently to fluctuations in pedestrian volume.

To implement the strategies discussed above using the graphic, the primary inputs required are major street through volumes and side street pedestrian actuation frequency. Typically, many cities gather volumes on arterials using some form of detection (loop, microwave, radar or video). The actuation frequency is easily logged through the signal controller (*13*).

Using time of day auto volumes and pedestrian actuation patterns, system operators can identify time periods during the day when a certain signal controller mode of operation is justified based on the lowest overall average delay per user.

As an example, Figure 7 shows the auto volumes and pedestrian actuations for the Multnomah Corridor on Thursday, October 3, 2013. As discussed earlier, the pedestrian volumes along the three analyzed intersections at this corridor are higher during mid-day and PM peak periods compared to the AM peak. Therefore, the corridor could stay in coordination during morning (6 AM – 11 AM) to prioritize auto, bicycle and transit volumes along the major street. This time period would represent the high auto scenario where coordinated operation is recommended as discussed earlier. Due to the higher pedestrian demand and low vehicle demand during noon and early afternoon, the signals could switch to free operation between 11 – 3 PM to benefit pedestrians (Low Auto – High Ped). Between 3 – 8 PM, the signals could switch back to coordinated operation to benefit the heavy PM peak period traffic volumes (High Auto – High Ped). Allowing the signals to operate in a free mode at night (after 8 PM) would allow the signals to be more responsive to the low traffic conditions (Low Auto – Low Ped).

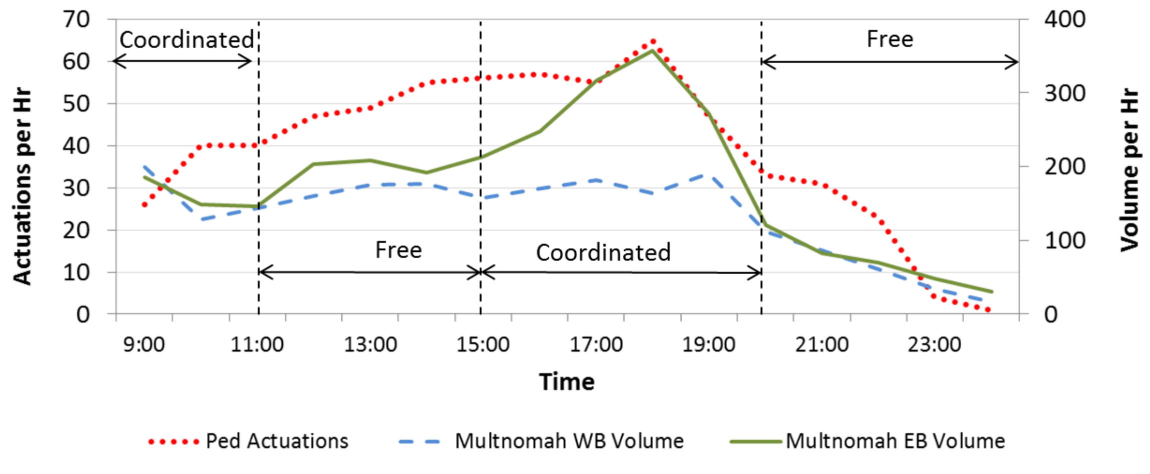


FIGURE 7 Concept Mode of Operation Based on Time of Day

Allowing free operation during certain times of the day could be easily applicable to signals that are close to high pedestrian demand generators such as shopping malls and theaters. This strategy could also be used at signals with low pedestrian compliance rate or high pedestrian crash rate, to improve safety by reducing pedestrian delay. While this research presented an empirical framework to assess the optimal mode of operation based on overall average delay per user, there are other factors that could also predispose certain locations towards coordinated operations. Closely spaced intersections (1/4 mile or less) can benefit from coordination due to platooning effect (*15*). The ratio of side street to major street volume is another factor that could impact the decision on mode of operation. If the ratio is low, coordinated operation may be preferred as it would benefit the higher volumes on the major street. Conversely, higher ratios would favor free operation. This strategy of changing the signal controller mode of operation would be best suited for minor arterials with intersecting cross streets that have low vehicular volumes, but may have moderate or high pedestrian demand.

The framework designed here is applied to another corridor, Division Street in Portland, Oregon to assess the transferability of the findings and the results are presented in the following section.

CASE STUDY APPLICATION

Division Street is an east-west arterial corridor in Portland, Oregon carrying approximately 18,000 vehicle trips per day. Three intersections were chosen for simulation analysis to test the robustness of the operational strategy described in the previous section based on recommendation from city staff: SE 119th Avenue, SE 122nd Avenue and SE 130th Avenue along SE Division Street. Along this stretch, Division Street has two lanes in each direction, with additional turn lanes at intersections. Figure 8 shows the network of three intersections that were included in the simulation.

FIGURE 8 Division Street Network used in VISSIM

All the data required for the simulation were obtained from the City of Portland records or other sources, and if unavailable, were assumed. Currently, the intersection of 122nd and Division is being operated in a free mode, however for the purpose of this analysis, it was placed in coordination with a cycle length of 120s and the signal timing parameters were obtained using VISTRO. The existing volumes corresponded to the medium auto-low ped scenario.

Based on the learnings from the Multnomah corridor, the expected finding was that overall percent difference in average delay for the medium auto-low pedestrian scenario, compared between the coordinated and free operation would be lower for the free operation. 10 simulation runs were performed for the coordinated and free operation (fully actuated) and average delay metrics were extracted. As expected, the overall average delay was lower in the free mode of operation as seen in Figure 9. Hypothetical pedestrian and auto volumes were chosen for the low auto – low ped and the high auto – high ped scenarios based on v/c ratios and pedestrian phase frequency. The analysis presented earlier for hypothetical Multnomah Street network was repeated for just the low auto-low ped and high auto-high ped scenarios along the Division Street corridor as the objective was to assess whether general trends seen earlier were followed. Figure 9 shows the difference in percent average delays on Division Street. Note that the medium auto-low ped scenario corresponded to the existing conditions.

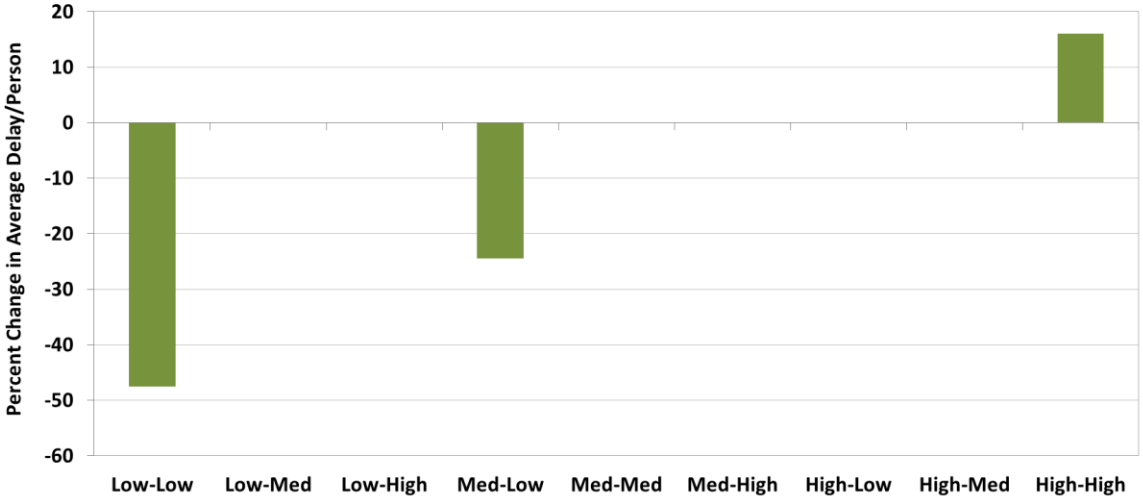


FIGURE 9 Percent Change in Average Delays across Scenarios

The plot above shows similar trends as seen in the hypothetical analysis on Multnomah Street. This analysis reinforces the prior findings that free operation shows benefits for light traffic conditions and coordination is preferred for heavy traffic conditions.

CONCLUSIONS AND IMPLICATIONS

Improving efficiency for pedestrians at intersections by reducing their delay is critical, if cities want to encourage walking. Using VISSIM, this study has empirically explored the impacts resulting from changing the signal controller mode from coordinated to free operation. The results revealed overall delay reductions between 7%-32% when the signals were operated in the free mode during lower volume conditions compared to coordinated operation (80s cycle length). Greater delay reductions (52%) were obtained with free operation during low volume conditions compared to coordinated operation with higher cycle lengths (120s). Similar trends were found when the analysis was repeated on Division Street. Free signal operation was found to benefit pedestrians by lowering their delay. When coordination is warranted at higher v/c ratios, pedestrian friendly strategies such as dropping signal coordination to service the pedestrian, increasing permissive length and utilizing lower cycle lengths can be helpful. These results provide guidance to practitioners in determining the appropriate mode of signal operation based on field inputs to improve efficiency at intersections.

The traditional practice of prioritizing vehicles over users of all other modes should be reevaluated in the context of livability. As communities engage in efforts to improve livability and aim to transform their streets into vibrant public spaces that foster interactions, a new approach that balances user needs is necessary to accommodate all modes and improve safety for all users.

ACKNOWLEDGEMENTS

Funding for this study was provided by the National Institute for Transportation and Communities (NITC). The authors gratefully acknowledge Alex Kiheri (PTV America) and Miranda Wells (HDR) for their assistance with the simulation set up.

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