GETTING THERE ON TIME: WHY TRAVEL TIME RELIABILITY ISN'T JUST FOR DRIVERS

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Presented for the ITE Western District Annual Meeting, June 2017, San Diego, California

Abstract

Travel time reliability has historically been analyzed in the transportation engineering and planning context as a metric to evaluate the consistency of travel times for motorists along a corridor. However, travel time reliability metrics may also be applied to other modes of transportation, such as pedestrians. One key situation where pedestrian travel time reliability issues are important is near fixed guideway transit stations. Signalized intersections with pedestrian crossings may be regularly affected by transit signal priority (TSP) or preemption. Signal preemption and TSP introduce variability into intersection operations that results in pedestrian phases being skipped or delayed. This not only increases pedestrian delay at the intersection, but can result in increased overall travel time if the pedestrian misses their bus or train. To avoid missing a transit connection, pedestrians may risk their safety by crossing against a red signal or by making other unsafe movements to ensure that they are able to catch their bus or train.

For three case studies, a complex multimodal station area transportation network was modeled using microsimulation software to measure travel time reliability for pedestrians. The effects of preemption and transit signal priority for side-running and median-running transit operations on pedestrian travel time reliability were modeled and compared to baseline predicted reliability. A Monte Carlo simulation approach is used to estimate the effects of travel time reliability on a typical pedestrian transit access trip. Signal operations, detection, and design strategies to improve pedestrian travel time reliability at crossings are explored to improve the user experience and promote multimodal safety.

Introduction

Travel time reliability relates the average duration of a trip to the range of trip durations over the course of many days. Unexpectedly long delays (relative to the typical duration of a trip) tend to be viewed very negatively by transportation system users. For transit trips, unexpectedly long delays for the portion of a transit rider's trip between the trip origin and transit station may result in a rider missing their train or bus. This delay penalty of one transit headway may be compounded if a rider must make transfers over the course of their trip. For transit systems with long headways (greater than 10 minutes), the excess delay may encourage a mode shift away from transit and towards private automobile. Also, a rider may choose to make unsafe pedestrian movements (such as crossing against a red signal or jaywalking) to ensure that they catch their bus or train. Generally, pedestrian compliance with signals begins to degrade after delays are in excess of 30 seconds[1]. The possibility of further delay due to missing a transit trip would tend to encourage noncompliance at smaller values of delay.

Fixed guideway transit facilities such as heavy rail, light rail, or high-frequency bus service use preemption or transit signal priority (TSP) to establish right-of-way priority and/or increase the overall speed of service along a transit line. These signal operations modifications introduce disruptions to vehicle and pedestrian signal phases alike, which will occasionally increase delays for some or all movements at an intersection. A motorist or pedestrian approaching an intersection cannot typically anticipate these increased delays. The delays may range from a few seconds (in the case of a low-impact TSP event) to several minutes (in the case of a multiple commuter train preemption event). For transit stations located immediately adjacent to intersections, preemption or TSP affect pedestrian travel time reliability for a large number of riders.

Traditional Methods of Estimating Pedestrian Delay at Intersections

Estimates of pedestrian delay at intersections have historically been calculated through the use of equations provided in the *Highway Capacity Manual (HCM)*. For example, the *2010 HCM* suggests the following model for calculating pedestrian delay at intersections[2]:

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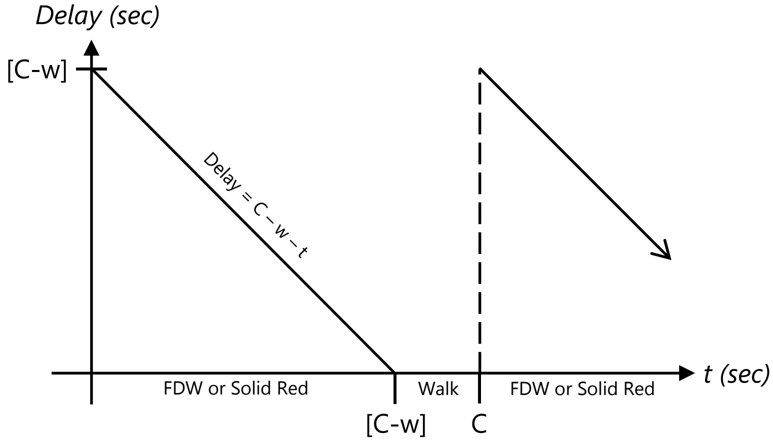
[1] Dunn, R., and R. Pretty. Mid-Block Pedestrian Crossings - An Examination of Delay. *Proc., 12th Annual Australian Road Research Board Conference,* Hobart, Tasmania, Australia, Aug. 1984.

[2] *Highway Capacity Manual 2010.* Washington, D.C.: Transportation Research Board, 2010. Page 18-68.



Arrival Time at Intersection Relative to Pedestrian Signal Indications and Cycle Length

Where:

C = Cycle Length

w = Effective Walk Time

Key Assumptions:

Uniform Pedestrian Arrivals

Pedestrian Call Present Every Cycle

Using the delay model and assumptions above, the equations representing average (expected value) pedestrian delay and the standard deviation of pedestrian delay are as follows:

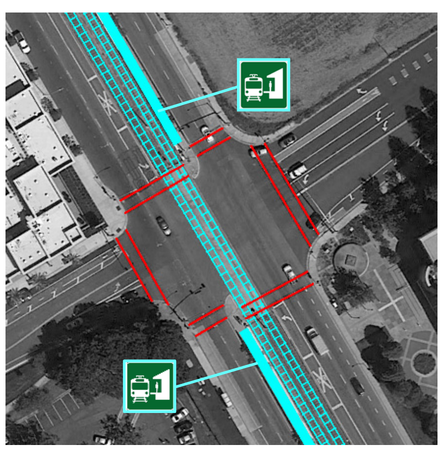
$$Average\ Delay\ (seconds) = \frac{(C-w)^2}{2C} \qquad Standard\ Deviation\ of\ Delay\ (seconds) = \left(\frac{(C-w)^3}{3C} - \frac{(C-w)^4}{4C^2}\right)^{\frac{1}{2}}$$

The above equations are good approximations of the average pedestrian delay and the standard deviation of pedestrian delay at intersections where ideal, predictable signal operations are present, and pedestrian arrival patterns are random and uniformly distributed. However, signal operations and pedestrian arrival patterns are rarely predicable, especially at intersections near transit stations with preemption or TSP, which makes the equations a less-than-ideal choice for modeling pedestrian delay. For example, pedestrian arrivals tend to bunch when a transit vehicle arrives at a transit stop, which may trigger preemption or TSP. Therefore, a microsimulation model should be considered when modeling pedestrian delay at locations where irregular signal operations or non-uniform pedestrian arrival patterns occur.

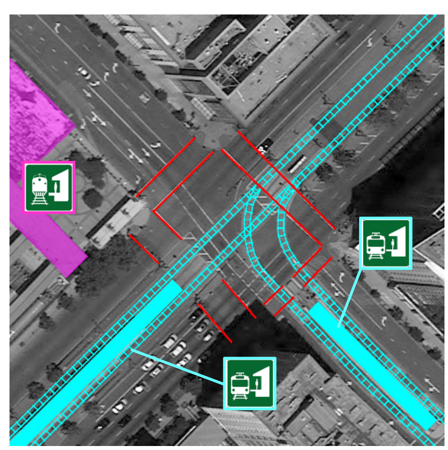
Case Studies

To measure the effects of TSP and preemption on pedestrians at intersections near transit stations, three case studies with a transit station adjacent to an intersection (shown in **Exhibit 1**, below) were modeled in the VISSIM microsimulation analysis package.

Side-running heavy rail transit (HRT) station adjacent to intersection with preemption



Median-running light rail transit (LRT) station adjacent to intersection with TSP



Intermodal hub (HRT terminal with median-running LRT) adjacent to intersection with TSP

Exhibit 1 – Transit Access Intersection Case Studies

The VISSIM models were calibrated and validated to existing year (2014-2016) conditions and used signal timing data provided by local agencies. These scenarios were tested against a baseline configuration where no TSP or preemption was provided to isolate the effects of transit-related signal operations. Uniform pedestrian arrivals were assumed as detailed pedestrian origin-destination and arrival pattern data was not available. The VISSIM models reported average pedestrian delay and the standard deviation of pedestrian delay for each crossing. The averages and standard deviations were aggregated for each crossing to determine the delays of pedestrian movements transverse and parallel to the fixed-guideway transit. **Table 1** presents the results of the VISSIM simulations.

TABLE 1: AVERAGES AND STANDARD DEVIATIONS OF PEDESTRIAN DELAY (SECONDS)

Pedestrian Movement	Baseline[1]		Preemption		Transit Signal Priority	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Side-Running Heavy Rail Transit Station Adjacent to Intersection						
Parallel to Tracks	71.2	18.2	68.8	20.7	N/A	
Transverse to Tracks *Primary Station Access*	72.1	8.1	109.7	20.6	N/A	
Median-Running Light Rail Transit Station Adjacent to Intersection						
Parallel to Tracks	58.9	6.8	59.6	9.5	58.3	14.2
Transverse to Tracks	60.9	11.0	87.7	23.6	58.4	10.3
Full Crossing of Street	60.2	10.1	86.3	21.5	57.7	10.9
LRT Station Access Trips	61.0	10.8	89.5	25.7	59.9	8.9
Intermodal Hub Adjacent to Intersection with LRT and Transit Signal Priority						
Parallel to Tracks	55.9	4.5	N/A		59.0	16.5
Transverse to Tracks	59.5	14.8	N/A		69.2	23.7
Full Crossing of Street	63.0	17.6	N/A		79.2	26.5
LRT Station Access Trips	56.9	9.3	N/A		62.7	16.7

All values in the table are expressed in units of seconds of delay.
Note 1: Baseline conditions reflect signal operations without preemption or transit signal priority. For heavy rail, this may take the form of a grade separation. For LRT, this may take the form of standard signal operations.

The data in **Table 1** shows, as expected, that introducing irregularities to traffic signal operations has the dual effect of (generally) increasing pedestrian delay and increasing the standard deviation of pedestrian delay at intersections adjacent to transit stations. Preemption appears to have the greatest increasing effect on average delay and standard deviation of delay; since preemption generally allows the movements parallel to the tracks to be served as a train is approaching, pedestrian crossings parallel to the tracks are not as severely affected as crossings transverse to the tracks.

Transit signal priority has a somewhat smaller effect on pedestrian delay, largely depending on the context. In the median-running LRT case study, the station is located at an intersection between a major arterial (which the LRT running in the median of the arterial) and a collector. The major arterial generally receives much more green time than the collector, so the effect of TSP on signal operations is low since the major arterial is typically already being served when a light rail vehicle places a call for priority. In the intermodal hub example, the intersection is between two major arterials, with green times more equally allocated on all approaches. Therefore, the effect of TSP is more pronounced.

The results of the analysis of real-world operations of the case study intersections indicate that the standard deviations of pedestrian delay range from 15%-35% of the average delays. Assuming that a transit rider does not want to miss their transit trip more than 2% of the time (five work days out of 260 working days per year), a transit rider would need to account for up to a 72% increase[3] over the average delay at an intersection nearest to a transit station. However, most transit access trips span multiple intersections with different operating conditions, which introduces more variability into a trip.

Monte Carlo Simulation of Typical Transit Access Trips

A typical transit access trip for pedestrians will span several intersections, many of which may be signalized. To capture the effects of multiple signalized intersections over the course of a trip, a Monte Carlo simulation analysis was performed for three representative pedestrian station access trips. A Monte Carlo simulation analyzes ranges of possible outcomes with a given set of probabilities over many trial runs. The sample pedestrian station access trips used in the Monte Carlo analysis include:

1. 1.0 mile suburban trip to heavy commuter rail station: four signalized intersections, including four crossings at standard intersections and one transverse crossing at intersection adjacent to station (with preemption)
2. 0.5 mile suburban trip to median-running LRT: five signalized intersections, including five crossings at standard intersections, one parallel crossing at intersection adjacent to LRT station, and one transverse crossing at intersection adjacent to LRT station (with TSP)
3. 1.0 mile urban trip to intermodal hub: seven signalized intersections, including seven crossings at standard intersections, and one transverse crossing at intersection (with TSP) adjacent to intermodal hub

The Monte Carlo simulation assumes a walking speed of 4.0 feet per second (a working-age commuter). Average delays and standard deviations of delay for crossing standard intersections are estimated using the equations derived from the *2010 HCM*. Cycle lengths for suburban environments are uniformly distributed from 120 seconds to 160 seconds, and the effective walk time is 7.0 seconds. Cycle lengths for urban environments are uniformly distributed from 80 seconds to 120 seconds, and the effective walk time is 7.0 seconds. Average delays and standard deviations of delay for crossings near stations are based on the transit signal priority/preemption values in **Table 1**. The results of the Monte Carlo simulation are presented below in **Table 2**. Each sample pedestrian trip was simulated 1,300 times (representing a typical transit rider's station access trip over five years of 260 working days per year).

TABLE 2: MONTE CARLO SIMULATION ANALYSIS RESULTS

Sample Trip	Travel Time (minutes)					% of Delay at Transit Access Intersection
	Average	Std. Dev.	98th Percentile	Minimum	Maximum	
Scenario 1: 1.0 mile suburban trip to heavy rail station	28.0	1.6	31.4	23.7	35.4	Average: 32% Range: 11%-79%
Scenario 2: 0.5 mile suburban trip to LRT station	17.2	1.3	19.9	13.7	23.0	Average: 33% Range: 15%-65%
Scenario 3: 1.0 mile urban trip to intermodal hub	26.8	1.1	29.0	23.5	30.6	Average: 25% Range: 5%-72%

[3] Assuming a normal distribution, the 98th percentile confidence interval yields a z-score of approximately 2.06;
2.06 * 35% ≈ 72%.

The results of the Monte Carlo simulation indicate that travel times for transit access trips are typically within a tight range relative to the average travel time. Transit riders would generally need to allow for a 15% buffer in travel times to arrive at the transit station in time to catch their train or bus 98% of the time. However, a disproportionate amount of delay over the course of a transit rider's journey to the station will occur at the intersection adjacent to the station, which leaves little opportunity to recover lost time and avoid missing a scheduled transit trip. This lack of opportunity to recover when unforeseen delays at the intersection adjacent to the station occur is a motivation for transit riders to make unsafe movements (crossing against a red signal, jaywalking, etc.) with the goal of making up time.

Strategies to Improve Pedestrian Travel Time Reliability

A number of signal operations, detection and design strategies are available to improve pedestrian travel time reliability, especially at intersections adjacent to transit stations.

Signal Operations Strategies

Strategies related to modifying signal operations involve increasing the frequency of pedestrian intervals, or increasing the length of time pedestrians are legally able to enter the intersection. Other strategies include taking advantage of preemption/TSP events to target key pedestrian movements and considering corridor-wide pedestrian movements. **Table 3** lists signal operations modifications that may minimize the effects of preemption/TSP on pedestrian travel time reliability, or by lowering overall delay.

TABLE 3: SIGNAL OPERATIONS MODIFICATION STRATEGIES

Strategy	Description
Pedestrian recall	Pedestrian recall, where pedestrian phases are automatically called at a signal, lowers the maximum delay as pedestrians will no longer "just miss" a pedestrian phase. If certain crosswalks at an intersection have sufficiently high pedestrian volumes, pedestrian recall would not have a substantial effect on vehicle operations as pedestrian phases would likely be called during most cycles.
Increasing walk times/ Leading pedestrian interval	Increasing the length of the walk phase is directly related to reducing the average delay at an intersection by allowing for a longer portion of a signal cycle where pedestrians would incur no delay at the intersection. The increased walk phase may also include a leading pedestrian interval, which reduces the number of vehicle-pedestrian conflicts associated with longer walk times.
Rest in walk phase	The rest in walk phase function allows the signal to rest in the walk phase until the signal controller calculates that the associated vehicle phase will time out. The rest in walk phase function is typically restricted to coordinated phases, but may be considered for intersections with low side-street volumes.
Reduced cycle lengths at station access intersections	Station access intersections located in urban or suburban downtown environments may be located near focal points for commercial activity. Reducing cycle lengths at uncongested intersections would allow for more efficient pedestrian movements.
Pedestrian phases during preemption event	Depending on the configuration and physical width of an intersection, pedestrian phases could be called in addition to, or instead of, vehicle phases during the dwell time of a preemption event if sufficient space to hold pedestrian queues exists between an intersection and a grade crossing. An intersection operations analysis may be required to verify that this does not substantially worsen vehicle operations.
Consider pedestrian flows along coordinated corridors	If a coordinated signal corridor carries a large number of pedestrians to a station, the offsets at signalized intersections may be adjusted to provide a "walk wave" (similar to a green wave) for pedestrians traveling to a transit station. At transit access intersections with irregular signal operations and a large number of transverse pedestrian crossings, free-running operation may be appropriate.

Detection and Design Strategies

Detection and design strategies to promote pedestrian travel time have an additional benefit of improving overall multimodal safety by providing modifications to areas of vehicle-pedestrian conflicts. Detection and design strategies may be combined with the strategies in **Table 3** into packages of improvements that provide dual benefits of improving pedestrian travel time reliability, while promoting a pedestrian environment that encourages compliance with restrictions to pedestrian movements. **Table 4** presents a listing of detection and design modifications that may lead to improvements in pedestrian travel time reliability by minimizing the effects of preemption/TSP on pedestrians, or by lowering overall delay.

TABLE 4: DETECTION AND DESIGN MODIFICATIONS STRATEGIES

Strategy	Description
Advanced pedestrian detection with Flash Don't Walk phase extension	Advanced pedestrian detection such as microwave or video may be used to extend Flash Don't Walk pedestrian phases to accommodate pedestrians with slower walking speeds. This allows for a baseline Flash Don't Walk timing at 4.0 feet per second, with the pedestrian detection holding the pedestrian phase to allow for longer crossing times.
Midblock station access crossings	Providing additional station access crossings (for example, at the end of a median platform away from a station access intersection) shortens the overall station access trip. Using pedestrian hybrid beacons or other demand-responsive signaling systems allows for the reduction of station access intersection delay for transit riders.
Two-stage crossings	Providing two-stage pedestrian crossings at large intersections may be an opportunity to more efficiently move large, unidirectional pedestrian flows to or from a transit station.
Adding missing crosswalks	Missing crosswalks at an intersection force pedestrians to use one crossing route at an intersection. At transit access intersections, providing a full set of pedestrian movements at an intersection may improve pedestrian travel time reliability by providing resiliency though providing alternate crossing paths between a corner of an intersection and a transit station.
Grade separated direct access	Providing grade separated access points to stations for high-volume pedestrian movements may be a cost effective solution. Pedestrian delay would be reduced and vehicle-pedestrian conflicts would be eliminated. At locations with a high incidence of vehicle-pedestrian collisions associated with transit access trips, grant funding may be available to design and construct the grade separation. A benefit to vehicle operations may also occur by removing conflicts from an intersection.
Wayfinding/transit departure time signage	Providing wayfinding signage with information on walking travel times to stations and transit departure times encourages transit riders to start their trips to transit stations with enough time to reach their destination.

Conclusions

In summary, variability in signal operations at intersections adjacent to transit stations decreases pedestrian travel time reliability. Conventional methods of estimating pedestrian delay at intersections fail to account for unique intersection operating characteristics that may change on a minute-by-minute basis. Microsimulation models may be used to estimate the average delay and variation in delay to quantify the effects of transit signal priority or preemption on a transit rider's station access trip. A Monte Carlo simulation may be used to evaluate the cumulative effects of signal delay over a range of pedestrian trips. Signal operations modifications along with detection and design strategies may be used to mitigate the effects of unanticipated delay at station access intersections; these improvements achieve a dual goal of promoting overall transit trip travel time reliability, while improving multimodal safety.