Strategies for
Maximum Vehicle Efficiency
at Walnut and 34th Street

CPLN 650 Transportation Planning Methods

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Executive Summary

The purpose of this intersection redesign is to maximize vehicle efficiency at 34th Street and Walnut Street in University City. We use four metrics to define vehicle efficiency: (1) aggregate delay, (2) queue lengths, (3) flow and capacity, and (4) traffic obstructions, including safety. Aggregate delay and queue length can be optimized using Webster's uniform delay model[i], while traffic obstructions are measure primarily through qualitative observation. Vehicle flow is more difficult to adjust, and we explore this further in our Redesign and Discussion sections.

Problem

1. Vehicle, pedestrian, and bicycle volumes continue to increase at the intersection. As one of the region's metropolitan centers and a hub for economic innovation in Philadelphia, this intersection is likely to see continued high travel volumes in the future.
2. The multimodal use of the intersection and vibrant land use nearby poses conflict between cars, trucks, buses, emergency vehicles, pedestrians, and cyclists. The conflict between modes negatively impacts vehicle efficiency and poses serious safety concerns.
3. The emergence of ride-hailing services, such as Uber and Lyft, and freight is adding to mode conflict and delay at the intersection.

Final Redesign Strategies

1. Shorten each signal cycle by 30 seconds to reduce queue length and delay time
2. Reconfigure lanes on 34th and Walnut Streets to reduce mixing zones and potential conflict between modes

I. Introduction

The purpose of this intersection redesign is to maximize vehicle efficiency at 34th Street and Walnut Street in University City. We use four metrics to define vehicle efficiency: (1) aggregate delay, (2) queue lengths, (3) flow and capacity, and (4) traffic obstructions, including safety. Aggregate delay and queue length can be optimized using Webster's uniform delay model, while traffic obstructions are measure primarily through qualitative observation. Vehicle flow is more difficult to adjust, and we explore this further in our Redesign and Discussion sections. Three trends highlight the need to evaluate vehicle efficiency at this intersection:

1. The University of Pennsylvania is Philadelphia's largest employer, attracting a high volume of workers, students, and visitors interacting with the intersection. As development of University City seeks to foster an innovation hub that will drive the region's economy, travel demand at the intersection is likely to increase.
2. The multimodal use of the intersection poses conflict between cars, trucks, buses, emergency vehicles, pedestrians, and cyclists. Planning for vehicle efficiency at this intersection must account for the multimodal nature of this intersection.
3. The emergence of ride-hailing services, such as Uber and Lyft, is adding to mode conflict and delay at the intersection. This redesign must acknowledge transformations in mobility by accounting for new modes and technologies impacting the intersection.

Furthermore, the October 2018 release of *Connect*, the City of Philadelphia's Strategic Transit Plan[ii], signals a shift in Philly's transportation policy. *Connect* prioritizes safety and transit to manage growth, adapt to a changing climate, and promote equitable development.

Considering these emerging trends and shifting policy priorities, planning for vehicle efficiency at the intersection level needs to be inclusive of all modes, adapt to climate change, and account for future changes in regional mobility patterns and mode choices. This report, which is subsequently be divided into three parts, seeks to address these trends. Part 1 will assess the existing conditions at the intersection; Part 2 will define vehicle efficiency and propose redesign strategies to maximize vehicle efficiency; and Part 3 will discuss the potential limitations of the proposed redesign.

II. Existing Conditions

The intersection of 34th and Walnut Streets is located at the heart of University City, one of the region's metropolitan centers. Given the high density of institutional and commercial land uses in the area, the *Philadelphia Complete Streets Handbook* classifies both Walnut and 34th streets as Urban Arterials with a "High Volume of Pedestrians" (Philadelphia Streets Department, 2017)[iii]. The primary trip attractor is the University of Pennsylvania, consisting of the academic campus and Penn Hospital, located at 34th and Spruce. The University of Pennsylvania is home to over 25,000 students and 40,000 employees, with an average of over 70,000 people visiting the University each weekday (UPENN, 2018)[iv]. The health system also attracts hundreds of thousands of patients per year (UPENN, 2014)[v]. Based on the high volume of students, workers, and visitors interacting with the intersection, any redesign of 34th and Walnut is likely to have regional implications.

Intersection Typology

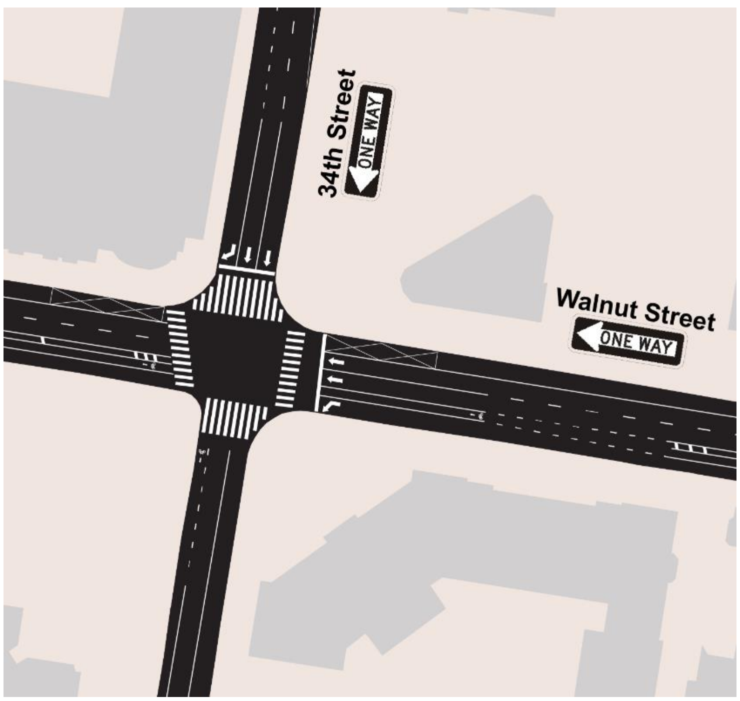
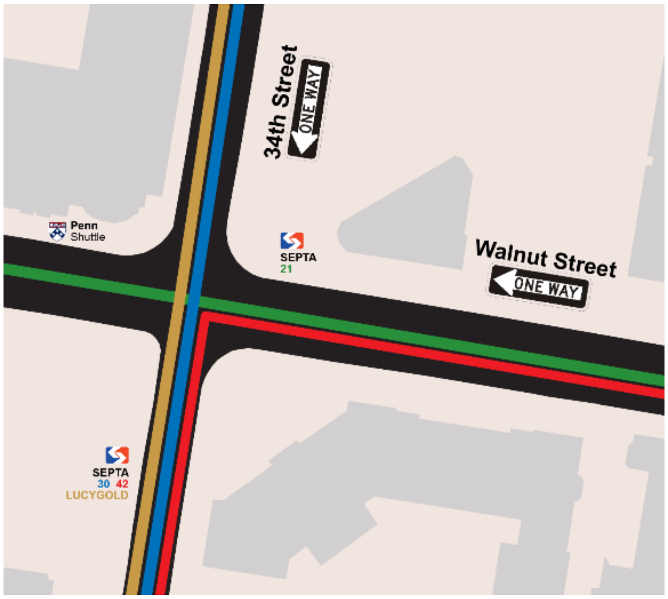
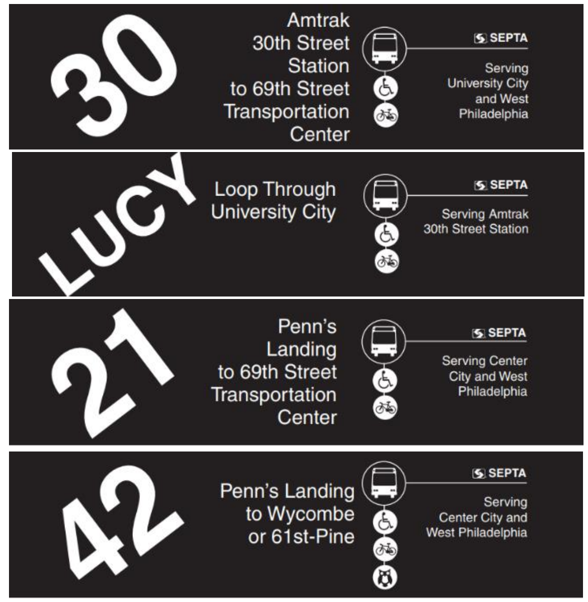


Figure 1: Existing Intersection Configuration

Figure 1 illustrates the lane configuration of the intersection. From north to south, the eastside of walnut features a bus stop and on-street parking, two thru lanes, a bike lane, and a left turn lane. The westside of Walnut Street features a shuttle stop and on-street parking, two thru lanes, a painted buffer bike lane, and on-street parking. From west to east, the northside of 34th street features a shared right-turn and bike lane, and two thru lanes. The southside of 34th street features a shared bike lane and bus stop, and two thru lanes.





Figures 2 and 3: Transit routes and stops serving the intersection

Figures 2 and 3 depict transit routes and stops at the intersection. The intersection is served by four SEPTA bus routes and the Penn Shuttle in the evening. Routes 21 and 42 are among SEPTA's busiest routes and their corresponding stops at the intersection are among the busiest on each route (SEPTA, 2018)[vi]. Route 42 provides service between Center City and the medical campuses, while Route 21 provides a vital service connecting Center City with transit dependent neighborhoods in West Philadelphia.

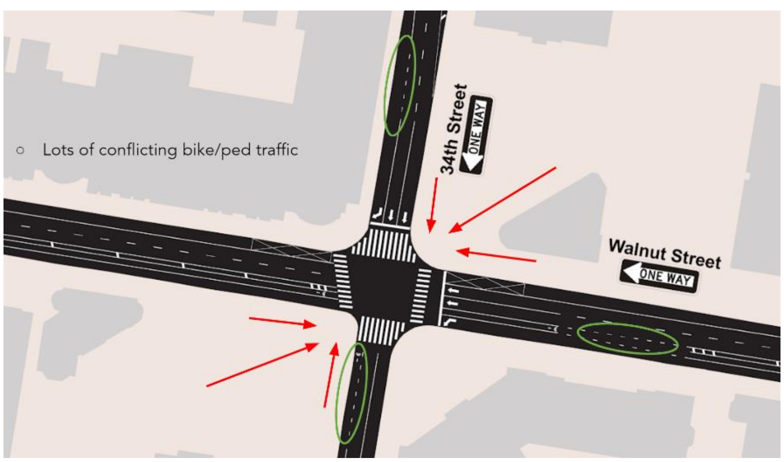


Figure 4. Mixing/Conflict Zones

Mixing zones are areas where bicyclists and motor vehicles must enter the same space following previously separated bike and travel lanes. Figure 4 depicts mixing zones at the intersection of 34th and Walnut. The green circles represent conflict between vehicles and cyclists. Two of these conflict areas occur on both legs of 34th street. On the northside, the bike lane merges into the right turn lane, forcing cyclists to stop or maneuver between vehicles. On the southside, bike lanes are obstructed at times by the 42, 30, or Lucy buses loading and unloading passengers. This forces cyclists to sometimes stop in the crosswalk or in the middle of the intersection. The red arrows depict mixing zones between vehicles and pedestrians. The high pedestrian volumes at the intersection result in conflict between vehicles and pedestrians. It is no surprise that the three pedestrian or cyclist involved collisions at the intersection over the past 5 have occurred on conflict zones. The presence of these mixing or conflict zones not only poses safety concerns but contributes to vehicle inefficiency by increasing delay, congestion, and traffic obstructions.

Mode Split

Field counts were conducted by researchers at the University of Pennsylvania’s Department of City and Regional during the morning (8 AM – 9 AM), midday (12 PM – 1 PM), and evening (5 PM – 6 PM) peak hour commutes. A camera was placed in Fisher-Bennett Hall, located on the southeast corner of the intersection, and vehicle counts were collected from the video footage.

During the noon hour, a notably high number of vehicles made right turns from 34th onto Walnut. The counts estimate that nearly 20,000 pedestrians, 44,500 vehicles (of all types), and 300 bicycles cross the 34th and Walnut on a typical weekday. However, traffic counts provided by the DVRPC[vii] offer significantly different counts, especially for pedestrians. Using a combination of traffic counts conducted by UPENN student researchers and traffic counts conducted by the DVRPC, **Figure 6** estimates an average mode split during peak periods travel, which indicates that walking is the dominant mode of transportation at the intersection.

	1	2	3	4
	34th		Walnut	
	Straight	Right	Straight	Left
Morning	570	96	798	168
Noon	270	210	592	90
Evening	510	164	960	165

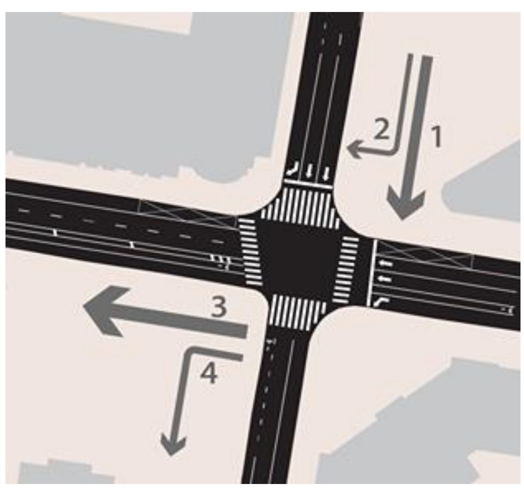


Figure 5. Vehicle traffic counts

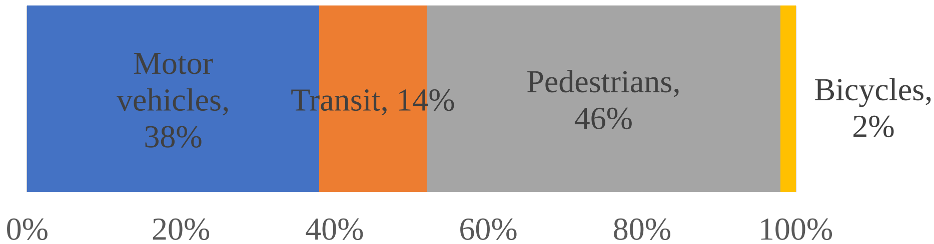


Figure 6. Mode share

Understanding peak hour travel patterns is critical to planning for vehicle efficiency, since the high volumes of all modes at these time periods contribute to delay, queue length, traffic obstruction, and vehicle flow.

Traffic Generators

Figure 7 indicates the major trip generators for vehicles, transit users, pedestrians, and cyclists. Major bike and ped trip generators include students and workers living on or around campus and living in Center City. An additional pedestrian trip generator are the transit stops located within a half-mile of the intersection. The 30th street station feeds into the intersection via the Woodland Walk. The 33rd, 36th, and 37th street SEPTA trolley stations, along with the 34th street MFL station generates a high number of pedestrians (DVRPC Traffic Counts, 2018)[viii]. The nearby Schuylkill Expressway, which is the primary trip generator for vehicles, feeds into Walnut Street, while 34th street offers access to the Schuylkill Expressway. **Figure 8** shows the regional distribution of where those working in the area live. While a high concentration of workers lives within walking, biking, and transit catchment areas, many live in areas where transit service is either nonexistent, inefficient, or unaffordable. Therefore, there is a need for vehicle access and mobility at 34th and Walnut, despite the high presence of peds, bikers, and transit users.

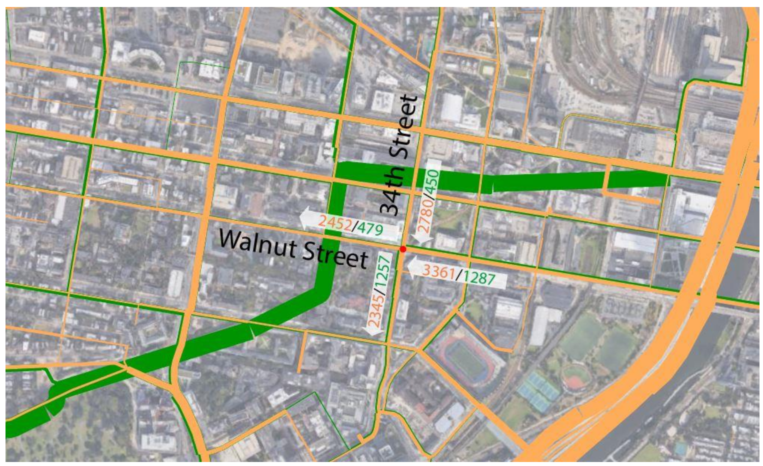


Figure 7. Trip Generators

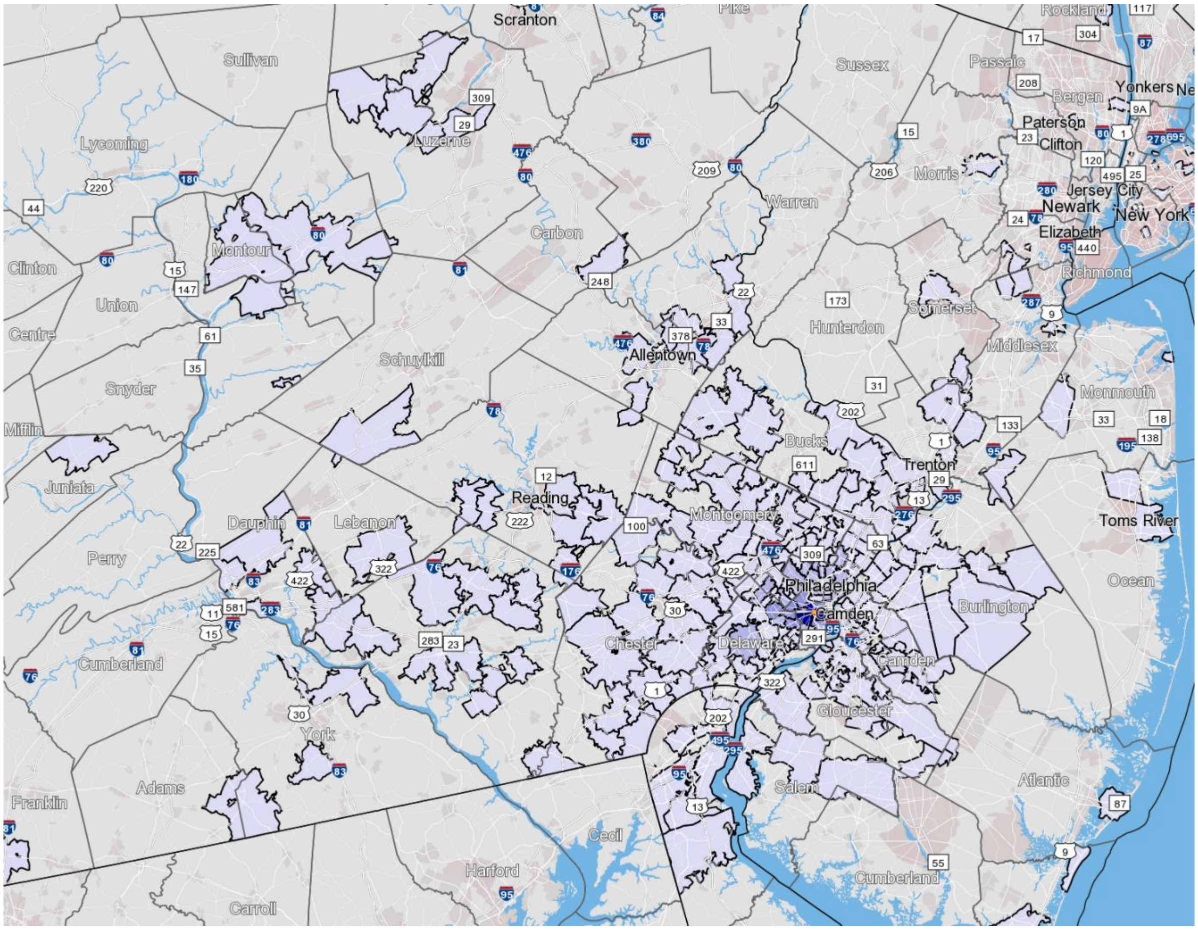


Figure 8. Where Area Workers Live

Emergency Vehicles

Given the intersection's proximity to Penn Hospital, the Children's Hospital of Philadelphia, and the Veteran's Hospital, 34^{th} street is a feeder arterial to these hospitals. Therefore, any redesign of this intersection must be cognizant of the flow of emergency vehicles. While emergency vehicles can simply bypass traffic in the event of an emergency, the narrow dimensions of 34^{th} street can pose significant design challenges when considering emergency vehicle flow.

Figure 9. Emergency vehicle at 34th and Walnut

Ride Share and Freight

While data on ride share and freight activity in the area is unavailable, field observations and recent literature on the impact of ride-shares to local roadways reveals the disruptive force of these activities. Double parked freight and ride-share vehicles contribute to congestion, traffic obstruction, and safety issues for all modes. The redesign section will discuss mode conflicts and mixing zones in more depth. Given the presence of these vehicles, curbside management will play a pivotal role in maximizing vehicle efficiency.

Figure 10. Roadway conflict caused by ride-share and freight

III. Defining Vehicle Efficiency

The *Highway Capacity Manual* defines vehicle efficiency at a signalized intersection as maximizing vehicle flow while minimizing delay. We adapt the following metrics from the *Manual* to measure efficiency: (1) delay time, (2) queue length, (3) flow and capacity, and (4) traffic obstructions.

(1) *Delay Time*

For vehicles, delay is the additional travel time experienced by drivers. It is the most common measure of the operational performance of a signalized intersection. A common classification of delay consists of stopped time delay, approach delay, travel time delay, and time-in-queue delay. Another boarder category includes total delay and control delay.

For this study, we use aggregate time-in-queue delay[ix] as the measure of delay since acceleration and deceleration are difficult to measure. The calculation is based on the Webster's uniform delay model. The model is based on the assumptions of stable flow and a simple uniform arrival function. In a vehicle-time diagram (**Figure 11**), the aggregate delay can be estimated as the area between the arrival and departure flow curves.

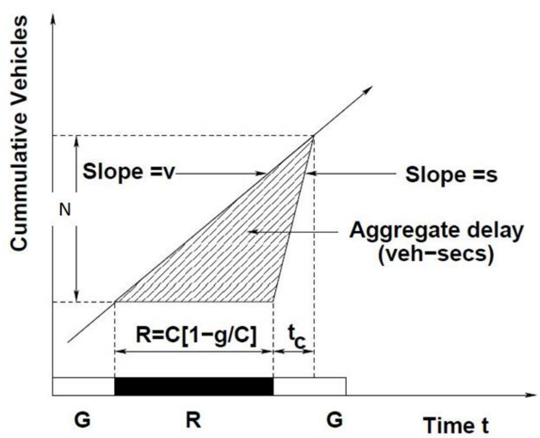


Figure 11. Webster's uniform delay model[x]

Length of the red phase is provided as the proportion of the cycle length which is not green:

$$T_R = T_C * (1 - \frac{T_G}{T_C})$$

Hence, the total uniform delay (TUD) is:

$$TUD = \frac{T_R * N}{2}$$

(2) *Queue Length*

Queue length is the physical space vehicles will occupy while waiting to go through an intersection. It is an important metric for evaluating the capacity and quality of the traffic control device at a signalized intersection.

In traffic engineering studies, the maximum queue is defined as the length of queues formed at the red-end. We use this metric as the measure of queue length. The maximum back-of length is also important, which is the maximum length of the stop line to the queue end of the queue has been created within the same cycle. The average queue reflects the capacity of traffic signals, and the 95th or 99th percentile queue are used for determining the length of turning lanes, in order to minimize the risk of a blockage in the through lanes. The last two queue lengths require more data to calculate.

The queue length and delay can be converted from each other by **traffic flow**, that is, the maximum queue length equals the red time multiplies the demand flow:

$$Maximum\ queue\ length = T_R * traffic\ flow$$

(3) *Capacity and volume-to-capacity ratio*

At signalized intersections, capacity for vehicle movement is defined by two elements: saturation flow rate, that is, the maximum rate vehicles can pass through a given point in an hour under prevailing conditions; and the proportion of green time, meaning the ratio of time vehicles may enter the intersection. The volume-to-capacity ratio, also known as the v/c ratio or the degree of saturation. Because this research focuses on one intersection and this measure is more suitable for a larger scale analysis, this report does not provide an operational redesign strategy for this metric. Instead, it could be improved from policy suggestions.

(4) *Roadway conflicts*

Signalized intersections serve a variety of road users including motorists, bicyclists, and pedestrians, and sequence the right-of-way between intersecting streams of road users. There are multiple functions of signalized intersections:

- Allow motorists to access new streets and change directions in travel
- Junctions for bike route
- Provide a primary connection to and from activity centers for pedestrians
- Signalized intersections on primary routes may involve motor carriers and other heavy vehicles

- Public right-of-way for public utilities, such as power and communication lines; water, sewage, and storm drainage pipes; and traffic signs and signal equipment.

However, the roadway conflicts between vehicles and bicycles, vehicles and pedestrians usually deteriorate the efficiency of a busy signalized intersection. **Figure 12** illustrates the bicycle-motor vehicle conflicts, such as motorist left turn facing the bicyclist, bicyclist left turn in front of a motorist and bicyclists riding-out from a stop sign or flashing red signal.

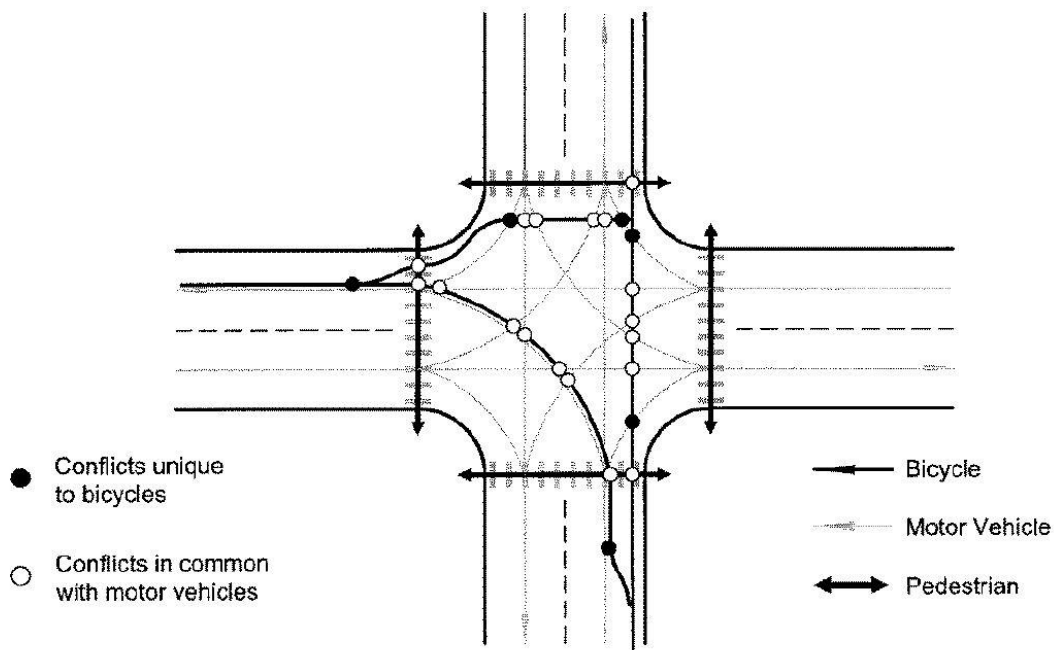


Figure 12. Bicycle-motor vehicle conflicts

Pedestrian-motor vehicle conflicts are more frequent at the intersection. **Figure 13** captures that pedestrian-motor vehicle conflicts may be due to the following:

- vehicles turning right on red or vehicles turning right on green, indicating vehicles do not yield to a pedestrian;
- vehicles turning left on a green light in permissive left turn intersection; and
- vehicles running the red light, which is the most dangerous conflict.

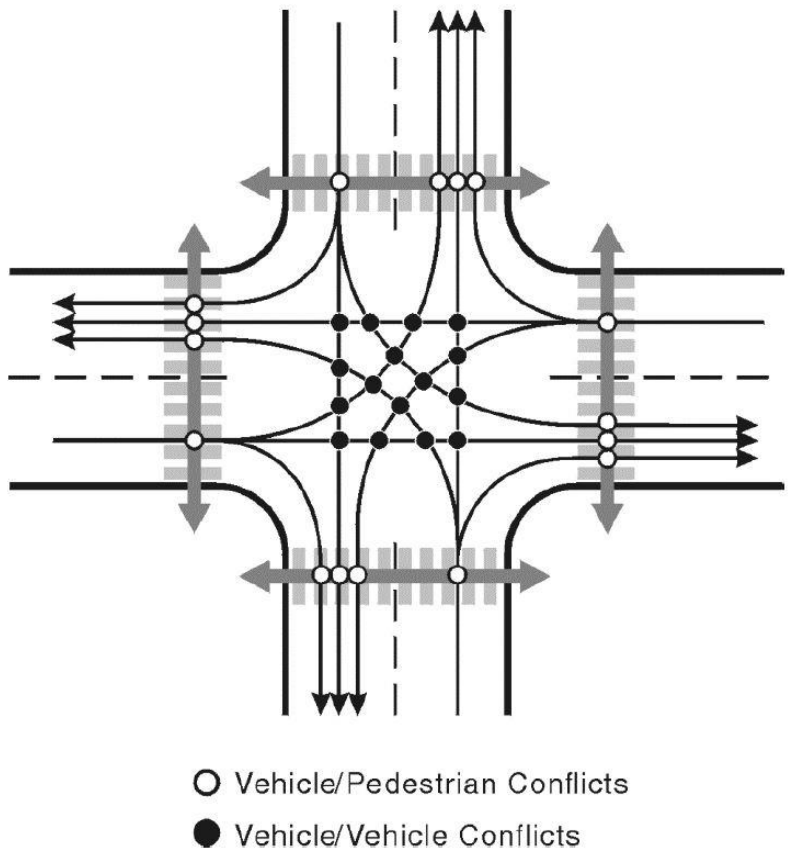


Figure 13. Pedestrian-motor vehicle conflicts

IV. Redesign Strategies

Among the metrics discussed above, delay time and queue are the most important. According to these definitions, this report came up with three redesign areas that seek to

#1: reduce delay time and queue length by adjusting signal timing,

#2: mitigate the relationship between demand flow and capacity, and

#3: minimize traffic obstructions.

Redesign # 1: Adjust Signal Timing

Existing Conditions for Signal timing

Walnut & 34th Street is signalized both ways. **Figure 14** summarizes the signal cycles at the intersection. The top row in the diagram below is Walnut Street. The first 3 seconds is the red clearance interval, and the following 3 seconds is the leading pedestrian Interval (LPI). Then there is 46 seconds of green time, which is followed by 3 seconds of yellow time. There is a total of 45 seconds of red time.

Though most turn and straight signals are the same, there is a split phase left turn signal on Walnut so that turning vehicles do not conflict with pedestrians.

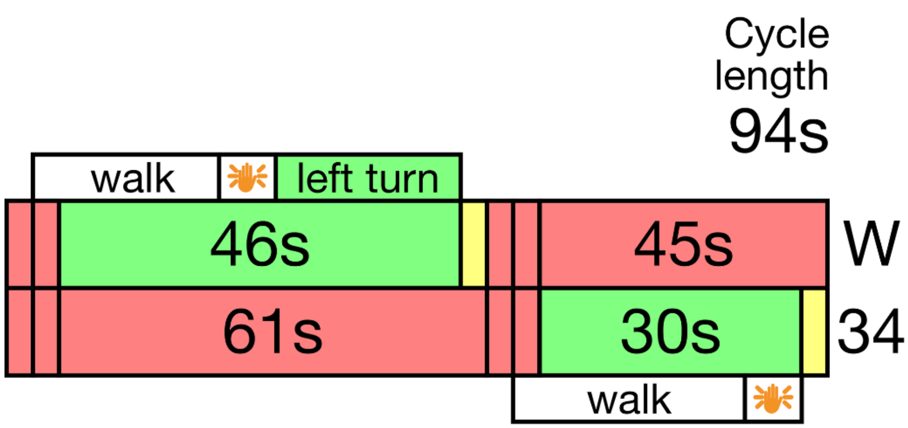


Figure 14. Pedestrian-motor vehicle conflicts

On 34th Street, the total red time is 61 seconds, the green time is 30 seconds, and the yellow time is 3 seconds.

The total cycle time at this intersection is 94 seconds, including three seconds of a Lead Pedestrian Interval (LPI) phase where all directions are stopped. With this signal timing pattern, we can calculate the current maximum queue length and the aggregated delay time.

Queue length

The maximum queue length, we use the demand flow multiplying the red time, where the demand flow is sourced from DVRPC's traffic counting. From the calculation in **Figure 15**, the current queue length on Walnut Street is about 9 to 10 vehicles in the thru lane, meaning that nearly half of the street is aligned with vehicles in the queue. For the left turn, the queue length is about 2 vehicles. The average maximum queue for the three peak hours is about 5.2 vehicles on Walnut.

34th Street has a similar queue length pattern, which also has more than 8 vehicles on the straight lane, and about 2 vehicles waiting to turn right. The maximum queue for the three peak hours is 4.9 vehicles on 34th Street.

Figure 15. Queue Length

8a-9a	**Speed Limit (mph)**	**Morning Demand flow (veh/h)**	**Saturation Flow Rate (veh/h/ln)**	**Jam density (veh/mile)**	**Queue length (veh)**	**Quene length (ft)**	**Cumulative vehicles (veh)**	**Aggregate delay time (s)**
Walnut	30	725.42	1390	225	7.9	184.4	15.1	293.6
Walnut LT	30	149	776	225	1.6	37.8	8.4	163.9
34th	30	526.15	1374	217	8.0	195.6	21.0	577.3
34th RT	30	93	632	217	1.4	34.5	9.6	265.4
12p-1p	**Speed Limit (mph)**	**Noon Demand flow (veh/h)**	**Saturation Flow Rate (veh/h/ln)**	**Jam density (veh/mile)**	**Queue length (veh)**	**Quene length (ft)**	**Cumulative vehicles (veh)**	**Aggregate delay time (s)**
Walnut	30	840	1506	225	9.1	213.7	16.3	318.2
Walnut LT	30	126	1008	225	1.4	31.9	10.9	213.0
34th	30	318	1319	217	4.9	118.2	20.1	554.0

34th RT	30	250	706	217	3.8	92.9	10.8	296.6
5p-6p	Speed Limit (mph)	Afternoon Demand flow (veh/h)	Saturation Flow Rate (veh/h/ln)	Jam density (veh/mile)	Queue length (veh)	Quene length (ft)	Cumulative vehicles (veh)	Aggregated delay time (s)
Walnut	30	760.75	1158	225	8.2	193.4	12.5	244.5
Walnut LT	30	134	1118	225	1.5	34.1	12.1	236.2
34th	30	504.64	1216	217	7.7	187.6	18.6	511.0
34th RT	30	159	592	217	2.4	59.2	9.0	248.8

Aggregated delay time

The aggregated delay time and queue length can be converted to each other by the demand flow as shown in **Figure 16**. We also calculated the aggregated delay time for each street and each direction. From the data derived from the three peak hours, the average aggregated delay per cycle length on Walnut is 326 seconds, meaning drivers lost more than 5 minutes when waiting in the queue. The average aggregated delay on 34th Street is nearly 500 seconds. The maximum delay occurs during the morning peak hour on 34th Street, which is more than 700 seconds for vehicles going straight. On Walnut, the noon peak hour has the longest delay of 424 seconds.

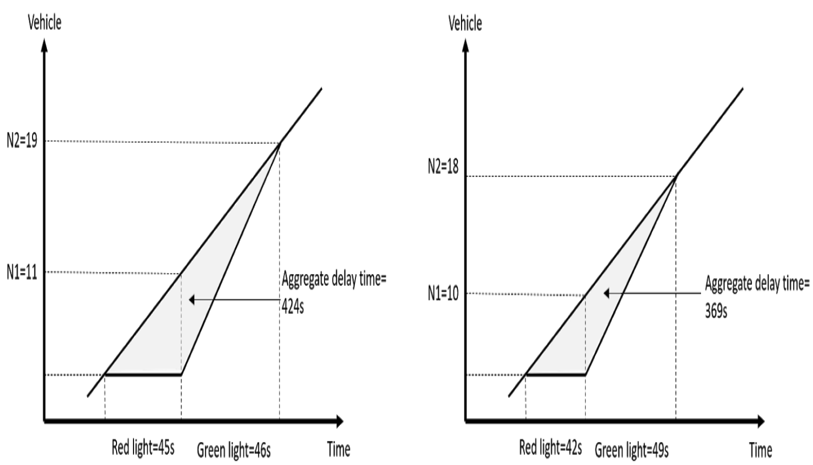


Figure 16. Aggregate Delay Time

Methodology

Delay and queue length are the primary metrics for maximizing vehicle efficiency, and largely influenced by signal timing. The first redesign strategy seeks to optimize signal timing on Walnut & 34th Street. Signal timing involves how much green time the traffic signal provides to an intersection approach, how long the pedestrian walk signal should be, and many other factors. The features affecting signal timing design includes location, transportation network characteristics, intersection geometry, and user characteristics. The design of signal timing should follow the basic timing functions of the signal, which consist of the minimum and maximum time of the green interval, yellow clearance, red clearance flashing 'don't walk' interval, cycle length, and offset.

There are several signal timing regulations in the United States and Philadelphia. According to the Manual of Uniform Traffic Control Devices (MUTCD), there must be at least 3 seconds of red light clearance and another 3 seconds of leading pedestrian interval (LPI) before each green time. Yellow time is usually 3 to 6 seconds. For the pedestrian signal timing, the MUTCD specifies the use of a walking speed of 3.5 feet/second to calculate pedestrian crossing time, which is 7 seconds at the intersection. The redesign strategy incorporates the regulations and assumptions specified in the MUTCD. Our redesign strategy offers two alternatives: shortening the cycle length and removing the LPI.

Alternative 1: Shortening the cycle length

The first signal timing strategy is to adjust the cycle length (or cycle time). According to the planning-level cycle length assumptions in FHWA's *Signal Timing Manual*, the typical cycle length is 60 to 120 seconds based on the signal complexity. The longer the cycle, the better it is for the turning vehicles and pedestrian crossing efficiency. From the DVRPC and UPENN traffic counting, the intersection only has a small portion of turning vehicles. Thus, we try to reduce the cycle time from **94 seconds to 64 seconds**, while maintaining the proportion of red and green phases.

After the adjustment, the new green time is 28 seconds on Walnut Street, and the new green time is 18 seconds on 34th Street (**Figure 17**). The new red time decreases to 33 seconds on Walnut, and 43 seconds on 34th Street. The yellow time, red clearance interval, and LPI are kept at 3 seconds for each.

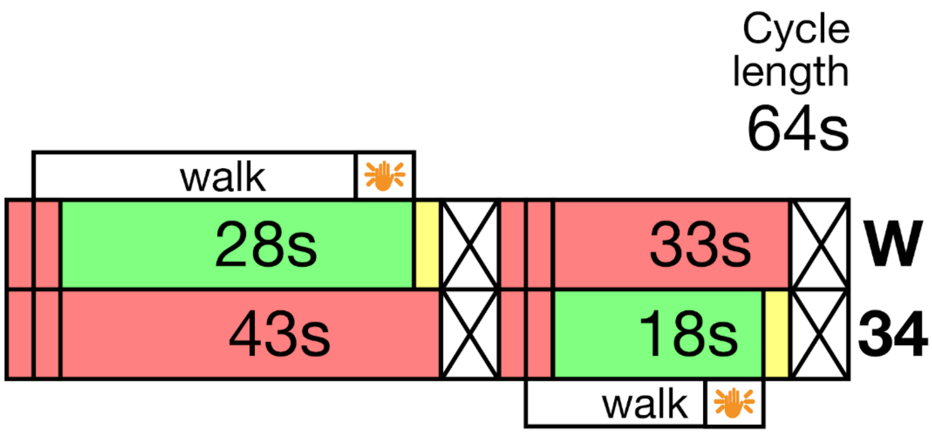


Figure 17. New Cycle Length

This adjustment decreases the maximum queue length about 1 vehicle for each intersection segment and decreases the delay time by 2 to 3 minutes, as shown in **figure 18**. The greatest optimization occurs on Walnut Street's thru lane during the noon peak hour, which now decreases from 9 to 8 vehicles; and the aggregated delay time decreases by nearly 200 seconds.

Figure 18. New Queue Length

8a-9a	Existing Queue length (veh)	New Queue length (veh)	Existing aggregated delay time (s)	New Aggregated delay time (s)
Walnut	7.9	6.6	293.6	210.2
Walnut LT	1.6	1.4	163.9	117.3
34th	8.0	6.3	577.3	352.9
34th RT	1.4	1.1	265.4	162.2
12p-1p	Existing Queue length (veh)	New Queue length (veh)	Existing Aggregated delay time (s)	New Aggregated delay time (s)
Walnut	9.1	7.7	318.2	227.8

Walnut LT	1.4	1.2	213.0	152.5
34th	4.9	3.8	554.0	338.6
34th RT	3.8	3.0	296.6	181.3
5p-6p	Existing Queue length (veh)	New Queue length (veh)	Existing Aggregated delay time (s)	New Aggregated delay time (s)
Walnut	8.2	7.0	244.5	175.1
Walnut LT	1.5	1.2	236.2	169.1
34th	7.7	6.0	511.0	312.3
34th RT	2.4	1.9	248.8	152.1

Shortening the cycle length appears to work well for decreasing the queue length during the noon peak hour for Walnut and reducing the overall delay time during the evening peak hour, as indicated in **figure 19**.

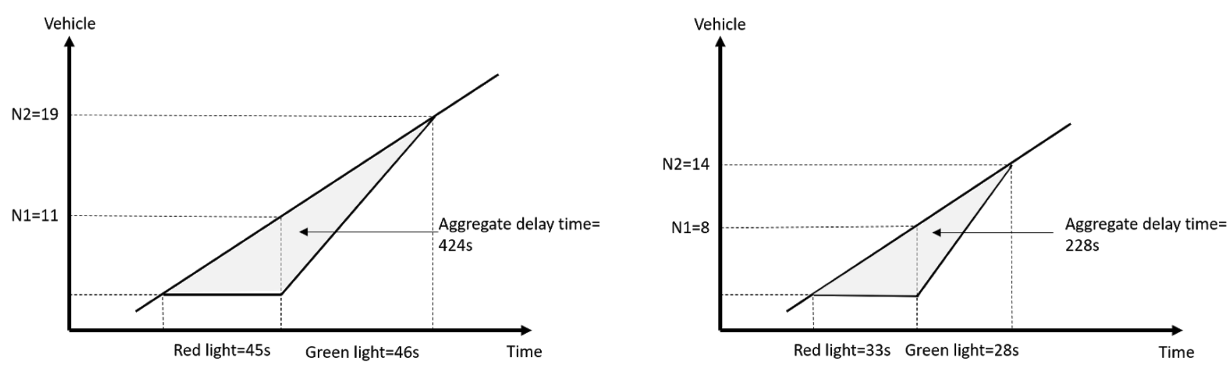


Figure 19. New Aggregate Delay

Alternative 2: Remove the Lead Pedestrian Interval

Based on our observations, vehicle efficiency is obstructed by pedestrian flow, especially for right turning vehicles on 34th Street. Therefore, the second possible strategy is removing the 3-

second leading pedestrian interval (LPI) at the intersection. The LPI typically gives pedestrians a 3–7 seconds head start when entering an intersection. We found that our intersection is not within Philadelphia's High Injury Network, and it has 0 fatal crash in the past 5 years. The data indicates that this intersection is relatively safe and is feasible to remove the LPI to add additional green time.

After the adjustment, the new signal timing is depicted in **Figure 20.** We maintain the 3 second red clearance interval for both streets. Compared with the existing signal timing, Walnut's green time increases from 46 seconds to 49 seconds. 34th Street's green time increases from 30 seconds to 33 seconds. Correspondingly, the red time for both streets decreases by 3 seconds.

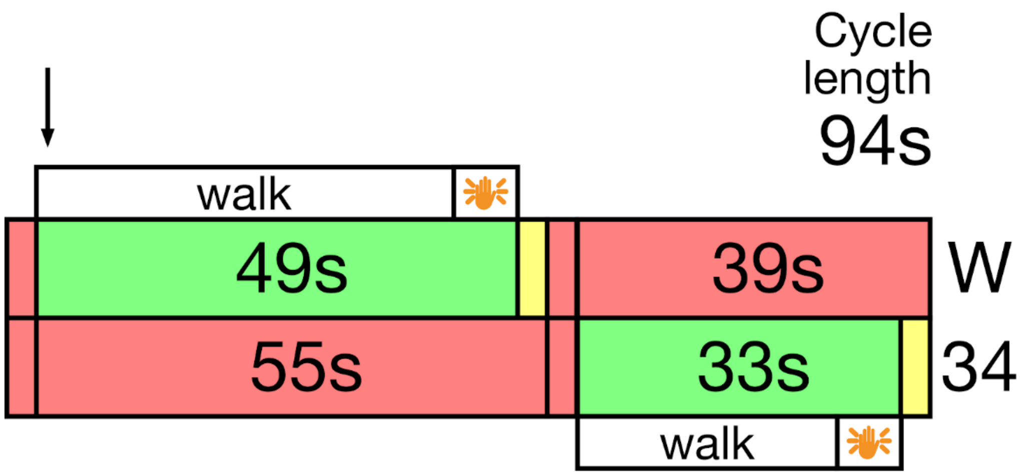


Figure 20. Cycle Length after removing LPI

Similarly, we calculated the new queue length and the aggregated delay time as shown in **figure 21**. Maintaining the current demand flow, removing the LPI shortens the maximum queue length by less than 1 vehicle, and reduces delay time by less than 1 min. The greatest optimization occurs on Walnut's thru lane during the noon peak hour, which decreases by 0.7 vehicles. The largest aggregated delay time reduction occurs on 34th Street's thru lane during the morning peak hour, which decreases by 68.1 seconds.

This adjustment works well for decreasing the queue length during the morning peak hour on Walnut, and it works well for reducing the delay time during the noon peak hour on 34th Street.

Figure 21. Queue Length after removing LPI

8a-9a	**Existing Queue length (veh)**	**New Queue length (veh)**	**Existing aggregated delay time (s)**	**New Aggregated delay time (s)**
Walnut	7.9	8.5	293.6	340.5
Walnut LT	1.6	1.7	163.9	190.1
34th	8.0	8.5	577.3	642.0
34th RT	1.4	1.5	265.4	295.1
12p-1p	**Existing Queue length (veh)**	**New Queue length (veh)**	**Existing Aggregated delay time (s)**	**New Aggregated delay time (s)**
Walnut	9.1	9.8	318.2	369.0
Walnut LT	1.4	1.5	213.0	247.1
34th	4.9	5.1	554.0	616. 1
34th RT	3.8	4.0	296.6	329.8
5p-6p	Existing Queue length (veh)	New Queue length (veh)	Existing Aggregated delay time (s)	New Aggregated delay time (s)
Walnut	8.2	8.9	244.5	284.0
Walnut LT	1.5	1.6	236.2	273.9
34th	7.7	8.1	511.0	568.2
34th RT	2.4	2.6	248.8	276.6

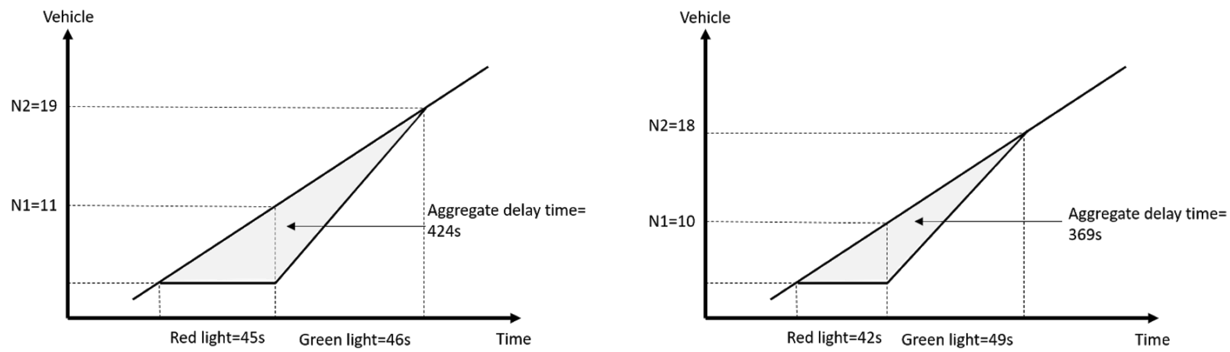


Figure 22. Delay Time after removing LPI

Recommendation

Finally, after testing the signal timing optimization alternatives, we recommend to adjusting the cycle length instead of removing the LPI. First, the decrease in queue length and aggregated delay time from the cycle length adjustment is greater than the reductions from removing the LPI.

Second, the intersection experiences a high volume of pedestrians and cyclists. LPI is a necessary measure for alleviating roadway conflicts and ensuring safety for all users. Therefore, the recommended cycle length for the intersection is **64** seconds. The new red time should be adjusted to **33 seconds** on Walnut, and **43 seconds** on 34th St. The new green time would be **28 seconds** on Walnut, and **18 seconds** on 34th St. For safety considerations, the yellow time, red clearance interval, and LPI will remain 3 seconds for each.

Redesign #2: Minimize Roadway Conflict

The second redesign strategy recognizes that the uniform delay model applied in the previous strategy does not effectively capture driver behavior, pedestrian behavior, and interaction of different modes.

Existing conditions

While there has not been a fatal collision at the intersection over the past five years, our eye-tracking study with drivers and user surveys conducted by UPENN researchers indicates that the intersection is perceived as dangerous. One of the primary concerns from both pedestrians, cyclists, and motorists is the conflict between the different modes. Adding to this conflict is the presence of a university campus, which is a hot spot for passenger and commercial loading. The existing lane configuration facilitates this conflict. On the north side of 34th street, for instance, the right-side bike lane interferes with the right-turn lane, which is often blocked by pedestrians waiting to cross. On the south side of 34th street, buses must obstruct the bike lane to load and unload riders at Meyerson Hall. On Walnut, drivers must cross the bike lane to make a turn.

While the data does not reveal any catastrophic events resulting from the mixing zones, the perception of danger and fear at the intersection may someday become a reality. Moreover, it discourages active mode choices, adding to vehicle volumes, which negatively impacts vehicle efficiency.

Alternative 1: Lane Reconfiguration

Lane Reconfiguration on Walnut Street

This intervention seeks to maximize vehicle efficiency by design a protected intersection that eliminates mixing/conflict zones at the intersection. This reconfiguration also serves to reduce the stress of drivers and bicyclists alike and to reduce the perception of this intersection as dangerous. As **figure 23** illustrates, our proposal switches the location of the bike lane and park lane, where the bike lane on 34th street will become a parking protected bike lane, with a 3-ft buffer between the parking and bike lanes. Additionally, two parking spaces nearest to the intersection will become designated ride-share drop off zones, while six parking spaces will be removed from the middle of the block. **Figure 24** provides a curbside management design concept incorporating the floating parking lane idea as 'flex zones' for parking along with designated freight and passenger unloading.

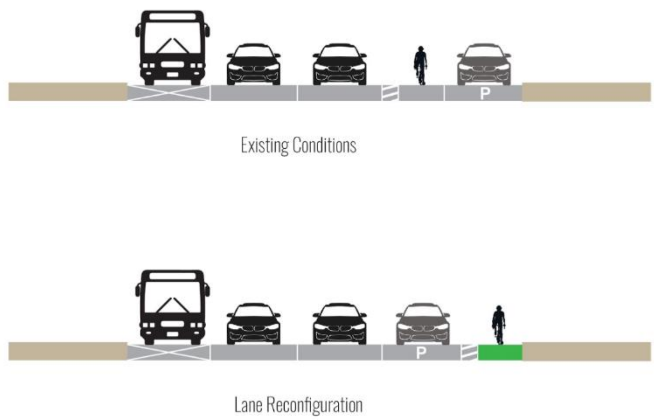


Figure 23. Walnut Street Reconfiguration

This redesign has three benefits. First, it eliminates mixing between bicycles and left turning vehicles at the intersection, allowing cyclists to cross the intersection during the pedestrian/thru signal phase. Second, it eliminates the possibility of ride-share or freight vehicles stopping in the bike lane, making the intersection safer for cyclists. Finally, this strategy allows for easier and more efficient left-turns onto 34th street for the SEPTA 42.

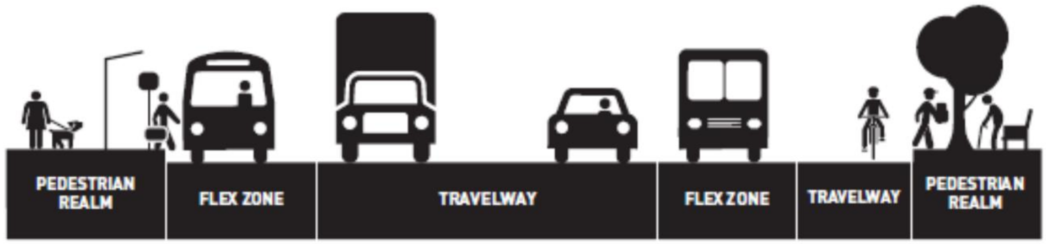


Figure 24. Seattle, WA curbside management design concept[xi]

Lane Reconfiguration on 34th Street

Figure 25 illustrates our proposed lane reconfiguration on 34th street. This redesign incorporates two changes. First, the bike lane is moved to the left side of the street for consistency with the City of Philadelphia's bike lane guidelines. This strategy also reduces conflict between cyclists on vehicles turning onto 34th street from Walnut Street, while reducing mixing between cyclists and buses at the intersection. Second, a portion of the curb is removed to accommodate bus loading and unloading while allowing thru vehicles to pass through the intersection. This strategy prevents the conflict between bus stops and private vehicles, which decreases queue length at the intersection.

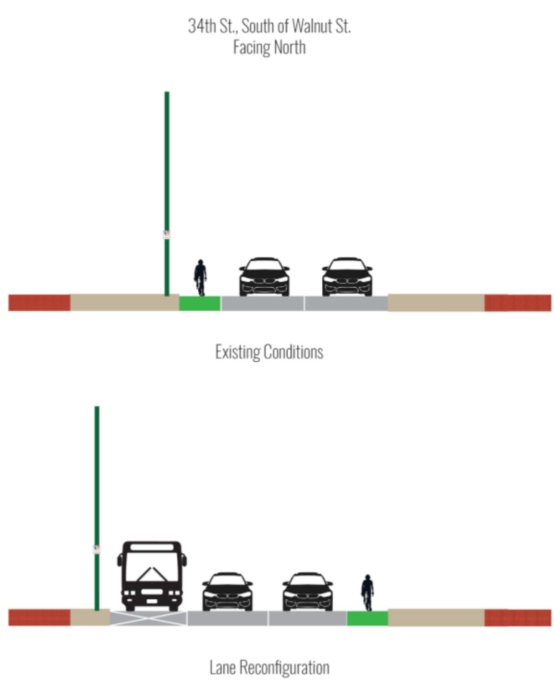
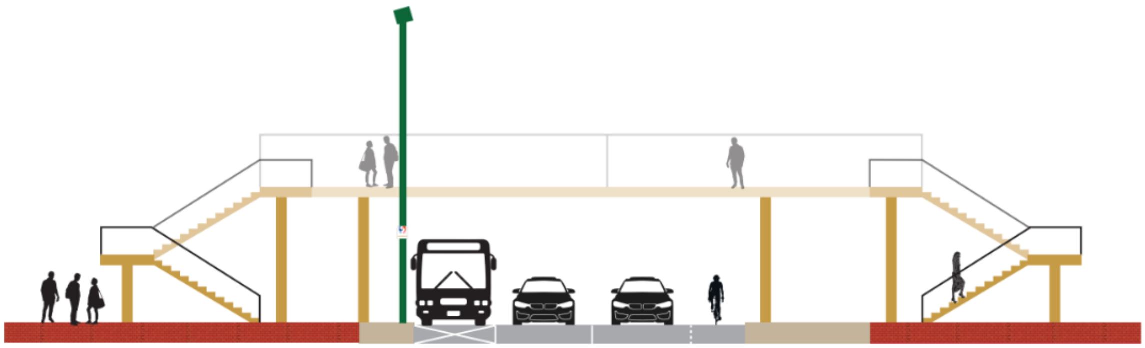


Figure 25. Lane Reconfiguration for 34th Street

<u>Alternative 2</u>: Pedestrian Bridge

Pedestrian Bridge

The most glaring roadway conflict at the intersection is between vehicles and pedestrians. Since pedestrians account for nearly half of all intersection users, maximizing pedestrian mobility serves as a strategy to maximize vehicle efficiency **Figure 26** provides a rendering of our proposed pedestrian bridge over the intersection.



<u>Figure 26. Proposed Pedestrian Bridge (view north on 34th street)</u>

This bridge creates an attractive pedestrian bridge allowing pedestrians to choose to cross over the bridge rather than cross over the roadway. The site plan would disable automatic pedestrian signals but maintain zebra crossings. The proposal also includes the addition of blue handicap pedestrian call buttons to discourage most pedestrians from using the zebra crossings.

When designing this pedestrian bridge, the planning limitations include federal ADA standards mandating a one-inch vertical ride per one-foot horizontal run. Since the standard truck is 14 ft tall, we incorporate 15 ft 2 in vertical clearance under the bridge. The bridge will feature the following:

- Two 182-ft ramps on Woodland Walk (southwest and northeast corners of the intersection.
    - 15 ft 2 in feet vertical rise = 182 ft horizontal run
    - 12-15 ft wide
- An attractive 5000-sq ft pedestrian plaza over the intersection itself.
- Four staircases near the intersection corners.
    - Southwest staircase can be at approximate midpoint of ramp (~7 feet tall) near Meyerson Hall.
        - 11 ft long (12 steps)
        - 6 ft wide
        - 7 ft tall.
    - Other staircases are full height.

    - 30 ft long (26 steps in two sections plus turnaround)
    - 12 feet wide
    - 15 ft 2 in tall
- Elevator connection to 3401 Walnut Street

This strategy would accommodate for the existing pedestrian flow at the intersection, reducing roadway conflict between vehicles and pedestrians, which makes the intersection safer for both modes and maximizes vehicle efficiency by reducing queue length and delay time. This strategy may also encourage more walking at the intersection, especially as the area's daytime population grows. Therefore, the pedestrian bridge alleviates burdens on vehicle efficiency in the event of economic and population growth.

Redesign Strategy #3: Congestion Pricing

Congestion Pricing

This report considers congestion pricing as a demand-side strategy to lower vehicle traffic demand at this intersection. **Figure 27** provides a supply and demand curve attempting to explain the market approach to alleviating congestion.

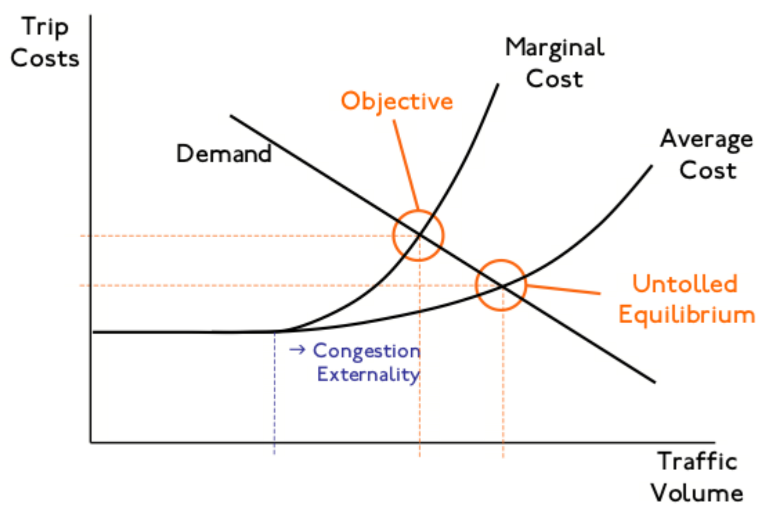


Figure 27. Supply and Demand Model for Congestion[xii]

Congestion pricing has been used in many countries in Europe, as well as some Asian countries such as Singapore. Raising the trip cost for every vehicle would bend the cost curve and lower overall traffic demand at a new equilibrium. For example, data from London reveals traffic in 2013 decreased by 10% compared to pre-congestion charging congestion levels. For this intersection, we propose three different charging scenarios.

Scenario 1: Toll on Walnut Street Bridge over Schuylkill River

Figure 28. Walnut Street Toll Bridge

In this scenario, we propose building a toll gate on the Walnut Street Bridge over Schuylkill River. Since most traffic on Walnut Street comes from Center City traveling westbound, we can lower traffic demand at the intersection. The actual toll amount could be linked to the real-time traffic demand and congestion levels on the street.

This would be the simplest scenario to implement, as only one electronic tolling gate is needed, thus a much lower capital and maintenance cost. However, this scenario would also be the hardest politically, as tolling a non-expressway bridge in an urban area has almost no precedence. In addition, vehicles would also “dodge” the tolls by using the Market or South Street Bridges, which may increase congestion on those streets and worsen the overall system performance in the region, which is counter-intuitive to our goal of increasing vehicle efficiency.

Scenario 2: Center City Congestion Charging

Figure 29. Center City Congestion Charging

In this scenario, we propose establishing a Center City Congestion Charge, like the Central London Congestion Charge[xiii]. In this scenario, vehicles entering the charging zone would be required to pay a toll. Compared to scenario 1, drivers won't be able to "dodge" the toll by taking alternative routes, as long as they are coming from Center City. However, since center city has much more entrances, a lot more toll gates would be required. Furthermore, the political opposition would be much greater, as more stakeholders would be involved.

Scenario 3: University City Congestion Charging

Figure 30. University City Congestion Charging

This proposed scenario would be like scenario 2, as we propose establishing a congestion charging zone in University City. This would also be the only scenario where our study intersection is located directly in the charging zone. Compared to the proposed Center City Zone or the Walnut Street Bridge toll, this zone directly manages the traffic demand on both Walnut and 34th Streets, as opposed to just Walnut Street. In addition, compared to Center City, street blocks in University City are much bigger, so that fewer toll gates are needed. As a bonus, revenues gained from the tolls could be used to fund transit in the area, such as the two SEPTA LUCY Routes. However, political opposition would also make implementation difficult. Recently, Councilmember Blackwell of Council District 3 has been critical of the Chestnut Street protected bike lane due to a perceived reduction in vehicle travel speeds[xiv]. Adding toll gates to the council district is likely to be met with opposition by District 3 residents and Councilmember Blackwell.

Overall, considering the topography and general political climate in Philadelphia, the three proposed scenarios will be difficult to implement. Nonetheless, congestion charges have been used around the world to manage traffic demand and reduce congestion externalities. However, since we are only managing vehicle efficiency at one intersection, as discussed before, there are more feasible approaches to achieving this goal.

V. Conclusion

This study sought to maximize vehicle efficiency at the intersection of 34th and Walnut in University. Addressing vehicle efficiency at this intersection is crucial. First, the intersection is located at the heart of one of the region's metropolitan centers, interacting with hundreds of thousands of visitors each day. Second, this intersection has a high volume of pedestrians, bikers, and transit users. The multimodal nature of this intersection is often at odds with vehicle flow and poses serious safety concerns. Finally, the increased presence of ride-share and freight activity in the area adds to mode conflict, hinders vehicle efficiency, and adds to roadway safety concerns.

In this study, we define vehicle efficiency as maximizing vehicle flow while minimizing delay. We used four metrics to evaluate vehicle efficiency: queue length, delay time, capacity & flow, and traffic obstructions. The strategies presented above maximize vehicle efficiency by reducing queue length, delay time, and traffic obstructions. However, one of the challenges of intersection redesigns is the narrow scope. A single intersection is influenced by many factors, including activity occurring at surrounding intersections. For instance, our signal timing adjustment will only work if signal timing is also readjusted at 34th and Spruce, and at other intersections. Since intersections are part of a larger network, any meaningful impact to vehicle efficiency must be cognizant of that network. Possible next steps of this research includes understanding how our proposed redesign impacts the entire network, and not just the intersection.

Citation

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