Simulation Analysis of Intersection Treatments for Cycle Tracks

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Abstract

The increased use of cycle tracks – also known as protected bike lanes – has led to investigations of how to accommodate them at intersections. The protected intersection (http://vimeo.com/86721046) is a concept that borrows from Dutch intersection treatments for bicyclists. The basic design is to provide a separate space for bicyclists between the pedestrian facilities – sidewalks and crosswalks – and the travel lanes. The bicyclist area is protected from the travel lanes using raised curbs at the corners. To improve visibility of bicyclists, the stop bar for bicyclists is placed ahead of the stop bar for vehicles and the bicyclist crossings are one vehicle length back from the intersection. The design allows bicyclists to make free right turns at the intersection and complete left turns in two stages. Although the protected intersection concept shows promise based on its Dutch legacy, engineers, planners and advocates lack sufficient information to confidently implement the concept in an American context.

The main operational issue and safety concern with the protected intersection design is how to manage the conflict between bicyclists and right-turning vehicles. This paper evaluates the operations of the following methods for controlling the interaction between right-turning vehicles and bicyclists at a signalized protected intersection.

1. Right-turning drivers yield to bicyclists during the vehicle green phase
2. Bicyclists (and pedestrians) are provided a leading interval
3. Bicyclists are provided a separate protected phase for all movements
4. Right-turning drivers are provided a separate protected signal phase, and bicyclists proceed concurrently with through vehicles

A typical traffic signal was modeled using the Vissim traffic analysis software. Vehicle, bicyclist, and pedestrian volume was added to the model to provide operating conditions equivalent to an average of about 55 seconds of delay per vehicle (level of service D/E conditions). Then, the protected intersection with the above control options was modeled to determine the change in vehicle, bicyclist, and pedestrian delay.

For the test case, motor vehicle delay was reduced with the first signal option (Right Turn Yield) since slower moving bicycles were removed from the regular travel lanes and crossing distances for pedestrians were shortened. Providing leading interval for bicycles or right-turn phases for vehicles to reduce vehicle-bicycle conflicts increases motor vehicle delay, but bicycle and pedestrian delay increases would be less. A scramble phase for bicycles and pedestrians would increase delay for all modes, so this is most appropriate at locations with very high bicycle volumes and where the motor vehicle delay tradeoff is acceptable. Additional considerations, including safety, need further study.

Introduction

Bikeway design in the United States since the 1960s has relied primarily on three types of bikeways: shared-use paths, bike lanes, and bike routes. Over the past decade, many transportation engineers and planners have sought to expand the bikeway types described by various design standards and guidance. Cycle tracks, popular in bicycle-friendly European countries such as the Netherlands and Denmark, are an emerging bikeway type in the United States. A cycle track is an exclusive bikeway that combines the user experience of a separated path with the on-street infrastructure of a conventional bike lane. Cycle tracks often feature vertical separation between the bikeway and the adjacent travel lane such as bollards, planters, raised curb, or on-street parking. When properly designed, cycle tracks are associated with a higher level of user comfort that attracts a broader cross-section of users.

Background

Signalized intersection design is a key challenge for the implementation of cycle tracks. Traditional bike lane design, which places bike lanes immediately adjacent to a travel lane, generally sought to minimize conflicts between right-turning drivers and through bicyclists to avoid “right hook” collisions. Separating a cycle track from the adjacent travel lane makes it more difficult to manage turn conflicts at intersections. Two solutions have been identified to reduce turn conflicts at signalized intersections: mixing zones and exclusive (protected) turn phases. Mixing zones, which merge bicyclists into bike lanes or shared lanes in advance of the intersection, typically do not provide a high degree of user comfort. Exclusive turn phases can reduce capacity at signalized intersections.

The protected intersection, or Dutch junction, is a concept that borrows from bikeway and intersection design in the Netherlands (see Figure 1). The key feature of a protected intersection is the corner refuge island that provides the following benefits.

- Puts the stop bar for bicyclists ahead of the stop bar for vehicles
- Sets the bicycle crossings approximately one car length back from the adjacent travel lane
- Allows for bicyclist two-stage left turns
- Allow for bicyclist free right turns

A key concern raised by American designers is the placement of the cycle track to the right of a shared through/right-turn lane or to the right of a dedicated right-turn lane. This configuration provides a potential for conflict between right-turning drivers and through bicyclists.

Protected intersections are already scheduled for construction in Davis, California; Salt Lake City, Utah; and other North American cities. Safety studies of these pilot installations will inform engineers and planners as to the suitability of the protected intersection in an American context. In addition to safety, American engineers and planners will frequently require an understanding of traffic operations (level of service) at locations where a protected intersection is proposed. Level of service is affected by many factors including traffic signal operation.

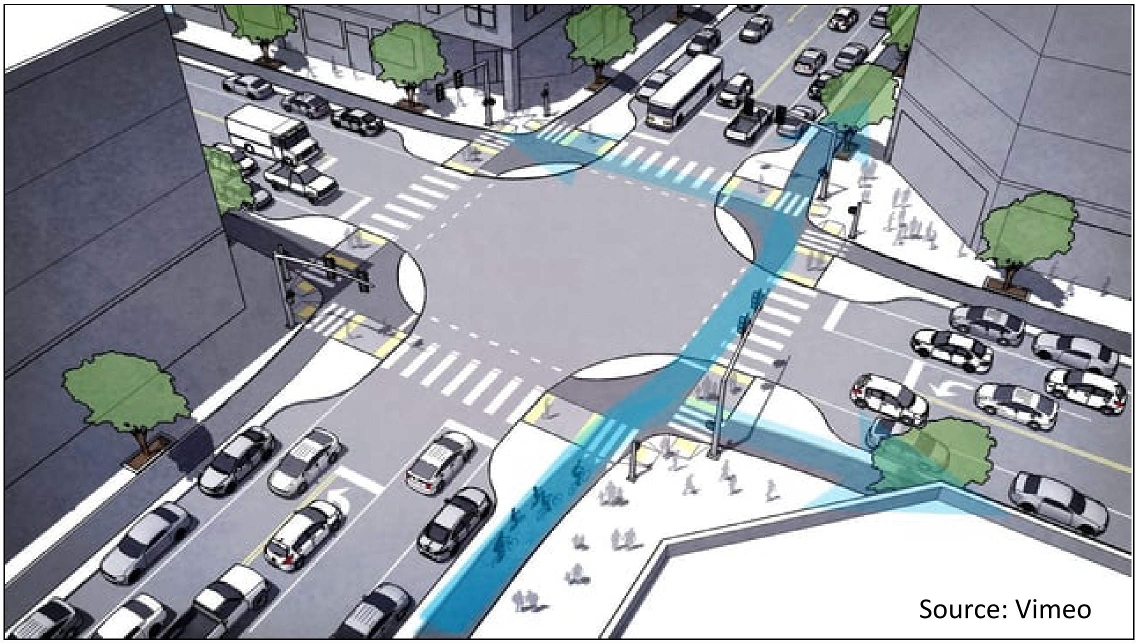

Figure 1. Conceptual design of a protected intersection

Based on a review of relevant Dutch design guidance and conversations with Dutch engineers, there are typically four ways to operate traffic signals at a protected intersection:

1. Right-turning drivers yield to bicyclists during the vehicle green phase
2. Bicyclists (and pedestrians) are provided a leading interval
3. Bicyclists are provided a separate protected phase for all movements
4. Right-turning drivers are provided a separate protected signal phase, and bicyclists proceed concurrently with through vehicles

The delay implications of these approaches were investigated using a traffic simulation model of a test case. The inputs and results of the investigation are presented in the following section.

Modeling

To test the performance of the signal control options for the protected intersection, a Vissim (version 7.00-08) microsimulation model was constructed. For comparison, a standard intersection model was also built. Screen captures of the model networks are shown in Figure 2. In the figure, bicycle-only links are shown in green, and pedestrian links are shown in red.

The modeling assumptions for the test case are provided below.

- Seeding interval of 15 minutes and four 15 minute analysis intervals for a one-hour period
- Peak hour factor of 0.95
- Truck volume of 3 percent
- Pedestrian volume of 20 pedestrians per hour in each direction in the crosswalks
- Turning movement volumes for motor vehicles and bicycles as shown in Figure 3
- Average speed of 25 mph for motor vehicles, 11.5 mph for bicycles, and 2.5 mph for pedestrians

- Left (150 feet) and right (100 feet) turn pockets on the major street and left (100 feet) turn pocket on the minor street
- Protected left turns for the major street and permissive left turns for the minor street
- Maximum recall for through movements and no recall (actuated) for major street left turns

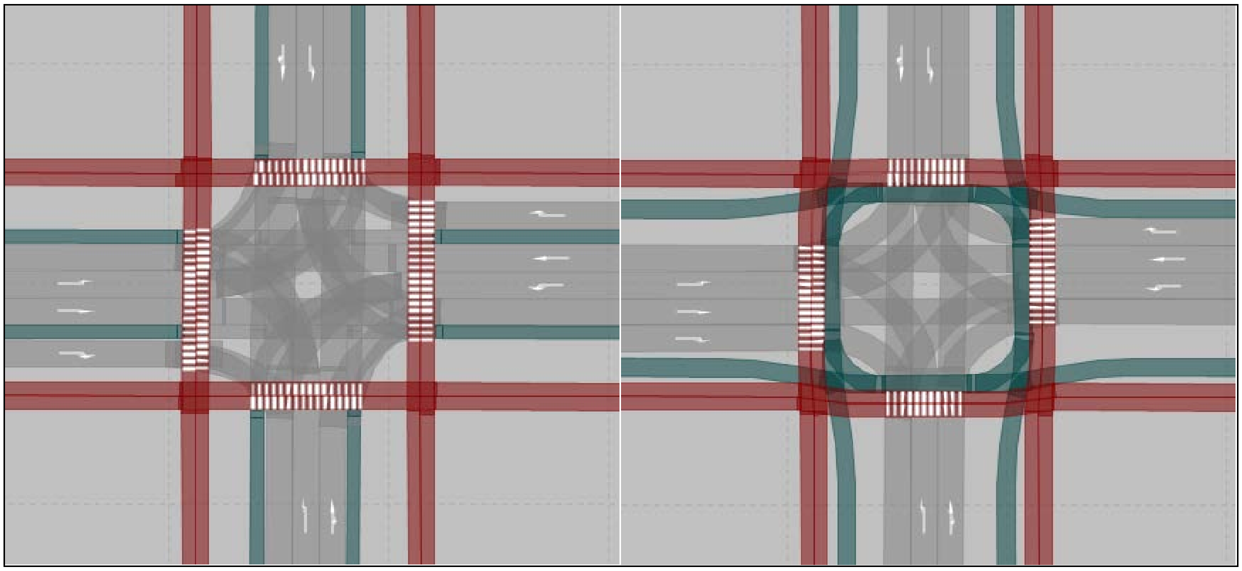

Figure 2. Standard (right) and protected (left) intersections in Vissim

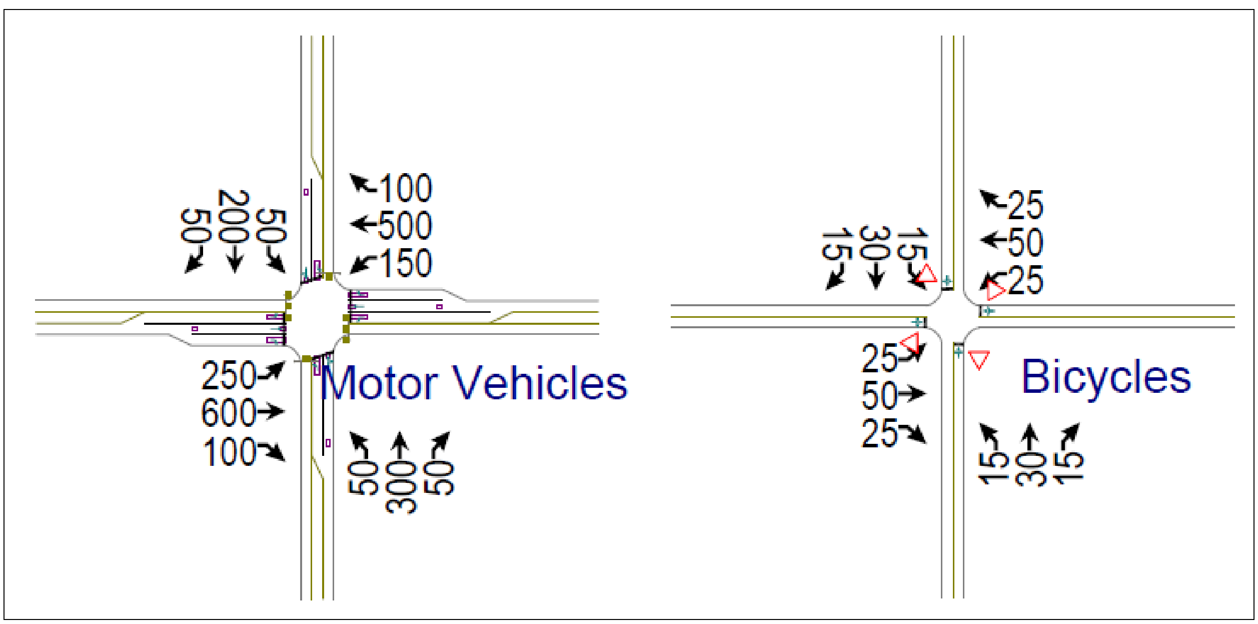

Figure 3. Motor vehicle and bicycle volumes

The standard intersection has a mixing zone on the major street so that bicyclists cross the right-turning motor vehicles in advance of the intersection. Left-turning bicyclists are assumed to use the left-turn pocket to complete their turn – no two-stage left turns. The minor street approaches have shared through/right-turn lanes so drivers must yield to through bicyclists. The signal timing used for the test case is a 90-second cycle length where 20 seconds is provided for the major street left turns, 40 seconds for major street through/right-turn movements, and 30 seconds for minor street approaches.

For the protected intersection scenarios, right turns on red are prohibited to reduce motor vehicle conflicts with bicycles. Bicycles are assumed to travel only via the cycle track network. For the first option – right-turning drivers yielding to bicyclists, the signal timing is the same as the standard intersection scenario. For the second option, a five-second leading interval for bicycles and pedestrians is added before the major street through/right-turn and minor street phases. For this scenario, the 90-second cycle length is maintained by reducing the corresponding vehicle phases by five seconds.

The third signal option is to provide a separate phase for bicycles and pedestrians. In this scenario, bicycles and pedestrians are only allowed during this exclusive 25 second phase. To accommodate the additional phase, the cycle length is increased from 90 to 110 seconds, and the minor street approach phases are reduced from 30 to 25 seconds.

The fourth signal option introduces right-turn phases of 15 seconds for the major street approaches, which have exclusive right-turn lanes. Major street right turns are prohibited during other phases. To accommodate the additional phases, the cycle length is increased from 90 to 100 seconds, and the minor street approach phases are reduced from 30 to 25 seconds.

Results

Table 1 presents the average intersection delay under the five analysis scenarios. The delay is reported in seconds per vehicle according to three modes – motor vehicles, bicycles, and pedestrians – and for all modes combined. The total intersection demand volume by mode is provided in the last row of the table. About 83 percent of the overall volume is motor vehicles. Bicycles are about 11 percent, and pedestrians are about 6 percent.

For the given conditions, the standard intersection configuration provides an average of 53.5 seconds of delay for motor vehicles. This is near the level of service D/E threshold of 55 seconds. Bicycles and pedestrians have lower congestion levels (due to lower volumes), so their delay is correspondingly lower at about 25 seconds and 43 seconds, respectively. The volume-weighted delay across all modes is about 51 seconds per vehicle for the standard intersection.

The first protected intersection scenario (Right Turn Yield) has a somewhat surprising result in that delay would be reduced for the motor vehicles by about 13 seconds on average. The delay savings would come from a few areas. First, left-turning bicycles are shifted to the cycle track network such that the motor vehicles are no longer slowed by their lower speed, particularly for left-turn movements. Second, the protected intersection has shorter crosswalks, which result in shorter minimum splits for low volume phases and therefore more green time for high volume phases. Third, the advanced stop line for bicycles and pedestrians allows these modes to leave the conflicting area of the intersection before turning vehicles can reach them so that the time spent yielding is lower. Bicycle delay increases by about three seconds due to the two-stage left-turn movement required for the protected intersection. Pedestrian delay decreases by about one second due to the shorter crosswalks.

TABLE 1. AVERAGE INTERSECTION DELAY

Scenario	Motor Vehicles	Bicycles	Pedestrians	Total
Standard	53.5	25.4	42.8	51.2
1. Right Turn Yield	40.5	28.1	41.8	40.3
2. Leading Interval	64.3	28.1	40.3	60.6
3. Scramble Phase	103.8	31.2	47.4	95.2
4. Right Turn Phase	66.1	29.8	45.5	62.7
Demand Volume (vehicles per hour)	2,400	320	160	2,880

Note: Average intersection delay reported in seconds per vehicle.

The second option (Leading Interval) would increase delay to motor vehicles by about 11 seconds compared to the standard intersection due to the loss of green time for the through phases. For bicycles, the average delay would be unchanged from the first protected intersection scenario. For pedestrians, the leading interval would provide a head start resulting in a delay reduction of 2.5 seconds.

The timing requirements for the third option (Scramble Phase) cause a significant increase in vehicle delay. The average motor vehicle delay nearly doubles, and the level of service worsens to F. Since bicyclists and pedestrians must wait for the scramble phase, this option also increases the delay for these modes.

The final protected intersection scenario (Right Turn Phase) provides conditions similar to the second scenario for motor vehicles and bicycles. The addition of the right-turn phases increases average delay to pedestrians by about five seconds compared to the leading interval option. The right-turn phases reduce the green time given to through phases that are associated with the pedestrian phases.

Findings

The findings of this analysis of signal control options for the protected intersection are summarized below.

- If standard signal phasing is retained, motor vehicle delay may be reduced compared to a standard configuration since slower moving bicycles are removed from the regular travel lanes and crossing distances for pedestrians are shortened.
- Providing a leading interval for bicycles or right-turn phases for vehicles to reduce vehicle-bicycle conflicts will increase motor vehicle delay, but increases in bicycle and pedestrian delay would be less.
- A scramble phase for bicycles and pedestrians would increase delay for all modes, so this is most appropriate at locations with very high bicycle volumes and where the motor vehicle delay tradeoff is acceptable.