3 Transit and Bicycle Integration

3.1 Downtown Transit Stop Configuration

Portland, Minneapolis, Seattle

Description

Transit service on Market Street is slow – average speeds are generally five to six miles per hour – and it may not be as easy to understand, or "as legible" to users as it could be. This best practice profile addresses three related issues: placement of transit stops to optimize access and travel time, assignments of routes to stops to optimize operations and system legibility, and issues associated with streetcar and electric trolleybus operations in a "skip-stop" configuration.

To maximize access, transit stops should be convenient to the key origins and destinations that generate ridership. In a high-density downtown environment, this would suggest more and closer stop spacing. However, the average outbound stop on Market Street requires approximately 35 seconds of running time during peak periods[1]. Adding stops to a route increases travel time, which may make transit less attractive to anyone who is riding through the stop. This must be balanced with the fact that convenient stop locations maximize access, especially for riders with mobility limitations who may prefer not to walk significant distances between stops.

Stops increase travel time in several ways: vehicles must remain at a stop as long as it takes to load and unload passengers, but they must also slow to a stop, return to full speed following each stop, and in many cases, they must wait to merge back into the flow of traffic after a stop.

In environments such as Market Street where there are multiple transit routes, and where routes might use either curb or island stops (or alternately, might "skip stops," stopping at some curb or island stops but not others), assignment of routes to stops should be done in a way that optimizes transit operations, but is also easy for users to understand. This suggests that routes should be grouped or clustered (with letters or numbers identifying categories of stops), and to the extent possible, routes should be assigned to the same types of stops (e.g., curbside stops) in both directions.

If vehicles powered by overhead wires – electric trolleybuses or streetcars – are to skip stops, then they must be able to pass one another "on the wire," and there are technical issues associated with such a configuration.

Design and/or Operational Considerations

1. Stop Spacing

In practice, stop location is a result of many factors, from proximity to major trip generators and concerns about travel time to geography, street design, equity concerns and basic precedent – often, stops have simply "always been there." Stop spacing can also be dictated to a certain extent by block sizes: the existing typical distance between stops on the F-Market and bus lines along Market Street is one (south side) block, or approximately 900 feet.

According to Transit Cooperative Research Program (TCRP) *Report 19: Guidelines for the Location and Design of Bus Stops,* distances between bus stops in the United States are typically shorter in core areas of central business districts than in other environments: the report provides a "spacing range" of 300 to 1,000 feet, and "typical" spacing of 600 feet. In other parts of urban areas, spacing of 750 feet is typical.

Distances between stops on streetcar lines are typically similar to those on local-stop (as opposed to limited-stop, skip-stop or express) bus lines: for example, average stop spacing on the segment of the Portland Streetcar line between Jamison Square and Portland State University, through that city's Pearl District and downtown area, is approximately 750 feet.

There are a number of reasons why transit stops might be more closely spaced in downtown areas than elsewhere, including a higher density of destinations as well as lower travel speeds. If a bus or streetcar is moving only a few miles per hour while in motion, as is typical in congested downtown conditions (including along Market Street, where speeds of 5 to 7 miles per hour are typical), then the acceleration and deceleration required at each stop and the resulting impact on travel time is reduced.

[1] Based on analysis of 2006-07 running time data.

A core tension that must be resolved in stop spacing is between access – essentially, travel time to and from stops, which is improved by adding additional stops – and on-board travel time, which is negatively impacted by additional stops. In general, overall “door-to-door” travel times should be minimized. However, this often means wider stop spacing, and for persons with mobility difficulties, longer distances to and from stops can be not just inconvenient but physically challenging.

That said, reduced on-board travel times are important not just because they can provide greater mobility for existing users and potential new ones, but because they can allow more frequent service to be provided at no additional cost, as vehicles pass each point more often.

Research conducted on optimal, as opposed to typical, stop spacing has found that transit stops are often sited too close to one another, at least if strictly technical concerns are taken into account. Modeling of optimal stop location based on existing patterns of demand for one bus route in Boston found that ideally, average stop spacing would be one-quarter mile (1,320 feet), rather than the existing one-eighth of a mile (660 feet).[2] Another study of a bus route in Portland found that based on access and operating costs, average stop spacing should be 1,222 feet rather than the existing 942 feet.[3]

Additional research has found that most users will travel longer distances in exchange for a higher quality of service; typically, this is defined as rail or rapid transit service, but more frequent service is also a factor in travel decisions. While the distances users will walk to a transit stop exist along a spectrum, a widely applied “rule of thumb” for bus stops is that a quarter-mile walk will be acceptable to most, and for rail and rapid transit stations, a half-mile walk is acceptable.

It should be emphasized that different services may have different stop spacing. The typical distances identified here are for local-, not limited-stop services. Limited-stop services typically make local stops within downtown areas. However, if frequent local service is available within the same corridor, it might be preferable to stop only at major nodes such as rail stations, or other major destinations such as important crossroads within a central business district.

[2] Furth, P. and Rahbee, A. (2000). “Optimal bus stop spacing through dynamic programming and geographic modeling.” *Transportation Research Record 1731*, Transportation Research Board, Washington D.C., 5-22.

[3] Li, Huan, Bertini, Robert, (2009). Assessing a Model for Optimal Bus Stop Spacing with High-Resolution Archived Stop-Level Data. Transportation Research Record: *Journal of the Transportation Research Board*, 2111, pp 24-32.

2. Stop Assignment

Stop assignment is an issue wherever all routes operating in a corridor do not make all stops within that corridor. The most common such arrangement involves local- and limited-stop services. In certain rare cases, routes of the same type (e.g., local service) may make different stops in the same corridor. In these instances, typically transit malls or transit-priority streets on which multiple routes operate routes are generally grouped.

This is the case on Market Street, although there are some variations: for example, Lines 71 and 71L make center island stops inbound west of Eighth Street, but then shift to the curb, while all center-running inbound lines except the F-Market shift to the curb for their final stop before turning right off of Market.

Key concerns in these cases are operational: on Market outbound, lines that must turn right off of the street prior to Van Ness Avenue operate along the curb, while lines that continue west of Van Ness operate in the center lane. This arrangement has the added benefit of being relatively logical and transparent for users: lines that run north of Haight Street are at the curb, while lines running on or south of Haight are in the center.

Inbound, the configuration is less obvious: in addition to the division of Haight Street service between the center and curb lanes, north-of-Haight lines might operate in either lane (the 21 and 31 are in the center lane, while the 5 is curbside). However, this is because routes are grouped inbound by terminus – lines terminating at the Transbay Terminal operate in the curb lane, while all others are in the center lane – which in turn is a function, just as it is in the outbound direction, of which lines must turn off of the street first. This is an operational practicality, but one that might be somewhat confusing to users, as routes might stop curbside in one direction and at center islands in the other.

The best practice in these situations, as illustrated by the case studies in this best practice profile, is to label categories of stops, for example using letters (e.g., “A” through “D”).

3. “Skip-Stop” Operations on Overhead Wires
If vehicles powered by overhead wires are to skip stops, then they must be able to pass one another “on the wire” – in other words, a vehicle that is stopping must be able to transition from one set of wires, or “track,” to another in order to allow other vehicles to pass. On one level, this is a fairly straightforward matter of providing “crossover” wires, and indeed, there are already crossover wires for electric trolleybuses on Market Street.

However, the Market Street crossover wires are designed and located to allow vehicles to change lanes only where their actual route alignments require them to do so, and are not designed to provide a moving trolleybus with the flexibility to pass a stopped trolleybus.

Additional crossovers designed for this purpose would provide this flexibility. Crossovers designed to allow trolley vehicles to pass essentially provide two sets of wire with connecting wires between them. Because crossing wires can’t be provided everywhere, trolley buses can never have the full flexibility of a diesel bus. Buses that are stopping switch from the “passing track” to the “main track” via the crossing wire, keeping the “passing track” clear for through buses. Because passing often requires changing lanes, crossover systems are challenging to design in ways that allow for gradual transitions that reduce potential dewireing. Transitions from one lane to another must be gradual, and drivers must be able to smoothly and accurately cross or stay on course.

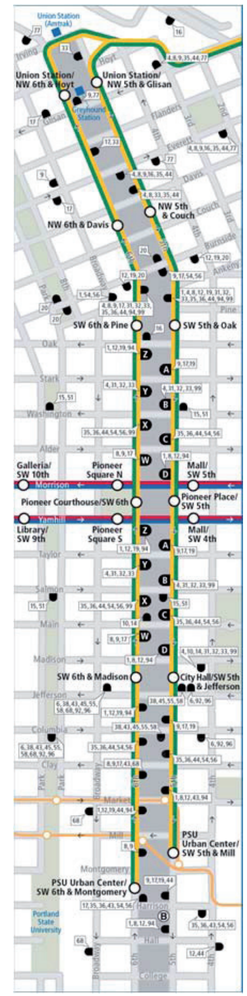
Case Studies

Portland, Oregon

Downtown’s Portland Transit Mall consists of two streets, Fifth and Sixth avenues, that make up a one-way couplet. Two lanes on each street are transit-only, allowing buses and light rail vehicles to pass one another. Routes generally stop every five blocks, or about one-quarter mile. Stops are assigned to one of eight categories labeled A-D (southbound) and W-Z (northbound). The following diagram by TriMet, the transit operator, illustrates this arrangement.

Stop categories are not necessarily coupled; for example, Routes 9, 17 and 19 use “A” stops, but while Routes 9 and 17 use “W” stops in the

Portland Transit Mall Stops



opposite direction, Route 19 uses “Z” stops. Under a previous configuration of the Mall, routes serving geographic sectors (for example, North Portland) used the same categories of stops, which were given colorful names (e.g., Red Fish) accompanied by decorative symbols.

Minneapolis, Minnesota

Minneapolis’ MARQ2 project sought to rationalize the configuration of transit services in the downtown core as well as increase transit capacity. It consisted of two primary components: relocation of express services from the Nicollet Mall (a transit-only facility) and other downtown streets to Marquette and Second avenues parallelling the mall; and significant increases in capacity on both Marquette and Second, which each gained a second peak-period transit-only lane allowing buses to pass one another. This alternative was selected over a transit-only configuration on Marquette and termination of express routes outside the downtown core, with a shuttle service providing access to the core, an arrangement used in Denver. (Marquette and Second are approximately 410 and 820 feet, respectively, east of the mall, but are nearer the core of the central business district.)

As in Portland, stops on Marquette and Second are assigned to one of four categories in each direction, in this case labeled A-D and E-H; also as in Portland, categories in each direction are not necessairly coupled, so that a “G” route might be a “D” or “A” route in the other direction, for example.

There are two stops per block, so that stops in each category are two blocks or approximately 820 feet apart. The following diagram by Metro Transit, the operator, illustrates this arrangement.

Minneapolis MARQ2 Stops

The new configuration improves user understanding by grouping types of routes: only express routes use Marquette and Second, and local routes use Nicollet. Additionally, all routes on each street stop every other block.

Seattle, Washington

Seattle’s Third Avenue is another example of a transit-priority street on which lines use alternating stops -- a “skip-stop” configuration. A number of electric trolleybus lines operate on Third Avenue, and just as on Market Street, trolleybuses pass one another. Unlike on Market Street, however, Third Avenue is not continuously “four-tracked”; instead, it features strategically located crossover wires between tracks used by vehicles operating in the same direction (i.e., wires over both the center and curbside lanes).

Unlike on Market Street, trolleybuses on Third Avenue don’t make stops in different lanes. Instead, they are required by the skip-stop arrangement to regularly pass one another. Thus, there are many more crossover wires. There are risks associated with such a configuration: where wires come into contact with one another, trolley poles may “dewire” or come unattached from the wires, a phenomenon that can occur in San Francisco at intersections where wires cross. The greater the speed, the greater the risk of such an event.

However, Seattle’s King County Metro transit agency has reduced the risk – and indeed, according to staff rarely experiences dewireing at non-interesection locations – by having only those vehicles slowing to a stop or pulling away from a stop make transitions off of and back onto the “main track.” These vehicles use crossover wires to change to the “passing track,” or set of wires over the curbside lane, where vehicles stop. Vehicles traveling through without stopping remain on the main track, in the center lane.

If a skip-stop arrangement were to be implemented on Market Street, and the center lane were to continue to be used for both through travel and stops, then the main track would need to transition or “slalom” from the center to the curb lane and back again. According to King County Metro staff, this can be done, but transitions would need to be relatively gradual for vehicles to maintain their speeds, requiring additional space. In San Francisco, trolleybuses share overhead wires with F Line streetcars, which cannot change lanes.

Potential Market Street Application

“Skip-stop” arrangements reduce on-board travel times, but by reducing access to stops, can increase overall “door-to-door” travel times. Given the relatively long block lengths inbound on Market Street – 907.5 feet including cross-street rights of way – stops on every other block would probably not be desirable. Eighteen hundred feet, or more than one-third of a mile, is simply too great of a distance between stops for local-stop service, particularly in a downtown environment, and access would be severely curtailed. Moreover, inbound buses are near the ends of their routes, so time savings for passengers from a skip-stop configuration would be limited.

It may, however, be possible to refine stop spacing outbound and in segments where blocks are shorter, west of Eighth Street and east of First Street. For example, there are currently island stops at both Ninth and Eighth streets, approximately 625 feet apart.

Alternately, stops could be located every one-and-a-half blocks apart, alternating between midblock and intersection locations. This would result in average stop spacing of approximately 1,350 feet.

Or, on busy routes a “skip-stop” arrangement in which alternating trips on the same line stop at alternating “A” or “B” stops could be implemented, although this would require some reconfiguration of existing overhead wire infrastructure in order to allow electric trolleybuses to pass one another. Such a configuration is possible, but transitions between wire “tracks” can result in derailment.

Stop assignment, meanwhile, should balance concerns of user understanding and operational efficiency. The existing arrangement of route assignments on Market Street to curb and island stops in- and outbound makes sense from an operational perspective, and outbound, the configuration also is logical from a user perspective, with its clear division of services into north- and south-of-Haight Street categories. Inbound, this is not the case, and the arrangement could be made clearer if terminuses for some lines were changed. However, all routes terminating at the Transbay Terminal operate in Muni Rapid Network corridors, making such a reconfiguration potentially undesirable.

For this reason, the existing configuration should probably be maintained *if* both curb and island stops were to continue to exist. In order to provide greater clarity for users, curb and island stops might be assigned “A” or B” designations that could be prominently displayed, although such a categorization scheme is more necessary in locations where stops of the same type (e.g. curbside) are used by different routes. Along Market Street, with its simple division of stops into “island” and “curb” categories, this may be less useful or necessary.

References

Transit Cooperative Research Program (TCRP) *Report 19: Guidelines for the Location and Design of Bus Stops* --
http://www.trb.org/Main/Blurbs/Guidelines_for_the_Location_and_Design_of_Bus_Stop_153827.aspx

3.2 Time-Restricted Transit-Priority Treatments

Seattle, Minneapolis

Description

When transit vehicles must share right-of-way with other vehicles, pedestrians and cyclists, service becomes slower and less reliable. Dedicated right-of-way is an obvious solution, but road space can be constrained. Bus-only lanes that are in effect only at certain times are relatively common, and indeed there are many such examples in San Francisco. However, limits on auto access to a transit-priority street (or a street on which transit service is prioritized over other uses), that are in effect only at certain times remain relatively rare. Typically, auto prohibitions or turn restrictions such as the existing forced turn requirements on Market Street inbound at Tenth and Sixth streets are in effect full-time.

This best practice profile briefly discusses issues associated with part-time prohibitions on auto access to a transit-priority street.

Design and/or Operational Considerations

Part-time application of transit-priority measures is an attractive idea: a flexibie approach can allow right-of-way to be allocated based on demand at different times, meeting the needs of different users. Large numbers of transit riders may benefit from a limited, weekday AM and PM peak-period only restriction on auto access, as demand for transit is greatest during commute hours. Delivery vehicles, shoppers and others in private vehicles, meanwhile, may not be significantly impacted if mid-day, evening and weekend auto access can be maintained.

However, there are obstacles associated with regulations that vary according to time of day. Most obviously, permanent design treatments such as physical barriers may be rendered impractical. This, in turn, means that an ongoing and potentially expensive enforcement effort may be required if the part-time prohibition is to be effective.

The problem is not just scofflaws; regulations with the potential to confuse users can further reduce compliance, as demonstrated by a a 2006 study of San Francisco's bus-only lanes[1] by Michael Kiesling and Matthew Ridgway.

Certain types of prohibition, however, may prove more effective than others. For example, when auto traffic is completely prohibited, any automobile in the area in question is in obvious violation, while violators of a "porous" prohibition such as forced turns may be more difficult to identify.

There are permanent design treatments that, while not serving as a barrier to traffic, might make a part-time prohibition on auto access somewhat more effective. Prominent, highly visible electronic signage is used on Market Street to alert motorists to the restrictions on through travel at Tenth and Sixth streets, and compliance at Tenth has been found to be approximately 80 percent. Electronic signage could just as easily be used to notify drivers of a part-time prohibition on Market Street traffic.

Case Studies

Seattle

Third Avenue is a transit-priority street in Downtown Seattle. Along with the Downtown Seattle Transit Tunnel under the street, it serves as the north-south spine for transit service in Downtown Seattle.

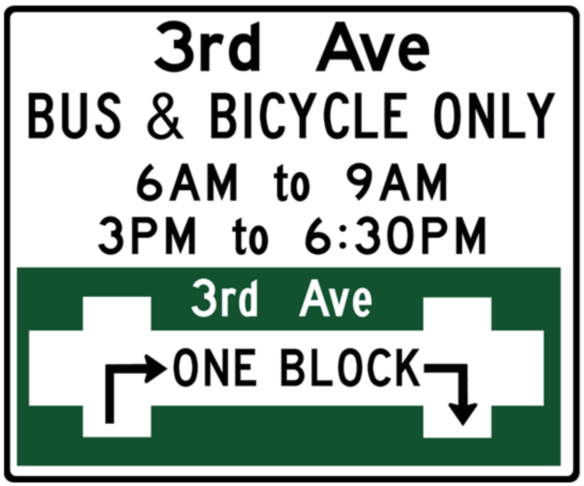
Despite this, there are no transit-only lanes on Third Avenue. Instead, peak-only turn requirements are enforced: Motorists may travel only one block before they are required to turn right off of the street, and left turns are not allowed.

Signs are used to notify motorists when the requirements are in effect, between 6 and 9 a.m. and 3 and 6:30 p.m., and enforcement consists of what the Seattle Department of Transportation calls a "focused police presence." According to the Seattle Police Department, the street is generally patrolled daily by two motorcycle officers as part of a larger effort to maintain peak-period traffic flow downtown, and violators are issued $124 citations for failure to obey signs. In other words, there is no 3rd Avenue-specific traffic law or enforcement effort, although there is regular enforcement. There is also an ongoing effort to "educate" magistrates about the visibility of signs, as some are initially skeptical about motorist awareness. No

[1] Kiesling, Michael, Ridgway, Matthew. (2006). Effective Bus-Only Lanes. ITE Journal, Volume 76, Issue 7, pp 24-29.

data have been collected on rates of compliance. The following diagram provided by the Seattle Department of Transportation shows a typical sign.

Seattle Third Avenue Signage



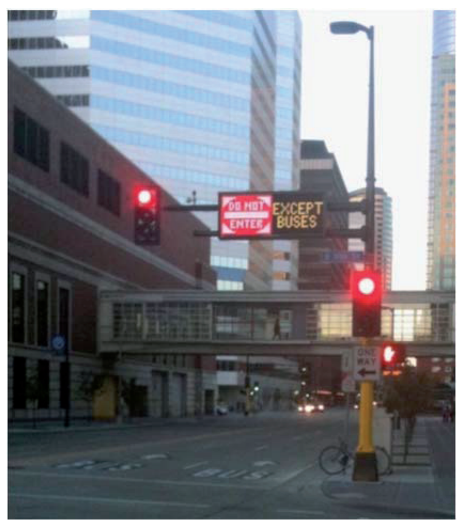
The current configuration of Third Avenue was implemented in 2005 as a temporary measure, while the Transit Tunnel was closed for reconstruction to accommodate light rail service. However, the arrangement was found to improve transit travel times by 20 percent, and was left in place after the tunnel reopened.

Minneapolis

The bus lanes on Marquette and Second Avenues in Downtown Minneapolis, described in the "Downtown Transit Stop Configuration" profile, are open to traffic outside of the peak periods of 6 to 9 a.m. and 3 to 6:30 p.m. As in Seattle, variable message signs are used to indicate whether autos are allowed.

The physical and service configurations of Marquette and Second may serve to make a part-time prohibition more effective: the part-time bus lanes are contraflow, meaning that during peak periods, one entire side of the street is closed to traffic. Additionally, several dozen routes use the lanes, so any motorist attempting to enter them would quickly find himself alone among a multitude of buses.

Minneapolis Second Avenue Transit Lanes



Potential Market Street Application

On Market Street, full-time turn requirements already exist, so any additional part-time transit priority treatment would likely consist of additional turn requirements or a total prohibition on certain types of traffic.

A total peak-period prohibition on private autos, and potentially delivery vehicles (as a form of transit service, taxis should probably continue to be allowed at all times), would be easier to enforce than the existing turn requirements: Any private auto on Market Street within the restricted zone during the time in question would be in clear violation, and violators could be identified using enforcement cameras on-board Muni vehicles.

In order to reduce confusion, it might be desirable to remove the existing turn requirements outside of peak periods. This would serve to simplify motorist understanding of the regulations in effect on Market Street: Market would simply be closed to traffic during rush hours.

Such an arrangement, however, would have traffic impacts on Mission, Folsom and other streets (including cross streets and east-west streets north of Market, as motorists would be unable to use Market for purposes of circulation), and it would reduce auto access to Market Street businesses during peak periods.

Alternately, different types of turn requirements and restrictions might be required part- or full-time. These might include regular forced-right requirements like those on Third Avenue in Seattle or those that used to exist on the Portland Transit Mall. It might also be possible to restrict some or all turns on to Market Street. Again, however, complexity can serve to reduce compliance, so any strategy should have as a key objective legibility for motorists. Extensive, regular enforcement would also be required.

3.3 Cycle Tracks

Multiple Locations

Description

Market Street is the most popular bicyclist thoroughfare in San Francisco because it offers a direct and flat connection between downtown, residential neighborhoods, commercial corridors, and recreational opportunities. Market Street, however, presents a unique design challenge as it seeks to accommodate a growing number of bicyclists. In short, numerous other modes also utilize Market Street, creating a strong competition for scarce right-of-way and the potential for various types of conflicts with vehicles, transit services, pedestrians, and other cyclists.

Cycle tracks are bicycle lanes that operate within the street right of way but are physically separated from vehicle traffic, pedestrian activity, and parked vehicles. Cycle tracks can be described as conventional bicycle lanes that have been "strengthened" by various engineering mechanisms offering a visual and/or physical buffer. Cycle tracks are diverse in form, design, and application. For example, cycle tracks can be one-way or bi-directional. Cycle tracks can be physically separated by medians or curbs, a row of parked vehicles, various barriers (bollards, landscaping, or street furniture), through vertical separation provided by a raised curb, or by a combination of multiple elements.

Cycle tracks present both opportunities and challenges. While research on cycle tracks in North American cities is largely incomplete, existing studies have shown that cycle track offer a number of benefits. First, cycle tracks have been shown to improve safety, as evidenced by a recent study that found that cycle tracks had a 28% lower injury rate than control streets.[1] A Copenhagen study found that accidents and injuries have declined on mid-block segment with cycle tracks by 10% and 4%, respectively.[2] Second, research strongly indicates that bicyclists feel safer in cycle tracks and have been found to use such facilities 2.5 times more than conventional facilities.[3] Third, a recent study of Portland cycle tracks found that support for those facilities was high among bicyclists and motorists.[4] Finally, evaluations of recent applications in the U.S. has shown that cycle tracks can result in increased bicycle ridership, reduced sidewalk riding, decreased traffic speeds and volumes, and consistent travel times for motorists.[5]

At the same time, existing research shows that cycle tracks do present key design challenges. First, the Portland cycle track study found that conflicts between bicyclists and crossing pedestrians was high, as over 40% of surveyed bicyclists stating that they had been involved in a near-collision with a pedestrian.[6] In addition, cycle tracks have been shown to increase the chance of collision at intersections. While the Copenhagen study found that safety improved on med-block segment, it also found that collisions and injuries at intersections increased by 18%.[7]

This best practice profile examines the use of cycle tracks and their potential applicability to Market Street. An overview of general design best practices is provided, but attention is primarily paid to intersection conflicts, managing turning movements, and integration with transit. In addition, case studies are provided to illustrate how jurisdictions have managed common design issues.

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[1] Lusk, A. C., Furth, P. G., Morency, P., Miranda-Moreno, L., Willett, W. C., & Dennerlein, J. T. (2010). *Risk of injury for bicycling on cycle tracks versus in the street.* Injury Prevention.

[2] Jensen, S. U., Rosenkilde, C., & Jensen, N. (2007). *Road safety and perceived risk of cycle facilities in Copenhagen.* Copenhagen: Trafitec Research Center.

[3] Lusk, A. C., Furth, P. G., Morency, P., Miranda-Moreno, L., Willett, W. C., & Dennerlein, J. T. (2010). *Risk of injury for bicycling on cycle tracks versus in the street.* Injury Prevention.

[4] Monsere, C., McNeil, N., & Dill, J. (2011). *Evaluation of Innovative Bicycle Facilities: SW Broadway Cycle Track & SW Stark/Oak Street Buffered Bike Lanes.* City of Portland: Bureau of Transportation.

[5] New York City DOT (2010). *Prospect Park West Bicycle Path and Traffic Calming: Before and After Results.* Accessed April 21, 2011. http://www.nyc.gov/html/dot/downloads/pdf/20110120_ppw.pdf

[6] Monsere, C., McNeil, N., & Dill, J. (2011). *Evaluation of Innovative Bicycle Facilities: SW Broadway Cycle Track & SW Stark/Oak Street Buffered Bike Lanes.* City of Portland: Bureau of Transportation.

[7] Jensen, S. U., Rosenkilde, C., & Jensen, N. (2007). *Road safety and perceived risk of cycle facilities in Copenhagen.* Copenhagen: Trafitec Research Center.

Design and Operational Considerations

1. Basic design best practices

In the U.S., the primary manuals for bicycle design – the American Association of State Highway and Transportation Officials (AASHTO) *Guide for the Development of Bicycle Facilities* and the *Manual on Uniform Traffic Control Devices* (MUTCD) – limit discussion of "separated" facilities to shared-use paths and do not explicitly address physically separated bicycle facilities. In short, there is no *formal* guidance in the U.S. for the design and implementation of cycle tracks. Therefore, much of the design guidance that is available in regards to cycle tracks comes from European jurisdictions, and recent applications of cycle tracks in U.S. cities have relied heavily on European best practices, as well as local professional engineering judgment.[8]

Cycle tracks present a wide range of complicated design challenges. It is not the intent of this best practice profile to provide an in-depth description of all of these design issues, but rather to offer a summary of design best practices synthesized from various bicycle plans, planning guidelines, publications, and websites.[9] Key design considerations are outlined below:

- **Lane width:** On one-way cycle tracks, the recommended minimum lane width is 6.5-7 feet, with 7 feet preferred on streets with high volumes or grades.[10] At pinch points or constrained intersections, 5 feet is acceptable.[11] On two-way cycle tracks, a 12-foot lane width is recommended, with 8 feet acceptable at pinch points.[12] Many international guidelines design cycle tracks width based on bicycle volumes, and often suggest even wider lane widths for streets with high volumes. This design consideration seeks to account for the speed differential that exists between bicyclists and allows for safer passing. For example, the CROW *Design Manual for Bicycle Traffic* (Netherlands) provides the following guidance.

Cycle track lane width guidance (Netherlands)[13]

One-way cycle track		Two-way cycle track	
Peak-hour bicycle volumes (both directions)	Width (ft.)	Peak-hour bicycle volumes (both directions)	Width (ft.)
0-150	6.5	0-50	6.5
150-750	8-10	50-150	8-10
750+	11-13	150+	11-13

- **Physical separation:** The amount of "buffer," or physical separation, between bicyclists and other roads users, including motorists, pedestrians, and transit vehicles is a key design consideration for cycle tracks. Depending on the street, the majority of "buffering" occurs in the mid-block segments, while intersections are usually managed with alternative treatments (see below). With cycle tracks of adequate width (7+ feet) additional buffer space is not required, although a baseline of 1-2 feet is ideal in most situations. When adjacent to parked vehicles, a 3-foot is preferred in order to clearly separate bicyclists from opening doors and avoid conflicts

[8] DuBose, B. (2011). Physically Separated Bikeways: A Game Change for Bicycle Mode Split? *ITE Journal*, 54-58.

[9] The National Association of City Transportation Officials (NACTO) recently created an on-line *Urban Bikeway Design Guide*, which is an compendium of best practices, especially for cycle tracks. http://nacto.org/cities-for-cycling/design-guide/

[10] City of Portland. (2010). *Portland Bicycle Plan for 2030: Bikeway Facility Design Survey of Best Practices.*

[11] NACTO. (2011). *Urban Bikeway Design Manual*. Retrieved April 21, 2011, from http://nacto.org/cities-for-cycling/design-guide/

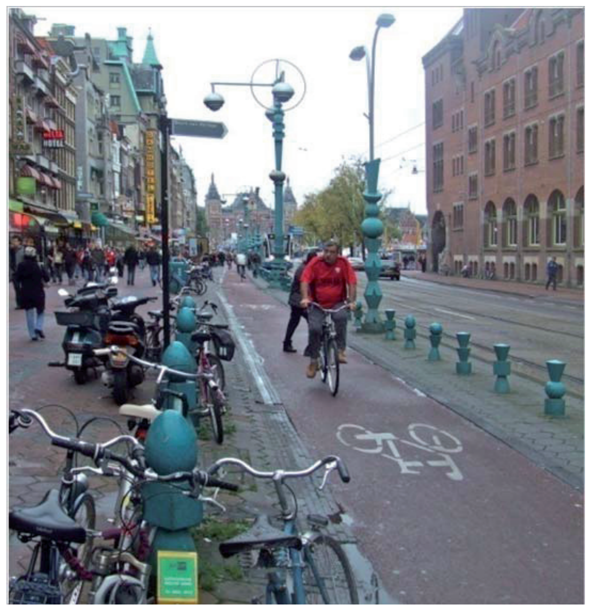
[12] Ibid

[13] CROW. (2007). *Design Manual for Bicycle Travel.* Netherlands: CROW. Page 173.

between bicyclists and drivers/passengers exiting a vehicle.[14]

The physical form of the cycle track buffer can take many forms: pavement markings, landscaping, raised medians, posts, lighting fixtures, bollards, street furniture, or a combination of several measures. In general, the more the physical separation affects sightlines, the greater the required buffer distance. For example, the CROW *Design Manual for Bicycle Traffic* recommends approximately 3.5 feet of buffer with bollards or posts, but a 7.5-foot buffer with vegetation.

Examples of physical separation on Hornby Street (left) and Dunsmuir Street (top right) in Vancouver and Amsterdam (bottom right)



Sources: Flickr users – Paul Krueger; Paul Krueger; Bill Barber

[14] Ibid

Raised lanes are another form of cycle tracks that provide both horizontal and vertical separation. Raised lanes (minimum of 2-3 inches in height) can be flush with the adjacent curb or installed at an intermediate distance between the roadway and sidewalk to offer additional separation with pedestrians.[15] If flush with the curb, additional separation is recommended to ensure that pedestrians do not encroach on the bicycle lane. Raised bicycle lanes typically employ a mountable curb (4:1 or flatter slope)[16] that enables bicyclists to enter and leave the bicycle lane with ease. While motorists could veer into the bicycle lane, the angle of the curb provides an early visual and tactile warning to motorists that they are leaving the travel lane. Many times, however, additional buffer space with some form of physical separation is also employed with raised lanes to further reduce conflicts.

[15] Alta Planning + Design. (2009). *Cycle Tracks: Lessons Learned.*

[16] City of Los Angeles. (2010). *Technical Design Handbook, 2010 Bicycle Plan.*

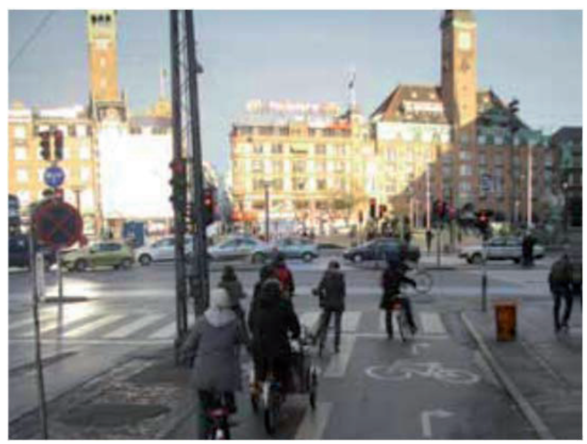
Raised cycle track

Copenhagen, Denmark

Copenhagen, Denmark

- **Signage:** Signage is a crucial element to ensuring the successful implementation of a cycle track. Signage is used to guide bicycle travel and inform motorists and pedestrians that the cycle track is designated for bicycle use. The exact type of signage is dependent on local standards, but best practices dictate that signage include a combination of both pavement markings (i.e. sharrows and "BIKE ONLY") to further differentiate the bicycle facility and elevated signage to warn all road users. Signage should be placed at the beginning of each cycle track and at periodic intervals along the facility.

Examples of cycle track signage



Right turning bicycle signage in the bicycle lane.
Copenhagen, Denmark

- **Colored pavement:** The use of colored pavement (typically blue, green, or red) is not a required treatment for cycle tracks, but it is recommended if feasible as a means to further delineate the cycle track from vehicle and pedestrian travel. Colored pavement is also a recommended treatment at intersections, as discussed in greater detail below.
- **Parking placement:** While not an explicit design issue for Market Street because general parking is prohibited, there is a considerable amount of loading that occurs on Market Street. Much of this loading is accommodated by 75-foot long and 14-foot deep loading bays at mid-block locations. In addition, illegal parking along the curb and double parking in the loading bays does occur along the corridor.

  Obviously, preserving and effectively managing commercial loading is an important cycle track design consideration for Market Street. In general, best practices dictate that cycle tracks should be placed between the curb/sidewalk and the parked vehicles. The recommended buffer between the parked vehicles is a minimum of two feet, but three feet is preferred to minimize conflict. When using pavement markings as the buffer, a minimum of 11 total feet is recommended for the parking lane and buffer zone.[17] On Market Street, it is likely that loading bays would also be placed to the inside of the cycle track. To accommodate such a facility, however, it is likely that the cycle track would also need to "shift" and extend further into the existing sidewalk zone.

Cycle track adjacent to parking[18]

Source: NACTO, Urban Bikeway Design Guide

New York, NY

In recent years, New York City has been one of the leading jurisdictions in bicycle facility design in North America, installing hundreds of miles of bicycle infrastructure, including numerous separated facilities. The NYC *Street Design Manual* outlines specific design guidance for bicycle facilities, including New York's two primary forms of separated facilities: bike lanes with buffers or bike paths with separation from vehicles. The buffered lane requires a minimum of 8 feet – a five foot lane with three feet of buffer (usually pavement markings). By contrast, New York's fully separated bicycle facilities require a minimum of 14 feet to accommodate the bicycle lane, buffer zone, physical treatments, and ensure safe interactions with parked vehicles.

Figure below provides a glimpse at two of New York's most well-know separated facilities, 9th Avenue in Manhattan and Sands Street in Brooklyn. Prior to its redesign, 9th Avenue was a 70-foot street that primarily served motorists. In 2007, the City reduced the number of travel lanes by 30 feet and added a one-way, 9-foot cycle track between the curb and parked vehicles. In addition, the City installed bicycle signals and pavement markings through the intersections to manage turning movements. Finally, a variety of traffic calming measures was also installed to facilitate safer pedestrian movement through the corridor. Sands Street in Brooklyn, the primary connection to and from the Manhattan Bridge, was also redesigned to separate bicycle and offer a safer route. A center-running, two-way cycle track (6-foot wide in each direction, not including the buffer zone) was installed. This facility also provides additional vertical separation with a mountable curb.

Sands Avenue (first and second) and 9th Avenue (third and fourth) in New York

[17] NACTO. (2011). *Urban Bikeway Design Manual*. Retrieved April 21, 2011, from http://nacto.org/cities-for-cycling/design-guide/

[18] Ibid

Sources: Flickr users – Steven Vance; Steven Vance; compujeramy; Kyle GradingerBCGP

2. Managing cycle tracks at intersections

If designed properly, cycle tracks will substantially reduce vehicle and bicyclist conflict along mid-block segments. However, intersections will remain a key conflict point and require additional mitigations. More specifically, intersections present the following design challenges:

- Limited visibility for motorists and bicyclists on intersection approach, especially with cycle tracks that incorporate parked vehicles, landscaping, or street furniture in the buffer zone.
- Integration of modes and merging of travel lanes, most notably at intersections where vehicle right turns are allowed.
- Difficult transitions from “dedicated” to “shared” facilities, especially with raised lanes and the need to bring bicyclists back down to street level.
- Allowing bicyclists to make left turns across vehicle travel lanes.

Best practices and practical experience indicates that cycle tracks at intersections can be managed in an efficient and safe manner if some basic design principles are consistently applied. For example, the CROW *Manual* includes several strategies to reduce potential conflicts at intersections:[19]

- Slowing the speed of vehicular traffic on approach to reduce the speed differential.
- Create recognizable intersection designs and ensure uniform traffic situations.
- Avoiding conflicts with traffic by ensuring good visibility and sufficient sight stopping distance between motorists and bicyclists as they approach the intersection.
- Minimize the number of potential conflict points in the intersection’s design.

The specific physical treatments used to achieve these design principles are varied and diverse. NACTO’s *Urban Bikeway Design Guide* provides a summary of mitigations that can be utilized at intersections to ensure that bicyclists and motorists interact safely. These include:

- Transition from a cycle track to a standard bicycle lane (4-6 feet wide) prior to the intersection. The transition distance varies depending on the context, but at least 16 feet is recommended.[20] In addition, the bicycle lane should be shifted closer to the vehicle travel lane to provide enhanced visibility. This transition also includes prohibiting parking or other visual obstructions 30-50 feet prior to the intersection to increase visibility.
- Highlight transitions zones with “reverse” color treatments (i.e. if the cycle track has colored

[19] CROW. (2007). *Design Manual for Bicycle Travel.* Netherlands: CROW.

[20] Alta Planning + Design. (2009). *Cycle Tracks: Lessons Learned.*

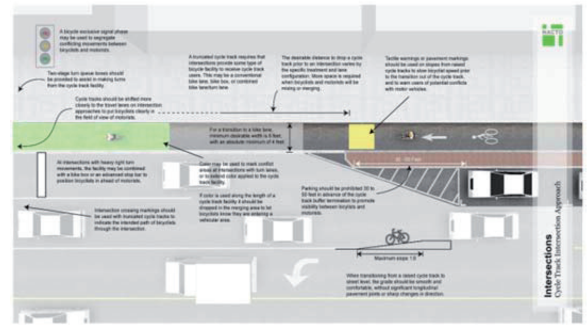
pavement, drop the coloring or vice versa) and pavement markings (i.e. sharrows through the intersection).

Colored intersection treatments on Dunsmuir Street in Vancouver

Sources: Flickr user – Paul Krueger

- With raised lanes, provide a gradual slope down to street grade and potentially employ the use of tactile pavement warning devices on the cycle track prior to the intersection to alert bicyclists.
- Install advance stop bars or bicycle boxes to create a designated waiting space for bicyclists. This is crucial to improving the visibility of bicyclists and allows bicyclists to begin their movements in advance of vehicles, especially at intersections with turning movements.
- It is highly recommended that pavement markings, such as sharrows, continue across the intersection both to guide bicyclists and their turning movements, but also to increase awareness for motorists.
- In addition, the CROW *Manual* recommends that the cycle track be "bent," or angled, towards the vehicle travel lane 65-98 feet before the intersection to "create optimal conditions for a good view of the cyclists" (188).[21]
- Reduce curb radii at intersections, which "increases predictability by ensuring that automobiles will cross in a smaller area" (7).[22]

Summary of Cycle Track Intersection Treatments[23]



Source: NACTO, Urban Bikeway Design Guide

3. Managing turning movements

The accommodation of both bicycle and motorist turning movements is a crucial design issue for cycle tracks. Conflicts can occur throughout the intersection, yet best practices show that with the proper mitigations, turning movements can be safely facilitated. These mitigations are summarized below:

- ***Right turns***: Right turns are best managed through the use of a combined right-turn bicycle lane at the intersection, which positions the bicyclist to the left of right turning traffic and allows "dual" use. Bicyclists can use the

[21] CROW. (2007). *Design Manual for Bicycle Travel.* Netherlands: CROW.

[22] Alta Planning + Design. (2009). *Cycle Tracks: Lessons Learned.*

[23] NACTO. (2011). *Urban Bikeway Design Manual*. Retrieved April 21, 2011, from http://nacto.org/cities-for-cycling/design-guide/

turn lane if making a right turn or utilize the bicycle lane if continuing straight. Another alternative is to transition from the cycle track to a shared lane, which allows vehicles to make right turns. In each case, management of transitions is crucial as the integration of these two modes can create collision hazards. The Grand Avenue cycle track in New York provides an example of how to address right turns for both bicyclist and motorists. It manages the transition by dropping the colored pavement, utilizing sharrows to direct bicyclists, and pavement markings to safely funnel vehicles into the right turn lane.

Grand Avenue at Broadway in New York

Source: Flickr user – K_Grandinger

- ***Left turns**:* Making left turns is especially problematic for bicyclists as it forces riders to enter vehicle travel lanes and integrate with other modes. Best practices typically offer two design solutions to accommodate left turns. One alternative is to facilitate bicyclists merging from the cycle track to the left turn lane with pavement markings and/or signage. At the vehicle left turn pocket, an adjacent bicycle turn lane is also usually provided. This solution is primarily appropriate for streets with low vehicle volumes that would allow for safe merging movements. In addition, such a treatment may not be appropriate for Market Street because of the fact that left turns are prohibited along most of the corridor.

  The other potential solution is a "Copenhagen left turn," also known as a "two-stage" or "jug-handle" turn. With Copenhagen left turns, bicyclists proceed straight through the intersection to the far side and wait with cross street traffic, preferably in a designated bicycle space (i.e. bicycle box). Bicyclists then proceed straight across the intersection when the traffic light changes. While this technique may take longer for bicyclists, it significantly reduces conflict points. Potential design considerations include excessive bicycle queuing within the bicycle lane and conflicts with cross-street bicycle traffic.

Example of a Copenhagen left turn

Copenhagen, Denmark

- ***Signalization**:* Signalization is another treatment that can be used to mitigate conflicts at intersections. By providing separated or protected signal phases, the potential for turning conflicts can be reduced. In general, bicycle signal heads can be used to fully separate bicyclist turning movements from vehicles or provide bicyclists a "head start," which increases visibility and provides a protected lead time for bicyclists. Most commonly, the additional lead time is accomplished with a bicycle countdown signal or the use of pre-green intervals.

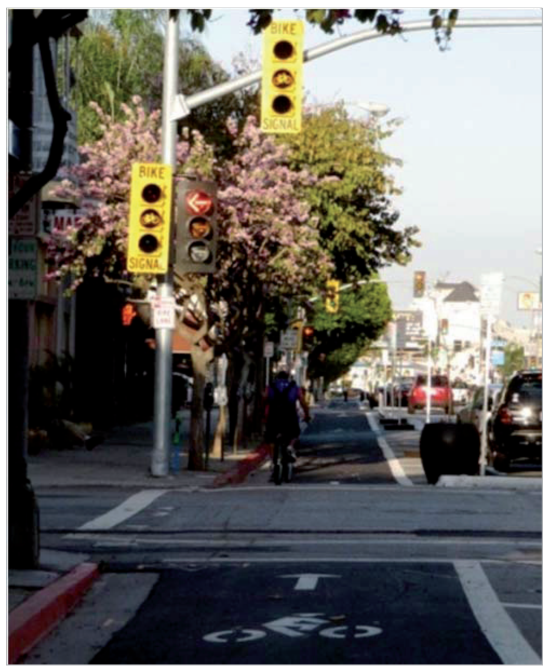
  When utilizing bicycle signals it is crucial that they be clearly differentiated from other traffic control devices. This can be accomplished by using a bicycle emblem within the signal head, the use of different size signal heads, installing on the near side of the intersection, or the use of signage. In addition, push-button activated bicycle signals can also be used in areas where bicycle volumes are lower.[24]

Long Beach, CA

In April of 2011, the City of Long Beach installed its first separated bicycle facility on a couplet of one-way streets running east-west (Broadway runs east and 3rd Street runs west) through downtown. The one mile long (each direction) cycle tracks run along the left side of each street, with physical separation from moving traffic provided by pavement markings, a raised curb, a parking lane, and limited installations of street furniture. The design allowed the City to preserve the vast majority of the parking along the street, with only 20 or so on-street spaces (out of several hundred) lost due to the street reconfiguration.

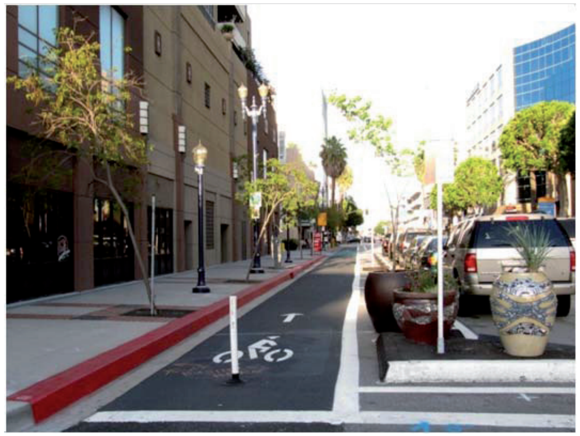
The project cost about $800,000 to complete, with approximately 90% of the costs going to installing about three dozen bicycle signal heads and reconfiguring signal timing to allow for separate bicycle and vehicle signal phases.[25] At each intersection, bicycles are given a green signal which allows them to turn left or proceed straight. Vehicles are allowed to turn left on a separate signal phase, indicated by a green arrow. In addition, the City also utilized various treatments to facilitate safe merging between modes prior to some intersections where motorists want to make left turns, but bicyclists wish to proceed straight.

Long Beach Cycle Track, including bicycle signal heads (1st and 2nd), merging treatments (3rd), and street furniture as physical separation (4th)



[24] Alta Planning + Design. (2009). *Cycle Tracks: Lessons Learned.*

[25] Linton, J. (2011, April 21). *Another Wonderful Long Beach First: Protected Bike Lanes*. Retrieved April 25, 2011, from Streetsblog: http://la.streetsblog.org/2011/04/21/another-wonderful-long-beach-first-protected-bike-lanes/



Sources: Flickr user – waltarrrrr

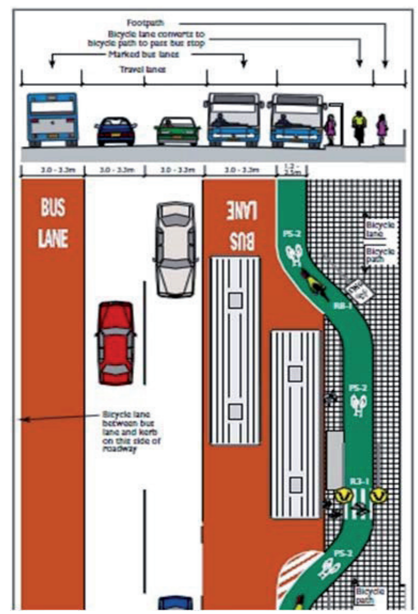
4. Cycle tracks and transit [26]

Given that bicycles routes and transit often utilize the same travel corridors, some important considerations must be made to ensure that bicycles and transit integrate in a safe and efficient manner. First, on corridors with streetcars, special attention must be paid to bicyclist crossings of the streetcar tracks, where the biggest issue is bicyclists catching a wheel in the gaps between the tracks and the roadway (the "flangeway") or slipping on the tracks when they are wet or when making a sharp turn. Potential design solutions include: implementing signage, pavement markings, and channelization to direct bicyclists to cross tracks as close to 90 degrees as possible; the potential use of flangeway fillers, although this technique is unproven with streetcar tracks; and the use of "Copenhagen left turns" to ensure safe left turns and perpendicular crossings.

The other key issue for cycle tracks and transit is the integration of cycle tracks at curbside bus stops. On most streets with transit service, bicycles will have to navigate with buses either in a bicycle lane or a shared bus/bicycle lane. In either case, at curbside bus stops, bicyclists will often have to move out into vehicle traffic to avoid the loading bus, and buses will often have to pass bicyclists as they accelerate away from the stop. While cycle tracks enable these modes to be separated, they still present similar challenges at bus stops. In short, cycle tracks cannot simply continue along the curb, but must be repositioned to allow bicyclists and buses to continue unobstructed.

Several cities have experimented with routing bike lanes behind the bus stop forming a "bus island". This design allows bicyclists to continue riding without interruption while buses pull in and out of bus stop areas. However, conflicts can arise between passengers boarding and alighting between buses and the sidewalk area. Passengers must cross the bike lane to reach the sidewalk, and may not be expecting bicyclists. In such cases best practices strongly encourage "formalizing" crossings for pedestrians between the sidewalk and the bus stop through the use of "ladder" and or raised crosswalks, median islands, and signage. By formalizing the crossing zone, the design raises the visibility of pedestrians to bicyclists and ensures that pedestrians understand that they are about to enter an area where bicycle traffic is to be expected. However, some cities have still found these treatments to be inadequate. For example, the City of Portland is in the process of reevaluating this design in the Pearl District due to pedestrian-bicyclist conflicts.

Bicycle Treatments at Bus Stops, New South Wales (top) and Paris (bottom)



[26] Additional discussion of track crossings can be found in the *Best Practice: Minimizing Bicycle Conflicts with On-street Infrastructure.*

Sources: New South Wales Design Guidelines; Flickr user - LiveStreets

5. Maintenance

Cycle tracks require consistent maintenance because debris can be trapped and accumulate more quickly in these facilities, thereby presenting a significant hazard to bicyclists. Cycle tracks have the potential to accumulate additional debris because the facility does not allow for the "sweeping effect" of motor traffic and many cycle tracks are channelized with raised curbs on both sides. More specifically, standard street sweeping vehicles are too large to enter the more constrained right-of-way of cycle tracks. Finally, the use of landscaping or street furniture within the buffer zone also requires additional maintenance.

Unfortunately, maintenance solutions are limited. In general, more regular and targeted maintenance is recommended for these facilities. There are also smaller street sweeping vehicles, such as the sidewalk sweepers that are currently used along Market Street, which can be used within the cycle track right-of-way.

Potential Market Street Applications

- Cycle tracks can be used to manage conflicts between the growing number of bicyclists on Market Street and other modes. Physical separation of these modes has been shown to improve safety and increase the desirability of bicycling as a travel mode, as well as improving street functionality. Recent experiments with separated facilities along certain segments of Market Street have been successful in decreasing Muni travel times by 3%.[27] However, the provision of dedicated space to bicyclists must be planned in the context of tradeoffs – specifically how reduced space for other modes will impact travel for pedestrians, vehicles, and transit services. On Market Street, for example, it is possible that a new cycle track could reduce sidewalk widths in some locations, thereby impacting pedestrian flow.
- Lane width guidelines, based on bicyclist volumes, can provide guidance on appropriate facility dimensions. On Market Street, any decision on cycle track lane width should also take into account flow for transit vehicles and how it could impact the travel times of vital surface transit services.
- The use of buffering, such as landscaping and street furniture, can further mitigate conflicts between modes while complementing future design elements within Market Street's streetscape. Once again, these elements can all improve the functionality of the cycle track, but may impact motorists and pedestrians. On Market Street, particular attention should be paid to how new buffers or sidewalk elements will affect pedestrians, especially those with mobility impairments.
- Treatments, such as bicycle boxes and separated signal phases, can be used to manage intersection conflicts, especially at intersections where bicycle volumes are high and queuing is likely. Intersection conflicts and management of transitions through intersections are one of the biggest concerns with cycle tracks. In the case of Market Street, particular attention should be paid to right turning vehicles and the need to mitigate "right hooks" with the vast majority of bicyclists proceeding straight through intersections.

[27] Bialick, A. (2011, March 1). *Market Street Right Turns Made Permanent by SFMTA Board.* Retrieved April 26, 2011, from Streetsblog: http://sf.streetsblog.org/2011/03/01/market-street-right-turns-made-permanent-by-sfmta-board/

- Treatments to “formalize” pedestrian crossings at cycle track will be useful in accommodating pedestrian access to transit loading areas. These treatments should be carefully considered on Market Street, as it might not be appropriate to encourage a pedestrian crossing through a busy cycle track with fast-moving cyclists. Convenient and safe access to transit stops, however, should remain a priority for pedestrians on Market Street.
- The streetcars on Market Street are center-running and have very limited turning movements, which is an ideal design situation when trying to accommodate separated bicycle facilities. However, additional treatments can be used to mitigate hazards caused by crossing of tracks. Any left-turning movements by bicyclists should be facilitated via multi-stage left turns. Such treatments, however, have the potential to result in significant queuing at the cross-intersections.
- Parking restrictions on Market Street currently limit curbside parking, which supports a right-side running cycle track. However, loading needs remain on Market Street. Loading bays on Market Street could serve as a buffer to the cycle track, but would likely require a “shift” in the placement of the cycle track that would extend into the current sidewalk zone. As a result, pedestrians could be negatively impacted by additional encroachment into the sidewalk zone.
- Market’s Street wide sidewalks may allow for “shifting” of cycle tracks to accommodate bicyclists at key pinch points, such as bus stops or at loading bays. Any decisions to reduce sidewalk width should be carefully evaluated in terms of impact on pedestrians. On Market Street, particular concern should be paid near the Powell Street shopping area, as well as some of the more highly trafficked section near the financial district.

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3.4 Shared Bus-Bicycle Lanes

Multiple Locations

Description

On constrained urban streets, there is often not enough space to provide conflict-free dedicated lanes for both transit vehicles and cyclists. One option is to have transit vehicles and cyclists share lanes with each other, but not with private vehicles. (in some applications, taxis and right-turning vehicles may be permitted to use these facilities). While fully separated facilities are generally the preferred option for both transit users and cyclists, shared bus-bicycle lanes have been utilized in many locations as an alternative treatment, especially on transit corridors that also serve as key bicycle routes.

Shared bus-bicycle lanes offer several benefits. First, shared bus-bicycle lanes help to maximize scarce road space and ensure that the travel of both buses and bicycles are prioritized. Second, allowing bicycles in dedicated bus lanes, where traffic volumes are typically lower, helps to mitigate conflicts between bicycles and autos. This is evidenced by the fact that implementing shared bus-bicycle lanes has been shown reduce bicycle-vehicle collisions. [1] Finally, implementing shared bus-bicycle lanes offers a low-cost and potentially lower impact alternative to providing dedicated facilities for each mode.

[1] Austroads (2005). "Bus-Bike Interaction within the Road Network." Austroads Publication No. AP-R266/05. Sydney, Australia.

Design and Operational Considerations

While shared bus-bicycle facilities offer a number of significant advantages, they also present some operational and design challenges. These issues are summarized below, including some examples illustrating how jurisdictions have implemented shared bus-bicycle lanes and mitigated their design challenges.

1. Speed differential and "leap-frogging"

The primary challenge presented by shared bus-bicycle lanes is the speed differential that exists between buses and bicycles. As buses frequently stop, bicyclists may pass the bus, only to be overtaken further on. In addition, the need for buses to navigate around bicyclists or wait behind for bicyclists can lead to delays. This "leap-frogging" is especially problematic in constrained areas with heavy adjacent traffic. The common conflict points include:

- ***Mid-block*** – As buses travel at higher speeds than bicyclists, a bus may catch up to a bicyclist mid-block. In constrained environments the bus may either be reluctant to overtake the bicyclist or the bicyclist may not have room to maneuver to allow the bus to overtake. While bicycles are legally allowed to control the lane, slowing down a bus in a transit lane undermines the purpose of having a shared lane.
- ***Intersections*** – Buses and bicyclists may catch up with one another at a signalized intersection when the signal is red. If a bicyclist is in front of the bus when the light turns green, the bicycle will accelerate and travel at a lower speed, causing delay to the bus. In addition, bicycles can often maneuver to the "head of the queue" requiring the bus to wait for the bicycle to go through the intersection to find clear space to overtake.
- ***Bus stops*** – While a bus is dwelling at a stop, a bicyclist may pass through the bus stop zone. Conflicts arise when a bicyclist wants to pass the dwelling bus, or when a bus is pulling away from the bus stop and accelerating.

Design Solution: Proper Lane Width

The issue of leap-frogging and potential for bus delay in shared bus-bicycle lanes can be partially addressed with the provision of adequate lane widths that ensure proper passing distances. Proper lane width is typically based on a number of key factors, including speed of travel, transit headways, and number of bicyclists. Several jurisdictions and independent transportation research organizations have developed specifications for shared bus-bicycle lanes. A summary of these design guidelines are provided below.

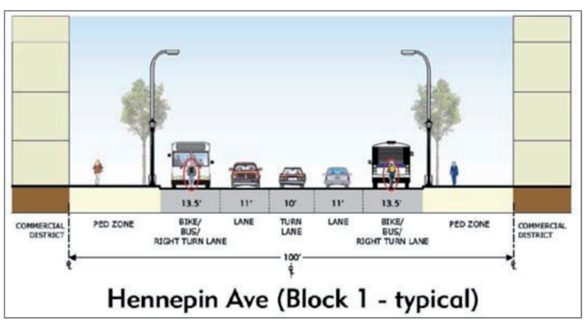
Shared Bus-Bicycle Lane Width Guidelines

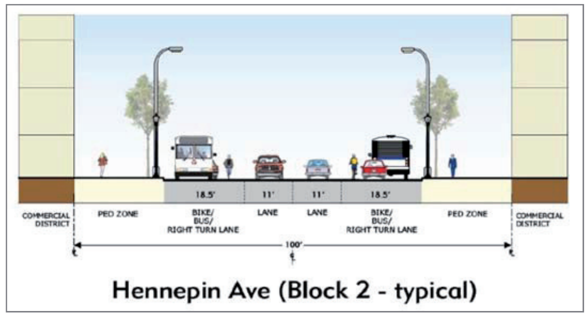
Jurisdiction / Organization	Speed Threshold	Recommended Lane Width
City of Madison	None	14-16' minimum. 12' bus + 4' bicycle lane preferred.
City of Minneapolis	None	12' minimum. 15-18' recommended.
City of Los Angeles	None	12' minimum. 14' where low volumes/headways. 16' preferred.
City of San Diego	None	12' minimum
German Bicycling Federation	Under 20 mph, lanes should be 11.5'. 30+ mph, lanes should be a minimum of 13'.	10.5-13'
Dutch CROW Standards	19+ mph, bus and bicycle facilities should be separated (physically or visually).	10.25' minimum
Austroads Design Toolkit	Narrower lane width (12’-14.5’) acceptable for speeds under 35 mph, wider (14’-16’) for speeds 35+ mph.	12’ -14.5’, if required minimum space is not available, widen lane wherever possible at occasional intervals for overtaking opportunities
London Department for Transport	None	14.5' preferred; 13' with moderate volumes
Ireland National Transport Authority Manual for Urban Areas	19+ mph, bus and bicycle facilities should be separated (physically or visually).	11-13'
New South Wales Bicycle Guidelines	18+ mph visual separation recommended; 30+ mph physical separation	10-15'

Minneapolis, MI

The City of Minneapolis recently installed a shared bus-bike lane along the Hennepin Avenue and 1st Avenue corridor. A primary goal of this project was to calm traffic and respond to safety concerns as a result of the existing street design. Along Hennepin Avenue the City decided to install shared bus-bike curb-side lanes. For block segments with center-turn lanes (see Block 1), the shared bus-bike lane is 13.5 feet, with sharrows marked in the center of the lane. Block segments without center turn lanes (see Block 2) have 18.5-foot shared bus-bike lanes with permitted right-turns, with sharrows marked on the left side of the lane. Bus headways on Hennepin Avenue are approximately five minutes during the peak hour, and the average bus speed will be approximately 8 mph, which includes dwelling time at bus stops and intersections. The posted speed limit is 30 mph. Counts conducted prior to implementation found daily volume on Hennepin of more than 1,500 cyclists.

Hennepin Avenue Street Section

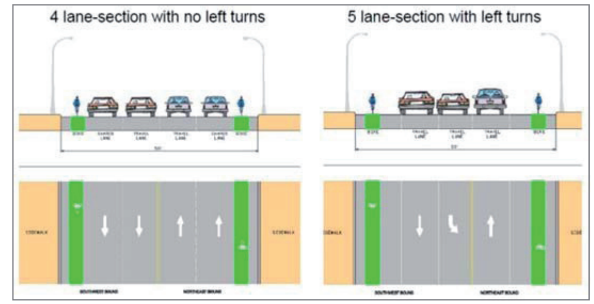




Source: City of Minneapolis

Evaluation of the design by the City has shown several positive benefits along the corridor as a result of the shared bus-bicycle lane, such as an increase in bicycle ridership, a decrease in bicycle crashes (and total crashes), consistent operational efficiency of the lane, and improved access and circulation. Despite these outcomes, the City has decided to make several design refinements to the pavements marking to improve traffic flow and user awareness of the facility. As described by the City these changes include "…enlarging the 'bus, bike, right turn' pavement text, adjustments to placement of the shared lane marking that better indicates where the bicyclist should ride, and adding green color to the shared lane enhancement to provide clarity on where bicycles should best ride and to further emphasize the shared nature of this right hand lane."

Hennepin Avenue Striping Refinements



Source: City of Minneapolis

Design Solution: Degree of separation

Depending on the context, some jurisdictions recommend that the standard shared bus-bicycle lane be enhanced by creating additional separation between modes. For example, rather than simply creating a wide curb lane for both buses and bicycles, additional separation between modes is provided by designating space for a bicycle lane that is adjacent to the bus lane. These bicycle lanes typically take one of two forms:

- ***Between bus lane and curb****:* When separate bus and bike lanes are designed, it is generally recommended to have the bike lane between the bus lane and the curb. This design provides the greatest degree of separation between bikes and vehicular traffic. However, conflicts arise with both buses and pedestrians at bus stop locations, as discussed in greater detail below.

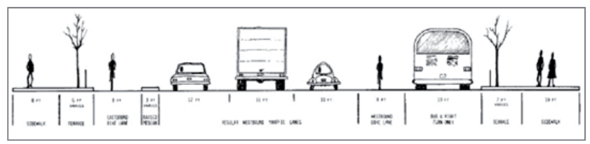
- ***Between bus and vehicle traffic***: The benefit of this design is that it removes conflicts with buses pulling in and out of bus stops and pedestrians boarding and alighting at stops. It also enables bicyclists to travel at continuous speeds without having to slow down for buses at stops. The challenge with this design is that bicyclists are more exposed and may feel less comfortable, particularly as they are traveling between vehicular traffic and buses.

Madison, WI

The City of Madison was one of the first U.S. cities to implement shared bus-bicycle lanes. The City's recommended standard for such facilities is 14-16 feet in width, which is wide enough to allow passing of bicyclists and buses with relative ease and safety. University Avenue in the downtown area, however, has higher bus, bike and pedestrian volumes and the City has developed an alternate shared facility that provides additional separation between modes. The roadway has 13-foot bus-only lanes adjacent to the curb, and eight-foot bike lanes between the bus lane and auto lanes (see below). According to City traffic engineering staff, the separate bus and bike lane operates very well because the volumes are so high in this area. By placing the bike lane on the left side of the bus lane, conflicts around bus stop locations are reduced. However, this configuration does expose bicyclists to a greater degree by placing the bike lane between moving auto and bus lanes.

The centrally located bicycle lanes serve long bike trips well, i.e. those that are not short block trips requiring turns in and out of the vehicular travel lanes.

University Avenue Section



Source: City of Madison

University Avenue in Madison, WI

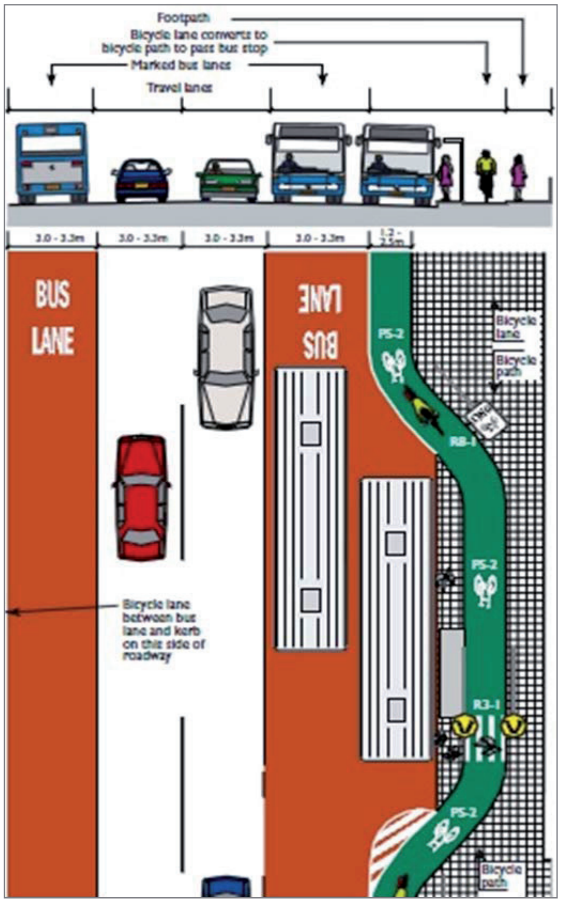
Source: John S. Allen. www.bikexprt.com

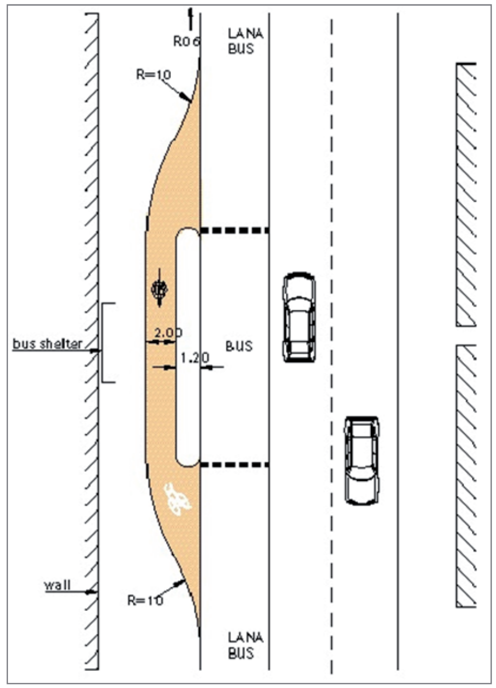
2. Bicycles at bus stops

As described above, one of the primary conflict points for buses and bicycles is at bus stops, where bicycles often seek to pass a dwelling bus or in cases when a bus pulls into traffic and accelerates as it leaves the stop. Several jurisdictions, including Ireland's National Transport Authority and New South Wales, Australia, have experimented with routing bike lanes behind the bus stop forming a "bus island" (see next page). This design allows bicyclists to continue riding without interruption while buses pull in and out of bus stop areas.

However, conflicts can arise between passengers boarding and alighting between buses and the sidewalk area. Passengers must cross the bike lane to reach the sidewalk, and may not be expecting bicyclists. In such cases best practices strongly encourage "formalizing" crossings for pedestrians between the sidewalk and the bus stop through the use of "ladder" crosswalks, raised crosswalks, signage, and raised islands. By formalizing the crossing zone, the design raises the visibility of pedestrians to bicyclists and ensures that pedestrians understand that they are about to enter an area where bicycle traffic is to be expected. However, some cities have still found these treatments to be inadequate. For example, the City of Portland is in the process of reevaluating this design in the Pearl District due to pedestrian-bicyclist conflicts.

Bicycle Treatments at Bus Stops, New South Wales (left) and Ireland National Transport Authority (right)





Sources: NSW Bicycle Guidelines; Provision of Cycling Facilities, Ireland National Transport Authority

3. Right-turning vehicles

In order to accommodate right turns, some jurisdictions allow vehicles to enter shared bus-bicycle lanes and make right turns. Such vehicle movements create a number of challenges for buses and bicyclists. First, as a vehicle merges it has the potential to hit a bus or bicyclist, or, as is often the case, impede the flow of traffic. Second, in locations with high pedestrian volumes, right-turning vehicles must often wait for pedestrians to clear an intersection. This can create delays or additional conflict points as buses or bicycles will often move around a waiting vehicle to proceed straight.

Solutions to this design challenge include the restriction of right-turning vehicles, either at all intersections or at selected intersections (i.e. every other intersection). Other design treatments may include a combined right-turn bicycle lane at the intersection, which positions the bicyclist to the left of right turning traffic and/or through lane and allows “dual” use. Such a facility must carefully consider lane transitions.

4. Enforcement:

Another crucial issue with shared bus-bicycle lanes is enforcement. While lane markings and signage are typically provided, the lack of physical separation with such facilities makes it difficult to enforce the designated restrictions. Such violations are especially prevalent in areas where there are high vehicle volumes and congestion, where right turns are common, and where curbside parking is also available. Potential mitigations include physical barriers, banning right turns, or removing curbside parking. However, these solutions are not always appropriate or popular.

Unfortunately, solutions are limited and many U.S. cities have struggled with this issue. Efforts to address this issue have primarily focused on improved enforcement by police and parking control staff. San Francisco has recently installed cameras on transit vehicles in an effort to catch illegal vehicle travel in its transit lanes. This nascent effort has yet to be fully evaluated. In short, enforcement of shared lanes largely comes down to this issue's level of priority and amount of resources allocated to reduce common violations.

Washington D.C. and Philadelphia

Both Washington D.C. and Philadelphia have experimented with shared use bus-bicycle lanes in recent years. In Washington D.C. shared facilities have been added to 7th and 9th Streets, while in Philadelphia a shared use lane was installed on Chestnut Street between 18th and 6th Streets. Each of these facilities has received negative reviews in their effectiveness to provide for buses and bicycles. In short, because enforcement of the shared lanes has been limited, unwanted vehicles have continually entered the lane and impeded the flow of both transit and bicycles. In Washington, D.C. cars and other vehicles are still allowed into the lane to make right turns and search for parking, thereby undermining the original intent of the restricted lane. Similarly, the Philadelphia Bicycle & Pedestrian Plan summarizes the problem: "As turning vehicles are also permitted to use the lane, and because there is a general lack of enforcement against vehicles illegally using the lane, it is often congested and not attractive for cycling."

In both cities, the problem with enforcement has led to both cities exploring other arrangements. For example, Washington DDOT is currently looking to mitigate the problem of unwanted vehicles in the lanes by improving police enforcement of the lane's restrictions and replacing some bus-bike lanes with bike-only lanes. In addition, the DDOT has also suggested adding some form of a physical barrier between vehicle traffic and the shared lane.

Shared Bus-Bicycle Lanes in Philadelphia (Chestnut Street, top and middle) and Washington D.C. (7th Avenue, bottom)

Source: Google Maps

5. Education

Education is a crucial factor for the safe and efficient operation of shared bus-bicycle facilities. Many road users, including drivers, transit operators, and bicyclists, are unsure about how to interact with other modes in these facilities. For bicyclists, the most important practice to promote is passing on the left – in particular of stopped buses. However, drivers and operators need to be made aware that bicyclists are allowed full use of the lane and how to properly pass slower bicyclists. Education campaigns that focus on these behaviors are essential to improved safety. In San Francisco, recent safety campaigns have sought to address this issue by instructing bicyclists on proper passing technique, as shown below.

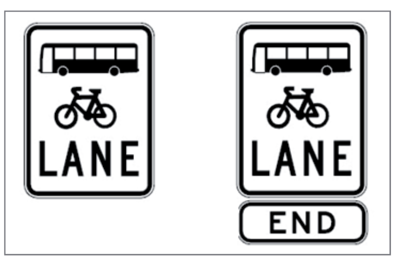
SFMTA Bicycle Safety Campaign

Source: SFMTA

6. Markings and signage

Guidelines for lane markings and signage are provided by numerous jurisdictions. In general, best practices include lane markings that indicate both buses and bicycle may use the lane. For buses, this typically includes "Bus Only" stencils, while sharrows are typically used to indicate the presence of bicyclists. Signage is varied, but typically includes language and symbols indicating that the lane has been designated as a shared use facility.

Shared Bus-Bicycle Lane Signage and Markings - Australia (top), Paris (middle), and Minneapolis (bottom)



Sources: VicRoads; Flickr user: Live Streets; City of Minneapolis

In addition, some jurisdictions have also begun to employ the use of colored markings to further delineate a shared lane and ensure that motorists are aware of the potential for a bicyclist within the travel lane. For example, the City of Long Beach installed a "green stripe sharrow lane" on 2^{nd} Street, which runs through a popular downtown commercial corridor. The green markings, which runs the entire length of the facility, supplements the sharrow and increases visibility of the shared space.

7. Legal Issues in San Francisco and California

Despite their widespread implementation elsewhere, there is debate in California, and especially in San Francisco, around the legality of allowing bicycles in bus lanes. California Vehicle Code Section 21655.7 states: "A local authority, with respect to any highway under its jurisdiction, may authorize or permit a portion of the highway to be used exclusively for a public mass transit guideway." Many cities, including San Francisco, have taken the conservative position that this language does not permit them to designate shared bus-bicycle lanes or explicitly permit bicycle traffic in transit lanes. At the same time, however, San Francisco statute allows taxicabs to use transit lanes.[2] To many, the exception for taxicabs in

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[2] SFTC 7.2.72: "[It shall be a traffic violation] to operate a vehicle or any portion of a vehicle within the area of any street designated in Division II as a transit-only area, except that public transit vehicles and taxicabs, vehicles preparing to make a turn, and vehicles entering into or exiting from a

transit lanes undermines the argument that San Francisco does not have the authority to grant bicycles a similar exception. In short, the debate around this issue does not hinge on the merit of allowing bicyclists to utilize transit lanes, but instead on whether San Francisco has the legal authority to do so. Based on initial research, it does not appear that other jurisdictions are dealing with any similar legal obstacle. To resolve this issue and move forward with implementation, either a change to state law must be made or the existing San Francisco statute must be revised, granting bicycles a similar right to transit lanes as taxis.

Potential Market Street Applications

- **Design flexibility:** Market Street's limited right-of-way and high number of competing modes may not allow for separated bicycle facilities at all locations. Shared bus-bicycle lanes allow for added flexibility at pinch points and locations with highly constrained right-of-ways.
- **Low-cost alternative:** The existing design of Market Street includes numerous elements that may be cost-prohibitive to redesign or relocate. Shared facilities offer an alternative at such locations.
- **Improved bus-bicycle integration:** Expanded lane widths allow additional passing distances at pinch points, such as bus stop locations along Market Street.
- **Improved travel speeds:** By having a designated space, shared facilities can improve travel time for transit and bicyclists.
- **"Leap-frogging" conflicts.** However, the tendency for buses and bikes in shared spaces to repeatedly pass one another – generating potential conflicts whenever they do – can both cause transit delays and discourage many cyclists from using such spaces. Greater lane widths can reduce the problem somewhat, but at the cost of additional space requirements.

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stopped position at the curb may be driven within a transit-only area."

3.5 Minimizing Bicycle Conflicts with On-street Infrastructure

Multiple Locations

Description

Market Street is utilized by a variety of modes, including vehicles, buses, streetcar, pedestrians, and bicyclists. On-street infrastructure, designed to manage the flow and interaction of these various modes, along the entire length of this corridor. As more and more bicyclists utilize Market Street, there is a need to explicitly address how these materials and engineering measures can be designed in a way that they ensure safety for bicyclists, a highly vulnerable user group. The need to minimize these types of conflicts is a priority concern for the future of Market Street.

Throughout the United States, the vast majority of bicyclists share street space with a wide variety of travel modes. On most streets, particularly in constrained urban environments, bicyclists must navigate infrastructure and facilities that were not originally designed optimally for their use. For example, in transit corridors, elements such as lane separators, raised pavement markers, or light rail or streetcar tracks themselves, all serve to optimize transit operations and reduce transit travel times by restricting the travel of other modes. However, because bicycles and transit service often share the same space, these on-street installations have the potential to impact bicyclist travel and safety. Another common conflict involves the interaction of bicyclists with traffic calming devices. Traffic calming measures, such as speed humps or bulb outs, have been utilized as a means to reduce vehicle speeds and improve safety for autos and pedestrians. At the same time, however, these devices can negatively impact a bicyclist's travel experience and safety unless careful consideration of the bicyclist is included in design.

This best practice profile examines how various cities and jurisdictions have addressed these conflicts. Particular attention is paid to design guidelines that provide recommendations on how to ensure that bicyclist conflicts are minimized and safety is enhanced.

Design and Operational Considerations

1. Crossing light-rail and/or streetcar tracks

One of the primary concerns related to the integration of bicyclists with light-rail or streetcars is ensuring safe crossing movements for bicyclists across tracks. Tracks can be a significant hazard to bicyclists. First, and foremost, when crossing tracks bicyclists can get their wheels caught in the gap between the track and roadway (known as the "flangeway"), causing bicyclists to fall. This is especially dangerous if it occurs in front of transit vehicles, which have particularly long stop distance requirements, especially if traveling at speed. Furthermore, given that many bicycles in the U.S. use very narrow tires, this design issue is especially common. Second, when wet, the tracks themselves can be slippery and create a hazard for bicyclists. Finally, the smoothness of the crossing is also of concern. Asphalt near the tracks can deteriorate, thereby creating uneven surfaces, which have the potential to damage bicycle tires or cause a bicyclist to fall.

Example of a streetcar track and flangeway

Source: Flickr user – Jason McHuff

Design solution: Crossing Angle

A survey of bicycle design guidelines indicates that one of the key design solutions is to ensure a proper crossing angle. In short, the crossing angle of any bicycle route that crosses a track should be as close to 90 degrees as possible. A perpendicular crossing ensures that a bicycle tire can roll over the flangeway and not get stuck. The farther the crossing angle is from 90 degrees, the greater chance that the tire will get stuck in the track. Finally, any bicycle turn across tracks should be designed to be as gradual as possible, as sharp turns create a significant slipping hazard. Table below provides a sampling of design guidelines as it relates to this issue:

Sample of Track Crossing Guidelines

Publication	Track Crossing Guidelines
Oregon Bicycle and Pedestrian Plan	The risk is kept to a minimum where the bikeway crosses the tracks at a 90 degree angle. If the skew angle is less than 45 degrees, special attention should be given to the bikeway alignment to improve the angle of approach, preferably to 60 degrees or greater.
Bicycle Transportation Plan for Madison Urban Area	If the crossing angle is less than 45 degrees, the outside lane, shoulder, or bicycle lane should be widened, where possible, to improve the angle of approach.
Wisconsin Bicycle Facility Design Book	30 degrees or less is considered exceptionally hazardous, particularly when wet. However, if the crossing angle is less than approximately 60 degrees, remedial action should be considered.
Edinburgh Tram Design Manual	Crossings should, ideally, be at right angles to the tram track or the street, with minimal physical barriers surrounding them.
CROW Design Manual for Bicycle Travel	Cyclists should be able to cross the rails at an angle of at least 45 degrees, but preferably 60 degrees. The cycle connection should be at least 2.5m wide.

In addition to crossing angle guidelines, several jurisdictions recommend the provision of additional street markings as a means to guide bicyclists over the tracks at the proper angle. For example, the *Edinburgh Tram Cycle Integration Study* recommends road markings "to increase the angle at which cyclists cross the tracks". As with all road markings, however, proper and ongoing maintenance is a concern.

Sample road marking across tracks

Source: City of Edinburgh

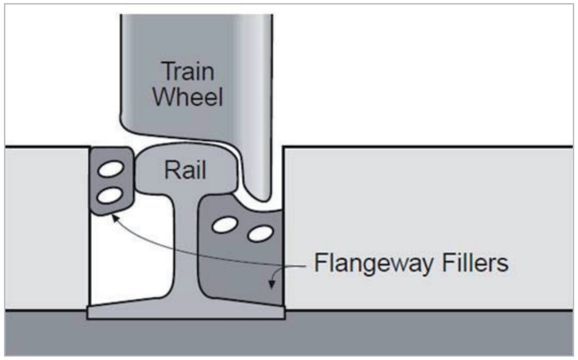
Making left turns across tracks is especially problematic for bicyclists as it forces riders to enter vehicle travel lanes, integrate with transit vehicles, and manage the gaps in the tracks. One potential design solution is to incorporate "Copenhagen left turns." With Copenhagen left turns, bicyclists proceed straight through the intersection to the far side and wait with cross street traffic, preferably in a designated bicycle space (i.e. bicycle box). Bicyclists then proceed straight across the intersection when the traffic light changes. While this technique may take longer, it also significantly reduces conflict points and helps to ensure that bicyclists cross tracks at a 90 degree angle. Potential design considerations include excessive bicycle queuing within the bicycle lane and conflicts with cross-street bicycle traffic.

Example of a Copenhagen left turn

Design solution: Flange filler

While design guidelines generally recommend keeping the gap between the track and the roadway as small as possible, often times this gap still presents a hazard to bicyclists. Flange "fillers" present a potential design solution to this challenge. Flange fillers are rubberized inserts that are placed inside the flangeway helping to create a more continuous surface. There are, however, several potential drawbacks to flange fillers. First, trains must move at slower speeds so that the filler has time to compress properly. If the train is moving too fast, there is an increased risk of derailment. Second, the fillers present another maintenance challenge as the rubber will eventually wear down and break apart. Third, the flange filler has the potential to disrupt the electrical current that is required to operate streetcars.

Diagram of flange filler for heavy rail



Source: Wisconsin DOT

Research shows that flange fillers are primarily used for crossings at heavy rail tracks and have yet to be commonly applied on streetcar tracks. Some cities, such as Eugene, have used fillers, but only at locations where transit use is very infrequent and travel speeds are low.[1] Switzerland has extensively experimented with flange fillers in recent years, yet eventually reached the conclusion that they were not appropriate for use on streetcar tracks.[2]

Design solution: Proper signage

Signage is crucial to ensuring safe track crossings for bicycles. Signage is typically designed to notify bicyclists that there is a crossing hazard, such a getting one's wheel caught or slipping on the tracks. Signage is typically placed along the entire route at regular intervals, but especially at intersections and locations where a bicyclist may turn across the tracks. Roadway markings are also strongly recommended to supplement signage, especially at locations where bicyclists must cross the tracks at the proper angle. Sample signage is provided below:

Sample streetcar track crossing signage

Source: Flickr user – rickie22

2. Managing physical separation

On many transit streets, various mechanisms (extruded curbs, raised pavements markings, etc.) have been employed to separate vehicles from transit or non-motorized modes. These mechanisms, however, have the potential to create on-street hazards for bicyclists and severely impact bicyclist travel. Outlined below is a brief overview of these challenges and some design alternatives that may enable easier integration of bicycle facilities with on-street infrastructure.

- ***Curbs as separators:*** Extruded and/or raised curbs by themselves are not recommended as the primary separation between vehicle traffic and bicyclists. Bicyclists can strike these facilities and lose control of their bicycle, while vehicles can also hit the curb, causing them to break up the asphalt and scatter debris across the roadway. In addition, extruded curbs can cast shadows on the road at night making it difficult for bicyclists to differentiate roadway space. Finally, extruded curbs often collect debris, accumulate runoff in the rain, and are difficult for street sweepers to navigate.

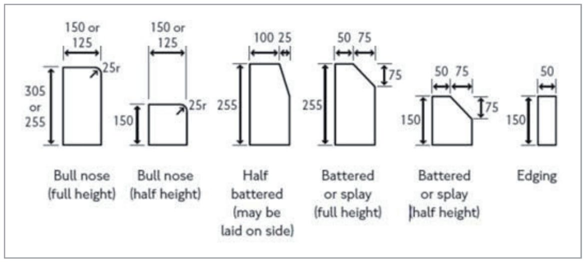
Design solution: Dropped or low curbs

Dropped curbs or low curbs offer an alternative and are appropriate as separation between bicyclists and pedestrians. Low curbs allow bicyclists to ride closer to them without striking their pedals and they present less of a collision hazard to bicyclists and motorists.

[1] Alta Planning + Design. (2008). *Bicycle Interactions and Streetcars: Lessons Learned and Recommendations.* Portland.

[2] Ibid.

London Curb Profile Types



Source: City of London, London Cycling Design Standards

Design solution: Use of tram separator

VicRoads, the transportation management agency for the state of Victoria in Australia, recently commissioned a study of the use of tram separators to evaluate their effectiveness as a traffic separator and applicability to bicycle travel. The separators are made of a hard, yellow plastic that is approximately 2 inches high and 14 inches wide and are installed directly into the roadway. The separators that were tested are identical to the ones used elsewhere in Victoria to separate tram routes from vehicle traffic. The separators were tested on three roads in Melbourne representing a variety of roadway conditions: Chandler Highway (a major arterial), Burnley Street (a busy urban street), and Yarra Boulevard (a low-volume street). Bicycle volumes along these streets also varied, with Chandler Highway and Burnley Street consisting of high volumes of commuters and Yarra Boulevard having predominantly recreational bicyclists.

The results of the study showed positive results for safety and bicycle travel. First, encroachment into the bicycle lane declined by 50% or more at all locations. Second, motorists tended to stay farther away from the curb and provided more space between their vehicles and bicyclists. Finally, an initial survey of bicyclists indicated positive support for the treatment.[3]

Tram Separators in Melbourne

Source: M. Daff and S. Merz

- ***Pavement markings**:* Reflectors and raised pavement markings can deflect a bicycle's tire and constitute a collision hazard. In general, these raised marking are not recommended on routes with high volumes of bicycles travel. If utilized, however, guidelines recommend that all raised pavement markings be installed on the vehicle side of the facility and include a beveled front edge to allow bicyclists to ride over them.

Design solution: Colored dots

The *Edinburgh Tram Cycle Integration Study* highlights practices in Manchester and Sheffield in England in which colored dots, as opposed to raised pavement markings, are utilized to delineate the envelop of transit vehicles. The colored dots

[3] Daff, M., & Merz, S. K. (2009). Evaluation of Strengthened Bicycle Lanes in Melbourne, Australia. *ITE Pedestrian & Bicycle Newsletter*.

are especially applicable for streetcars, as they assist operators in judging whether a bicyclist is within the turning envelop of a turning streetcar. The *Edinburgh Tram Cycle Integration Study* summarizes the intent and application of this dot system:

"Marking of the tram 'envelope', using painted yellow dots provides cyclists (and other road users) with a clear indication of the behaviour of a tram, enabling them to avoid conflict. Even more importantly, these yellow dots enable tram drivers to determine if a vehicle, pedestrian, cyclist or other obstruction are within the swept path of the tram. This enables the tram driver to take action...Note that it is crucial that these yellow dots are not raised as this constitutes a significant additional risk to cyclists already coping with complex situations." (36).[4]

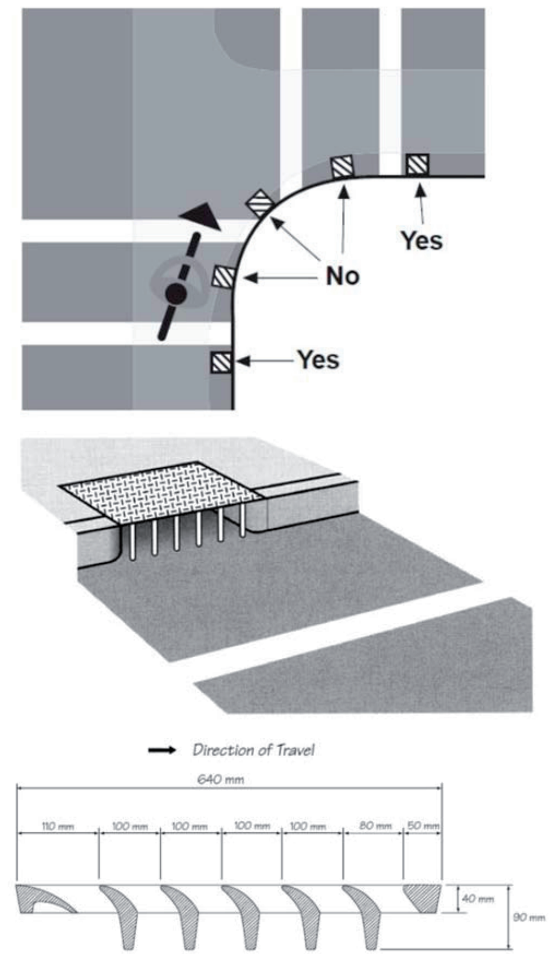
3. Managing other street elements

Typical street design includes a number of physical elements that can pose significant risks to bicyclists. These elements can catch bicycle wheels, cause bicyclists to slip, or collect debris and water. The placement and design of these elements are crucial to ensuring that bicyclists can navigate the street in a safe manner. Outlined briefly below is a summary of design guidance as it relates to common street elements.

[4] Transportation Planning (International) Ltd. (2009). *Edinburgh Tram Cycle Integration Study.* City of Edinburgh.

- ***Utility covers***: Utility covers should be located outside the bicycle facility and primary travel path. Utility covers should be flush with roadway and include some texturing to reduce the chance of a bicycle wheel slipping when wet.
- ***Drainage grates***: Drainage grates should be located as close to the curb as possible and the grate itself should be within the gutter pan. Grates should also be located prior to all crosswalks and not placed within the curve of the curb radius. Like utility covers, grates should be flush with the surface of the roadway to provide a smooth travel surface. In addition, all grates should be "bicycle safe," which requires the bars of the grate to be perpendicular to the direction of travel and preferably angled to maximize flow rate. The state of Victoria in Australia often uses "vane" grates. Finally, drainage inlets installed within the curb face itself offers the ideal solution.

Drainage grate placement (top), flush inlet (middle), and "vane" grates (bottom)



Sources: Wisconsin DOT; Oregon DOT; VicRoads

4. Managing traffic calming measures

The use of traffic calming devices has become common practice in the U.S. as a means to slow vehicle speeds, reallocate space to other modes, and improve safety in key travel corridors. Traffic calming consists of a broad range of treatments from comprehensive street redesigns and “road diets” to the installation of individual street elements, like speed humps. In general, traffic calming measures improve the functionality and safety of the street for bicyclists. However, special attention should be paid to the design of traffic calming elements to ensure that they do not negatively impact bicyclist travel. A brief overview of selected traffic calming measures is provided below with specific attention paid to how these elements can properly integrate bicyclist travel.

- ***Raised calming devices**:* Raised traffic calming devices are one of the more common traffic calming measures currently utilized. These raised elements can take a number of forms, including speed bumps, speed humps, and speed tables or cushions. Speed bumps are probably the most well-known, as these devices are often used on residential streets to slow vehicle speeds. Speed bumps usually have steep slopes and a narrow table, forcing vehicles to proceed very slowly over them. Design best practices all indicate that speed bumps should not be utilized on bicycle routes. The profile of these bumps makes bicycling both uncomfortable and a potential hazard. Instead, speed humps or speed tables should be utilized as the gradual slope of these elements allows bicyclists to travel more comfortably over them. Speed humps offer a more gradual slope than a speed bump and a flatter table. In general speed humps are 3-4 inches high and extend the length of the street. By contrast, speed tables are very broad, have wider tables, and are designed for higher speeds. Speed tables can either be parabolic (curved) or trapezoidal (flat top). Key design considerations for bicyclist integration with speed humps and tables include:
  - ○ Smooth and flush transition from roadway to the ramp face.
  - ○ Use of road markings, signage, pavement coloring, or textures to delineate the hump or table, especially at night.
  - ○ Use of bicycle wheel cuts or additional space (1-2 feet) between the hump/table and curb to allow for bicyclist wheels to pass through.
  - ○ Limited use on curves or streets with steep grades.
- ***Bulb outs:*** A bulb out is a commonly used traffic calming measure used at intersections that is designed to reduce crossing distances and improve visibility for both pedestrians and motorists. In most applications bulb outs still allow bicycles to proceed straight without having to enter traffic lanes. However, bulb

Examples of raised traffic calming measures – speed bump (top) and hump (bottom)

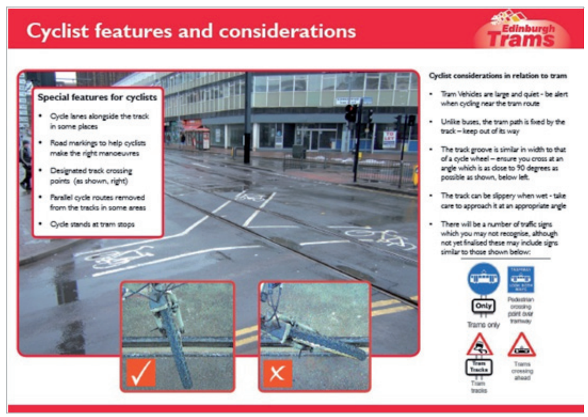
Sources: Flickr users – atomicity; Richard Drdul outs have the potential to "squeeze" bicycle travel, especially in highly constrained right-of-ways. In general, design guidelines suggest that bulb outs be placed so that at a minimum of 12-14 feet of travel lane is available so that bicyclists can pass through the intersection safely.

- ***Traffic barriers and diverters**:* Barriers and diverters are often used to block vehicle travel and restrict access. When designing these elements for bicyclists a number of key issues should be considered, including:
  - Appropriately sized gaps to allow bicycles to cut through safely.
  - Setting barriers back from intersections to improve visibility and allow bicyclist to navigate turns onto traffic clamed streets more comfortably.
  - Use of other traffic calming techniques to reduce speed upon approach.
  - Use of proper signage and directional information.

5. Education

Education is a crucial component to ensuring that motorists and bicyclists navigate on-street infrastructure properly. Even the best designs can be undermined by consistent travel behaviors that place individuals at risk. With the installation of any new facility, but especially infrastructure that individuals may not be familiar with, proper education is recommended. For example, many bicyclists are unfamiliar with how to operate in streetcar corridors and what the proper technique is for crossing tracks. The City of Edinburgh recognized this challenge and developed an education campaign targeting bicyclists and demonstrating proper integration with streetcars. An example of the campaign is provided below, which highlights bicycle crossing behavior.

City of Edinburgh Bicycle and Streetcar Leaflet



Source: City of Edinburgh

6. Maintenance

Proper maintenance of roadways is a crucial component to ensuring that all modes travel safely and comfortably. For bicyclists in particular, the comfort of the ride is a key determinant of travel behavior. If a key bicycle route is improperly maintained, bicyclists will either operate their bicycle erratically in an effort to avoid hazards, or seek out other streets where bicycle travel is less than ideal and bicycle facilities may not be provided.

Seattle, WA

The quality of the roadway surface and the smoothness of the ride are crucial factors in the quality of a bicycle network. As jurisdictions across the country face reduced roadway maintenance budgets, however, the ability for cities to respond to roadway repairs is increasingly limited. Seattle has responded to this challenge by creating the Bike Spot Safety Program, in which citizens provide the city with data on where repairs to bicycle facilities are needed. This program capitalizes on local knowledge of facilities and leverages public involvement to target priority areas for bicyclists, an effort that is infeasible with staff alone.

Individuals can fill out a form or contact the bicycle program online to indicate where repairs are needed. Typical issues addressed include surface improvements (potholes, drain grates), signing and striping, access improvements, or bicycle rack installations. Staff will receive the notice and respond with an estimated repair time (usually with a phone call). Depending on the issue, staff may conduct a field check to determine the appropriate remedy.

This program is popular among residents and with elected officials, as it offers personalized follow up to complaints and turnaround time is relatively fast. The number of repairs made by the program is dependent on available funding, but the low-cost nature of the repairs generally allows for solid response to many issues. The program spends approximately $200,000 per year.

Potential Market Street Applications

- **Improving integration with streetcars:** While the streetcar tracks on Market Street are center-running, bicyclists must still navigate the tracks when making turns or when they pass vehicles obstructing the far right lane. Properly managing crossing angles and addressing the track gaps will be crucial to making Market Street a safe and accessible multi-modal street, especially as bicycle travel continues to increase on this corridor. The use of proper signage and pavement markings are a crucial tool in this effort. However, these mitigations may result in initial confusion among various users groups about their meanings. Educational campaigns and consistent maintenance will likely be needed.
- **Addressing bicycle obstructions:** Properly designed and installed street elements can improve the smoothness of a bicyclist's ride, increase comfort, and mitigate common collision hazards. When evaluating the specific measures to be implemented on Market Street, it is also crucial that the overall safety impacts for each user be carefully considered.
- **Managing modal separation:** The highly contested nature of Market Street makes it difficult to manage conflicts between travel modes. Properly designed and installed infrastructure can guide traffic flow and separate modes at key pinch points or intersections. There is potential to "over design" Market Street and create a too rigid separation of modes, which may limit flexibility to respond to changes in the street in future years, or even adjust to non-recurrent incidents.
- **Targeting travel behaviors:** Education campaigns demonstrating proper technique and targeting common violations can significantly improve safety along the corridor. This will be crucial for a "redesigned" Market Street that will likely implement infrastructure that motorists, bicyclists, and pedestrians are not yet familiar with. These efforts, however, will cost additional resources and may result in a larger burden on City departments.
- **Improving knowledge base and functionality:** Spot safety programs can leverage local knowledge and can be used to address priority maintenance and safety issues within a constrained fiscal environment. On Market Street a consistent and comprehensive database of potholes or maintenance needs can significantly improve functionality. Initial set-up and ongoing costs for such a program may be too burdensome.

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3.6 Signal Synchronization and Timing to Create Traffic Calming

Copenhagen, San Francisco

Description

Vehicle speed is one of the most important factors in the safety and experience for pedestrians and bicyclists on a street. High speeds can result in more severe crashes and also make a neighborhood less pleasant for walking. Traffic signal synchronization and timing can be used to slow down vehicles and thus create safer, more comfortable environment for all street users.

Signal timing can also be used to optimize transit speeds and bicycle travel along a corridor.

Design and/or Operational Considerations

1. Signal Synchronization to Calm Traffic

The timing of traffic signals can have an effect on the speed of cars. Signals are often coordinated so that a platoon of cars driving down the street at a particular speed will hit all green lights and not have to stop. In the case of Market Street, drivers often speed up between intersections to make a green signal. Signal timing can be adjusted to encourage a certain speed.

However, it can be difficult to time signals so that they are coordinated in both directions. Often this type of signal coordination is applied to one-way streets. On two-way streets, an alternative is to directionally focus signal synchronization by time of day (i.e., synchronize the inbound direction in the AM and the outbound direction in the PM). Also, groups of signals can be timed together, rather than the entire corridor.

Design solution: Green Wave for Cyclists or Transit

One strategy for signal synchronization is to time signals based on the average bicycle speed, thus allowing bicycles to hit all green lights while traveling down the street. This strategy is known as a “green wave”. Beyond the benefits to bicyclists, this strategy can also slow traffic and create a safer environment for pedestrians.

Green waves are most effective on one-way streets, since it is not always possible to coordinate the wave in both directions. A green wave coordinated for bicycles can also be appropriate for transit vehicles, which typically have slower travel speeds than cars. However, the Inner Geary Boulevard corridor was recently timed for average transit speeds with documented benefits.

Copenhagen implemented a green wave for bicycles on Nørrebrogade St. in 2006 involving 12 traffic lights over a stretch of 1.2 miles. The signals are timed for bicycles traveling 12.4 mph (20km/hr). Since it is difficult to time the green wave in both directions, the wave is applied in the inbound direction towards the city center in the morning and in the outbound direction in the afternoon. Studies have shown that the green wave had an effect of increasing bicycle speeds and decreasing car speeds. Green waves were subsequently implemented on other streets in the city.

San Francisco has also implemented a green wave for bicycles on Valencia St. between 16th St. and 25th St. The signal coordination is timed to keep vehicles traveling at 13 mph. The green wave has helped to contribute to safer, calmer speeds which benefit the thriving commercial corridor.

Sign for and bikeway for Copenhagen’s Green Wave

Source: Pedestrian and Bicyclist Safety and Mobility in Europe report, Federal Highway Administration

Similar to the green wave for bicyclists, signals can be synchronized based on the average speed for transit.

Potential Market Street Application

The traffic lights along Market Street from The Embarcadero to Octavia Boulevard could be coordinated to create a green wave for both transit and bicycles. An appropriate speed for the wave would be 13mph. This would help to address the following issues:

- **Traffic calming:** The green wave has the effect of slowing car speeds, thus enhancing pedestrian safety.
- **Reduce stopping frequency for bicycles:** The green wave should reduce the number of intersections where bicycles are stopped at a red light, thus reducing the number of potential conflicts between bicycles and pedestrians.
- Signal timing along Market Street may be reevaluated along with potential design modifications, such as relocating transit boarding islands to the far side of the intersection.

References

More information on the Green Wave can be found on the website for Fietsberaad, a Dutch center for bicycle policy information:
http://www.fietsberaad.nl/index.cfm?lang=en&section=Voorbeeldenbank&mode=detail&repository=Green+wave+for+cyclists

More information on the Green Wave in San Francisco can be found on SF StreetsBlog:
http://sf.streetsblog.org/2011/01/06/green-wave-becomes-permanent-on-valencia-street/

3.7 Bicycle Sharing

Multiple Locations

Description

Bike sharing programs are an innovative and relatively new concept designed to allow users free or relatively cheap alternatives to the automobile for short trips. Bike sharing involves the short-term rental of a bicycle to get between two points, typically in an urban area. The programs are designed to provide fast and easy access for commute-type trips and differ from leisure-oriented rental services generally found in popular tourist areas. The goal of bike share programs is to reduce traffic congestion, vehicular parking demands, noise pollution, air pollution, and the use of the automobile.

Source: Wired

Bike share programs work by creating parking "stations" strategically located in major destinations and transportation hubs. Bicycles can be rented (generally through an automated process) at one station, ridden to a destination, and then returned to a station near the destination. With advances in technology, bike share programs are becoming "smarter" and are allowing for more efficient and advanced rental and bicycle features.

The bicycle sharing/rental model has gained popularity in Europe in recent years. Historically, some European cities have had free bicycle programs that have been plagued with theft, vandalism, and overall poor quality or reliability. Bicycles in the recently successful programs are electronically checked out and monitored as opposed to requiring long, manual check-out processes that result in high overhead costs. Riders share the same bicycles but are personally responsible for their safe return. This approach does three key things: one, it keeps bikes from being stolen or abandoned; two, it keeps bikes in areas of highest demand, and; three, it keeps tabs on the maintenance needs of the bikes themselves.

Program participants typically register once with the program operator and receive an electronic pass or smartcard that unlocks bikes from their computerized racks and checks them out for any

Source: Samtrans

Source: M. Haynes

period of time. Riders are then responsible for checking them back in by returning bikes to any rack that is part of the service. Costs for renting the bikes are low, especially for a short time period.

Source: M. Haynes

Bicycle sharing is becoming increasingly prevalent in Europe, and it has been implemented in several major cities across the United States, including Boston, Washington, Minneapolis, and Denver. The City of San Francisco is currently working with the MTC to implement its version of a bicycle share program. The project would initially be focused within Downtown San Francisco. Other areas in the region are planning bicycle sharing stations at major transit stations, including Caltrain Stations.

The following are general benefits of implementing a bike sharing program:

- Encourages alternative modes of travel and provides those who already use alternative modes more options.
- Provides a fast alternative mode of transportation, specifically in downtown settings where vehicular congestion and parking shortages exist.
- Provides an environmentally-friendly option for short-distance links in the transportation network.
- Provides low cost, sustainable transportation.
- Increases the awareness of bicycling and introduces more commuters to the benefits of cycling.
- Potential to increase commuter health through physical activity.

Design and/or Operational Considerations

1. Bicycle Sharing is usually specific to one city
2. Bicycles can typically be dropped off at any location; however, some programs limit this.
3. The program is typically designed to accommodate and encourage short-term rentals. The first half-hour is generally free, with a fee for each additional half-hour.
4. Bicycles may or may not come with a lock
5. Bicycles are generally checked out electronically using a membership card or credit card.

6. Depending on the system, the bicycle share can be member-based or open to the public. Fees are generally $5-$10 per day or up to $60-$90 dollars per year. The first 30 minutes is generally less than $3.

Potential Market Street Application

The SFMTA is currently exploring bicycle sharing in San Francisco. The following elements could guide the program's delivery on Market Street.

- Stations should be placed at major anchors for jobs, transit, retail, or public facilities. Potential locations include BART/Muni Stations, UN Plaza, Halladie Plaza, Justin Hermann Plaza, Union Square, and the Public Library/Civic Center Plaza.
- Stations can be used in privately owned, but public open space, or on sidewalks, plazas or parking lanes. Stations should be placed after coordinating with City partners and the public

References

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