Station Platform Height: Safety and Precedents

TECHNICAL MEMORANDUM

August 2016

Prepared for:

pace
Connecting Communities

Prepared by:

HNTB

[This page intentionally left blank.]

Table of Contents

Figures

Tables

Appendices

1 Background

In 2001, Pace Suburban Bus (Pace) published Vision 2020, which identified Milwaukee Avenue as one of 24 corridors that would be enhanced with arterial rapid transit (ART) to improve the regional transit network and intersuburban travel. In 2009, Pace's Arterial Rapid Transit Study evaluated and prioritized these corridors for phased implementation. The Milwaukee Corridor ART was identified as the first ART project to be implemented with the second being the Dempster Corridor. Since that time, Pace has rebranded ART as Pulse and the individual ART corridors are referred to as "Lines" (e.g. the Pulse Milwaukee Line and the Pulse Dempster Line).

The Milwaukee Line is currently in the design and permitting phase, while Pace concluded the Project Definition phase for the Dempster Line at the beginning of August 2016. Both the Milwaukee and Dempster Lines will operate in mixed traffic with off-street terminal stations and on-street intermediate station pairs, primarily on roadways with posted speeds of 35 miles per hour that are under the jurisdiction of the Illinois Department of Transportation (IDOT). This speed limit classifies the project corridor as low speed arterial according to AASHTO standards. When implemented, the Milwaukee Line will be the third bus rapid transit (BRT) line to be implemented in Illinois, following the Chicago Transit Authority's Loop Link, which operates in the City of Chicago and the Champaign-Urbana Mass Transit District's MCORE project.[1]

STATION DESIGN

For each of these Pulse projects, the design concept for the service and stations was detailed in the respective project definition reports, which identified a need for a 12-inch raised platform with ADA-accessible ramps at both ends that connect the station to the surrounding sidewalk network. The raised platform will provide near-level boarding that facilitates faster boarding and alighting and creates a more accessible transit station by enabling passengers to enter the bus without the need to step up.

As part of the design phase for the Milwaukee Line, the design for the station platforms has been refined to incorporate station elements such as electrical cabinets. Planned station amenities include the following features:

- 12-inch raised platform for near-level boarding, enabling passengers to board the bus without requiring the bus to kneel;
- Semi-custom branded shelters;
- Benches, trash receptacles, and bicycle racks;
- A vertical marker conveying the Pulse brand and featuring real-time information signage, Pulse route information, and local/regional transit maps;

[1] http://www.mcoreproject.com/

- Infrared overhead heating within the shelter;
- Electric pavement snow-melt system;
- Railings along the back of the platform and along the access ramps;
- Landscaping.

A rendering, plan, and section of a typical Pulse station are shown in Figure 1-1, Figure 1-2, and Figure 1-3.

FIGURE 1-1: TYPICAL STATION RENDERING

FIGURE 1-2: TYPICAL STATION PLAN

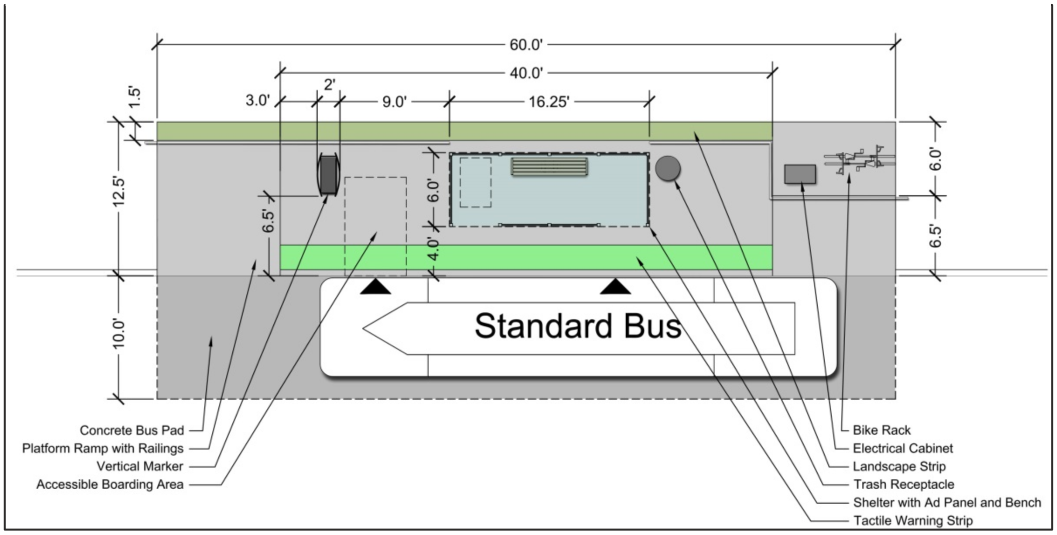
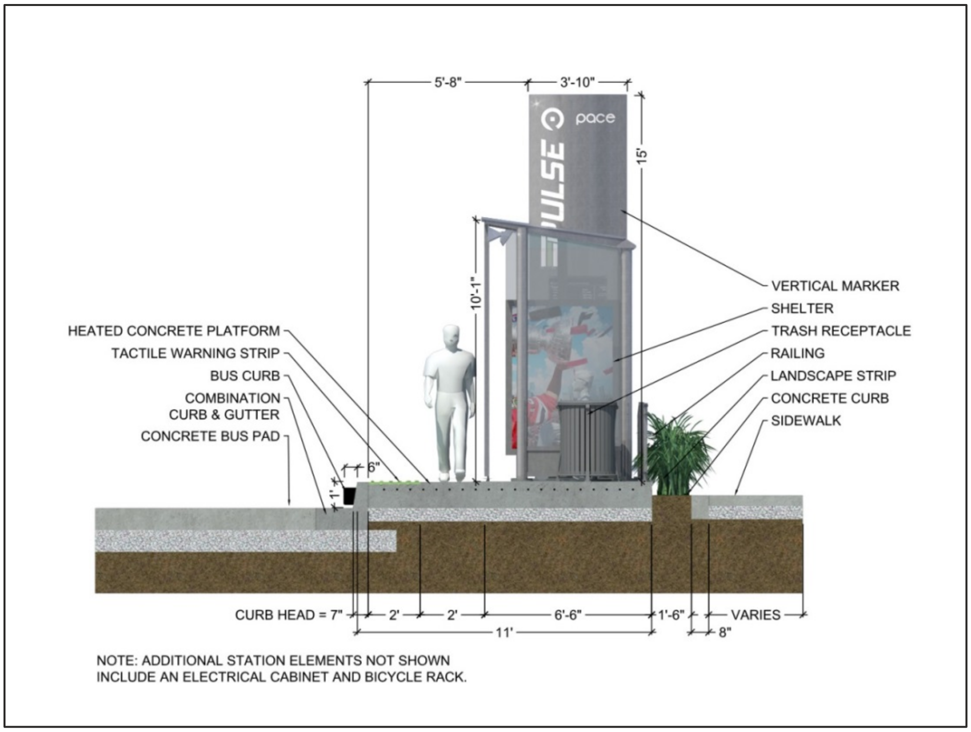


FIGURE 1-3: TYPICAL STATION SECTION



Per individual station site plans, concrete curb and gutter will be removed and reconstructed with gutter widths matching existing conditions (either B6.12 or B6.24) unless otherwise specified. The height of the barrier curb will follow the height of the proposed platform and slope from the existing curb height to the 12-inch curb along the boarding platform area.

PLATFORM HEIGHT

The proposed 12-inch raised platform is provided in accordance with recommended standards for Bus Rapid Transit, as documented in the American Public Transportation Association's (APTA) *Recommended Practice* guidance for planning and designing bus rapid transit stations and stops as well as the Transit Cooperative Research Program's (TCRP) *Bus Rapid Transit, Volume 2:Implementation Guidelines for Bus Rapid Transit*. The APTA report suggests raised platforms, provided at height between 6 and 15 inches, will offer "the benefits of a level platform but reduces the potential for vehicle damage."[2] The TCRP Implementation Guidelines suggest low-platform stations at a height of 12 to 15 inches because they can accommodate low-floor vehicles, such as the ElDorado

[2] APTA BTS-BRT-RP-002-10, Bus Rapid Transit Stations and Stops, October 2010 (Section 5.5.3)

Axxes that Pace is procuring for Pulse and its regular fixed route services, and further "this platform height is much more readily integrated into a typical in-street environment."[3]

Recently, IDOT brought forward safety concerns regarding the proposed 12-inch raised platforms and noted that IDOT does not have a standard for a 12-inch high curb (IDOT does have standards for a 6-inch and a 9-inch curb).[4] In raising this concern, IDOT requested information on the safety of such curbs and examples of other projects/situations where a 12-inch curb has been constructed. This document addresses both IDOT requests.

[3] TCRP Bus Rapid Transit, Volume 2: Implementation Guidelines (Section 5-.3.6)

[4] IDOT Bureau of Design and Environment Section 34-2.02 (b) Curb Types, references the IDOT Highway Standards to provide information on design details and placement for various curb types used by the Department. The IDOT Highway Standard that includes the barrier curb details is standard 606001-06 Concrete Curb Type B and Combination Concrete Curb and Gutter.

2 Safety

TRANSIT SHELTER SAFETY STUDY (2009)

In 2009, the Regional Transportation Commission of Southern Nevada (RTC) commissioned a study to identify ways to improve the safety of transit stops, citing the Las Vegas region's safety challenges as a "24-hour city with large numbers of tourists, high rates of driving under the influence (DUI), and high levels of pedestrian-involved traffic accidents." The *Transit Shelter Safety Study* (Appendix A), authored by Parsons Brinckerhoff, considered the different types of transit stops within the Las Vegas metro region, including 12-inch raised platforms for Metro Area Express (MAX) service, reviewed crash data related to transit stops, conducted a review of a site-specific crash involving a 5" curb, performed a literature review of industry research, and completed a survey of peer agencies regarding bus stop safety and roadside encroachments. Finally, the study provides a "toolbox" of strategies and methodologies to improve the safety of transit stops

As part of the literature review, the authors reference the Institute of Transportation Engineers (ITE) report *Design and Safety of Pedestrian Facilities*, noting that the ITE report identifies three purposes of curbs: "drainage, visual delineation of roadway from the roadside, and vehicle redirection at low speeds with shallow angles of impact." Further, the authors cite ITE's recognition that safety discussions generally focus on vehicular traffic and quoted the ITE report in stating that "curbs alone do not constitute a barrier to protect pedestrians from an errant vehicle."[5] The *Transit Shelter Safety Study* referenced ITE as making a distinction between "barriers" such as curbs and "'positive (crashworthy) barriers' – the latter designed to protect pedestrians from errant vehicles that leave the roadway [e.g. jersey barriers and bollards, etc.]. ITE recognizes that 'universal warrants for pedestrian barriers do not presently exist in any nationally recognized manual or study."[6] Further, the *Transit Shelter Safety Study* references the ITE guidance that "engineering judgment must discern the risk of roadside vehicle encroachment" in determining whether positive crashworthy barriers such as bollards are warranted, citing "three factors that may contribute to this risk: traffic volume, traffic speed and vehicle-pedestrian conflicts."[7]

In its survey of peer agencies, the authors inquired about agency experiences "with accidents at transit shelters that resulted from errant automobiles leaving the roadway, encroaching into the roadside and striking an occupied, or unoccupied, transit shelter." Among the agencies surveyed were Pace Suburban Bus and Valley Metro, the transit

[5] Regional Transportation Commission of Southern Nevada (RTC), *Transit Shelter Safety Study*, p. 12

[6] Regional Transportation Commission of Southern Nevada (RTC), *Transit Shelter Safety Study*, p. 12

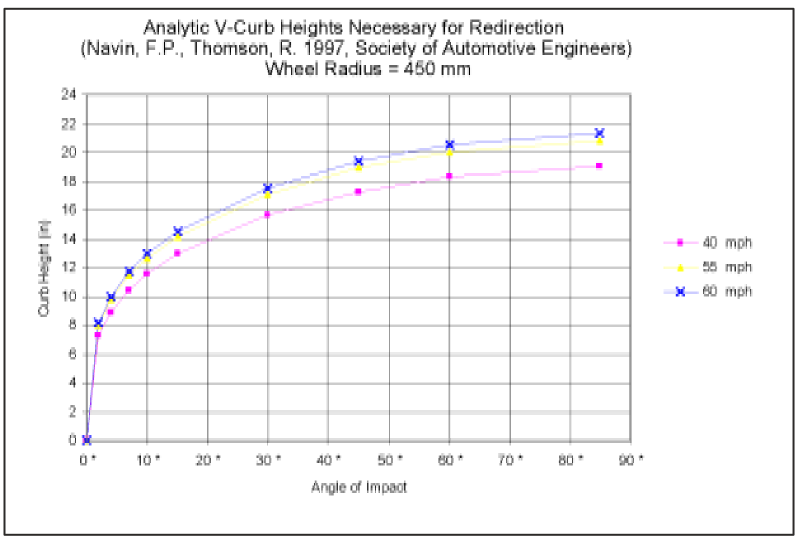
[7] Regional Transportation Commission of Southern Nevada (RTC), *Transit Shelter Safety Study*, p. 13 and p. 38

provider in the greater Phoenix area. Valley Metro reported approximately two to three accidents occur per year region-wide.

The recommendations presented in the "Toolbox" section of *Transit Shelter Safety Study* include suggestions to improve the design of transit stops. One such suggestion is to raise the curb height of the transit stop.[8] Within this section, the authors review the history of roadside curb safety research, reference the testing conducted by the California Division of Highways in 1953, which included "149 full-scale crash tests on 11 different types of curb geometries", and note that this testing "forms the basis for current AASHTO policy relating to the use of vertical faced curbs – particularly regarding the use of vertical faced curb on high-speed facilities." The authors also cite a 1997 study, *Safety of Roadside Curbs",* conducted at the University of British Columbia (UBC) by Dr. Francis Navin and Dr. Robert Thomson with the Society of Automotive Engineers. With respect to the UBC study, the *Transit Shelter Safety Study* summarized the relevant research as follows:

> The study used California Division of Highways and Transport and Road Research Laboratory (UK) data to obtain (among other things) average propensity for the redirection of automobiles back into the roadway based on the height of the curb. Figure 2-1 illustrates the redirective capabilities of curbs based on speed, angle of impact and curb height.[9]

FIGURE 2-1: ANALYTICAL CURB HEIGHT ESTIMATES NECESSARY FOR VEHICULAR REDIRECTION



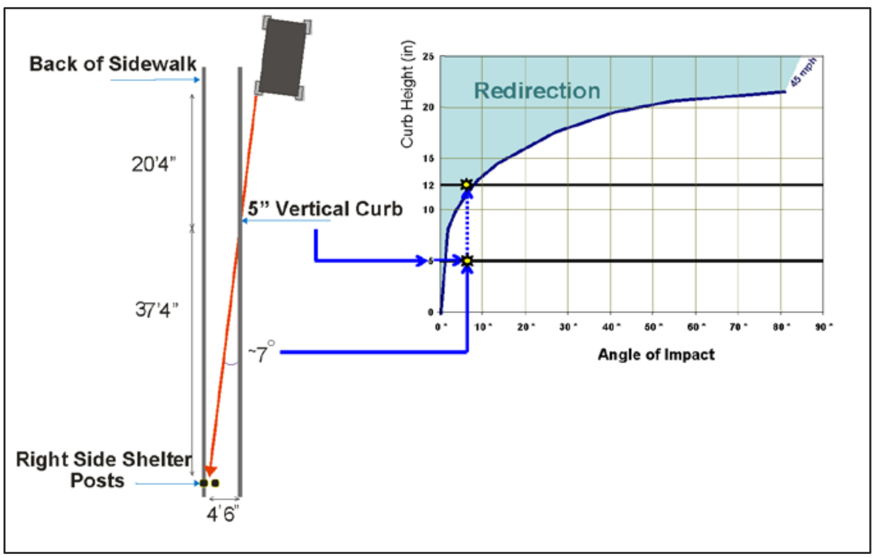
[8] Regional Transportation Commission of Southern Nevada (RTC), *Transit Shelter Safety Study*, p. 30

[9] Regional Transportation Commission of Southern Nevada (RTC), *Transit Shelter Safety Study,* p. 31

The *Transit Shelter Safety Study* authors applied the Navin and Thomson equation to a site-specific crash in the Las Vegas region involving an errant vehicle:

> The equation developed by Navin and Thompson requires the radius of the wheel impacting the curb as an input. In the interest of conservative estimates a wheel radius of 450 millimeters (mm) was used. A wheel radius of 450 mm implies a diameter of 900 mm—or, a diameter of 35 inches, slightly bigger than a large, fully inflated SUV tire (Hummer)… [Figure 2-2] illustrates site level measurements for the accident at Tropicana and Mojave during September of 2008. The Navin and Thompson data suggests that a 45 mph seven degree angle of impact with a 5-inch vertical curb would not redirect an automobile away from the roadside. However, the same data suggests that, with the same speed and angle of impact, ***a 12-inch vertical curb would perform better regarding the redirection of the vehicle*** [emphasis added].[10]

FIGURE 2-2: ANALYTICAL CURB HEIGHT ESTIMATES NECESSARY FOR VEHICULAR REDIRECTION AND SITE LEVEL DATA



It is not possible to estimate the potential angle(s) of encroachment of an errant vehicle on the Milwaukee Avenue or Dempster Street Pulse corridors, where the posted speed is 35 miles per hour. However, the above referenced data suggests that the greater the angle of encroachment, the more effective a raised curb would be in redirecting an errant vehicle and that a 12-inch curb is more effective than a 6-inch or 9-inch curb at increasingly higher

[10] Regional Transportation Commission of Southern Nevada (RTC), *Transit Shelter Safety Study,* p. 31

speeds and increasing angles of encroachment. Further, it appears that a curb height of 6 inches is only effective at redirecting vehicles at angles of encroachment less than approximately two to three degrees.

The Transit Shelter Safety Study also highlights Navin and Thomson's UBC study findings that indicate alternative curb designs can "promote the redirection of errant vehicles back into the roadway."[11] The examples provided are similar to the Kassel kerbs that are used in Europe and, a variation of which, have been used in San Bernadino, and are being proposed in Champaign-Urbana.[12] The addition of a plastic bus curb or rub rail, as proposed for the Milwaukee Line may also effectively serve this purpose.

TRANSIT STOP SAFETY STUDY UPDATE (2013)

In 2013, Parsons Brinckerhoff submitted to the RTC the *Transit Stop Safety Study Update* (Appendix B) [the Update] as an update to the 2009 *Transit Shelter Safety Study*. The Update brings up to date the previously conducted literature review and "includes safety measures presented in the original *Transit Shelter Safety Study*, along with additional safety mitigation measures and strategies at transit stops within the [Las Vegas Metro] Valley."

The recommendations for improving transit stop safety are prioritized into categories as follows: "Primary Strategies", "Primary Strategies But Needs Collaboration", "Secondary Strategies", "Secondary Strategies If Other Measures Cannot Be Implemented", and strategies of "Last Resort". Among the Secondary Strategies recommended to improve transit stop safety is the provision of a raised curb to allow for level boarding.[13] The Update states "Raising the curb at transit stops will not only deter vehicles from leaving the roadway, but it will also make drivers visually aware of the transit stop location."[14]

The Update then goes on to highlight the Las Vegas MAX BRT service that includes raised curbs at a height of 10 to 11 inches adding that the 10 or 11 inch curb[15] is marginally effective as a safety measure and less effective than a curb of 14 to 15 inches, which is in line with the research summarized in the 2009 *Transit Shelter Safety Study* and which indicates that it is a safety improvement over a 6 inch or 9 inch curb.

---

[11] Regional Transportation Commission of Southern Nevada (RTC), *Transit Shelter Safety Study,* p. 32

[12] National Association of City Transportation Officials (NACTO), *Transit Street Design Guide*, 2016, p. 102.

[13] Regional Transportation Commission of Southern Nevada (RTC), *Transit Stop Safety Update,* p. ES-2 and p. 19

[14] Regional Transportation Commission of Southern Nevada (RTC), *Transit Stop Safety Update,* p. 19

[15] Despite this documentation and other published literature stating that the Las Vegas MAX stations consist of a 10-inch curb, Carl Scarborough, Manage of Transit Advertising & Amenities, at the RTC stated unequivocally that all of their rapid transit platforms, including MAX stations and except for the Sahara Express line, consist of a 12-inch curb.

For reference, the recommendations in each of the categories identified in the Update are listed here briefly[16]:

Primary Strategies

- Move shelters behind the sidewalk
- Implement a pedestrian buffer
- Implement a bus turnout
- Conduct a Public Service Announcement Campaign

Primary Strategies But Need Collaboration

- Implement Complete Streets design concepts including evaluating the reduction of speed limits on arterials with transit routes, where appropriate
- Implement random sobriety checkpoints on all arterials with transit routes

Secondary Strategies

- Implement concrete planters with trees planted inside
- Relocate shelters adjacent to block walls
- Add solar powered LED shelter lighting
- **Raise curbs at transit stops to allow for level boarding**

Secondary Strategies If Other Measures Cannot Be Implemented

- Implement a low profile barrier
- Implement high containment curbs
- Add “Bus Stop Ahead” pavement markings
- Add shoulder rumble strips
- Brightly paint the curb next to the transit stops

[16] Regional Transportation Commission of Southern Nevada (RTC), *Transit Stop Safety Update,* p. ES-1 and ES-2

- Brightly paint the transit shelters
- Install a reflective coating on the outside of the transit shelters
- Install rear facing transit shelters

Last Resort

- Implement a bollard system
- Implement reinforced concrete trash receptacles
- Implement a handrail system
- Move the transit shelter to a side street

3 Precedents

As suggested in APTA's *Recommended Practice* guidance and the TCRP *Bus Rapid Transit, Volume 2: Implementation Guidelines for Bus Rapid Transit*, many transit agencies have integrated raised platforms into their station designs. The curb height for the raised platform varies by agency and, as suggested by the TCRP guidance, by vehicle as the floor height of a vehicle varies by vehicle make and model.

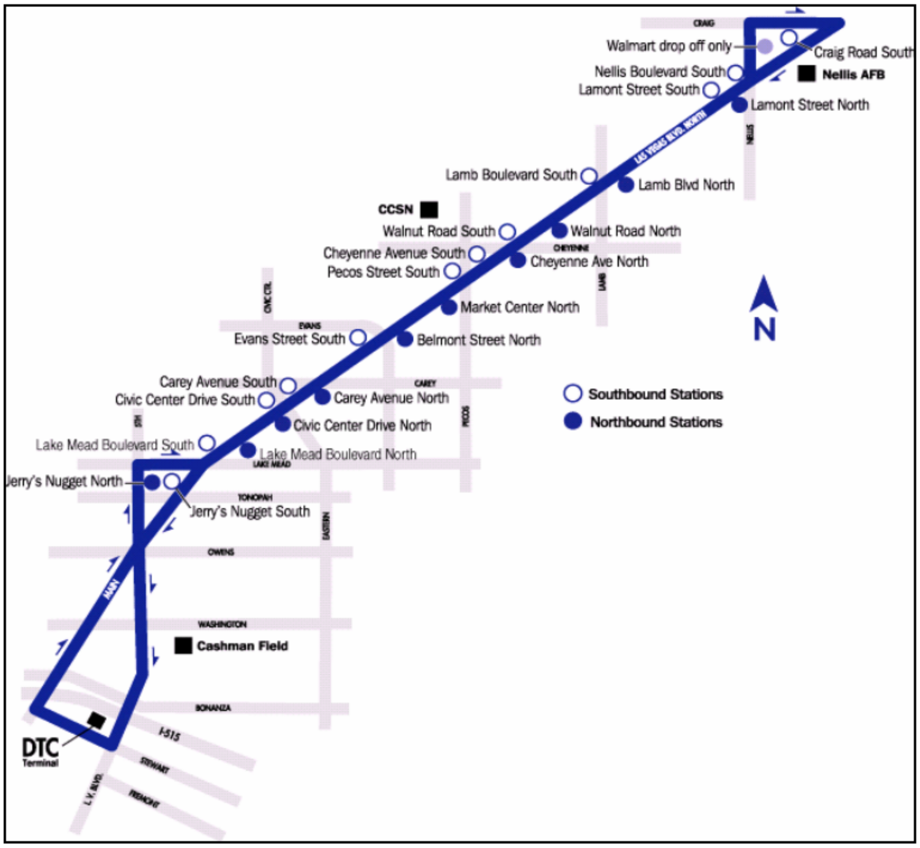
12-INCH CURB EXAMPLES

Two transit agencies were identified that are currently using 12-inch raised platforms for frequent and rapid transit service. These include the Las Vegas RTC and the Phoenix-area transit provider - Valley Metro.

Las Vegas RTC

In Las Vegas, BRT service was first implemented in 2004 on the MAX line, which operated on Las Vegas Boulevard with the routing shown in Figure 3-1. Las Vegas Boulevard North has a posted speed of 45 miles per hour (mph). The MAX brand and some of the BRT features have since been discontinued, but the raised platforms remain in place and continue to be used by Route 113. Both MAX and current Route 113 operate in a dedicated lane for a portion of the route (primarily in downtown Las Vegas) and in mixed traffic along State Route 604 for the remainder. Additional details of the MAX service are summarized in Table 1. Examples of MAX stations are provided in Figure 3-2 through Figure 3-5.

FIGURE 3-1: LAS VEGAS MAX ROUTE MAP



Source: Las Vegas Metropolitan Area Express (MAX) BRT Demonstration Project Evaluation, 2005.

FIGURE 3-2: MAX/ROUTE 113, BELMONT NORTH STATION, LAS VEGAS BOULEVARD NORTH AT BELMONT STREET, NORTHBOUND

FIGURE 3-3: MAX/ROUTE 113, CAREY NORTH STATION, LAS VEGAS BOULEVARD NORTH AT CAREY AVENUE, NORTHBOUND

FIGURE 3-4: MAX/ROUTE 113, LAS VEGAS BOULEVARD NORTH AT CIVIC CENTER DRIVE, NORTHBOUND

FIGURE 3-5: MAX/ ROUTE 113, LAS VEGAS BOULEVARD AT LAKE MEAD BOULEVARD

Since the MAX service was implemented, additional rapid transit lines have opened and provide 12-inch platforms, including the SDX or Strip and Downtown Express, line, which is shown in Figure 3-6 and Figure 3-7.

FIGURE 3-6: SDX, FREMONT EXPERIENCE STATION, S CASINO CENTER BOULEVARD AT CARSON AVENUE

FIGURE 3-7: SDX, BONNEVILLE TRANSIT CENTER, S CASINO CENTER BOULEVARD AT BONNEVILLE AVENUE

Valley Metro

In the Phoenix area, Valley Metro provides BRT service under the branded name LINK. Two LINK corridors use 12-inch curbs: the Main Street and Arizona Avenue/Country Club Dr. The Main Street route opened in 2008 and runs through Mesa in mixed traffic with on-street stations along Main Street, which has a posted speed of 45 mph. Examples of the LINK Main Street corridor stations are depicted in Figure 3-8 and Figure 3-9.

FIGURE 3-8: VALLEY METRO LINK, MAIN STREET, POWER ROAD STATION, EASTBOUND

FIGURE 3-9: VALLEY METRO LINK, MAIN STREET, POWER ROAD STATION, WESTBOUND

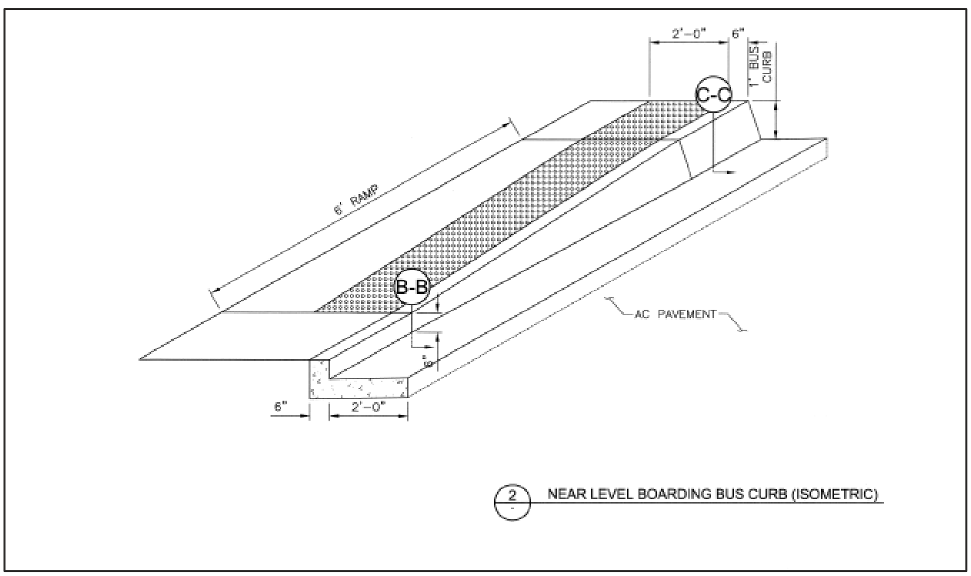
The Arizona Avenue/Country Club Drive corridor runs through Chandler, operating in mixed traffic along State Route 87 which has a posted speed of 35 mph. The route uses both on-street stations as well as bus turnouts. Examples of the Arizona Avenue corridor stations are provided in Figure 3-10 through Figure 3-12. A detail of the 12-inch curb used for these stations was provided by Valley Metro and is featured in Figure 3-13.

FIGURE 3-10: RAY ROAD STATION, SOUTHBOUND

FIGURE 3-11: PECOS ROAD STATION, NORTHBOUND

FIGURE 3-12: GERMANN ROAD STATION, EASTBOUND

FIGURE 3-13: ARIZONA AVENUE CORRIDOR NEAR LEVEL BOARDING BUS CURB DETAIL



Source: Arizona Avenue/Country Club BRT, Germann Rd to Broadway Rd, 100% Permit Set, 2009, Valley Metro

ALTERNATIVE CURB HEIGHT EXAMPLES

In addition to the 12-inch curbs that have been used for raised platforms in the examples above, there are several additional examples of rapid transit services that utilize raised platforms at heights of 11, 14 and 15 inches. These include the following services and their curb heights:

- Silver Line (Grand Rapids) 15 inches
- HealthLine (Cleveland) 15 inches
- Red Line (Minneapolis) 14 inches
- M-1 Rail (Detroit) 14 inches
- EmX (Eugene) 14 inches
- VelociRFTA (Aspen) 14 inches
- Atlanta Streetcar (Atlanta) 14 inches
- Loop Link (Chicago) 11 inches
- MCORE (Champaign-Urbana) 11 inches

Details on each of these services are provided in Table 2. Images for each of the examples are provided below.

Silver Line (Grand Rapids)

FIGURE 3-14: SILVER LINE, 60TH STREET STATION, NORTHBOUND

FIGURE 3-15: SILVER LINE, KELLOGG WOODS STATION, NORTHBOUND

The Silver Line operates in both dedicated bus lanes and mixed traffic. A mixed traffic condition is shown in the two examples above.

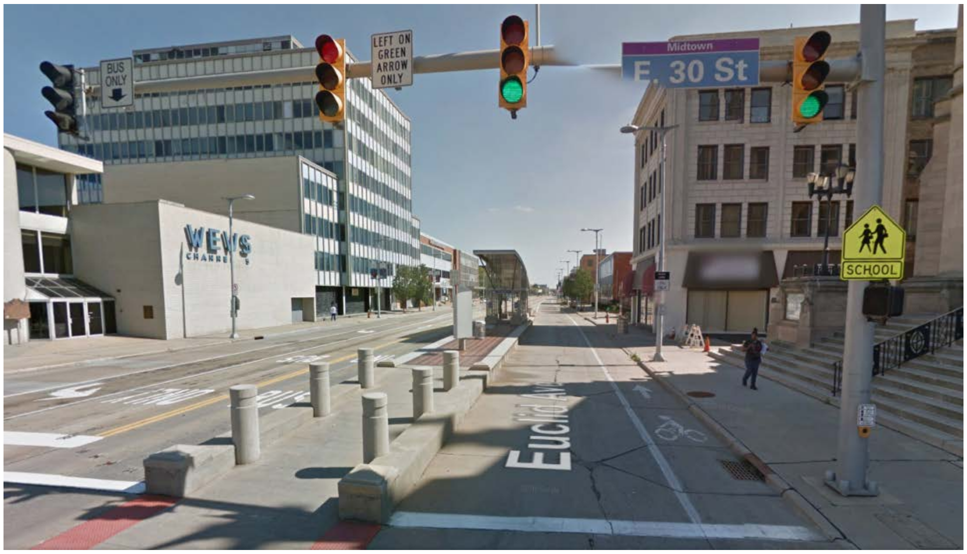
FIGURE 3-16: SILVER LINE, FRANKLIN STREET STATION, NORTHBOUND

HealthLine (Cleveland)

FIGURE 3-17: HEALTHLINE, E 19TH STREET STATION, WESTBOUND

FIGURE 3-18: HEALTHLINE, E 24TH STREET STATION, EASTBOUND

FIGURE 3-19: HEALTHLINE, E 30TH STREET STATION, WESTBOUND



The HealthLine operates in median dedicated bus lanes as well as in mixed traffic. As shown in the examples above, the median platforms serving the dedicated bus lanes have mixed traffic running along the backside of the raised platform.

Red Line (Minneapolis)

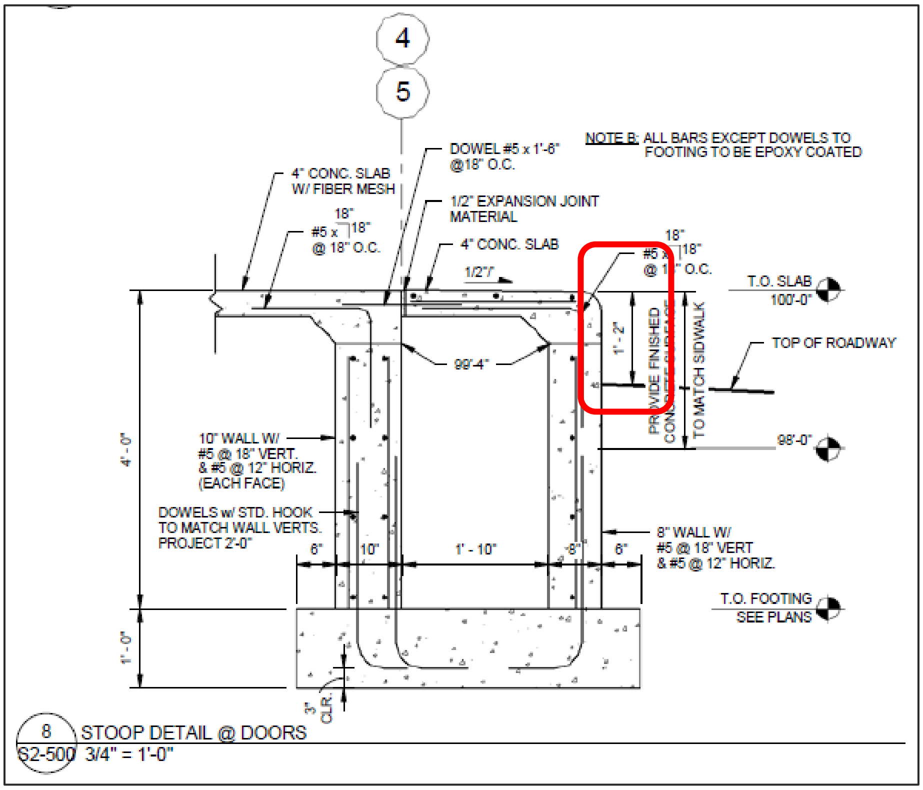
FIGURE 3-20: RED LINE, 140TH STREET STATION, WESTBOUND

FIGURE 3-21: RED LINE, 147TH STREET STATION, WESTBOUND

FIGURE 3-22: RED LINE, 147TH STREET STATION, WESTBOUND

FIGURE 3-23: RED LINE, APPLE VALLEY STATION

FIGURE 3-24: RED LINE, 140TH / 147TH STREET STATIONS, PLATFORM EDGE DETAIL

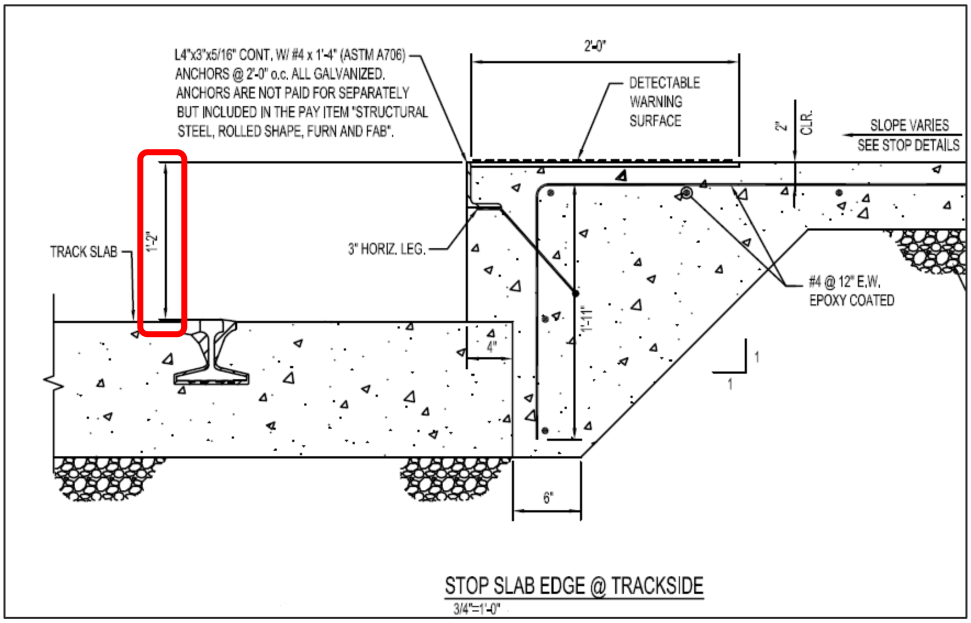


Source: MVTA Red Line – BRT, 140th-147th Station Stops, Conformed Set, 9/12/12

M-1 Rail (Detroit)

M-1 Rail is a planned streetcar that is currently being constructed in Detroit. The streetcar will operate in mixed traffic along State Route 1 (Woodward Avenue), with the streetcar track integrated into the travel lane. The M-1 Rail curbside stations will have a level boarding platform height of 14 inches. The service is anticipated to be operational in 2017.

FIGURE 3-25: M-1 RAIL, PLATFORM EDGE DETAIL



Source: M-1 Rail Final ROW Plan Revisions, 2/14/14

EmX (Eugene)

FIGURE 3-26: EMX, HILYARD STATION, NORTHBOUND

The Emerald Express (or EmX) operates in exclusive bus lanes for approximately 60% of its length, but for the remaining 40%, it operates in mixed traffic. At the Hilyard station shown in the image above, through traffic operates in the lane adjacent to the bus lane and also runs immediately adjacent to the back of the platform. At the Walnut station, shown below, the station is in a drop lane with vehicles entering mixed traffic upon exiting the station.

FIGURE 3-27: EMX, WALNUT STATION, NORTHBOUND

VelociRFTA (Aspen)

FIGURE 3-28: VELOCIRFTA, BUTTERMILK STATION, NORTHBOUND

Atlanta Streetcar (Atlanta)

Like M-1 rail, the Atlanta Streetcar is a rail service operating in mixed traffic. Opened in 2015, the streetcar has both median and curbside stations constructed at a height of 14 inches. For the median stations like the Sweet Auburn Market station, mixed traffic runs alongside the backside of the raised station platform.

FIGURE 3-29: ATLANTA STREETCAR, KING HISTORIC DISTRICT STATION, WESTBOUND

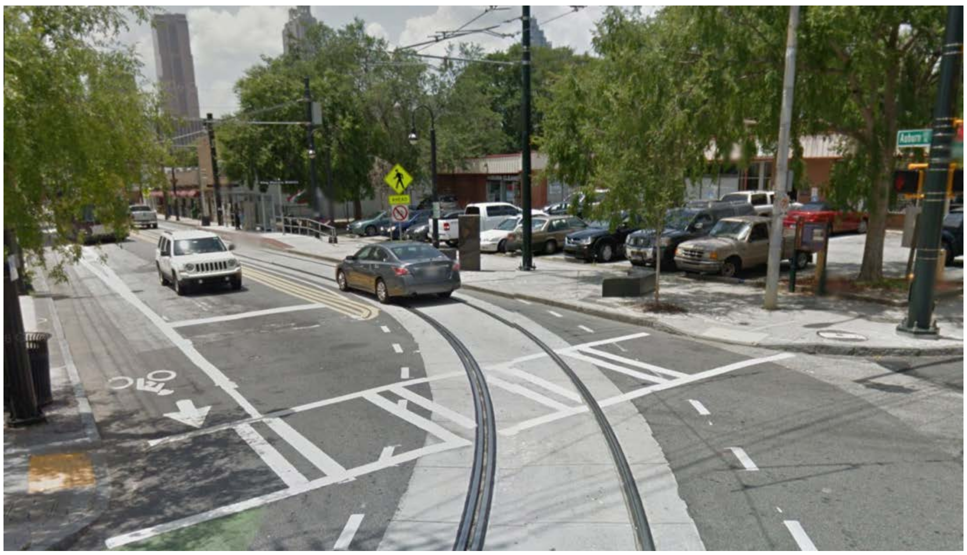


FIGURE 3-30: ATLANTA STREETCAR, KING HISTORIC DISTRICT STATION, WESTBOUND

FIGURE 3-31: ATLANTA STREETCAR, SWEET AUBURN MARKET STATION, EASTBOUND

FIGURE 3-32: ATLANTA STREETCAR, HURT PARK STATION, EASTBOUND

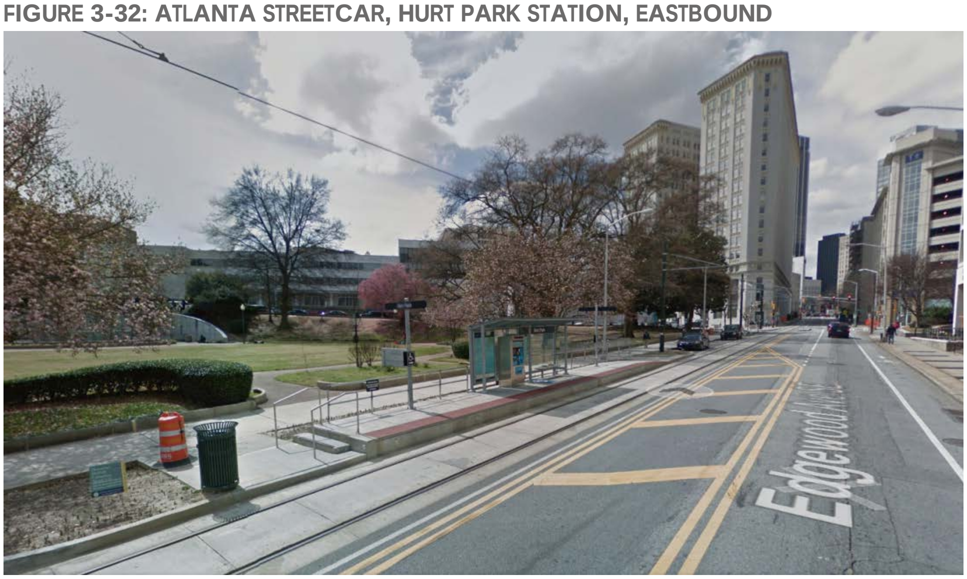
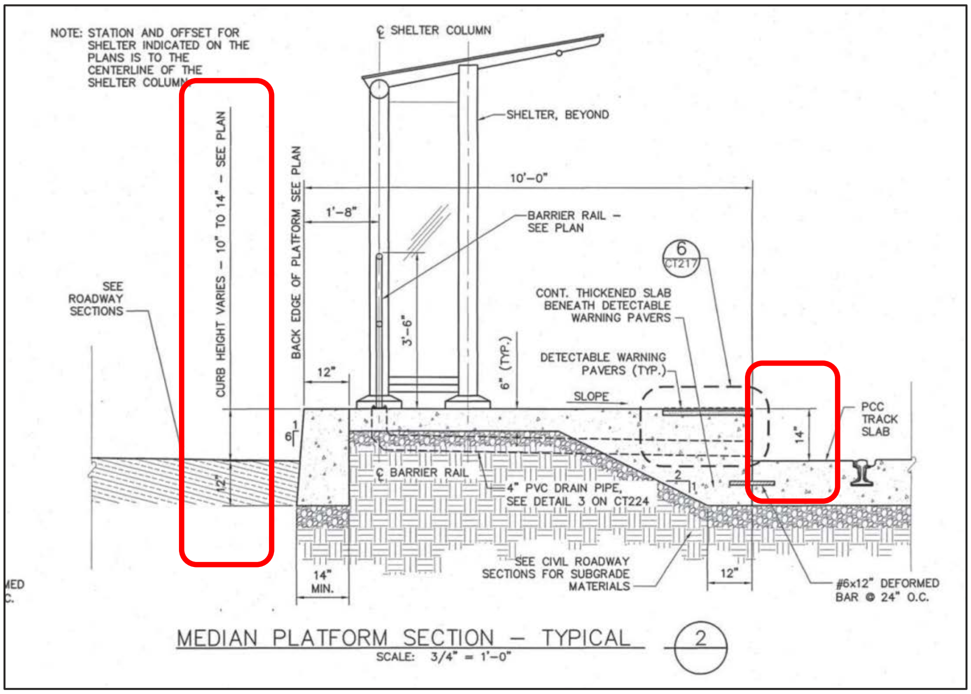


FIGURE 3-33: ATLANTA STREETCAR, CURB DETAIL



Source: Atlanta Streetcar Plan Set, Issued for Construction, Platform Stop Typical Sections

Loop Link (Chicago)

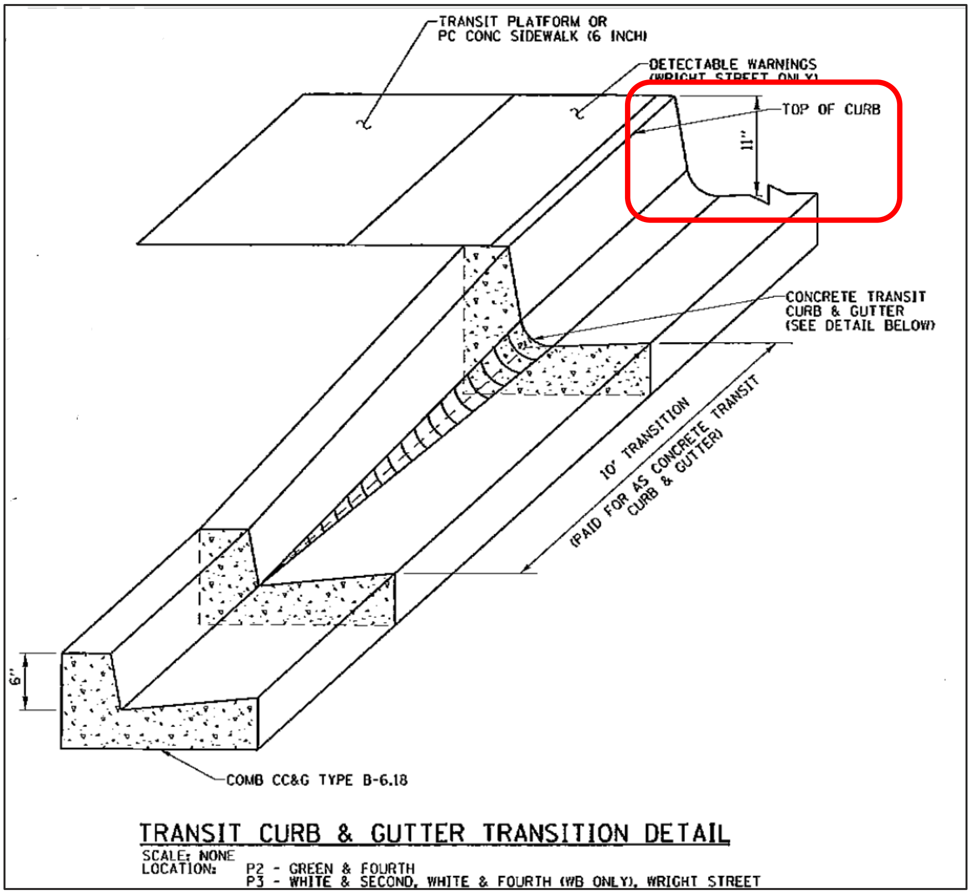
FIGURE 3-34: LOOP LINK, MADISON STATION, WESTBOUND

The Chicago Transit Authority's Loop Link went into service in 2015, using dedicated lanes along Washington and Madison Streets in downtown Chicago. The raised platforms are constructed at a height of 11 inches and include a bus curb.

MCORE (Champaign-Urbana)

The Champaign-Urbana Mass Transit District is currently developing a BRT service that will operate on key corridors surrounding the University of Illinois campus. One project included in the MCORE program is a BRT route that will run along Wright Street, US Route 45. Project plans include an 11-inch raised platform along with a transit curb, as shown in Figure 3-35.

FIGURE 3-35: MCORE TRANSIT CURB DETAIL



Source: Transit Details, MCORE Project 2/3, Dated February 2016

4 Conclusion

The research documented in Chapter 2 indicates that a 12-inch raised curb serving a transit stop or station would perform better than a 6 or 9-inch curb regarding the redirection of an errant vehicle and provides a safer transit /pedestrian environment.

The examples provided in Chapter 3, all further support the safety, precedent and generally accepted standard practice of providing raised transit platforms of heights between 10 and 15 inches. The 2004 and 2008 implementation of 12-inch raised platforms in Las Vegas and the Phoenix-metro area, respectively, provide a long service history on similar road profiles and configurations and their continued use and replication further confirms their acceptability and safety.

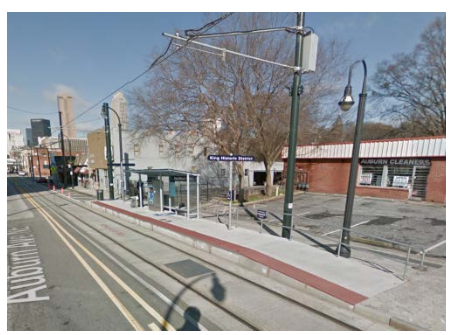
However, given IDOT's safety concerns regarding the proposed 12-inch raised platform, it is recommended that the Pulse Milwaukee Line serve as a demonstration project that is designed and constructed with a 12-inch raised platform. As a demonstration project, both Pace and IDOT may evaluate the performance and safety of the stations, which would then be taken into consideration for the final design of the Dempster Line and other future Pulse corridors.

TABLE 1: 12-INCH CURB EXAMPLES

Service	Photo	Running Way/ Separation Type	Platform Height	Station Features	Additional Information	References
MAX **Now Route 113** **(Las Vegas Blvd North)** **Las Vegas, NV**		• Dedicated lane for 60%; mixed traffic for 40% • Dedicated lane is not barrier separated on MAX line • Previously used precision docking	12 inches	• Shelters	• Posted speed 45mph • Nevada SR 604 • Opened 2004 • The MAX service name was discontinued, but frequent service now provided as Route 113 using MAX raised platforms and other MAX facilities • Various sources cite curb height at 17 inches; the two document references at right specifically identify the MAX platform height at 10-11 inches. However, in speaking with RTC staff, they stated that ***all*** MAX platforms were designed as 12-inch platforms. • Other Express Routes (SDX, etc.) also use 12-inch platforms, except for the Sahara Express, which uses 10-inch platforms due to vehicle requirements	• http://www.nbrti.org/media/evaluations/Las_vegas_final_report.pdf (page 2-3) • http://media.jrn.com/documents/bus_stop_study.pdf (page 19) • http://www.rtcsnv.com/transit/routes-maps-schedules/ • Carl Scarbrough, 702-676-1608, scarbroughc@rtcsnv.com
Valley Metro LINK: Main Street BRT **(Main Street)** **Mesa, AZ**		• Mixed traffic • On-street stations	12 inches	• Shelters • Seating • Bicycle parking	• 45 mph posted speed • Opened 2008	• http://archive.azcentral.com/news/traffic/lightrail/articles/2009/01/14/20090114mr-buses1014.html • http://routes.valleymetro.org/timetables/8/route_list • Jay Yenerich, PE, Manager of Design, Valley Metro, (602) 495-8269, jyenerich@valleymetro.org
Valley Metro LINK: Arizona Avenue/ Country Club Dr BRT **(Arizona Avenue)** **Mesa/Chandler, AZ**		• Mixed traffic • On-street stations as well as some turnout stations	12 inches	• Shelters • Seating • Bicycle parking	• 35 mph posted speed • Arizona State Route 87	• http://routes.valleymetro.org/timetables/8/route_list • Jay Yenerich, PE, Manager of Design, Valley Metro, (602) 495-8269, jyenerich@valleymetro.org

TABLE 2: ALTERNATIVE CURB HEIGHT EXAMPLES

Service	Photo	Running Way/ Separation Type	Platform Height	Station Features	Additional Information	References
Silver Line (Division Street) Grand Rapids, MI		• Bus operates in mixed traffic and in semi-dedicated lane; lane is not barrier separated and mixed traffic tends to use bus lane	15 inches	• Ticket vending and validation machines • Digital real time arrival signs • Electrical cabinets are in close proximity to the shelter	• 45 mph/40 mph posted speed in areas where bus operates in mixed traffic (south of 28th St) • Opened 2015 • Station platform includes bus rub rail	• https://www.transit.dot.gov/about/regional-offices/region-5/silver-line-bus-rapid-transit-brt • https://www.ridetherapid.org/ride/routes/sl • http://www.masstransitmag.com/article/12050911/the-rapids-silver-solution • Conrad Venema, cvenema@ridetherapid.org
HealthLine (Euclid Avenue) Cleveland, OH		• Mix of dedicated median bus lane and mixed traffic; dedicated lanes not physically separated; thru traffic travels adjacent to raised platform • Precision docking via use of a guide wheel	15 inches	• Real time information displays • Marker with maps and wayfinding information • Fully enclosed shelters	• 25 mph posted speed • Opened 2008 • Signed US Route 20 • Electrical cabinet incorporated into station landscaping	• http://nacto.org/case-study/euclid-avenue-brt-cleveland-oh/ • www.nbrti.org/docs/ppt/TRB%207-22-08%20A.%20HL%20Opers.ppt • http://library.ite.org/pub/54322fd1-94e9-7dc1-042d-8948c891a4ae • Mike Schipper, GCRTA, Deputy General Manager - Engineering and Project Management, 216-566-5084, mschipper@gcrta.org
Red Line (Cedar Avenue) Minneapolis/St. Paul, MN		• Stations are in bus turnouts that are not physically separated from thru traffic • Uses precision docking and a transitway in some locations	14 inches	• Fully enclosed branded shelters • Real time arrival signs	• 45 mph posted speed • Opened 2013 • Stations include plastic bus curb	• http://www.metrotransit.org/metro-red-line • https://www.co.dakota.mn.us/Transportation/Transit/CederAvenueBRT/Pages/default.aspx • http://www.metrocouncil.org/Transportation/Publications-And-Resources/Transit/CedarBRTFacts-pdf.aspx
M-1 Rail (Woodward Avenue) Detroit, MI	Not Available	• Streetcar will operate in mixed traffic with curbside stations • Stations are under construction	14 inches	• Shelters • Ticket vending machines	• Opening planned for 2017 • M-1 Rail is being implemented in Detroit on Woodward Avenue (State Route 1) from Downtown Detroit to New Center • The streetcar will operate in mixed traffic utilizing level boarding platforms adjacent to through traffic	• http://m-1rail.com/ • http://m-1rail.com/station-stops/ • https://www.transportation.gov/briefing-room/us-transportation-secretary-ray-lahood-announces-25-million-woodward-ave-streetcar

EmX **(Franklin Blvd)** **Eugene, OR**		• Exclusive single and dual bus lanes for 60%; mixed traffic for 40%	14 inches	• Real time arrival signs • Electrical cabinet incorporated into station landscaping	• 35 mph posted speed • Opened 2007 • Stations include plastic guide strip and rub rail	• https://www.ltd.org/system-map/route_101/ • https://www.transit.dot.gov/about/emx-franklin-corridor-brt-project-evaluation
VelociRFTA **(CO-82)** **Aspen, CO**		• Mixed traffic • Stations are typically placed in turnouts	14 inches	• Shelters • Ticket vending machines • Seating • Pavement snow melt	• 55 mph posted speed • Opened 2013 • Colorado State Highway 82	• http://www.rfta.com/routes/velocirfta-brt/ • http://aspenjournalism.org/2013/08/30/valley-transit-to-pick-up-the-pace-with-new-brt/ • http://www.kutc.ku.edu/powerpoints/TRB20/PFF%205%20Chase%20RuralTransitVelociRFTA.pdf
Atlanta Streetcar **(Auburn Avenue and Edgewood Street)** **Atlanta, GA**		• Curbside and median stations • Streetcar operates in mixed traffic	14 inches	• Shelters with advertising • Ticket Vending Machines	• 30 mph posted speed • Opened 2014	• http://streetcar.atlantaga.gov/
Loop Link **(Madison and Washington Streets)** **Chicago, IL**		• Dedicated lanes with striped separation	11 inches	• Real time arrival signs • Vertical markers • Digital advertising and information signs	• Opened 2015 • Platforms feature a plastic bus curb	• http://www.transitchicago.com/looplink/ • http://chi.streetsblog.org/2015/09/14/despite-reduced-features-loop-link-should-still-prove-the-benefits-of-br http://chi.streetsblog.org/2015/09/14/despite-reduced-features-loop-link-should-still-prove-the-benefits-of-brt/t/
MCORE **(Wright Street)** **Champaign-Urbana, IL**	Not Available	• BRT will operate in mixed traffic with curbside stations	11 inches	• Shelters and kiosks	• Project construction planned for 2017 • US Route 45 • 30 mph posted speed	• http://www.mcoreproject.com/

Appendix A

Transit Shelter Safety Study (2009)

Transit Shelter Safety Study

June 16, 2009

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

RTC	Regional Transportation Commission of Southern Nevada
DUI	Driving Under the Influence
CAT	Citizens Area Transit
MAX	Metropolitan Area Express
ACE	All City Express
LVMPD	Las Vegas Metropolitan Police Department
FHWA	Federal Highway Administration
TCRP	Transit Cooperative Research Program
ITE	Institute of Transportation Engineers
AASHTO	American Association of State Highway Transportation Officials
ADA	Americans with Disabilities Act
RSA	Road Safety Audit
TheBus	Oahu Transit Services
SFMTA	San Francisco Metropolitan Transit Authority
WMATA	Washington Metropolitan Area Transit Authority
CTA	Chicago Transit Authority
TriMet	Tri-County Metropolitan Transportation District of Oregon
MTA	Metropolitan Transportation Authority, State of New York
AADT	Average Annual Daily Traffic
OTP	On-Time Performance
ADT	Average Daily Traffic

1. Introduction

It is the goal of the Regional Transportation Commission of Southern Nevada (RTC) to provide safe transportation facilities for all people in the Las Vegas Valley, including transit passengers, pedestrians, and motorists. Several severe traffic accidents have occurred recently at local transit shelters, and the RTC is undertaking a comprehensive analysis of issues related to transit stop safety. This analysis will address existing transit stop conditions, accident history, best practices of other transit agencies, and solutions for improving safety in and around transit shelters.

The goal of the RTC is to provide safe transportation facilities for all people in the Las Vegas Valley, including transit passengers, pedestrians, and motorists.

Each transit corridor and each individual transit shelter has unique design chalenges, including setbacks, available right-of-way, curb heights, nearby buildings or other strucutres, traffic conditions, or other constraints. The purpose of the *Transit Stop Safety Study* is to develop a strategy for evaluating and prioriztizing safety improvements at transit stops (relating to roadside encroachments) as well as the development of a "toolbox" of alternative approaches. It is recognized that the Las Vegas region faces distinct challenges because it is a 24-hour city with large numbers of tourists, high rates of driving under the influence (DUI), and high levels of pedestrian-involved traffic accidents.

This study is a first step toward implementing safety improvements at bus stops. By developing a method for identifying transit stops where pedestrians and transit customers face the greatest risk, the RTC will be equipped to target improvements in the areas of greatest need. The range of design alternatives for safety improvements can be applied to transit shelters throughout the region, as appropriate.

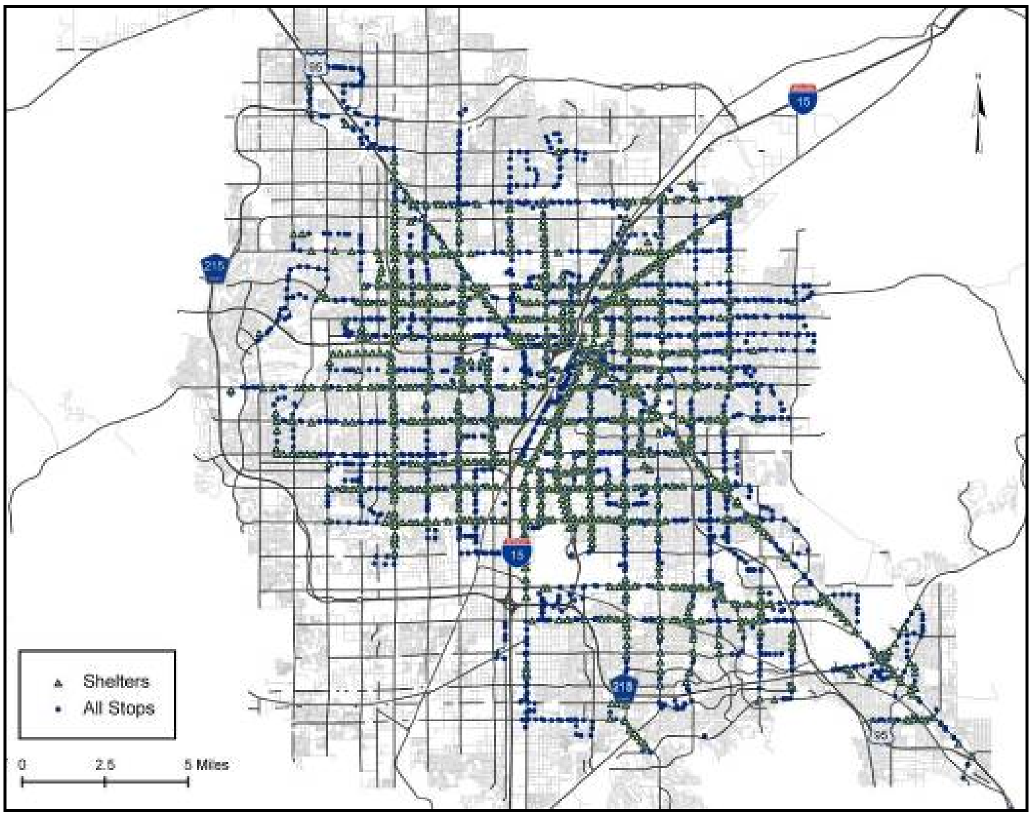
The RTC continues to partner with the local community to address safety concerns. The preliminary findings of this *Transit Stop Safety Study* were presented to the Bus Shelter and Bench Advisory Committee on October 16, 2008. Coordination with community groups and interested citizens is ongoing.

Chapter 2 of this study describes the existing transit stop facilities in the Citizens Area Transit (CAT), Metropolitan Area Express (MAX), and All City Express (ACE) systems. Chapter 3 documents the history of traffic accidents at transit shelters, including the location and contributing factors. Chapter 4 presents a literature review and industry survey of best practices for transit stop safety. Chapter 5 presents a prioritization methodology for targeting improvements to the areas of greatest need; and Chapter 6 provides a toolbox of alternative safety enhancement strategies and designs.

2. Existing Transit Stops

The RTC currently manages over 3,000 stops and 1,200 shelters in the Las Vegas service area. These stops serve more than 200,000 riders daily, and the RTC system as a whole serves more than 65 million passengers annually. On average, two passengers board an RTC vehicle every second—24 hours a day, seven days a week, and 52 weeks a year. Existing bus stops are shown in Figure 1.

Figure 1. All Existing Transit Stops and Transit Stops with Shelters



A variety of bus stop types are provided. The range of facilities includes signs marking the bus route, benches, shelters, and higher-amenity transit stops for ACE and MAX service. Examples of these facility types are shown in Figure 2.

Figure 2. Existing Transit Facility Types

Sign

Bench

Shelter

Custom ACE/MAX Station

3. Crash History

In order to obtain as much information as possible, regional crash data were researched from three sources: Outdoor Promotions Inc., Las Vegas Metropolitan Police Department (LVMPD), and print media. Table 1 lists the data sources with time horizons and descriptions. At the time of this study, there was no single source for accident data. Furthermore, the three data sources maintained different data types. For example, Outdoor Promotions Inc. tracked shelter accidents for the purpose of asset management and thus did not track information on crash type or related injuries. Therefore, Outdoor Promotions tracked shelter accidents regardless of severity but did not have information on crash type or related injuries. The Las Vegas Metropolitan Police Department tracked shelter accident crash types with related injuries and arrest records but did not have data for minor shelter accidents that did not result in a responding officer. LVMPD did not have easy access to the exact location of the shelter accident and only provided two years of data at the time of this study. For information about accidents resulting in a fatality, print media sources were utilized.

Table 1. Regional Crash Data Sources

Source	Time	Data Description
LVMPD	2005–2008	Crash type Time of day Citation/arrest Occupied/unoccupied Area command DUI
Outdoor Promotions, Inc.	2007–2008	Location Date Type Shelter Salvage
Las Vegas Review-Journal, Las Vegas Sun	2002–2008	Date Location Only injury/fatality*

*Limited to “major” incidents

3.1 Regional Crash Review

According to data from LVMPD, from 2005 to the present, there were 73 accidents at bus stop shelters in the RTC system. Table 2 lists the LVMPD crash types by category and DUI involvement. Of these accidents, 21 resulted in a citation for DUI, and 10 shelters were occupied at the time of the collision. All accidents at occupied shelters involved a citation and/or arrest.

Table 2. Accident Data from Las Vegas Metropolitan Police Department

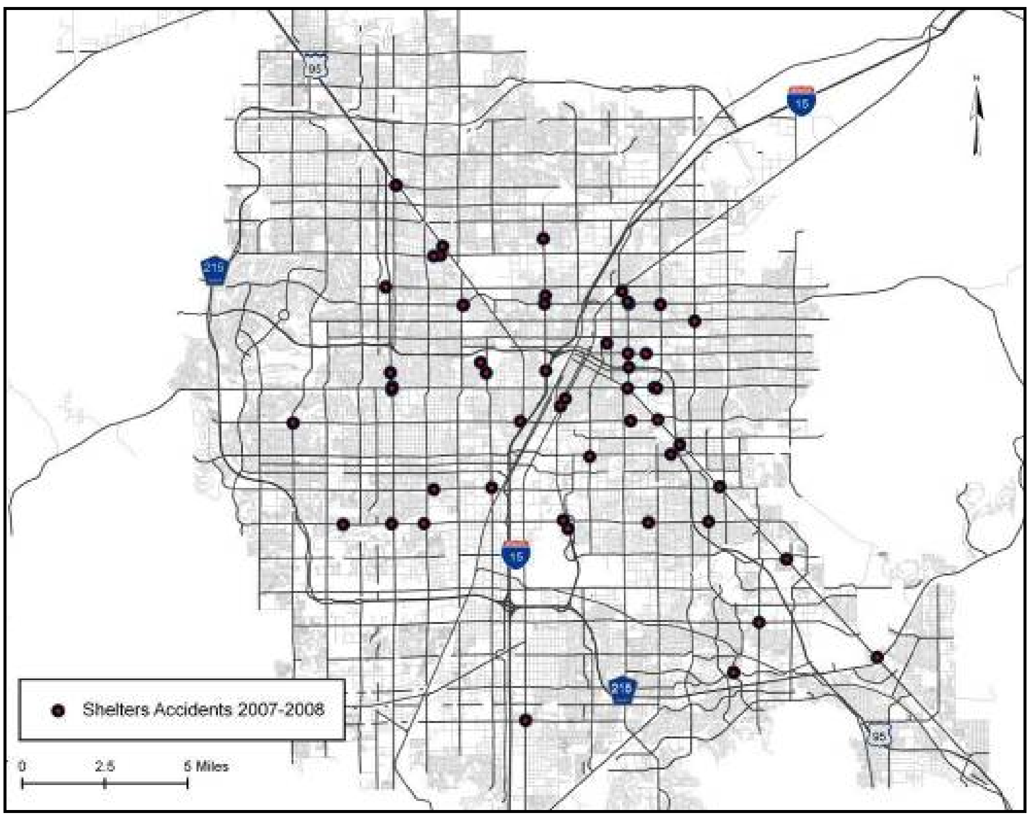
Categories	# of Accidents
Failure to maintain lane	38 (13 DUI)
Miscellaneous	10 (3 DUI)
Reckless driving/major moving violation	10 (1 DUI)
Turn or U-turn	9 (2 DUI)
Speeding	6 (2 DUI)
TOTAL	**73 (21 DUI)**

On average, Las Vegas incurs two transit shelter accidents every month and one injury/fatality every five months.

It was determined that shelter location and/or site improvements could improve the safety at the shelters involved in two of the five categories of accidents—failure to maintain lane and turn or u-turn accidents. However, of the 47 accidents that occurred in these two categories, 15 were DUIs, which are nearly impossible to address through shelter location and site design.

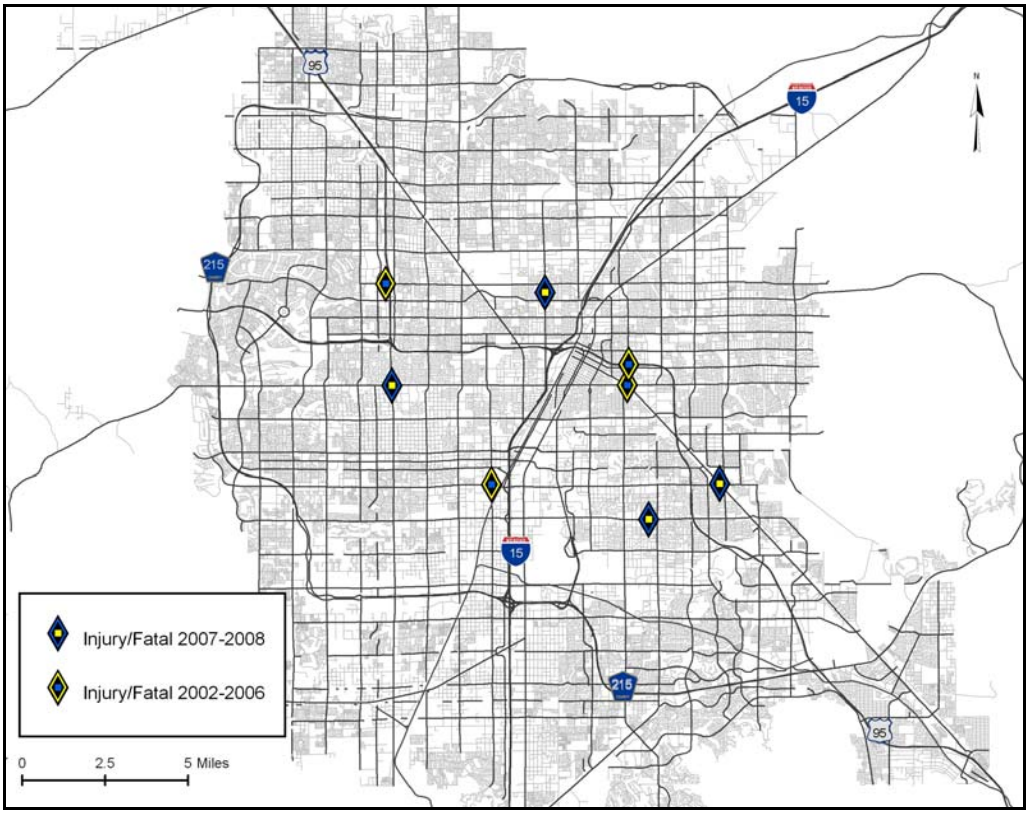
According to data from Outdoor Promotions Inc., from 2007 to 2008 there were 50 accidents at bus shelters. Figure 3 illustrates the location of shelter accidents from January 2007 to September 2008 as obtained from Outdoor Promotions Inc. Prior to 2008, Outdoor Promotions did not track shelter damage severity. For 2008, 23 shelter accidents (92 %) resulted in the shelter being replaced. On one occasion, the shelter was stolen from the scene, resulting in lost data and a lost shelter.

Figure 3. Shelter Accidents, 2007–2008 (Outdoor Promotions Inc.)



According to print media research, from 2002 to 2008 there were eight accidents at bus shelters that resulted in at least one injury or fatality. Figure 4 illustrates the location these accidents. These eight incidents resulted in eight fatalities and seven injuries (15 persons). On average the transit system in Las Vegas incurs one injury or fatality every five months. Of these eight incidents, all resulted from a traffic violation and four resulted in an arrest for DUI. One incident, a fatality in 2005, prompted the Nevada Assembly to pass Assembly Bill 295 which created the crime of Misdemeanor Vehicular Manslaughter in Nevada.

Figure 4. Shelter Accidents Resulting in an Injury/Fatality (Print Media)



3.2 Site Level Crash Review

On September 9, 2008, an automobile struck a bus shelter located on the southeast corner of Tropicana and Mojave. The crash involved a single vehicle (passenger car) that vaulted the curb and encroached into the roadside striking a bus shelter that was occupied by a single passenger. The passenger was transported to Sunrise Hospital by emergency medical personnel and was treated for injuries sustained in the accident. Figure 5 illustrates the site measurements taken at the scene on the morning of the accident. Figure 6 illustrates the accident scene at Tropicana and Mojave.

Based on police and tire markings, it is believed that the automobile struck a 5-inch vertical-faced curb at an angle of approximately 7 degrees. After vaulting the curb, the automobile continued to travel another 37 feet 4 inches coming to rest after striking the occupied bus shelter. The bus passenger was located approximately 4.5 feet behind the face of the curb. If the automobile was traveling in the outermost lane, then the car first began to deviate from its normal path approximately 20 feet prior to encroaching into the roadside. Based on the location and angle of the curb impact, it is believed that the automobile was traveling straight (eastbound) prior to the accident and would be classified as “failure to maintain lane.” The posted speed limit in this area is 45 miles per hour (mph) and the nearest NDOT traffic count location estimates an average of 50,000 ADT.

Figure 5. Site Measurements Tropicana/Mojave Accident

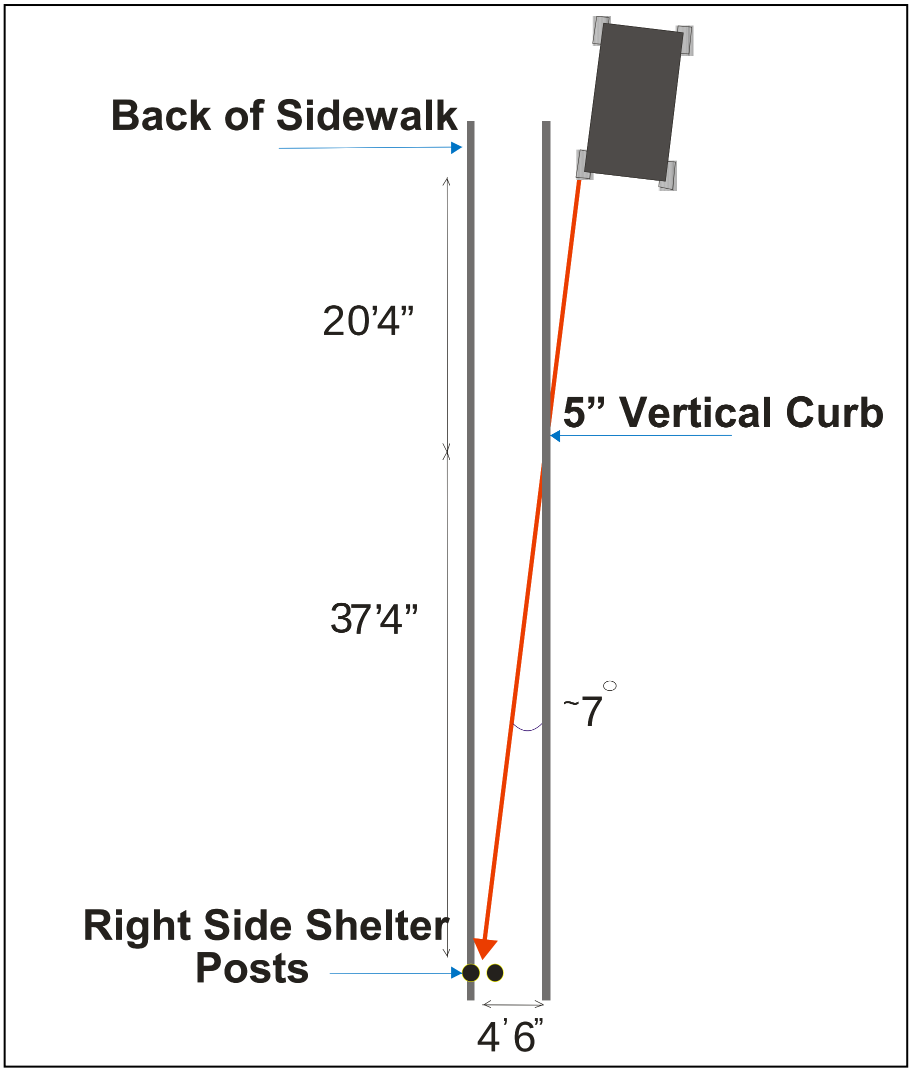


Figure 6. Tropicana and Mojave Accident Scene

4. Literature Review

This section provides an overview of industry research/literature and a survey of peer transit agencies relating to safety at bus stops related to roadside encroachments. The review of literature focused on three families of sources: agency-sponsored policy, government- or industry-sponsored research, and academic research. Table 3 summarizes each source.

Table 3. Sources Summary with Key Points

Source	Key Points Relating to Transit Stops in General or Passenger Safety from Roadside Vehicle Encroachments
AASHTO—*A Policy on Geometric Design of Highways and Streets*	• Bus stop location and land use • Bus stops and roadway operation • Farside/Nearside/Mid-block Stops and traffic operation • Transfers and stop location • Bus stops following left turning buses • Bus Turnouts: on shoulders, on frontage roads, on arterials (with/without barriers) • Bus Bays • Reserve bus lanes (traffic control) • Bus stops/routes collocated with freeways • Pedestrian Safety, Sidewalks, Pedestrian Warrants (lack of) and Buffers/Boarders—on urban, rural, arterial or highway facilities • Grade Separated Pedestrian Facilities Curbs, Curb Function on Different Facilities and General Considerations
AASHTO—*Guide for the Planning, Design and Operation of Pedestrian Facilities*	• No significant direction
AASHTO—*Roadside Design Guide*	• Roadside Safety and The Forgiving Roadside for Urban, Rural or Highway Environments • The Clear Zone • Curbs on Urban, Rural or Highway Facilities • Roadside Features/Obstacles • Barriers • Work Zones
Institute of Transportation Engineers (ITE)—*Design and Safety of Pedestrian Facilities*	• Roadway Design Considerations • Americans with Disabilities Act (ADA) • Sidewalk Design (Curbs, Barriers vs. Positive (crashworthy) Barriers) • Signing and Striping • Barriers • Traffic Control • Transit Stops
Transit Cooperative Research Program (TCRP)—*Report 19: Guidelines for the Location and Design of Bus Stops*	• Street-side factors: placement, types, vehicle interface and roadway design • Curb-side factors: access, pads, shelters, amenities
Transit Cooperative Research Program (TCRP)—*Legal Research Digest 24*	• Ownership, jurisdiction and liability • Selected case history
Transit Cooperative Research Program (TCRP)—*Report 125: Guidebook for Mitigating Fixed-Route Bus-and-Pedestrian Collisions*	• Pedestrian safety from bus-pedestrian crashes • Mitigating bus-pedestrian crashes

Source	Key Points Relating to Transit Stops in General or Passenger Safety from Roadside Vehicle Encroachments
Transit Cooperative Research Program (TCRP)—*Report 33: Transit-Friendly Streets: Design and Traffic Management Strategies to Support Livable Communities*	• Traffic calming and public safety • Balancing uses: auto, transit, pedestrian
Federal Highway Administration (FHWA)—*Pedestrian Safety Guide for Transit Agencies*	• Identification of pedestrian safety issues • Enhancing pedestrian safety
Federal Highway Administration (FHWA)—*An Analysis of Factors Contributing to "Walking Along Roadway" Crashes: Research Study and Guidelines for Sidewalks and Walkways*	• Study focuses on the specific risk of pedestrians hit while on the roadside (not while crossing or otherwise in the realm of the auto) • Pedestrian risk and roadside encroachments
US DOT National Highway Traffic Safety Administration—*Literature Review on Vehicle Travel Speeds and Pedestrian Injuries*	• Vehicle speed and pedestrian injuries
Florida Department of Transportation (FDOT)—*Design Handbook for Florida Bus Passenger Facilities*	• Curb-side guidelines: stop attributes, landscaping, lighting and bollards • Street-side guidelines: stop location and stop types • Facility prototypes: line stops, primary stops and transit hubs • Land use guidelines
Transport for London—*Accessible Bus Stop Design Guidance*	• Transit stop location and layout • Curb (kerb) profiles and heights • Bus boarders • Bus bays
TriMet—*Bus Stop Guidelines*	• Bus stop: location, spacing, attributes, access, layout/design and the roadway • Maintenance • Organizational support
Orange County Transit Authority (OCTA)—*Bus Stop Safety and Design Guidelines*	• Roadway geometrics • Bus stop specifications and passenger amenities • Other general considerations
Moudon, A.V., Hess, P. "Pedestrian Safety and Transit Corridors" Washington State Transportation Center	• Examines the relationship between pedestrian accident locations and the presence of transit passengers • Concludes that roadways with high degrees of transit ridership should incorporate elements to enhance safety related to pedestrian-vehicle crashes
Vukan R. Vuchic "Urban Public Transportation: Systems and Technology "	• Bus stop (on streets, highways, bays or terminals): spacing, location and design • Pedestrians and the walking mode • Safety: as a system measure and in terms of vehicle operation
Vukan R. Vuchic "Urban Transit: Operations, Planning and Economics"	• Bus/transit stop properties relating to the provision of service • Stop-station coverage vs. operating speed with network implications • Safety and security
Avishai Ceder "Public Transit Planning and Operation"	• Transit stop: location and spacing • Passenger safety

Source	Key Points Relating to Transit Stops in General or Passenger Safety from Roadside Vehicle Encroachments
Canadian Transit Handbook (2nd Edition)	• Transit stop: location, spacing and design categories • Design considerations (safety) • Safety and training
Lassarre S., Papadimitriou, E., Yannis, G., Golias, J., "Measuring Accident Risk Exposure for Pedestrians in Different Micro-environments" Accident Analysis and Prevention	• Exposure as measured by risk and time
Pulugurtha, S.S., Vanapalli, V.K., "Hazardous Bus Stop Identification: An Illustration Using GIS" Journal of Public Transportation	• Identification of hazardous bus stops by analysis of existing transit ridership and existing pedestrian crashes • The illustration was preformed on the Las Vegas area utilizing NDOT crash data and RTC transit data (Jacob Simmons is thanked in the acknowledgments).
Navin, F.P., Thomson, R., "Safety of Roadside Curbs" Society of Automotive Engineers	• Redirective capabilities of different curb designs

4.1 Government and Industry Research and Guidelines

The guidance supplied by AASHTO generally supports highway engineering functions that "provide for the needs of highway users while maintaining the integrity of the environment."[1] The AASHTO *A Policy on Geometric Design of Highways and Streets* discusses transit activity as it relates to traffic operations. AASHTO considers bus stop location as driven by land use and passenger activity but does not offer direction or reconciliation when the goals of transit users differ from the goals of traffic operations. The documents generally discuss pedestrian interactions with traffic inside the roadway. However, transit stops are generally located in the roadside. The AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* contains the majority of pedestrian-specific guidance.

The AASHTO *Roadside Design Guide* presents a synthesis of current information and operating practices related to roadside safety and design. In general, the text covers the safety of drivers if the vehicle leaves the roadway. The *Forgiving Roadside* concept states that "a roadside free from fixed objects with stable, flattened slopes enhances the opportunity for reducing crash severity." The *Clear Zone* concept enumerates the forgiving roadside concept by introducing variable distances (that should remain clear) extending from the outside shoulder of the roadway based on traffic volume, speeds, and roadside geometry.

[1] "A Policy on Geometric Design of Highways and Streets," AASHTO Forward

The Institute of Transportation Engineers' (ITE) *Design and Safety of Pedestrian Facilities* opens with a discussion of typical problems relating to pedestrian accidents. The report specifically discusses alcohol-related accidents from the standpoint of intoxicated pedestrians. The report lists the top five most frequently occurring types of pedestrian collisions from 1970 to the present as:

- Dartout-first half (24%)
- Intersection dash (13%)
- Dartout-second half (10%)
- Mid-block dash (8%)
- Turning vehicle accidents (5%)

"Dartout" refers to the crossing maneuvers a pedestrian will make on streets with a median island. The "first half" refers to the first crossing maneuver a pedestrian will make from a roadside to a median island, while the "second half" refers to the second crossing maneuver a pedestrian will make from the median island to the opposite roadside. According to ITE, 60 percent of pedestrian-auto collisions are accounted for in the top five categories and "walk along roadway" crash types are not specifically addressed.

ITE discuses curbs and barriers in the context of cross section elements. The purposes of curbs are three-fold according to the document: drainage, visual delineation of roadway from the roadside, and vehicle redirection at low speeds with shallow angles of impact. The authors also note that curbs may act as a hazard to some pedestrians and that any barrier system constitutes an additional fixed-object roadside hazard. The authors note that as "with many other elements of roadway design, most discussions of traffic barriers in the highway design literature focus entirely on vehicular traffic"[2] and that "curbs alone do not constitute a barrier to protect pedestrians from an errant vehicle."[3] The authors discuss pedestrian barriers to discourage pedestrians from making improper maneuvers into the roadway and curb extensions that "have significant effect[s] on speed and can improve the safety of an intersection by providing pedestrians and drivers with an improved view of one another."[4] The authors distinguish "barriers" from "positive (crashworthy) barriers"—the latter designed to protect pedestrians from errant vehicles that leave the roadway. ITE recognizes that "universal

[2] "Design and Safety of Pedestrian Facilities," Institute of Transportation Engineers, page 67
[3] "Design and Safety of Pedestrian Facilities," ITE, page 67
[4] "Design and Safety…," ITE, page 94

warrants for pedestrian barriers do not presently exist in any nationally recognized manual or study."[5]

The document notes one particular exception to the lack of nationally recognized standards for pedestrian-based positive separation of the roadway and roadside. This exception focuses on bridges with pedestrian walkways. However, ITE does not discuss the reason for the exception. The authors point out the difference between a sidewalk, a bridge and a walkway along a roadway. According to the authors, bridges have lateral constraints that remove a potential escape path for the pedestrian. But, ITE does not address human perception-reaction time as it relates to pedestrians making use of their "escape path." The authors specify that engineering judgment must discern the risk of roadside vehicle encroachment and outline three factors that may contribute to this risk:

- Traffic volume
- Traffic speed
- Vehicle-pedestrian conflicts

The third consideration (vehicle-pedestrian conflicts) in this context refers to any environmental factor that may contribute to pedestrian-accident risk. These environmental factors include, but are not limited to, the lateral separation between the pedestrian walkway and the traffic stream, the propensity of both vehicles and pedestrians to make illegal maneuvers, or a history of accidents.

ITE stresses particular cases for consideration of possible barrier installation. These include:

- Areas of heavily concentrated and vulnerable foot traffic
- Narrow cross-section widths in conjunction with high foot traffic
- The outside of horizontal curves on higher-speed facilities with consistent and substantial pedestrian usage
- Permanent roadway segments where a significant concentration of consistent accident experience has occurred involving off-road impacts with pedestrians
- Highway and street work zones where the protection of both workers and pedestrians is needed by preventing vehicle encroachments

The interpretation of these categories is left to the judgment of the planner or designer, as there are no nationally recognized warrants for crashworthy pedestrian barriers.

[5] "Design and Safety of Pedestrian Facilities," Institute of Transportation Engineers, page 66

Transit Cooperative Research Program (*TCRP) Report 19: Guidelines for the Location and Design of Bus Stops* addresses street-side and curb-side factors relating to bus stop location and design. Street-side factors are those associated with the roadway that affect transit and traffic operations. These factors include:

- Stop spacing and placement (location and orientation)
- Stop type (bus bay, bus nub, etc.)
- Transit vehicle characteristics (length, turning radius, etc.)
- Roadway and intersection design (pavement, corner radii, curbs, etc.)
- Safety

Curb-side factors include those that can influence the comfort, safety, and convenience of bus patrons. These factors include:

- Pedestrian access
- Americans with Disabilities Act (ADA) compliance
- Waiting/accessory pads
- Shelters and amenities

Report 19 discusses transit passengers and adjacent traffic in the context of stop placement and safety. The report states that "passenger protection from passing traffic should be considered when evaluating a location for the placement of a bus stop."[6] However, the report does not address how to identify a stop as dangerous or what to do with an identified stop.

The discussion of stop orientation focuses on the advantages and disadvantages of near-side, far-side, or mid-block stop orientations. The discussion of stop types focuses on the advantages and disadvantages of curb-side stops, bus bays, or bus nubs. The discussion of neither stop types nor stop orientation addresses passenger safety from roadside encroachments.

TCRP Report 19 addresses roadway and intersection design contextually with the interactions between transit vehicles and roadway and traffic elements. The section also addresses bus stops and driveway interaction. The discussion of roadway and intersection design does not address passenger safety from roadside encroachments.

TCRP Report 19's section on safety states, "the bus stop should be located so that passengers may board and alight with reasonable

[6] "TCRP Report 19: Guidelines for the Location and Design of Bus Stops," page 19

safety."[7] But, this section does not continue with a definition of safety. The reader should discern whether "safety" refers to crime, injuries from poor pavement conditions, or inclement weather. This section discusses pedestrian accidents at bus stops but only in the context of pedestrian-vehicle interactions inside the roadway. An example of pedestrian interactions inside the roadway is a bus passenger stepping into the roadway to look for the next bus.

The Federal Highway Administration's (FHWA) *Pedestrian Safety Guide for Transit Agencies* is designed as a reference for transit agency staff. The guide reports on:

- Tools for identifying pedestrian safety and access issues
- Policy and organizational approaches to enhancing pedestrian safety and access
- Actions to increase the safety of pedestrians accessing transit
- Legal issues

The guide opens with a discussion of pedestrian safety in the context of a road safety audit (RSA). The primary tools for identifying pedestrian safety issues are field observations noted by a formal RSA. In this context, pedestrian safety at transit stops focuses on elements of placement, condition, connectivity, lighting and visibility, traffic characteristics, and signage but does not include a discussion of roadside encroachments.

4.2 Industry Survey

Twenty-three peer agencies were identified and contacted. Of these, representatives from sixteen agencies responded to inquiries. The agencies' representatives were asked about their experience with accidents at transit shelters that resulted from errant automobiles leaving the roadway, encroaching into the roadside and striking an occupied, or unoccupied, transit shelter.

In general, the responses were anecdotal in nature because data on this type of accident were not tabulated regularly by staff of the responding agencies. When specific information was available, the data were kept by transit shelter operations and maintenance contractors. Table 4 lists the different agencies contacted and the representative[s] of the agency. In addition to transit agencies, three contacts were added from transit shelter operations and maintenance contractors in Phoenix, Los Angeles and New York.

[7] "TCRP Report 19: Guidelines for the Location and Design of Bus Stops," page 50

Table 4. Industry Survey Contacts

Transit Agency	Location	Contact	Title
Metro Transit	Minneapolis, MN	Adam Harrington	Manager, Route and System Planning
PACE Suburban Bus	Arlington Heights, IL	Bob Huffman	Supervisor of Planning Department
Oahu Transit Services (TheBus)	Honolulu, HI	John Nouchi	
Central Ohio Transit Authority	Columbus, OH	Doug Moore	Vice-President of Planning and Customer Service
Greater Cleveland Regional Transit Authority	Cleveland, OH	Joel Freilich	Manager of Service Planning
Maryland Transit Administration	Baltimore, MD	Michael Deets	
San Francisco Municipal Transportation Agency	San Francisco, CA	Peter Straus	
Memphis Area Transit Authority	Memphis, TN	Roy Boggs	Director of Schedules/Route and Schedule Planning
Southwest Ohio Regional Transit Authority (METRO)	Cincinnati, OH	Tim Reynolds	Director of Transit Development
Washington Metropolitan Area Transit Authority	Washington DC	Vince Jackson	Manager, Transit Route Development
Alameda-Contra Costa Transit District	Oakland, CA	Nancy Skowbo	Deputy General Manager, Service Development
		Nathan Landau	Transit Planner
Metro Transit	Seattle, WA	Sharon Slebodnick	Supervisor, Transit Route Facilities Service Development
Los Angeles County Metropolitan Transportation Authority	Los Angeles, CA	Pete Serdienis	Planning
Tri-County Metropolitan Transportation District	Portland, OR	Ben Baldwin	
Arlington County Transit	Arlington, VA	Steve Yaffee	Transit Service Planner
		Jason Quan	Consultant, Author of Design Guidelines
Chicago Transit Authority	Chicago, IL	John Paquet	Planning
		Amy Kovalan	VP Safety
		Linda Rhodes	Safety
New Jersey Transit	Newark, NJ	Paul Speigel	Bus Stop Shelters and Signs
Shelter Clean	Los Angeles, CA	Alan Mudge	General Manager
Shelter Clean	Phoenix, AZ	Robert Lassner	General Manager
Shelter Express	New York, NY	Akash Chabra	General Manager

The Maryland Transit Administration had an incident of a passenger struck by an encroaching automobile while waiting at a bus stop but no actions were taken to reduce the likelihood of future incidents and staff could not recall the exact date of the incident.

The San Francisco Metropolitan Transit Authority (SFMTA) has a variety of problems with pedestrian-vehicle incidents. However, passengers struck by errant vehicles while at a transit stop are uncommon and not currently addressed by SFMTA. At specific stops—those which utilize loading islands—handrails are used to keep passengers on the loading island. Figure 7 illustrates a SFMTA center island station and a MUNI bus stop that is set back approximately 30 feet from the roadway.

Figure 7. SFMTA Loading Islands and MUNI Shelters

SFMTA Loading Island	MUNI Bus Shelter
	

Oahu Transit Services (TheBus) does not directly address transit stop safety related to roadside encroachments by errant automobiles. The agency attempts to set bus stops back from the curb to account for ADA guidance relating to the distance between the bench and the curb. This moves waiting passengers away from the flow of traffic, creating separation between passengers and the adjacent traffic stream.

Southwest Ohio Regional Transit Authority (Ohio Metro) in Cincinnati, Ohio, has no information on and does not directly address incidents of automobiles encroaching into the roadside and striking passengers waiting at bus stops. However, in reaction to an accident at a light rail station, design modifications were made at two major transit centers. Bollards designed to arrest a bus traveling under 5 mph were installed at the end of sawtooth bays in these transit centers.

Washington Metropolitan Area Transit Authority (WMATA) in Washington, DC, does not directly address transit stop safety related to errant automobiles encroaching into the roadside and striking passengers. WMATA is currently developing new bus stop guidelines in order to provide consistency to bus stop design. The guidelines will recommend new bus stop setbacks of at least 5 feet from the face of curb.

According to staff recollection, Pace Suburban Bus in the suburbs of Chicago has not had an incident like this in recent memory and does not keep data related to roadside encroachments resulting in automobile-passenger accidents at transit stops. Despite this, Pace planning staff have considered (but not acted on) various items, such as rumble strips, corner guard rail, illumination, and passenger education programs. Rumble strips installed around the dedicated space for a bus stop might alert drivers that they are leaving the roadway if a transit stop is near. This noise could also alert waiting passengers that the bus (or an errant vehicle) was approaching. Corner guardrails installed when a bus stop is located very close to a corner can be used to keep automobiles from encroaching on the roadside during the turn. In some instances in Chicago, bus shelters are oriented with the solid side of the shelter facing the roadway. This is done to protect passengers from street-splash during wet weather conditions. Increasing illumination at bus stops and initiating education programs reminding passengers to remain alert and stay back from the curb could be effective in promoting safety, according to Pace staff.

Arlington County Transit published bus stop guidelines that include a recommendation for the installation of a crash barrier on roads which have a speed limit of 45 mph or over. San Bernardino includes language identical to that used by Arlington County, but it is unclear which property included this language first. Arlington County Transit and San Bernardino are the only properties in the sample that directly addressed transit stop safety related to roadside encroachment by errant vehicles. Currently no crash barriers have been installed at Arlington County or San Bernardino transit shelters for this express purpose. Agency staff contacted as part of this survey is unsure about the origins of this guideline and assumed it was included as a commonly used standard. However, based on the literature review in Section 4.1, this is neither a common practice nor a published standard. According to staff recollection, among the 11,000 bus stops in Arlington County, there have only been two incidents of an encroaching automobile striking a bus stop in recent years. Both transit stops were unoccupied when the incidents occurred. Staff recalls that one incident was due to drunk driving while the other occurred when a driver swerved to avoid another vehicle.

However, the agency does not keep specific data related to these types of incidents.

The Tri-County Metropolitan Transportation District of Oregon (TriMet) replaces or repairs approximately 10 shelters per year because of accidents involving errant vehicle roadside encroachment. According to staff, most of these incidents occur late at night when buses are not in service. No occupied shelters have been hit in recent memory. One particular shelter, located on an island at the intersection of three streets (52^{nd}, Powell, and Foster), has been hit three times by errant vehicles. Despite these incidents, TriMet does not directly address transit stop safety related to roadside encroachments.

The Chicago Transit Authority (CTA) has not had recurring problems with transit shelters stuck by encroaching automobiles. In general, CTA routes are not located on high-speed arterials but operate in urban settings with relatively low travel speed and ample on-street parking. The presence of on-street parking plays a vital role in curbing roadside encroachments (the parked cars act as a barrier). CTA is conducting a study of pedestrian safety near bus stops, but this work focuses on the crossing behavior of passengers and pedestrian interactions inside the roadway, not the roadside.

Manhattan sees about 2 shelter accidents per year.

Los Angeles has 1.4 shelter accidents per month.

Shelter Express in New York City is one of the transit stop operations and maintenance contractors for New York Metropolitan Transportation Authority (MTA). Transit stop accident rates in New York are relatively low and average two accidents per year. The low travel speeds of congested Manhattan may serve to reduce the accident rates. On-street parking also provides positive separation between the roadway and the roadside.

Los Angeles County Metropolitan Transportation Authority has accident rates for transit shelters similar to those of the Las Vegas area (two per month) in recent years. However, since September 1979, the Los Angeles MTA has seen 244 shelter accidents—or, an average of 1.4 shelter accidents per month. The majority of shelter accidents happen overnight when service is not running and no staff members could remember any fatalities. The MTA has discussed bollards as a solution to shelter accidents but concluded bollards to be unsafe, cost ineffective, and jurisdictionally infeasible. Shelter Clean—LA, the MTA's operations and maintenance contractor, maintains transit shelters throughout the county.

Shelter Clean—Phoenix maintains transit shelters for Valley Metro. Accident rates in the Phoenix area are low (two to three per year). An encroaching automobile hit an occupied shelter in October 2008. Two transit passengers were hospitalized, and the incident was recorded on surveillance video.

New Jersey Transit (NJTransit) has installed bollards at 24 transit shelters. The infrequent installations are primarily due to safety concerns. In general, the bollards installed by NJTransit are located at malls, parking lots, and transit stations or anywhere travel speeds are anticipated to be low.

5. Strategic Risk Assessment

The RTC must allocate efforts in a logical and strategic manner and must identify transit stops that need attention in the short term, mid-term and long term. The assessment takes place along five axes of measurement. The five components are:

- Traffic Volume (NDOT ADT, RTC Regional Model)
- Traffic Speed (posted speed limit, design speed)
- Site-specific Factors
- Estimated Average Wait Time
- Passenger Boardings

The first three components partially, yet sufficiently,[8] estimate the risk faced by an individual passenger. The fourth component measures the amount of time the average passenger faces risk. The fifth component accounts for the number of passengers facing the risk over an amount of time.

5.1 Exposure

All passengers face some degree of risk while waiting for transit vehicles. The average passenger faces this risk during the time spent waiting for a transit vehicle. Exposure is the amount of risk-time confronted by a passenger. For example, a passenger facing risk level **ρ** for one hour accumulates a **ρ**-hour of risk-exposure. While the average passenger faces individual risk-exposure, the agency confronts the individual average risk-exposure multiplied by the number of passengers exposed, resulting in “cumulative risk-exposure.” When the risk level is unknown, non-risk-weighted exposure-hours may be considered.

[8] Traffic volume, traffic speed and the site-specific factors (outlined in Section 5.3) as necessary and sufficient conditions for the estimation of risk at transit shelters are a working assumption. Tests of this hypothesis are left for future study.

5.2 Route and Site-Specific Factors

Certain measurable factors apply to both routes and individual stops. Route level factors and site-specific factors include traffic volume, traffic speed and passenger exposure-hours.

5.2.1 Traffic Volume

Average daily traffic (ADT) measures the amount of average traffic on a roadway segment during a 24-hour period. The Nevada Department of Transportation collects traffic count data from numerous locations throughout the state. However, NDOT ADT counts do not differentiate between directions of travel, are sparsely located and do not provide forecasts of traffic growth. For these reasons, ADT counts are used on a route or corridor basis. For site-specific assessment, the RTC Regional Transportation Plan Model (TransCAD) will be used to estimate current and forecast future traffic volumes.

5.2.2 Traffic Speed

The speed of the traffic stream, all things being equal, affects the risk faced by waiting transit passengers. In general, high-speed facilities incur relatively fewer accidents while the average accident is of relatively high severity. Low-speed facilities incur relatively higher accident rates of generally lower severity. The relationship between travel speeds and pedestrian injury severity is well documented. In a meta-study of three prior research efforts, Pasanen (1992) estimated that nine out of ten pedestrians survive being struck by an automobile traveling 5 mph, three out of five for an automobile traveling 30 mph and only one in five pedestrians survive being struck by an automobile traveling 40 mph. The survival rates of pedestrians struck by automobiles traveling 50 mph and above are extremely low.

5.2.3 Headway, Wait-Time and Passenger Boardings

The time spent waiting for a transit vehicle is directly related to the headway of the route. In general, without information about service reliability or the specific distribution of passenger arrivals, the estimated average wait-time on a transit route is one-half the arrival interval for headways at or below 20 minutes. For headways above 20 minutes and at or below 45 minutes, one-third the arrival interval estimates the average wait-time. One-fourth the arrival interval for headways above 45 minutes up to 60 minutes can be used as an estimator for average wait-time (see Wait-time Technical Appendix). For example, if a transit vehicle comes every 15 minutes, the estimated average wait-time will be 7-1/2 minutes; if that vehicle were to come every 30 minutes, the estimated average wait-time would be 10 minutes; and if the vehicle arrived on the hour, the estimated average wait-time would be 15 minutes. The estimated average wait-time multiplied by total passenger boardings at a single stop or over an entire route comprises the time component of cumulative risk-exposure-hours.

5.3 Site-Specific Factors

The physical environment of the transit stop affects the risk faced by waiting passengers. Site-specific factors include elements that separate the waiting area from the traffic stream, the location and design of the transit stop, and the design of the adjacent roadway. Measurements of site-specific factors at the stop will be:

- Distance between the shelter and the adjacent traffic stream
- Distance between the shelter and the face of curb
- Distance to the nearest upstream driveway or intersection[9]
- Curb height in front and upstream of the transit shelter
- Near-side, far-side or mid-block stop orientation
- Proximity, speed and volume of left-turning automobiles[10]
- Auto accidents within 100 feet of the transit shelter, or evidence of roadside encroachments[11]

5.4 Procedures

In general, individual routes will be identified first through route factors such as boardings-weighted[12] average NDOT ADT counts, boardings-weighted average speed limits and estimated cumulative exposure-hours. Once a route has been identified, stops within the route will be assessed based on transit stop level measures of traffic volume (RTC Model), posted speed limit, cumulative exposure-hours at the stop and the site-specific factors outlined in Section 5.3. A separate risk analysis will weight the site-specific factors based on site measurements and previous shelter accidents. The sample of roadside encroachments at transit shelters can be enhanced by acquiring the same site-specific measurements at other identifiable encroachment sites, such as damaged streetlights or roadside facilities.

Route identification begins by collecting corridor level data on traffic volume, traffic speed, passenger boardings and route headways. Table 5 illustrates sample route level data. The items considered are

[9] Downstream driveways are hypothesized to be less significant than upstream driveways because the momentum of an accident downstream of a transit shelter moves the accident away from the transit stop.
[10] See: Section 6.1.4, Left-Turn Cone (of intersection)
[11] There are various methods of estimating roadside encroachments involving tire marks on curbs or the replacement/repair of roadside facilities such as streetlights, signal boxes or signage.
[12] Boardings-weighted averages of route factors, such as posted speed limits, improve on distance-weighted averages by accounting for the spatial distribution of passengers along the route.

boardings-weighted average traffic speed, boardings-weighted average traffic volume and monthly cumulative exposure-hours. The monthly cumulative exposure-hours are based on April 2007 data with current headways and are used for illustrative purposes only. In this example, the route with the highest monthly ridership is the Charleston 206, with over 300,000 boardings in that month. Accounting for 15-minute weekday headways, the estimated average wait-time for the 206 is seven and one-half minutes, resulting in 41,866 estimated monthly cumulative exposure-hours. The boardings-weighted average speed limit on the Charleston route is 42.8 mph, reflecting that, while approximately three miles of the route has a posted speed limit of 35 mph, nearly a quarter of the boardings occur in these sections. In a similar fashion, the boardings-weighted average traffic volume is 40,340 vehicles per day. The value of the last column in Table 5 is a non-weighted[13] index of the items under consideration. The exact values of the index have no meaning and are only used to order the routes. The Charleston 206, in this example, has the highest index value and would be considered first for risk analysis.

Table 5. Route Identification Example

Route	Monthly Passenger Boardings (April 2007)	Boardings-Weighted Average Speed Limit (mph)	Boardings-Weighted Average ADT (veh/day)	Monthly Cumulative Exposure Hours (man hours)	Non-Weighted Index (no scale)
206 - Charleston	334,931	42.8	40,340	41,866	72
101 – Rainbow	94,604	40.4	55,521	15,773	35
103 – Decatur	165,706	44.0	32,328	21,173	30
102 – Jones	67,757	38.8	31,002	11,292	14
104 – Valley View	37,674	37.1	25,465	8,372	8

Once a route is identified, stop-level risk assessment begins with the collection of relevant data.

Table 6 illustrates stop-level data for a sample of transit shelters on the Charleston 206. The site-specific data items (from Section 5.3) are included, with the exception of information about left-turn volume and existing auto accidents or encroachments. These data items require coordination with other agencies and are excluded from the example, but can be added at a later date. The items considered are distance to the traffic stream, the face of curb, and the nearest upstream driveway or

[13] At the conclusion of this study, a formal risk analysis required to weight the data items has not been completed.

intersection. Other site-specific items include the curb height, nearside/farside/mid-block stop location, traffic volume, posted speed limit and cumulative exposure-hours. The cumulative exposure-hours are based on April 2007 ridership data and used only for illustrative purposes.

In the example of shelters on Charleston Boulevard in

Table 6, Stop 515 is ranked first and would be addressed first through the application of the Toolbox in Section 6. While 518 is nearest to the traffic stream, 515 has a lower curb height and more cumulative exposure-hours and is therefore ranked ahead of 518. Stop 474 is the farthest from the traffic stream but is not ranked last. Stop 487 is closer to the traffic stream than 474, but is ranked last because the exposure-hours are relatively low.

Table 6. Stop Identification Example

Stop	Distance to Traffic (feet)	Distance to Face of Curb (feet)	Distance to Driveway/ Intersection (feet)	Curb Height (inches)	Near/ Far /Mid	Traffic Volume (veh/day)	Speed (mph)	Exposure -Hours (man hours)	Non-Weighted Index (no scale)
515	5.5	3.0	175	4.0	Far	20,000	45	2,019	55
518	3.0	3.0	145	6.0	Far	21,000	45	1,181	41
474	44.5	7.0	151	4.0	Far	20,000	45	1,740	3
487	21.5	6.5	113	5.0	Far	20,000	45	749[14]	2

6. Toolbox

The solutions and methodologies outlined in the Toolbox will be specific to individual stops. In general, RTC will utilize the unique environment and ridership characteristics of the transit stop to develop solutions customized to each stop. Failing to treat each stop individually might overlook solutions that are optimal for a specific stop.

6.1 Move the Stop

Relocation can be the most efficient solution for addressing a potentially dangerous transit stop. Relocating an existing stop can take the form of a setback (moving the stop away from traffic), a longitudinal adjustment (moving the stop up or down the street), moving a stop from the far-side to the near-side of an intersection or reorienting the shelter with respect to the street. These options may be combined based on the needs of the

[14] The distribution of boardings by stop used in this example was generated before the construction of an apartment complex adjacent to this stop. The current exposure hours at Stop 487 are likely greater than 749 man-hours.

individual locations. Each option should be considered independently for each stop, as there is no set solution for all transit stops.

6.1.1 Setback

Where possible, a shelter may be relocated to a position further away from the traffic stream. This solution increases the separation between the shelter and the traffic stream. Figure 8 illustrates a transit shelter setback approximately 10 feet from the face of curb, an existing shelter with significant right-of-way constraints and an existing shelter that can be setback.

Figure 8. Existing Shelter Setback Scenarios

Existing Shelter Setback	**Existing Shelter with ROW Constraint**
	
Existing Shelter Abutting a Utility Easement	
	

6.1.2 Upstream/Downstream Shelter Relocation

The shelter in Figure 9 could be moved downstream approximately 100 feet to another location, which may increase the opportunity to set the shelter back farther away from traffic. Other reasons for moving a transit stop in a longitudinal manner might include excessive left-turn volume before a farside stop, close proximity to a driveway or proximity to a median cut.

Figure 9. Longitudinal Shelter Relocation

Existing Shelter Location

6.1.3 Nearside/Farside Stop Orientation

Under some circumstances, existing transit shelter safety concerns can be addressed by moving a stop from the far side of an intersection to the near side of an intersection, or visa versa. Figure 10 illustrates a stop that cannot be setback because of right-of-way constraints but could be relocated to the near side of the intersection. Figure 10 illustrates the relocation of Stop 515 that serves the Charleston 206 in the eastbound direction at Rainbow. The current location of the stop is approximately 154 feet east of the eastern crosswalk at Charleston and Rainbow. As an additional benefit, relocation from farside to nearside, in this case, would place the new stop only 30 feet away from a crosswalk, increasing the propensity for bus passengers to use the crosswalk when exiting the transit vehicle or arriving at the transit stop.

Figure 10. Nearside Stop Reorientation at Charleston and Rainbow

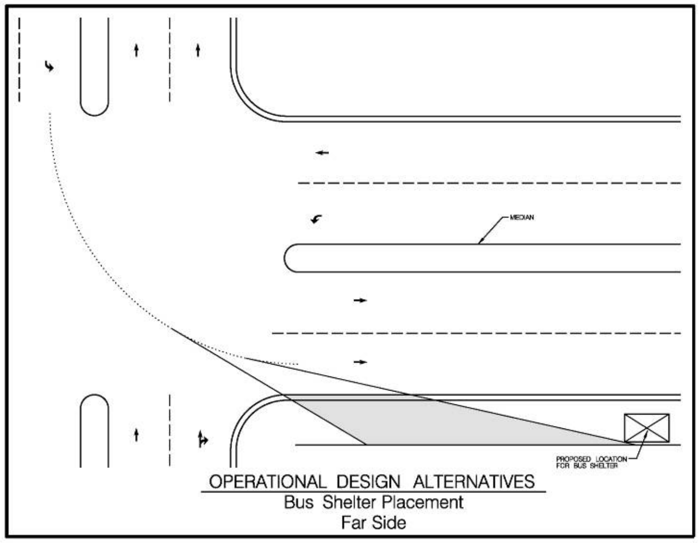
<table>
<tr><th>Stop 515 Eastbound Charleston Farside Rainbow</th><th>Stop 515 Nearside Relocation</th></tr>
<tr><td></td><td>
</td></tr>
<tr><td></td><td>Eastbound Charleston Nearside Rainbow Site Measurements</td></tr>
<tr><td>Existing Stop
Relocated Stop</td><td>
</td></tr>
</table>

Because the stop being relocated is used as a time point, nearside orientation would be inappropriate because the bus may need to stand in an active travel lane when ahead of schedule. Standing in this active travel lane for the purpose of schedule adherence would block right turning automobiles for an unacceptable duration of time. RTC Transit Operations Planning staff would need to consider alternative operating practices relating to the use of this location as a time-point. Figure 10 illustrates some of the site level measurements of the hypothetical stop location. The Citizens Area Transit Bus Stop Guidelines require the location of nearside stops to be between 30 feet and 100 feet prior to the curb return and that 40 feet or 60 feet of clear space exist for use by transit vehicles. At the near side of Rainbow there is 90 feet of space from the curb return to a private driveway. Following RTC bus stop guidelines and leaving 30 feet of clear space from the curb return, there are 60 feet available for the transit vehicle to use while stopping. Additionally, the use of a nearside stop at this location would not adversely affect the line of sight for automobiles exiting the private driveway upstream of the hypothetical stop. While it is generally believed that nearside stops encourage exiting passengers to cross in front of the transit vehicle, utilizing a crosswalk in this context is preferred to jaywalking from a stop located over 150 feet away from a crosswalk. Further, the 30 feet distance between the transit stop and the crosswalk, required by RTC standards, implies that passengers may be less likely to cross directly in front of the bus.

6.1.4 Left-Turn Cone

The left-turn cone region of an intersection, illustrated in Figure 11**,** is the section of roadside that is shadowed by the path of left-turning automobiles. The cone is formed by the intersection of two tangent lines extending from the left-turn path. The two tangent lines represent an automobile leaving the left-turn path prematurely, continuing straight, and intersecting with the opposing curb. The first tangent line is chosen so that it represents the first departure from the left-turn path that intersects with the opposing curb of the roadway segment that accepts the left turn. The second tangent line is chosen so that the angle of intersection (angle of impact) is equal to the lowest angle of impact expected to vault the curb, given the design speed of the facility and the existing curb height. Different facility types and lane configurations will result in different dimensions for the left-tune cone. Transit shelters located within a left-turn cone should be considered for relocation or improvement if exposure-hours, site-specific factors or roadway characteristics suggest that such actions are appropriate. The Left-Turn Cone Technical Appendix provides examples of different left-turn cone regions based on different lane configurations. The left-turn cone regions in the technical appendix do not consider curb height at the locations and are provided for illustrative purposes only.

Figure 11. Left Turn Cone



6.1.5 Shelter Reorientation (Side Street)

Under certain circumstances an existing transit stop can be relocated onto a side street. There are many locations throughout the Las Vegas area where residential areas abut major arterials. In these areas, the pedestrian realm and roadside areas are often constrained by a concrete wall on one side and the roadway on the other. Under these circumstances, moving an existing shelter upstream or downstream will accomplish little safety improvements. Because these areas are heavily populated, the removal of the stop is undesirable. The physical improvement of the stop is also constrained because of the lack of right-of-way. With no other option, the existing transit shelter may be relocated onto a side street. Figure 12 illustrates an existing transit shelter located on Charleston Boulevard. Moving the shelter upstream or downstream would not offer safety improvements and the stop area is heavily constrained by private property. The shelter could be relocated onto the residential street shown in Figure 12 and operated in conjunction with a passenger actuated bus stop sign.

Figure 12. Reorientation onto Side Street

Stop 510

Stop 510 Reorientation onto Side Street

Existing Stop   Relocated Stop

I-Stop

Reoriented Stop 510

6.2 Improve the Stop

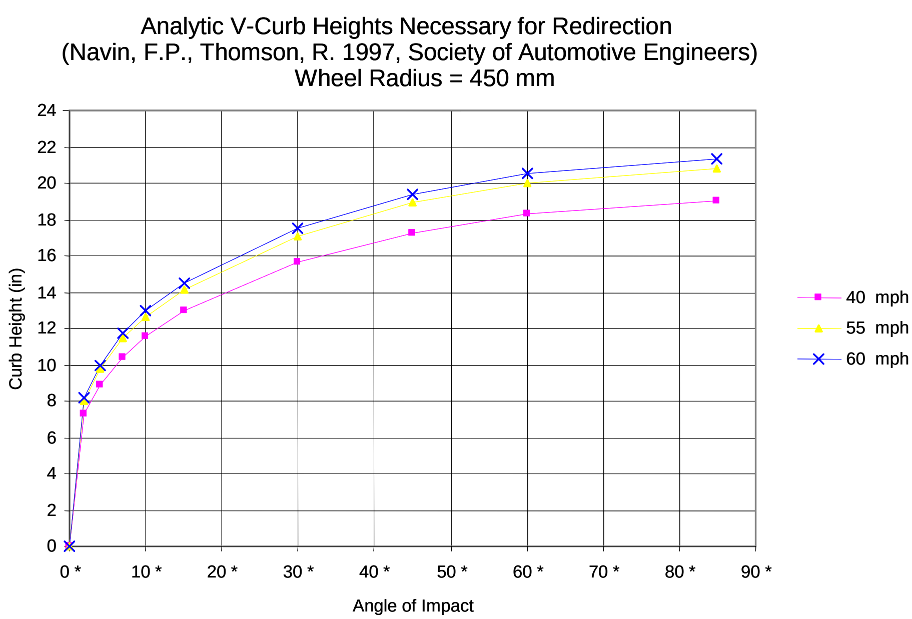
This section describes options to improve existing bus stops at their current location. These alternatives are focused on providing greater separation between transit customers waiting at bus stops and oncoming traffic. These protections can be in the form of physical barriers to redirect or block potential errant vehicles and increasing the distance between the pedestrian area and the auto travel lane.

6.2.1 Raised Curb Height

Research into the effectiveness and safety of roadside curbs attracted attention in the early decades of roadside safety research. Curbs were considered a low-cost method of keeping vehicles from encroaching into the roadside. In 1953, the California Division of Highways performed a series of 149 full-scale crash tests on 11 different types of curb geometries. Subsequent analysis utilized the data obtained from the California Division of Highways tests. The results of the early tests form the basis of the current AASHTO policy relating to the use of vertical faced curbs—particularly regarding the use of vertical faced curb on high-speed facilities. While the distribution of vehicle types has changed considerably since the 1950s and 1960s, "the current version of the AASHTO Green Book contains substantially the same recommendations as the 1965 Green Book regarding the use of curbs."[15]

In 1997, Dr. Francis Navin and Dr. Robert Thomson, of the Department of Civil Engineering at the University of British Columbia, published "Safety of Roadside Curbs" with the Society of Automotive Engineers. The study used California Division of Highways and Transport and Road Research Laboratory (UK) data to obtain (among other things) average propensity for the redirection of automobiles back into the roadway based on the height of the curb. Figure 13 illustrates the redirective capabilities of curbs based on speed, angle of impact and curb height. The equation developed by Navin and Thompson requires the radius of the wheel impacting the curb as an input. In the interest of conservative estimates a wheel radius of 450 millimeters (mm) was used. A wheel radius of 450 mm implies a diameter of 900 mm—or, a diameter of 35 inches, slightly bigger than a large, fully inflated SUV tire (Hummer).

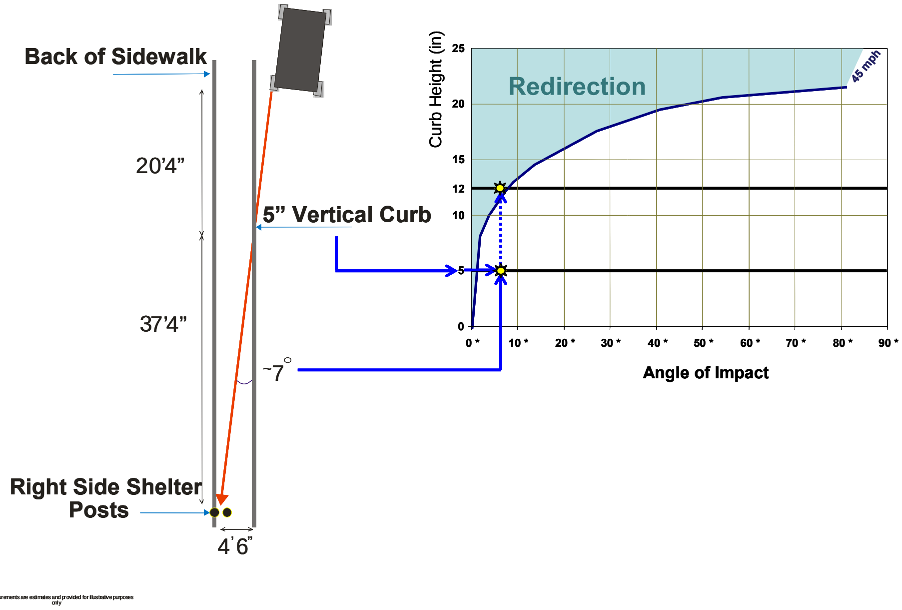
Figure 13. Analytic Curb Height Estimates Necessary for Vehicular Redirection



15 NCHRP Report 537: Recommended Guidelines for Curb and Curb-Barrier Installations pg. 5

Figure 14 illustrates site level measurements for the accident at Tropicana and Mojave during September of 2008. The Navin and Thompson data suggests that a 45 mph seven degree angle of impact with a 5-inch vertical curb would not redirect an automobile away from the roadside. However, the same data suggests that, with the same speed and angle of impact, a 12-inch vertical curb would perform better regarding the redirection of the vehicle.

Figure 14. Analytic Curb Height Estimates Necessary for Vehicular Redirection and Site Level Data for the Tropicana/Mojave Accident



6.2.2 Alternative Curb Design

Vertical-faced curbs are used in the estimation of curb heights necessary for vehicle redirection conducted by Navin and Thompson and illustrated in Figure 13. However, in the same study, Navin and Thomson investigated curbs of alternative geometries and concluded that the geometric design of the curb face can have significant effects on the propensity of the curb to redirect an errant vehicle back into the roadway. In Europe, alternative curb designs – known as Anti-Vehicular Kerbs – are designed and manufactured by private suppliers. These curbs are designed to promote the redirection of errant vehicles back into the roadway. Figure 15 illustrates various alternative curb designs from Charcon, Inc., a European manufacturer of pre-cast concrete and granite curbs. Charcon Inc. manufactures the curbs following EU engineering standards (BS EN1340:2003).

Figure 15. Charcon HGV Anti-Vehicular Curb (Kerb)

6.2.3 Bus Turnout

A bus turnout is a special zone on the side of the main roadway primarily used for buses to stop for a designated bus stop in order to pick up and drop off passengers. The purpose of the bus turnout is to avoid blocking a lane of traffic and to improve passenger safety during boarding and deboarding. Bus turnouts may also be the location of minor bus termini, and may be extended to accommodate bus stands and left-turn movements into private properties.

Bus turnouts are most often lacking in cities with little or no usable right-of-way for their construction. In younger cities, particularly in the United States, where there is sufficient right-of-way bus turnouts are installed on roads either as part of upgrading the road or installed by requirement of the local government during development of the lot.

A disadvantage of bus turnouts is that buses must merge back into the flow of traffic after using the bus stop, which can cause delay to the bus. Although many jurisdictions worldwide have instituted *yield to bus* laws, motorist compliance with these laws is often non-existent.

In some jurisdictions, bus turnouts can be used as an emergency turnout for the general public to prevent blocking a lane of traffic. However, should a bus attempt to enter the turnout during this time, the automobile must make way. Figure 16 illustrates two bus turnouts on Charleston Boulevard.

Figure 16. Bus Turnouts

Stand Alone Bus Turnout	Bus Turnout with Right-Turn Pocket
	

6.2.4 Curb Extension

A curb extension is a traffic calming measure, intended to slow the speed of traffic and increase driver awareness, particularly in built-up and residential neighborhoods. They also allow pedestrians and drivers to see each other when vehicles parked in a parking lane would otherwise block visibility. Additionally, the curb extension provides distance between the pedestrian realm (which includes transit shelters).

A curb extension comprises an angled narrowing of the roadway and a widening of the sidewalk. This is often accompanied by an area of enhanced restrictions (such as a "no stopping" or "no parking" zone) and the appropriate visual reinforcement. This is achieved using painted road markings (e.g. lines, colored areas, or chevrons), barriers, bollards, or the addition of pavement or street furniture (e.g. planters, lamp standards, or benches).

Curb extensions are often used in combination with other traffic calming measures such as chicanes, speed bumps, or rumble strips, and are frequently sited to "guard" pedestrian crossings. In these cases the "squeeze" effect of the narrowed roadway shortens the exposed distance pedestrians must walk.

Curb extensions can pose a hazard to cyclists, as they force cyclists from their position at the road side (or in a roadside bike lane) into the narrowed gap. Consequently, many curb extensions are built with the bike lane passing through (making the extension an island, separated from the main sidewalk by a narrow bike lane).

Curb extensions are also used in a number of special circumstances:

- To provide additional horizontal space to allow retrofitting of existing sidewalks with ramps, where the sidewalk would otherwise be too narrow.
- To provide additional visibility and protection for pedestrians (particularly children) when leaving premises. The curb extension may contain a pedestrian barrier, preventing pedestrians from running straight from the premises over the road.
- In combination with a controlled urban parking scheme, where parking spaces are shielded from oncoming traffic by the extended sidewalk element.
- At a four-way, signalized intersection, to slow and calm traffic, particularly fast traffic turning from a major to a minor road.
- To protect passengers embarking and particularly disembarking from trams, buses, and level-grade urban light rail systems, particularly when retrofitting existing streets.

Figure 17 illustrates an existing curb extension at 4th Street and Charleston Boulevard in Las Vegas. The purpose of this curb extension is to provide a parking lane that is protected from automobiles making left turns from northbound 4th Street to westbound Charleston.

Figure 17. Curb Extension (Bulb-Out)

4th Street and Charleston

6.2.5 Pedestrian Buffer

Pedestrian buffers are areas alongside roadways that are often separated by planting strips consisting of natural vegetation or landscaping that create a buffer from the noise and splash of moving vehicles and separate the sidewalk from the roadway. Like curb extensions, pedestrian buffers may also enhance transit stop safety related to roadside encroachments by positively separating pedestrians and transit passengers from the adjacent roadway. Planting buffers (also referred to as planting strips, landscape strips, landscape buffers, and nature strips) are generally considered to be an effective separation treatment between walkways and streets in all types of settings. The added separation of a planting buffer helps a pedestrian feel more comfortable when walking along the street. The buffer area also provides space for streetlights, fire hydrants, utility boxes, and bike racks. Other advantages of buffer areas include:

- Sidewalks at a constant level grade across driveways, avoiding dipping at every driveway cut.
- Buffers providing for drainage runoff.
- Aesthetic enhancement, increasing the appeal of the walkway and pedestrian environment.
- Planted trees providing shade and wind protection.

Figure 18 illustrates different pedestrian buffers throughout the Las Vegas area. In general, these sites are located in recently developed, upper income areas.

Figure 18. Existing Pedestrian Buffers

Pecole Ranch	
	
Centennial Hills	**Summerlin**
	

6.2.6 Positive (Crashworthy) Barrier

The Institute of Transportation Engineers (ITE) notes that as "with many other elements of roadway design, most discussions of traffic barriers in the highway design literature focus entirely on vehicular traffic."[16] ITE recognizes that "universal warrants for pedestrian barriers do not presently exist in any nationally recognized manual or study."[17] There is one particular exception to the lack of nationally recognized standards for pedestrian-based positive separation of the roadway and roadside: pedestrian walkways on bridges. The authors briefly discuss the main difference between a bridge and a general walkway, and conclude a potential escape path for the pedestrian as the pivotal feature (due to lateral constraints, bridges offer no refuge from an errant vehicle). However, based on the analysis of the transit shelter crash at Tropicana and Mojave in Section 3.2, pedestrians on a general walkway do not have time to react to an errant vehicle because of human perception-reaction time. This inconsistency is not addressed by the Institute of Transportation Engineers.

The authors specify and outline three factors that may contribute to the risk confronted by pedestrians related to roadside encroachments:

- Traffic volume
- Traffic speed
- Vehicle-pedestrian conflicts

ITE stresses particular cases for consideration of possible barrier installation. These include:

- Areas of heavily concentrated and vulnerable foot traffic
- Narrow cross-section widths in conjunction with high foot traffic
- The outside of horizontal curves on higher-speed facilities with consistent and substantial pedestrian usage
- Permanent roadway segments where a significant concentration of consistent accident experience has occurred involving off-road impacts with pedestrians
- In highway and street work zones where the protection of both workers and pedestrians is needed by preventing vehicle encroachments

The interpretation of these categories is left to the judgment of the planner or designer, as there are no nationally recognized warrants for crashworthy pedestrian barriers. Figure 19 illustrates different crashworthy barriers throughout the Las Vegas area.

[16] "Design and Safety of Pedestrian Facilities," Institute of Transportation Engineers
[17] "Design and Safety of Pedestrian Facilities," Institute of Transportation Engineers, page 66

Figure 19. Positive (Crashworthy Barriers)

Las Vegas Boulevard

Silverado Ranch
Crashworthy Barrier Protecting Automobiles from Wash

Flamingo at Las Vegas Boulevard
Crashworthy Barrier Protecting Roadside Asset

6.2.7 Bollards

Figure 20 illustrates the use of bollards for different purposes and on different facilities. In general, bollards should only be used on low speed facilities such as parking lots or passenger drop off areas. The presence of bollards within the Clear Zone of a roadside presents an additional roadside hazard and the use of such items should be minimized where possible. Additionally, traditional bollards are not designed to arrest an errant vehicle traveling at 40 mph or above and the impact during such an incident may present additional hazards to pedestrians in the vicinity of the impact. The use of bollards along a roadside requires careful analysis and precise engineering judgment that includes the expected speed and general use of the roadway.

Figure 20. Bollards in Differing Contexts

Bollards Used on Low Speed Facilities

Bollards Protecting a Roadside Asset

6.3 Close the Stop

In some cases, safety improvements or relocation of transit stops may not be feasible due to right-of-way or other site constraints. For example, stations may abut existing buildings or other barriers that prevent relocation of the stop. In these instances it may be desirable to close the transit stop. Factors to consider in the decision close a stop are the distance and access to other nearby transit stops and level of utilization.

The impacts of transit stop closures are multifaceted and the measurements rely on ridership and operational contexts. In general, removing an existing transit stop reduces the average travel time on the section of the route where the removed stop was located. However, the operational benefits of stop closures must be compared to the impacts of passengers that use the stop. The general framework for this decision considers the average number of passengers per bus trip that utilize the stop to be removed against the average number of passengers onboard the transit vehicle per trip that pass the stop to be removed. Cumulative benefits are measured by the travel time savings multiplied by the number of passengers experiencing the savings. Cumulative costs are measured by the additional time incurred by passengers that must walk to a different stop multiplied by the number of passengers that must walk to a new stop if the existing stop is closed. In this context, if the benefits (time savings) outweigh the costs (time additions) then the existing stop should be closed.

6.4 Regulate New Stops

The development of new transit stops provides an opportunity to increase the safety and comfort of transit customers. Development codes and development agreements can be used to integrate safe and convenient access to transit into the site design process. The placement and design of bus stops, encompassing the orientation of stops to new developments, pedestrian access, relays on coordination between RTC, local government entities, and developers.

Consideration of transit stop location, pedestrian access, and design should be included in the design and implementation of development regulations. Form-based codes are one approach to promote transit supportive development and convenient pedestrian access to transit stops. Traditional zoning separates land uses (e.g., residential uses and building types separated from commercial, retail, and employment centers). Implicit with transit supportive development is a mixed use development pattern that combines complementary land uses with good design to create pedestrian friendly neighborhoods. Safe, direct, and convenient access to transit stops is a key component of transit supportive land use.

Form-based code elements related to transit stops include the following:

- High density mixed use development patterns that promote transit use

- Buildings that are oriented to the public street and entrances accessible from the sidewalk
- Transit stops located within a short walking distance of activity centers with direct sidewalk connections to building entrances
- Bus stops that conform to best safety practices

6.5 Public Outreach

The RTC will engage in a proactive public outreach program to raise transit passenger and motorist awareness of potential safety risks at transit shelters and surrounding areas. The goal of a public safety awareness campaign is to encourage transit customers to use safe pedestrian practices, such as crossing roadways at appropriate locations and visually scanning oncoming traffic for erratic driving. Messages can also be targeted to motorists to encourage awareness of the presence of pedestrians, particularly at transit stops, and to discourage illegal practices such as DUI. Elements of the public outreach effort could include announcements on transit vehicles, messages or signs posted at transit stops, billboards, and radio or other media announcements.

7. Conclusion

Several severe traffic accidents have occurred recently at Las Vegas transit shelters. Transit shelters in the Las Vegas area are involved in collisions with errant vehicles that leave the roadway two times per month and a major injury/fatality occurs on average every five months. While these accidents occur at other properties, the accident rates in Las Vegas are higher than at any of the transit agencies contacted in the industry survey. One major limiting factor of the industry survey was that none of the contacted agencies tracked these types of accidents (only transit shelter operations and maintenance contractors recorded these types of accidents). From antecdotal data, one conclusion of the survey is that these incidents are not tracked because the accident rates in other cities are relativly low when compared to Las Vegas. Enhanced data tracking capabilities are recommended as a conclusion to this study.

Existing transit stop conditions can affect the safety of a transit stop related to roadside encroachments. Items such as shelter location, roadway and traffic caharacteristics can influence the relative safety of a particular site. However, each site is belived to be unique and should be individually considered in relation to the surrounding environment. A comprehensive review of site characteristics at existing shelters is recommended as a conclusion of this study.

Accident histories and realtime analysis of accidents are not collected in a central location at this time. As a best practice, the RTC should partner with law enforcement and the transit shelter operations and maintenance contracotr to build and update a crash database of incidents at Las Vegas transit stops. Data items in the database should inculde, but are not limited to, time of day, estimated speed, angle of impact, curb height, weather conditions and damage severity.

Each transit corridor and each individual transit shelter has unique design issues, including setbacks, curb heights, traffic conditions, or other constraints that affect the general risk level of each stop. The RTC should develop a strategy for evaluating the estimated risk relating to roadside encroachments at individual stops and prioritize existing transit stops for targeted improvement. By developing a method for identifying transit stops where pedestrians and transit customers face the greatest risk, RTC will be equipped to target improvements in the areas of greatest need.

Chapter 6 outlines a general toolbox of alternative safety enhancement strategies and designs for existing transit stops. The RTC should improve on the different strategies and encourage the use of the elements in the toolbox to guide the thinking of roadway designers.

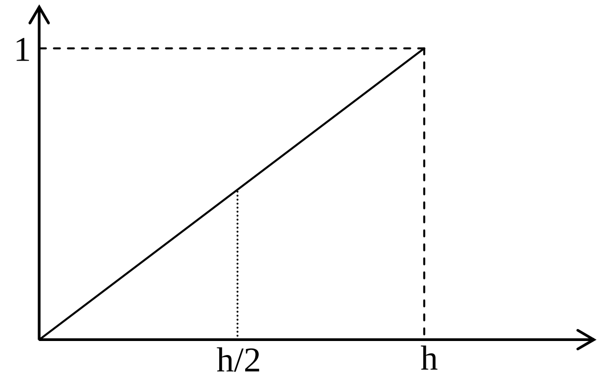
Specific recommendations are outlined in Table 7.

Table 7. Specific Recommendations

Recommendation	Personnel/Groups	Use
Transit Shelter Safety Database	RTC Bus Stop Facilities Law Enforcement Outdoor Promotions Inc.	Track transit shelter accidents and record relevant parameters of the accident for use in the prevention of these accidents
Comprehensive Review of Existing Site Level Characteristics	RTC Bus Stop Facilities	The review of existing site level characteristics is the primary input to the risk analysis and improvement prioritization method
Transit Stop Safety Toolbox	RTC Engineering Staff Local Engineering Consultancy Entity Engineering/Planning Staff	Affect the safety of transit stops – related to risk from roadside encroachments – by the consideration of this risk at the engineering and planning level

Appendix A—Average Wait-Time

Low Headway—Constant Passenger Arrival Rate between Transit Vehicles

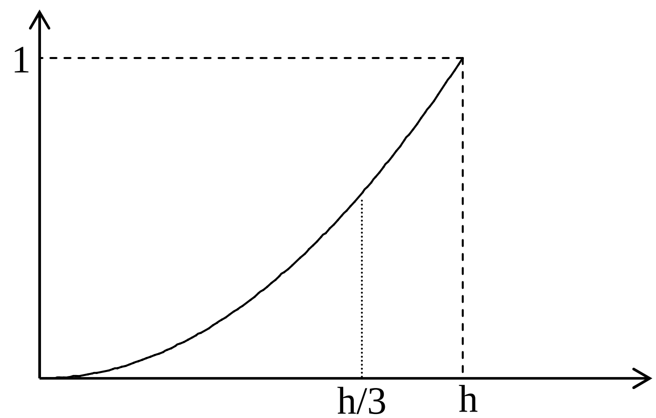


$$CDF(X) = \frac{X}{h}$$

$$f(x) = \frac{1}{h}$$

$$E[x] = \int_0^h xf(x)dx = \frac{1}{h}\int_0^h xdx = \left.\frac{x^2}{2h}\right|_{x=0}^{x=h} = \frac{h}{2} \Rightarrow \hat{w} = h - \frac{h}{2} = \frac{h}{2}$$

Medium Headway—Quadratic Passenger Arrival Rate between Transit Vehicles

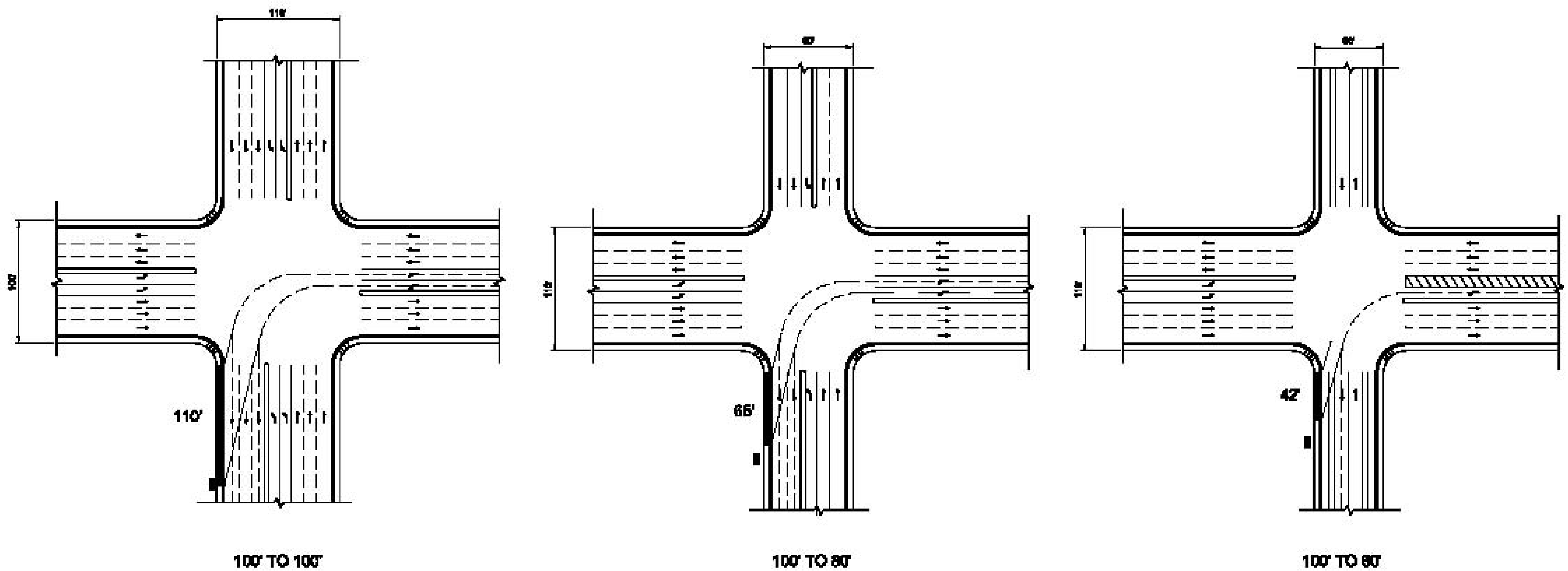


$$CDF(X) = \left(\frac{X}{h}\right)^2$$

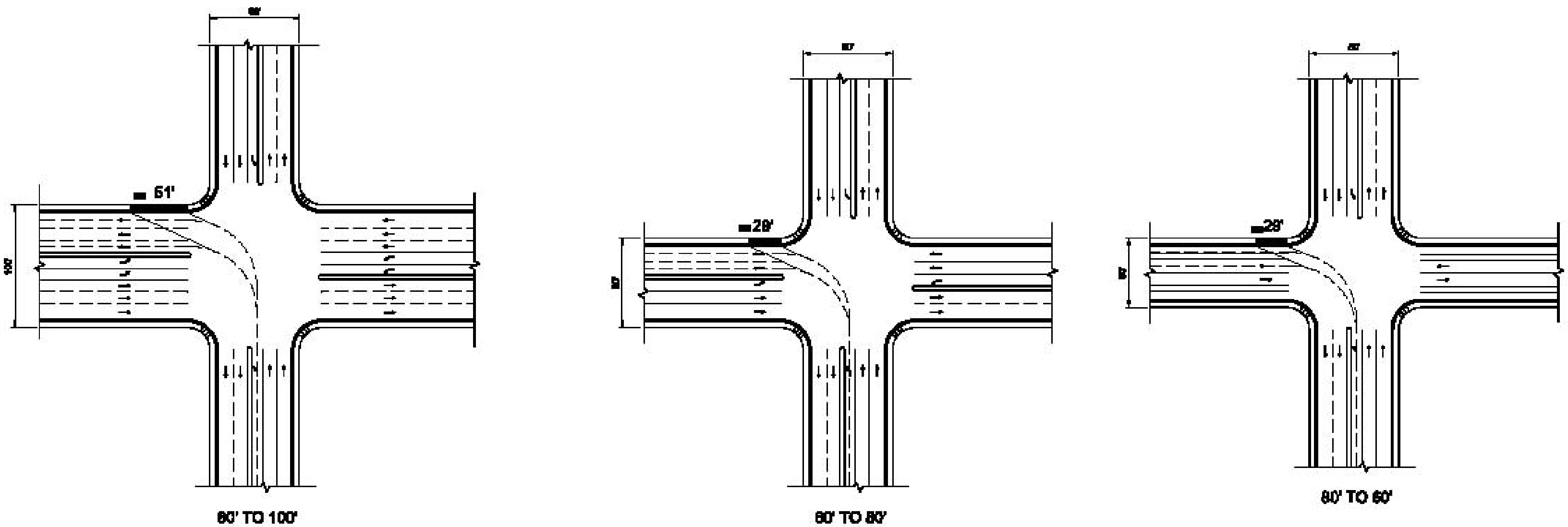
$$f(x) = \frac{2x}{h^2}$$

$$E[x] = \int_0^h xf(x)dx = \frac{2}{h^2}\int_0^h x^2 dx = \left.\frac{2x^3}{3h^2}\right|_{x=0}^{x=h} = \frac{2h}{3} \Rightarrow \hat{w} = h - \frac{2h}{3} = \frac{h}{3}$$

Appendix B—Left-Turn Cone

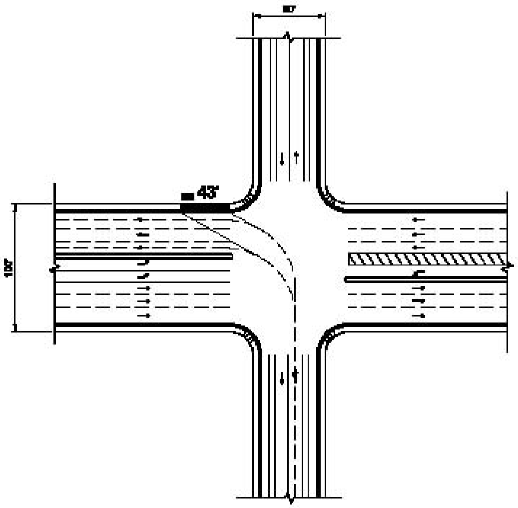


PROHIBITION ZONE BASED ON LEFT TURN APPROACHES FOR
100' RIGHT OF WAY

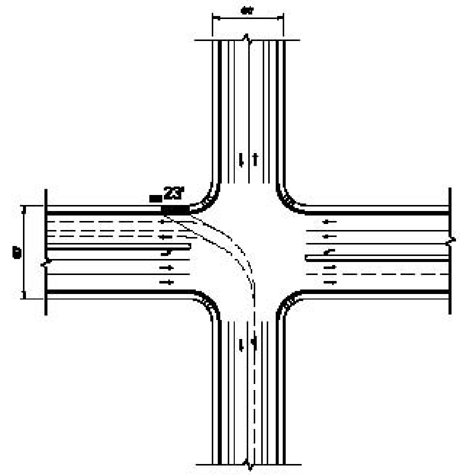


PROHIBITION ZONE BASED ON LEFT TURN APPROACHES FOR

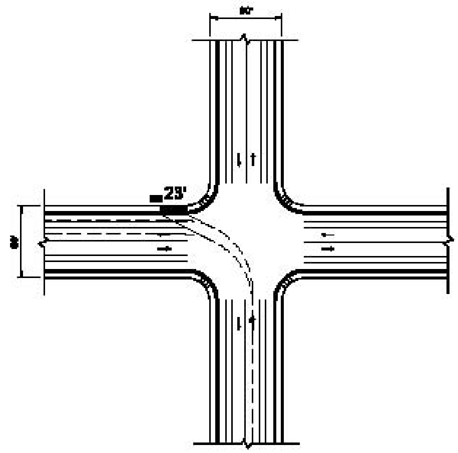
80' RIGHT OF WAY



60' TO 100'



60' TO 80'



60' TO 60'

PROHIBITION ZONE BASED ON LEFT TURN APPROACHES FOR 60' RIGHT OF WAY

Appendix B

Transit Stop Safety Study Update (2013)

TRANSIT STOP SAFETY STUDY UPDATE

January 2013

Prepared by:

PARSONS BRINCKERHOFF

On Behalf of:

RTC

Regional Transportation Commission of Southern Nevada

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF EXHIBITS

LIST OF TABLES

EXECUTIVE SUMMARY

In the fall of 2008, one person was killed and another seriously injured when a vehicle lost control and crashed into a transit shelter on Boulder Highway near Flamingo Road. The Regional Transportation Commission of Southern Nevada (RTC) commissioned an independent safety study, and in 2009, Parsons Brinckerhoff submitted the original *Transit Shelter Safety Study* to the RTC. The original study developed a ranking methodology and a toolbox of solutions that could be implemented depending on site specific conditions.

Since that time, the RTC has been working hard to implement suggested safety measures at transit stops Valley wide. Since 2008, the RTC has spent approximately 15 million dollars per year implementing new transit stop improvements that incorporate the recommendations of the original study, such as placing pads and shelters behind the sidewalk, and relocating shelters where possible. Each year, a new list of approximately 150 stop locations are prioritized based on available right-of-way, stop ridership, roadway traffic volumes, and cost of construction.

Sadly, on Thursday, September 13, 2012, four people were killed and eight were injured after a speeding car impacted a RTC transit stop. As with nearly all incidents where transit shelters are involved and where a police report was filed, vehicle speed and driver impairment are listed as factors for these crashes.

Since 2007, there have been 112 crashes at transit shelters within the Las Vegas Valley. Due to the large number of crashes at transit shelters, and the recent fatalities on September 13, the RTC has asked Parsons Brinckerhoff to conduct a *Transit Stop Safety Study Update*. This update includes safety measures presented in the original *Transit Shelter Safety Study*, along with additional safety mitigation measures and strategies at transit stops within the Valley.

Through crash analysis it was determined that 94 of the 112 vehicle to transit shelter accidents (84%) occurred when the transit shelter was located on the sidewalk. The percentage of transit shelter accidents correlates to findings in the *2011 AASHTO Roadside Design Guide*[2] that 80 percent of all roadside crashes were with an object that was less than four feet from the roadway. Therefore, moving transit shelters further from the roadway should greatly reduce the chances of a vehicle running off of the roadway and crashing into a transit shelter.

After analyzing numerous options, Parsons Brinckerhoff has developed recommendations for the RTC to consider. These options are ranked in categories of their importance and are described in the following paragraphs.

Primary Strategies – The "Primary Strategies" category includes options that should be thoroughly considered to increase the safety of transit riders and pedestrians at and around transit stops. It is noted that the RTC is already implementing most of these measures as part of the adopted *Uniform Standards* and annual construction projects. The "Primary Strategies" options include:

- Move shelters behind the sidewalk
- Implement a pedestrian buffer

- Implement a bus turnout
- Conduct a Public Service Announcement Campaign

Primary Strategies But Needs Collaboration – The "Primary Strategies But Needs Collaboration" category includes options that should be thoroughly considered, however the RTC would need to collaborate with other agencies in order to follow through with the improvements. The "Primary Strategies But Needs Collaboration" options include:

- Implement Complete Streets design concepts including evaluating the reduction of speed limits on arterials with transit routes, where appropriate
- Implement random sobriety checkpoints on all arterials with transit routes

Secondary Strategies **–** The "Secondary Strategies" category includes options that will improve the safety at transit stops, however not as much as the previous two categories. The "Secondary Strategies" options include:

- Implement concrete planters with trees planted inside
- Relocate shelters adjacent to block walls
- Add solar powered LED shelter lighting
- Raise curbs at transit stops to allow for level boarding

Secondary Strategies If Other Measures Cannot Be Implemented **–** The "Secondary Strategies If Other Measures Cannot Be Implemented" category contains options that need to be considered if previous options mentioned are not feasible. The "Secondary Strategies If Other Measures Cannot Be Implemented" options include:

- Implement a low profile barrier
- Implement high containment curbs
- Add "Bus Stop Ahead" pavement markings
- Add shoulder rumble strips
- Brightly paint the curb next to the transit stops
- Brightly paint the transit shelters
- Install a reflective coating on the outside of the transit shelters
- Install rear facing transit shelters

Last Resort **–** The "Last Resort" category consists of options that could improve the safety of transit riders at transit stops, however they could also introduce additional safety hazards that do not currently exist. These options should be considered only if all other options are not feasible. The "Last Resort" options include:

- Implement a bollard system
- Implement reinforced concrete trash receptacles
- Implement a handrail system
- Move the transit shelter to a side street

This is a work in progress and it is not a one-size-fits-all solution. Addressing this concern is a communitywide issue and requires a significant investment from our community, local entities, engineers, and law enforcement through education and awareness.

The RTC has already incorporated most of the measures that are recognized as primary safety enhancement strategies and best practices. The findings and recommendations of this report will provide the RTC additional options to continue to improve transit stop safety and provide a positive experience for our transit community. These efforts, along with other programs for Complete Streets and safety awareness are what make the RTC a leader in the nation.

1.0 INTRODUCTION

In the fall of 2008, one person was killed and another seriously injured when a vehicle lost control and crashed into a transit shelter on Boulder Highway near Flamingo Road. The Regional Transportation Commission of Southern Nevada (RTC) commissioned an independent safety study, and in 2009, Parsons Brinckerhoff submitted the original *Transit Shelter Safety Study* to the RTC. The original study developed a ranking methodology and a toolbox of solutions that could be implemented depending on site specific conditions. It identified the nationally recognized industry practice of moving the shelter at least 5-feet behind the curb as the most effective safety measure.

Since that time, the RTC has been working hard to implement suggested safety measures at transit stops Valley wide. Since 2008, the RTC has spent approximately 15 million dollars per year implementing new transit stop improvements that incorporate the recommendations of the original study, such as placing pads and shelters behind the sidewalk, and relocating shelters where possible. Each year, a new list of approximately 150 stop locations are prioritized based on available right-of-way, stop ridership, roadway traffic volumes, and cost of construction. This work continues as a priority fund expenditure.

The RTC transit system serves over 60 Million riders every year. There are 3,156 stop locations in the Las Vegas Valley, and 1,780 of those currently have a transit shelter and/or bench. Since 2008, the RTC has relocated or placed 515 new pads and shelters behind the sidewalk. Additionally, 478 stop locations are located at transit turnouts and nearly 80 percent of all transit stops are located on the far-side of an intersection. New legislation in 2009 (SB173) required ten new bus turnouts to be completed by the end of 2012, and another bill in 2011 (SB137) required a total of 15 new bus turnouts to be completed by the end of 2014. These improvements to the transit system demonstrate a focused commitment to incorporate the findings of the original *Transit Shelter Safety Study* as fully and quickly as possible.

Sadly, on Thursday, September 13, 2012, four people were killed and eight were injured after a speeding car impacted a RTC transit stop. The incident occurred just before 6:30 AM at the intersection of Decatur Boulevard and Spring Mountain Road.[1] The transit shelter at this location was located on the sidewalk, whereas the shelter in the 2008 incident was located behind the sidewalk. As with nearly all incidents where transit shelters are involved and where a police report was filed, vehicle speed and driver impairment are listed as factors for these crashes.

Since 2007, there have been 112 crashes at transit shelters within the Las Vegas Valley. Due to the large number of crashes at transit shelters, and the recent fatalities on September 13, the RTC has asked Parsons Brinckerhoff to conduct a *Transit Stop Safety Study Update.* This update includes safety measures presented in the original *Transit Shelter Safety Study*, along with additional safety mitigation measures and strategies at transit stops within the Valley.

1.1 Literature And Industry Practices Review Update

The original *Transit Shelter Safety Study* conducted a literature review of industry practices and recommendations for transit stop and transit rider safety. Several national standards have been updated since that time, and a new effort to identify changes in those recommended practices was completed. The most significant change was added to the *2011 AASHTO Roadside Design Guide*[2], which increased the recommended setback for fixed objects to at least 4-feet behind the face of curb. Changes to this and other AASHTO standards reflect longer pedestrian walk times, emphasis on pedestrian and transit rider accessibility issues, and a growing "Complete Streets" initiative nationwide.

As part of the original *Transit Shelter Safety Study*, twenty three peer agencies were identified and contacted. Of the sixteen responses received, it became clear that the Las Vegas Valley experiences a higher rate of transit shelter crashes and transit rider fatalities than other agencies with larger transit systems. For example, the Tri-County Metropolitan Transportation District of Oregon (TriMet) reported an average of ten transit shelters impacted by an errant vehicle per year, compared to an average of almost 19 per year in the Las Vegas Valley since 2007. Additionally, the Los Angeles County Metropolitan Transportation Authority (MTA) reported an average of 1.4 shelter crashes per month since 1979, whereas the Las Vegas average is over 1.5 shelter crashes per month since 2007. All other agencies contacted reported significantly fewer incidents of vehicles impacting a transit shelter. A summary of transit agency's incidents and actions are tabulated later in the document.

A new outreach to eighteen peer agencies was conducted to identify new developments and industry practices. The new outreach confirmed the unique nature of the Las Vegas Valley environment, as well as a growing effort to incorporate Complete Streets and traffic calming elements as tools for enhancing the transit rider experience and safety. All agencies are focused on the recognized primary strategies of increased offset and pedestrian buffers. Additionally, those who have considered positive protection strategies do so in limited applications, which are discussed later in the document. Table 1 identifies the agencies contacted and the information obtained regarding their traffic calming measures and safety barriers.

TABLE 1: TRANSIT AGENCY TRAFFIC CALMING MEASURES AND SAFETY BARRIERS		
Agency	**Safety Barriers**	**Traffic Calming Measures**
Arlington County Transit - Arlington VA	Cannot locate any information regarding transit stop design guidelines and safety features such as bollards.	Does not identify any traffic calming measures nor mentioned any information regarding reducing speeds on roadways to improve safety at transit stops.
BC Transit - Victoria, BC, Canada	Does not provide any information on safety bollards design.	Identified traffic calming measures: reduce vehicle speeds and volumes and improve safety for non-motorized users (pedestrians and cyclists)
Chicago Transit Authority - Chicago, IL	Cannot locate any information regarding transit stop design guidelines and safety features such as bollards.	Does not identify any traffic calming measures nor mentioned any information regarding reducing speeds on roadways to improve safety at transit stops.
City and County of Honolulu - Honolulu, HI (Wayne Yoshioka, Director for the City and County of Honolulu)	No information on bollards.	• While location of the bus stop along a street could be a factor in bus stop safety, the issue of far side versus near side is primarily an operational efficiency issue. We have consciously been eliminating mid-block stops where feasible because they generally lead to pedestrian crossings at unsignalized locations. • Location of the bus waiting area is a bus stop safety issue, but if your problem is vehicles leaving the travelled way, what you do in this regard pales in relation to the concern you should have regarding why vehicles are leaving the travelled way in the first place. • Bus stop turnouts are usually a traffic flow efficiency measure: good for traffic flow on the street but decreasing efficiency for the transit operator (under heavy traffic conditions, drivers have difficulty re-entering traffic). Of course, on high-speed roadways, bus turn outs are a good idea to reduce the probability of vehicle-bus accidents.
City of Toronto (Toronto Transit Commission) - Toronto, CA, Canada (Jim Smith, Supervisor, Data Analysis)	No information on bollards.	1. 129 bus shelter incidents. 2. 125 incidents could be classified as "light contact" between the bus and the shelter. These are caused by the operator misjudging clearance as they approach the stop. Typically the only damage is to the bus mirror. 3. 4 incidents were classified as "collision" between the bus and the shelter. Of these, 3 were documented as having excessive speed as a factor. In the 4th collision, a car ran a red light, hit the bus and the bus in turn hit the shelter. 4. In all the 129 incidents, 1 resulted in injury - this injury was sustained during one of the 4 collisions.
Los Angeles County Metropolitan Area Transit Authority - Los Angeles, CA	Have installed bollards at transit station platforms in conjunction with accidents involving errant vehicles.	Does not identify any traffic calming measures nor mentioned any information regarding reducing speeds on roadways to improve safety at transit stops.
Massachusetts Bay Transportation Authority - Boston, MA	Cannot locate any information regarding transit stop design guidelines and safety features such as bollards.	Does not identify any traffic calming measures nor mentioned any information regarding reducing speeds on roadways to improve safety at transit stops.
Metro Transit - Seattle, WA	Cannot locate any information regarding transit stop design guidelines and safety features such as bollards.	Does not identify any traffic calming measures nor mentioned any information regarding reducing speeds on roadways to improve safety at transit stops.
New Jersey Transit - Newark, NJ	Cannot locate any information regarding transit stop design guidelines and safety features such as bollards.	A Bus Stop Safety toolbox acknowledged that traffic calming measures can be used to reduce speed and improve pedestrian access to bus stops. Bicycle lanes buffer pedestrians from vehicles and lower speeds by narrowing the road. It also mentioned that traffic speed is more critical to pedestrian safety because at higher speeds, motorists are less likely to see a pedestrian or stop in time.
New York City Department of Transportation - New York, NY	Does not provide any information on safety bollards design.	Several traffic calming measures were identified to enhance pedestrian safety. Lane narrowing benefits include the reduced opportunities for speeding and aggressive driving, reducing the severity and frequency of crashes. Curb extensions can enhance pedestrian safety by reducing crossing distances and creates space that may be used for bus stops, etc. The traffic calming measures did not specify improvement of pedestrian safety at bus stops.

TABLE 1: TRANSIT AGENCY TRAFFIC CALMING MEASURES AND SAFETY BARRIERS		
OmniTrans - San Bernardino, CA	Vehicle barriers were identified in the DRAFT Transit Design Guidelines to provide pedestrian safety from both errant and terrorist vehicle attacks. Structural barriers were identified as natural and fabricated barriers such as bollards, guardrails, fences, and walls.	Traffic calming techniques such as curb extensions, chokers, speed bumps, and raised sidewalks are suggested to be used to channel traffic and minimize impacts on the community. Does not identify such traffic calmers to improve safety at bus stops though it slows the speed of traffic.
Orange County Transportation Authority - Orange, CA	Cannot locate any information regarding safety features such as bollards.	Does not identify any traffic calming measures nor mentioned any information regarding reducing speeds on roadways to improve safety at transit stops.
Pace Suburban Bus - Arlington Heights, VA	Does not provide any information on design guidelines for transit stops, amenities, and safety features such as bollards.	Does not identify any traffic calming measures nor mentioned any information regarding reducing speeds on roadways to improve safety at transit stops.
San Francisco Municipal Transportation Agency - San Francisco, CA	Cannot locate any information regarding transit stop design guidelines and safety features such as bollards.	SFMTA has a traffic calming program through their Livable Streets initiative. The program addresses issues such as speeding, reckless driving, pedestrian safety, to name a few. It does not specify any information regarding reduction of speeds within a bus stop that will aid in enhancing pedestrian safety.
Southeastern Pennsylvania Transportation Authority - Philadelphia, PA	Cannot locate any information regarding transit stop design guidelines and safety features such as bollards.	Does not identify any traffic calming measures nor mentioned any information regarding reducing speeds on roadways to improve safety at transit stops.
Tri-County Metropolitan Transportation District - Portland, OR	Provides information on safety bollard design.	In "Pedestrian Network Analysis Report", roadway narrowing is identified as a vehicle speed reducer and increases safety for all roadway users including pedestrians. Curb extensions and crossing islands are different traffic calming measures listed to reduce vehicular speeds in roadways. The report indicated that high speeds contribute to higher chances of pedestrian fatality if struck by the moving vehicle. It also suggests ways of assessing areas for pedestrian and transit stop accessibility.
Utah Transit Authority - Salt Lake City, UT (Dave Goeres, UTA Chief Safety Officer)	No information on bollards in Salt Lake City, but he believes the RTD in Denver uses bollards in front of sawtooth cutouts at bus stops.	Most bus stops are located behind the sidewalk, which is behind a 6' pedestrian buffer. Therefore stops are located 10' - 15' from the roadway. Flagpoles are places to shield bus shelters. Railings around shelters that are closer to the roadway. Reflector sticks placed at bus shelters to alert bus drivers that a passenger is waiting. Cannot have top bar on a fence within 18" of curb. Bicyclists loading their bikes on the front of buses have stepped out in front of the bus before it has stopped.
Valley Metro - Phoenix, AZ	Identified bollards as a safety feature in bus stop design with shelter, but does not provide any design for bollards.	Does not identify any traffic calming measures nor mentioned any information regarding reducing speeds on roadways to improve safety at transit stops.

Source: Parsons Brinckerhoff, January 2013

2.0 CRASH COMPARISON

A crash analysis was performed within Clark County to compare the difference between crashes involving vehicle to vehicle, vehicle to pedestrian, vehicle to bicycle, and vehicle to transit shelter. Crash data (January 2007 through July 2012) for all reported crashes was supplied by the Nevada Department of Transportation (NDOT). Whereas, crash data (January 2007 through October 2012) for vehicle to transit shelter crashes was supplied by the RTC. A breakdown for each year and the total combined crashes can be viewed in Table 2.

Table 2: Crash Type Comparison						
Crash Type	**Total Crashes**	**Percent of Total Crashes**	**Total Injuries**	**Percent of Total Injuries**	**Total Fatalities**	**Percent of Total Fatalities**
2007						
All	49,939	100.00%	25,619	100.00%	244	100.00%
Pedestrian	712	1.43%	926	3.61%	38	15.57%
Bicycle	320	0.64%	341	1.33%	6	2.46%
Transit Shelter	24	0.05%	0	0.00%	0	0.00%
2008						
All	45,658	100.00%	23,594	100.00%	200	100.00%
Pedestrian	733	1.61%	1,062	4.50%	43	21.50%
Bicycle	243	0.53%	250	1.06%	6	3.00%
Transit Shelter	30	0.07%	2	0.01%	1	0.50%
2009						
All	41,450	100.00%	22,595	100.00%	144	100.00%
Pedestrian	612	1.48%	664	2.94%	25	17.36%
Bicycle	421	1.02%	432	1.91%	5	3.47%
Transit Shelter	17	0.04%	0	0.00%	0	0.00%
2010						
All	40,756	100.00%	23,076	100.00%	148	100.00%
Pedestrian	557	1.37%	571	2.47%	28	18.92%
Bicycle	380	0.93%	399	1.73%	3	2.03%
Transit Shelter	8	0.02%	3	0.01%	0	0.00%
2011						
All	34,523	100.00%	20,852	100.00%	50	100.00%
Pedestrian	1,057	3.06%	1,023	4.91%	31	62.00%
Bicycle	371	1.07%	347	1.66%	1	2.00%
Transit Shelter	17	0.05%	0	0.00%	0	0.00%
2012* (All, Pedestrian, and Bicycle Crashes Are From January 2012 - July 2012. Transit Shelter Crashes Are From January 2012 - October 2012)						
All	15,415	100.00%	9,205	100.00%	24	100.00%
Pedestrian	360	2.34%	332	3.61%	7	29.17%
Bicycle	165	1.07%	154	1.67%	1	4.17%
Transit Shelter	16	0.10%	13	0.14%	4	16.67%
2007 - 2012*						
All	227,741	100.00%	124,941	100.00%	810	100.00%
Pedestrian	4,031	1.77%	4,578	3.66%	172	21.23%
Bicycle	1,900	0.83%	1,923	1.54%	22	2.72%
Transit Shelter	112	0.05%	18	0.01%	5	0.62%
Source: NDOT Traffic and Safety Division, November 2012; RTC, November 2012; Parsons Brinckerhoff, November 2012						

From January 2007 through July 2012, there were a total of 227,741 crashes resulting in 124,941 injuries and 810 fatalities. The most common vehicle involved in the crashes was a 4-door sedan. Out of the total number of crashes, vehicle to pedestrian crashes only accounted for 1.77% of the total crashes (4,031 vehicle to pedestrian crashes). However, they accounted for 3.66% of the total injuries (4,578 vehicle to pedestrian injuries) and 21.23% of the total fatalities (172 vehicle to pedestrian fatalities). The calculations show that it is much more likely for a fatality to occur in a vehicle to pedestrian crash than a vehicle to vehicle crash. Additionally, it is highly likely that an injury will occur when a vehicle to pedestrian crash takes place. Similar to vehicle to pedestrian crashes, vehicle to bicycle crashes also have a high likelihood of resulting in an injury. However, the fatality rate isn't as high as it is for pedestrians.

Vehicle to transit shelter crashes have lower rates of injuries and fatalities than vehicle to pedestrian crashes, because most of the shelters were hit at night when no one was occupying the transit shelter. However, it is still alarming that 112 vehicle to transit shelter crashes have occurred since 2007; resulting in 18 injuries and 5 fatalities. The question that keeps getting asked is why? Why have there been almost 20 crashes a year at transit shelters? What do these crashes have in common?

After a field review and evaluating the crash data supplied by the RTC, the most common type of vehicle to transit shelter crashes occur with transit shelters located on the sidewalk on 45 mph major arterials. 94 of the 112 vehicle to transit shelter crashes (84%) occurred when the transit shelter was located on the sidewalk. A list of the each vehicle to transit shelter crash and a corresponding map can be viewed in Appendix.

The percentage of crashes where the driver was under the influence is unknown due to the large number of shelters that were hit at night and the driver left the scene of the accident. However, according to the RTC, there have been 12 fatalities in the last 10 years at transit stops caused by vehicles leaving the roadway. In every instance the driver was impaired, distracted, or was not following the law. Therefore, this factor needs to be considered when focusing on protecting transit stops, transit riders, and pedestrians.

The original *Transit Shelter Safety Study* cited other agencies where vehicle to transit shelter crashes occurred and the agency's action to the crashes. The summary of the findings can be viewed in Table 3.

TABLE 3: TRANSIT AGENCY INCIDENTS AND ACTION		
Agency	**Incidents**	**Action**
Maryland Transit Administration	Incident of a passenger struck by an encroaching automobile while waiting at a bus stop.	No actions were taken to reduce the likelihood of future incidents.
San Francisco Metropolitan Transit Authority (SFMTA)	Variety of problems with pedestrian-vehicle incidents. However, passengers struck by errant vehicles while at a transit stop are uncommon and not currently addressed by SFMTA.	At specific stops, those which utilize loading islands, handrails are used to keep passengers on the loading island.
Oahu Transit Services (TheBus)	Does not directly address transit stop safety related to roadside encroachments by errant automobiles.	The agency attempts to set bus stops back from the curb to account for ADA guidance relating to the distance between the bench and the curb. This moves waiting passengers away from the flow of traffic, creating separation between passengers and the adjacent traffic stream.
Southwest Regional Transit Authority (Ohio Metro) in Cincinnati, Ohio	No information on and does not directly address incidents of automobiles encroaching into the roadside and striking passengers waiting at bus stops.	In reaction to an accident at a light rail station, design modifications were made at two major transit centers. Bollards designed to arrest a bus traveling under 5 mph were installed at the end of sawtooth bays in these transit centers.
Washington Metropolitan Area Transit Authority (WMATA) in Washington, DC	Does not directly address transit stop safety related to errant automobiles encroaching into the roadside and striking passengers.	Currently developing new bus stop guidelines in order to provide consistency to bus stop design. The guidelines will recommend new bus stop setbacks of at least 5 feet from the face of curb.
Pace Suburban Bus in the suburbs of Chicago, IL	Has not had an incident like this in recent memory and does not keep data related to roadside encroachments resulting in automobile-passenger accidents at transit stops.	Planning staff have considered (but not acted on) various items, such as rumble strips, corner guard rail, illumination, and passenger education programs. Rumble strips installed around the dedicated space for a bus stop might alert drivers that they are leaving the roadway if a transit stop is near. This noise could also alert waiting passengers that the bus (or an errant vehicle) was approaching. Corner guardrails installed when a bus stop is located very close to a corner can be used to keep automobiles from encroaching on the roadside during the turn. In some instances in Chicago, bus shelters are oriented with the solid side of the shelter facing the roadway. This is done to protect passengers from street-splash during wet weather conditions. Increasing illumination at bus stops and initiating education programs reminding passengers to remain alert and stay back from the curb could be effective in promoting safety, according to Pace staff.
Arlington County Transit	Among the 11,000 bus stops in Arlington County, there have only been two incidents of an encroaching automobile striking a bus stop in recent years. Both transit stops were unoccupied when the incidents occurred. Staff recalls that one incident was due to drunk driving while the other occurred when a driver swerved to avoid another vehicle. However, the agency does not keep specific data related to these types of incidents.	Arlington County Transit published bus stop guidelines that include a recommendation for the installation of a crash barrier on roads which have a speed limit of 45 mph or over. Currently no crash barriers have been installed at Arlington County transit shelters for this express purpose.

TABLE 3: TRANSIT AGENCY INCIDENTS AND ACTION		
Tri-County Metropolitan Transportation District of Oregon (TriMet)	Replaces or repairs approximately 10 shelters per year because of accidents involving errant vehicle roadside encroachment. According to staff, most of these incidents occur late at night when buses are not in service. No occupied shelters have been hit in recent memory. One particular shelter, located on an island at the intersection of three streets (52nd, Powell, and Foster), has been hit three times by errant vehicles.	TriMet does not directly address transit stop safety related to roadside encroachments.
Chicago Transit Authority (CTA)	Has not had recurring problems with transit shelters stuck by encroaching automobiles.	In general, CTA routes are not located on high-speed arterials but operate in urban settings with relatively low travel speed and ample on-street parking. The presence of on-street parking plays a vital role in curbing roadside encroachments (the parked cars act as a barrier). CTA is conducting a study of pedestrian safety near bus stops, but this work focuses on the crossing behavior of passengers and pedestrian interactions inside the roadway, not the roadside.
Shelter Express in New York City (one of the transit stop operations and maintenance contractors for the New York Metropolitan Transportation Authority (MTA)	Transit stop accident rates in New York are relatively low and average two accidents per year.	The low travel speeds of congested Manhattan may serve to reduce the accident rates. On-street parking also provides positive separation between the roadway and the roadside.
Los Angeles County Metropolitan Transportation Authority	Has accident rates for transit shelters similar to those of the Las Vegas area (two per month) in recent years. However, since September 1979, the Los Angeles MTA has seen 244 shelter accidents, or an average of 1.4 shelter accidents per month. The majority of shelter accidents happen overnight when service is not running and no staff members could remember any fatalities.	The MTA has discussed bollards as a solution to shelter accidents but concluded bollards to be unsafe, cost ineffective, and jurisdictionally infeasible. Shelter Clean-LA, the MTA's operations and maintenance contractor, maintains transit shelters throughout the county.
Valley Metro in Phoenix	Accident rates in the Phoenix area are low (two to three per year). An encroaching automobile hit an occupied shelter in October 2008. Two transit passengers were hospitalized, and the incident was recorded on surveillance video.	Shelter Clean-Phoenix maintains transit shelters for Valley Metro.
New Jersey Transit (NJTransit)	Limited information.	Installed bollards at 24 transit shelters. The infrequent installations are primarily due to safety concerns. In general, the bollards installed by NJTransit are located at malls, parking lots, and transit stations or anywhere travel speeds are anticipated to be low.
Source: *Transit Shelter Safety Study*		

The following pages focus on presenting mitigation measures that will improve rider safety. It is followed by Parsons Brinkerhoff's recommendations for the RTC.

3.0 MITIGATION MEASURES

3.1 Reduce Speed Limit

The majority of the transit routes within the Las VegasValley exist on major arterials. These major arterials typically have 6-lanes (3-lanes in each direction) with a 45 mph speed limit. However, drivers typically travel faster than the posted 45 mph speed limit. According to America Walks[3]:

> If a pedestrian is hit by a vehicle that is traveling 20 mph, the pedestrian survival rate is 95 percent. This drops to 60 percent at 30 mph, and just 20 percent at 40 mph.

The relationship between vehicle speed and accident outcome severity is well established. An OECD/ECMT report[4] states "a 5% decrease in average speed leads to approximately a 10% decrease in injury accidents and a 20% decrease in fatal accidents." A couple of examples where speed reduction decreased the number fatalities include:

- France – Over three years (2002 through 2005), the average speed on French roads decreased by 5 km/h (3.1 mph) and fatalities decreased by over 30%.
- Hungary – The speed limit was reduced from 60 km/h (37.3 mph) to 50 km/h (31.1 mph) and resulted in a reduction of 18.2% accident fatalities.

In order to help reduce the fatality rate of pedestrians, bicyclists, transit riders, and drivers, the speed limit could be reduced from 45 mph to 35 mph on major arterials with transit routes. However, people tend to drive at the speed limit they feel is safe. Therefore, the only way to keep everyone at the newly posted 35 mph speed limit is through Engineering, Enforcement, and Education.[5] In addition, regional consensus for this measure would be required, after demonstrating that system-wide delays and air quality standards would not be compromised. Effective ways to enforce a 35 mph speed limit include:

- Synchronizing traffic signals to turn green based off of a vehicle traveling at 35 mph. In other words, if a vehicle is stopped at a traffic signal and the signal turns green, that vehicle would have to stop at the next traffic signal if it traveled faster than an average speed of 35 mph between the consecutive traffic signals. The synchronization process could be accomplished through coordination between the local entities and the RTC's Freeway and Arterial System of Transportation (FAST) department. Signage would be crucial in alerting drivers that the signals are set for a vehicle traveling at 35 mph. An example of a sign that could be used to alert drivers is shown in Figure 1.
- Increase the police enforcement along arterials with transit routes and pull over drivers that are speeding and running red lights.

Figure 1: Signals Set For 35 MPH Sign

- Incorporate traffic calming through the implementation of Complete Streets concepts. "Traffic calming consists of engineering and other measures put in place on roads for the intention of slowing down or reducing motor-vehicle traffic. This is done in order to improve the living conditions for residents living along the road as well as to improve the safety for pedestrians and cyclists."[6] The RTC has approved a Complete Streets policy and is in the process of developing a *Complete Streets For Living Communities Design Guide* to support local entity efforts. Complete Streets are described in more detail later in this document.

A common fear that exists for motorists is that decreasing the speed limit will greatly increase their travel time. However, according to the Monash University Research Centre[7], this is often a misleading assumption. Table 4 summarizes the amount of time lost when decreasing the speed limit by 5 km/h (3.1 mph) for a trip of 10 km (3.1 mph).

TABLE 4: EXTRA TRAVEL TIME ON A JOURNEY OF 10 KM (6.2 MILES) WHEN AVERAGE SPEED IS REDUCED BY 5 KM/H (3.1 MPH)

Original Speed [km/h (mph)]	35 (21.7)	45 (28.0)	55 (34.2)	65 (40.4)	75 (46.6)	85 (52.8)
Reduced Speed [km/h (mph)]	30 (18.6)	40 (24.9)	50 (31.1)	60 (37.3)	70 (43.5)	80 (49.7)
Travel Time Difference [mins:secs]	2:51	1:40	1:05	0:46	0:34	0:26

Source: Monash University Accident Research Centre, January 2008; Parsons Brinckerhoff, January 2013

From Table 4, it can be calculated that reducing the travel time from 45 mph to 35 mph will only decrease your travel time for a 10-mile trip by approximately 3.5 minutes (roughly 20 seconds per mile), as shown in Table 5.

TABLE 5: EXTRA TRAVEL TIME ON A JOURNEY OF 10 MILES WHEN AVERAGE SPEED IS REDUCED FROM 45 MPH TO 35 MPH					
Original Speed [km/h (mph)]	65 (40.4)	70 (43.5)	75 (46.6)	75 (46.6)	**72.4 (45)**
Reduced Speed [km/h (mph)]	60 (37.3)	65 (37.3)	70 (43.5)	60 (37.3)	**56.3 (35)**
Travel Time Difference per 10 km [mins:secs]	0:46	0:40	0:34	2:00	**2:08**
Travel Time Difference per km [mins:secs]	0:04	0:04	0:03	0:12	**0:12**
Travel Time Difference per Mile [mins:secs]	0:07	0:06	0:05	0:19	**0:20**
Travel Time Difference per 10 Miles [mins:secs]	1:14	1:04	0:54	3:13	**3:27**

Source: Parsons Brinckerhoff, January 2013

Lowering the speed limits along transit routes within the Las VegasValley will help reduce the number of fatalities, while minimally affecting travel times, and help start the process of changing the culture of focusing primarily on vehicular traffic.

3.2 Sobriety Checkpoints

A large number of vehicles that left the roadway and struck a transit shelter occurred at night and were not reported to the police because the drivers left the scene of the accident. However, it is assumed that those crashes occurred because the person driving was under the influence of alcohol and/or drugs. Additionally, a large percentage of the crashes that were reported involved a driver who was under the influence of alcohol and/or drugs.

Las Vegas is unlike most cities because it is a 24-hour city where people are allowed to drink alcohol at public establishments at all times of the day. This characteristic alone could account for the higher than average vehicle to transit shelter crash rate. If sobriety checkpoints are placed on the major arterials where transit routes are located, drivers will be less likely to drink and drive on those arterials. According to the National Highway Traffic Safety Administration (NHTSA):

> The number of DUI arrests made by roving patrols is nearly three times the average number of DUI arrests made by officers at a sobriety checkpoint. However, police officers believe that roadblocks are effective, even if drunk drivers get around them, because they show the public that driving under the influence is not tolerated.[8]

Additionally, the Centers for Disease Control and Prevention (CDC) found that alcohol-related crashes were reduced by approximately 20% when sobriety checkpoints were implemented.[9] An example of a sobriety checkpoint can be viewed in Figure 2.

Implementing more sobriety checkpoints along roads that have transit routes, and continuing to use existing sobriety checkpoint locations, will help reduce the number of drivers who are under the influence of alcohol and/or drugs. In turn, fewer crashes will occur at transit stops.

Figure 2: Sobriety Checkpoint[10]

3.3 Public Service Announcement

The Clark County Regional Flood Control District does an excellent job of educating the public about the dangers of flash flooding and informing the community about the progress of flood control in Clark County.[11] Figure 3 is an example of one of their billboards, which was designed around their annual License Plate Billboard Contest.

Similarly, the RTC should educate drivers about watching out for pedestrians, bicyclists, and transit riders. A large percentage of local residents and tourists are unaware of the number of pedestrians, bicyclists, and transit shelters that are hit every year. Therefore it is necessary to get the word out about the incidents.

One method to increase awareness would be to come up with a campaign revolving around pedestrian, bicycle, and transit rider awareness. This campaign can be advertised on billboards, television commercials, radio commercials, newspapers, internet, and mailings. Additionally, RTC staff can go to local schools and educate children on the importance of watching out for pedestrians, bicyclists, and transit riders when driving and riding in a car. The goal is to educate, which will help prevent crashes from occurring.

Figure 3: Clark County Regional Flood Control District Public Service Announcement

Educating the public, particularly drivers, about the importance of watching out for pedestrians, bicyclists, and transit riders will help prevent crashes from occurring at transit stops. Local efforts through the RTC Pedestrian Safety Task Force, the UNLV Safe Communities Coalition, the NDOT Strategic Highway Safety Plan teams, Metro, and other collaborative programs have provided progressive advertising and outreach efforts to enhance pedestrian awareness. By continuing to work alongside these groups, the RTC can improve the focus on transit rider safety.

3.4 Lighting

Many transit shelters and stop locations throughout the Las Vegas Valley are not well-lit, which could be a safety concern for transit riders. According to the American Public Transportation Association[12]:

> Station lighting serves several functions. It provides illumination, assists in station location and identification, and makes station features visible during periods of darkness. It aids bus operators in locating stations and determining whether passengers are waiting to board. Station lighting provides a sense of security for riders waiting to board a vehicle. Attractive station lighting can further highlight station architectural and design elements, which enhance the rider experience and the appeal of the BRT station for the community. Lighting also communicates when a station is closed, such as by changing the color and intensity of the lighting when the station is closed.

There are some very positive improvements underway by the different local entities to improve street lighting along roadways. The City of Henderson has completed a system wide upgrade to inductive lighting and the other entities are in the process of upgrading their lighting systems to LED lighting technologies. These new technologies provide significant object visibility improvements over the current High Pressure Sodium technology in use. The light spectrum and average luminance increases will allow drivers to better identify objects and people within the roadway cross section. This is anticipated to have a significant impact on nighttime incidents.

By utilizing the amount of sunshine Las Vegas receives, along with low energy LED lighting, the transit shelters could run off of solar energy alone. The RTC has already started adding new solar-powered bus shelters throughout the Las Vegas Valley. According to the Clark County, Nevada website[13]:

> The Regional Transportation Commission of Southern Nevada (RTC) will install 150 new solar-powered bus shelters throughout the Las Vegas Valley as part of its federally funded transit amenities program. These new transit shelters will not only provide an attractive, comfortable and shaded place for riders to wait for transit, but it will also save thousands of dollars in energy costs.
>
> The new shelters feature energy-saving LED lighting and solar panels that enable the shelters to power their own illumination without being connected to the local power grid. As a result, these 150 new bus shelters are estimated to save taxpayers about $54,000 a year in energy costs. They are built with recyclable materials; have room to accommodate a passenger in a wheelchair and will feature a bench, a receptacle bin, a display case for transit information, and two advertising panels that will improve the experience of transit riders.
>
> The purchase and installation of the 150 new energy-saving shelters was funded by a $1.8 million formula grant from the Federal Transit Administration (FTA) for transit enhancement projects. All 150 transit shelters are scheduled to be installed by Dec. 31 in Las Vegas, Henderson, North Las Vegas and unincorporated Clark County

An example of a solar powered bus stop located in the Las Vegas Valley can be viewed in Figure 4.

Well-lit transit shelters will not only make transit riders feel safer, they will also help drivers locate them on the side of the road. Additionally, easier identification of transit shelters will help prevent drivers from hitting them. The RTC has made the effort to light transit shelters using solar/LED lighting, and should continue to achieve adequate lighting at all transit shelters throughout the system.

Figure 4: Las Vegas Valley Solar-Powered Bus Shelter

3.5 Move Shelter Behind Sidewalk

The most common theme of the transit shelters hit since 2007 is the location. Eighty four percent of the transit shelters hit were located within the sidewalk. When the transit shelters are placed within the sidewalk, they are typically within two to three feet from the edge of the curb. Not only does this create an Americans with Disabilities Act (ADA) problem, it leaves little room for a vehicle to avoid crashing into a transit shelter if it has left the roadway. According to the *2011 AASHTO Roadside Design Guide*[2]:

> In an urban environment, approximately 80 percent of roadside crashes involved an object with a lateral offset from the curb face equal to or less than 4 feet and more than 90 percent of urban roadside crashes have a lateral offset less than or equal to 6 feet.

This is strongly corroborated by local crash data, where 84 percent of shelters impacted were less than 4 feet from the face of curb. Hence, if transit shelters can be moved beyond 6-feet from the curb face, it will greatly diminish the amount of crashes that occur at transit stops.

The RTC is currently in the process of altering 150 bus stops per year, which includes moving transit shelters behind the sidewalk. According to Carl Scarbrough (RTC Transit Amenities Manager), "We've already moved back 515 shelters. We now have 478 turnouts, which is also a way to move bus stops back."[14] Figure 5 illustrates a bus stop that is located within the sidewalk, whereas Figure 6 illustrates a bus stop that is located on a bus pad behind the sidewalk.

Figure 5: Las Vegas Valley Bus Shelter Located On Sidewalk

Figure 6: Las Vegas Valley Bus Shelter Located On Bus Pad Behind Sidewalk

Moving the transit shelters back behind the sidewalk will greatly reduce the number of transit shelters that are struck by a vehicle that has left the roadway. The RTC has made the effort to move transit shelters further away from the road, however there are multiple locations where easement rights or right-of-way is not available behind the sidewalk to implement this strategy. Given the economic and right-of-way constraints, strides should continue to be made to move all transit shelters at least 6-feet from the edge of the curb throughout the Las Vegas Valley.

3.6 Move Shelter Away From Block Wall

According to the American Public Transportation Association (APTA)[12], bus shelters should have no entrapment areas and should provide escape routes, wherever possible. Putting shelters against block walls leaves transit riders limited opportunity to move out of the way if an oncoming vehicle has left the roadway and is heading toward the transit stop. Note: The entrapment concern is not as critical as the offset distance to the curb, since prior analyses have demonstrated that the reaction time available to a pedestrian who identifies a vehicle approaching is insufficient to allow for any type of evasive action.

The real issue of stops and shelters against block walls in the Las Vegas Valley is that the stop or shelter is often too close to the curb. All shelters against block walls should be considered for relocation or the right-of-way could be purchased to move the wall and shelter back. Positive shelter protection measures could be implemented where relocation is not feasible.

Figure 7 is an example of a transit shelter that is located against a block wall. This transit shelter could be moved to a different location that offers a greater offset distance from the curb or other positive protection measures could be implemented.

Figure 7: Las Vegas Valley Transit Shelter Located Against A Block Wall

3.7 Bus Turnouts & Bus Bulbs

A bus turnout, or bus bay, is a special zone on the side of the main roadway for buses to stop in order to pick up and drop off passengers. The purpose of the bus bay is to help buses avoid blocking a lane of traffic and to improve passenger safety during boarding and alighting. Additionally, bus turnouts add extra distance between the vehicles traveling on the roadway and the transit shelter. An example of a bus turnout in the Las Vegas Valley can be viewed in Figure 8.

Figure 8: Las Vegas Valley Bus Turnout

A bus bulb, or bus boarder, is where a sidewalk is extended outwards for a bus stop and typically it replaces a portion of an existing parking lane. The purpose of the bus bulb is to allow a bus to stay in its traffic lane to pick-up and drop-off passengers, without having to pull over to the curb. Similar to bus turnouts, bus bulbs add extra distance between the vehicles traveling on the roadway and the transit shelter. An example of a bus bulb (where the transit shelter is backed up to the curb for splash protection in wet weather) can be viewed in Figure 9. Note: Bus bulbs can be configured similar to Figure 8, where the transit shelter is located behind the sidewalk and facing the roadway.

Figure 9: Bus Bulb[15]

Bus turnouts and bus bulbs help keep transit shelters further than 6-feet from the roadway, which accomplishes the same goal as moving bus shelters back behind the sidewalk. Bus turnouts are much more common in the Las Vegas Valley because there is not an abundance of on-street parking; in fact 478 bus turnouts have already been implemented. Therefore, bus turnouts should be added in all transit shelter locations where right-of-way is available.

3.8 Raised Curb

Raising the curb at transit stops will not only deter vehicles from leaving the roadway, but it will also make drivers visually aware of the transit stop location. The original *Transit Shelter Safety Study* briefly describes how the height of a curb can help redirect a vehicle.

In addition to providing a buffer between vehicles and transit riders, raising the curb at bus shelters allows for level or near-level boarding onto buses. According to the APTA[12]:

> This option attempts to most closely resemble rapid transit applications by eliminating the vertical and horizontal gap between the vehicle and the platform. While no comprehensive empirical data yet exist, level boarding suggests a seamless transition into the vehicle and a perception of reduced dwell times and faster boarding attributed to customer ease… Depending on the vehicle type, station platform heights are raised to 14 to 15 inches above the roadway… The

benefits of a level platform include increased customer perception of service; ease of boarding for all customers (anticipated to manifest as quicker boarding and reduced dwell times); potentially the elimination of the need for wheelchair access ramps or lifts; stronger brand identity; and greater similarity to rail-type services.

Level boarding already exists at some of the Las Vegas MAX transit shelters and along the Sahara and Boulder Highway BRT routes. The curb height along these alignments is 10 or 11 inches to accommodate the vehicles in use, and this height is much less effective in redirecting a vehicle than the 14 or 15 inch height mentioned in the APTA document. As such, raising the curb height as a safety measure is marginally effective, given the types of crash incidents experienced locally. Figure 10 illustrates the curb height at a Las Vegas MAX stop and Figure 11 illustrates the ease of riders boarding and leaving the Las Vegas MAX.

Figure 10: Raised Curb At Las Vegas MAX Stop

Figure 11: Las Vegas MAX Level Boarding[16]

Although raised curbs provide limited protection in preventing vehicles from leaving the roadway, they allow for easier access into and out of the bus. The RTC has made the effort to raise curbs at numerous transit stops, and consideration should be given to raise curbs at other stops throughout the system where high boarding rates or ADA access needs are demonstrated.

3.9 High Containment Curbs

The original *Transit Shelter Safety Study* briefly described an alternative curb design known as anti-vehicular curbs. These curbs are designed to promote the redirection of errant vehicles back into the roadway.

High containment curbs, a type of anti-vehicular curb, "are used to prevent traffic leaving the carriageway and are often used to protect vulnerable footpaths or sensitive roadside equipment, such as fuel pumps at filling stations, pedestrian islands, dangerous curves, etc."[17] An example of a high containment curb, used in the United Kingdom, can be viewed in Figure 12.

High containment curbs are an alternative to simply raising the curb and are used to not only prevent vehicles from leaving the roadway, but actually safely redirect the vehicle back onto its intended path.

Figure 12: High Containment Curb

3.10 Barrier

Positive (crashworthy) barriers were briefly discussed in the original *Transit Shelter Safety Study*. According to the *2011 AASHTO Roadside Design Guide*[2]:

> A roadside barrier is a longitudinal barrier used to shield motorists from natural or man-made obstacles located along either side of a traveled way. It also may be used to protect bystanders, pedestrians, and cyclists from vehicular traffic under special conditions.

It is important to note that barriers are "used to protect bystanders, pedestrians, and cyclists", which is the goal of this study. Barriers are an intimidating obstruction that will help prevent drivers from leaving the roadway and crashing into transit stops. A couple of examples of barrier rails can be viewed in Figure 13 and Figure 14.

The *2011 AASHTO Roadside Design Guide* recognizes low profile barrier rails as an acceptable barrier on roadways with a speed limit of 45 mph or less. They are an alternative to high containment curbs and raised curb options previously described. Barriers are described in more detail later in this document.

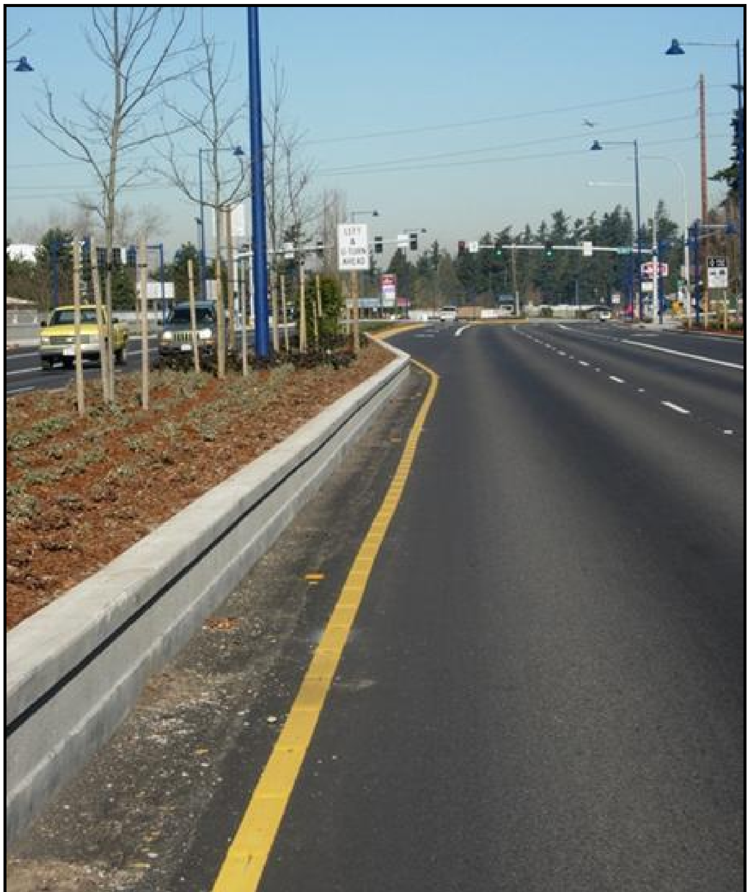


Figure 13: Low Profile Barrier In Des Moines[18]

Figure 14: Caltrans' "Test" Low Profile Barrier[19]

3.11 Bollards

In general, bollards are typically used on low speed facilities, such as parking lots. However, due to the circumstances that exist in the Las Vegas Valley, it is necessary to consider bollards as an alternative to help prevent vehicles from running off of the road and crashing into transit stops.

Other agencies have implemented bollards, however they have done so in limited scenarios. For example:

- Palm Beach County, Florida uses bollards, but only at the end of bus bay turnouts at transfer stations to prevent the bus from encroaching into pedestrian waiting areas[20].
- As of December 20011, the Singapore Land Transit Authority had provided 2,659 out of 4,600 bus stops with safety bollards. However, the standards used for implementation violate current US national standards for offset, strength, and layout[21].
- Miami Dade County considered implementing bollards in 2007 for transit shelter protection, but the study recommended against bollards for multiple reasons, including minimum clearance from the curb, underground utility conflicts, vehicle impact damage concerns, and the limited protection provided[22].

Bollards could have a couple of benefits to help prevent vehicles from leaving the roadway and hitting transit stops. First, bollards are intimidating and would catch the eye of a person driving a vehicle. Vehicles would be less likely to leave the roadway for fear of crashing into the bollard. Second, a properly placed bollard system would stop a vehicle from approaching a transit stop and striking people waiting at the stop. However, there is a concern that a bollard could break apart a vehicle, causing a shrapnel effect, and potentially increase the number of injuries in an impact. An example of a bollard system protecting pedestrians from vehicles on a low speed roadway can be viewed in Figure 15.

Bollards are an available option, when other measures cannot be implemented, to help reduce the number of vehicles crashing into transit stops. However, the safety of motorists cannot be ignored when adding bollards because little is gained by trading one type of injury for another. In addition, when determining the location of a transit stop, it would be desirable to utilize existing features to shield and protect transit passengers; such as existing utility poles, trees, and fire hydrants. Since other measures such as moving transit stops away from the curb and providing landscape buffers are recognized successful primary strategies, bollards should only be considered after these measures are not feasible. Additional bollard information can be found in the Appendix.

Figure 15: Bollards Separating The Roadway And The Sidewalk[23]

3.12 Handrail

In addition to the raised curb, a handrail could help pedestrians adjust to the changing slope in the sidewalk. Furthermore, it could be a supplementary barrier between vehicles and pedestrians and can be used as an alternative to bollards. The handrail would have a similar visual affect as the bollard system, in that it would catch the eye of a driver and it would help prevent a vehicle from leaving the roadway and hitting a transit shelter. Additionally, a handrail would be more aesthetically pleasing than a traditional bollard. However, the handrail could have similar issues as the bollard system, in that it could actually endanger people by causing a shrapnel effect when impacted by a vehicle. In addition, the end of the top of the handrail would need to be designed to prevent the handrail from becoming a spear and injuring the driver of an oncoming vehicle. An example of a handrail protecting a sidewalk from a roadway can be viewed in Figure 16.

A handrail is an option to not only help reduce the number of vehicles crashing into transit stops, but as an assistance mechanism for pedestrians who need help adjusting to the change in slope of the sidewalk.

Figure 16: Handrail Separating Sidewalk And Roadway[24]

3.13 Concrete Planters

Concrete planters, with trees planted inside of them, could be used as an alternative to a bollard system. The concrete planter and tree would prevent a car from hitting a shelter and provide much needed shade during the hot summer months. In addition, it would be a much more aesthetically pleasing option than a typical bollard system. However, the width required to incorporate planters behind the curb is a major consideration, moreover the RTC would need to resolve the maintenance issue. One possibility would be to give property owners an option between the concrete planters or other measures, and if the owners choose the concrete planters they must agree to maintain the trees. Figure 17 and Figure 18 are examples of concrete planters that could be used as a barrier between pedestrians and vehicles.

Concrete planters with trees, placed in front of transit shelters, would not only provide shade but they could help stop or slow down vehicles that are airborne, similar to the one described at the beginning of the document. However, the trees would have a negative effect on solar panel operation. If implemented, it is recommended that they are placed at least 6 feet from the edge of the curb.

Figure 17: Concrete Planters With Trees[25]

Figure 18: Concrete Planters With Trees[26]

3.14 Concrete Trash Receptacles

Similar to concrete planters, the concrete trash receptacle can double as a bollard. They can be cast-in-place with reinforcing steel to act as a barrier between an on-coming vehicle and a transit rider. An example of a concrete trash receptacle can be viewed in Figure 19.

Figure 19: Concrete Trash Receptacle[27]

Since trash receptacles are necessary at all transit shelters, it could be beneficial to construct heavy-duty trash receptacles that could be used as a barrier to help stop a vehicle approaching a transit stop. If implemented, it is recommended that they are placed at least 6 feet from the edge of the curb.

3.15 Side Street Placement

If safety measures cannot be made at particular transit stops, it may be possible to move the transit stop to a side street that has lower traffic volumes. The original *Transit Shelter Safety Study* briefly discusses placing transit shelters on side streets when operated in conjunction with a passenger actuated bus stop sign.

Side street placement should only be used if the existing transit stop cannot be relocated to a safe location on the existing transit route.

3.16 Complete Streets With Pedestrian Buffer

Complete streets are designed and operated to enable safe access for all users, including pedestrians, bicyclists, motorists, and transit riders of all ages and abilities.[28] Incomplete Streets focus mainly on vehicular traffic and vehicular traffic alone.

One option included in many Complete Street studies involves the implementation of a pedestrian buffer, which adds a more comfortable distance between the transit stop and the roadway, and it makes pedestrians feel safer when walking alongside a major arterial. Additionally, it is aesthetically pleasing and could be used for trees which would provide much needed shade in the hot summer months. Figure 20 is an example of a pedestrian buffer between the roadway and meandering sidewalk within the Las Vegas Valley.

Figure 20: Pedestrian Buffer Between Roadway And Meandering Sidewalk

The RTC recently completed a *Regional Complete Streets Study* and is in the process of developing a *Complete Streets For Living Communities Design Guide* which will focus on improving corridors throughout the Las Vegas Valley with Complete Streets in mind. Items that have already been implemented include bicycle lanes (see Figure 21) and “Bus Only” lanes (see Figure 22). The “Bus Only” lanes are another way to add distance between passenger vehicles on the roadway and the transit stop.

Complete Streets keep all modes of travel in mind which makes it safer for pedestrians, bicyclists, and transit riders at transit stops. The RTC has started to make the effort to implement Complete Streets throughout the Las Vegas Valley, however strides should continue to keep the focus of transportation projects on all modes of travel.

Figure 21: Bicycle Lane Within The Roadway

Figure 22: Diamond Lane For Buses And Right-Turning Vehicles

3.17 Rumble Strips And "Bus Stop Ahead" Pavement Markings

Rumble strips are a road safety feature that alerts inattentive drivers, by causing a tactile vibration and audible rumbling, transmitted through the wheels, into the car body.[29] They could be used to help alert drivers that a transit stop is approaching, which will make them less likely to run off the road and crash into a transit shelter.

Two types of rumble strips that could be used in this situation include transverse ruble strips and shoulder rumble strips. Transverse rumble strips are either raised bars or groves placed across the travel lane. They would be placed on the far outside lane only, which would cause cars to avoid traveling in the lane closest to the sidewalk to steer clear of the rumble strips. The further a vehicle is away from the curb, the less likely it is to run off of the road. An example of transverse rumble strips can be viewed in Figure 23.

Figure 23: Roadway Rumble Strips[30]

Shoulder rumble strips are either raised bars or grooves placed along the edge of the curb. They would help alert drivers if they started to get too close to the edge of the curb and the sidewalk. If a driver is alerted that they are too close to the curb, they will adjust their vehicle and avoid running off of the road and crashing into a transit shelter. An example of a shoulder rumble strip along the edge of the road can be viewed in Figure 24, an example of a shoulder rumble strip separating the edge of a roadway and a bicycle lane can be viewed in Figure 25, and an example of a shoulder rumble strip at a bus stop in the United Kingdom can be viewed in Figure 26. Due to the impact to bicycle riders and the types of transit shelter crashes experienced locally, rumble strips should be used only where other measures are not available, or where site conditions demonstrate a driver lane drift problem.

Figure 24: Shoulder Rumble Strips[31]

Figure 25: Shoulder Rumble Strips Between Roadway And Bike Lane[32]

Figure 26: Shoulder Rumble Strips At Bus Stop In The United Kingdom[33]

In addition to or an alternative to the rumble strips would be “Bus Stop Ahead” pavement markings. The pavement markings would alert drivers that a transit stop is ahead. Similar to the rumble strips, if a driver is alerted that a transit stop is ahead, they will become more aware of the transit stop location and be less likely to run off the road and crash into a transit stop. The implementation of pavement markings should be used only where considered site-appropriate. An example of a “Bus Stop” pavement marking that exists in Massachusetts can be viewed in Figure 27.

Rumble strips, “Bus Stop Ahead” pavement markings, or a combination of the two would help drivers become aware that a transit stop is approaching. This awareness would help reduce the number of crashes that occur at transit stops each year.

Figure 27: "Bus Stop" Pavement Markings In Massachusetts[34]

3.18 Additional Options

Numerous options were considered when trying to find the best ways to reduce, and eventually eliminate, the number of crashes at transit stops throughout the Las Vegas Valley. These additional options are available as an added tool to enhance shelter and stop location visibility and safety, and are not necessarily a system wide application. A few additional options that were discussed include:

- Brightly Painted Transit Shelters – the more noticeable a transit shelter is, the less likely a vehicle will run off the road and crash into it. The transit shelters could have a similar theme that is aesthetically pleasing to the community; each one could be designed by a local artist within the community; and/or a contest could be held to allow people to design their own transit shelter (could coincide with the public service announcement described earlier in this document).

- Brightly Painted Curbs – similar to the transit shelters, the more noticeable a transit stop is, the less likely a vehicle will run off the road and crash into it.
- Reflective Coating – add a reflective coating to transit shelters that will enhance the visualization of the transit shelters during the night. Similar to the brightly painted transit shelters, the more noticeable a transit stop is, the less likely a vehicle will run off the road and crash into it.
- Rear-Facing Transit Shelters – rather than having the transit shelters open facing the road, transit shelters could be designed to have a protective barrier between the roadway and the shelter. The design would have to accommodate for easy access in and out of the shelter and still allow for riders to sit and see if a bus is approaching. An example of a rear-facing transit shelter can be viewed in Figure 28. Note: This would require a redesign of the current general market shelters to accommodate advertising panels that do not restrict visibility. In addition, this option normally places the shelter closer to the curb, therefore supplemental protection measures may be needed.

Figure 28: Rear-Facing Transit Shelter[35]

Brightly painted and reflective transit shelters and curbs could make a transit stop more recognizable, which would help prevent some of the vehicle to transit shelter crashes. Additionally, designing a transit shelter that protects riders from the roadway traffic would be beneficial to the transit riders and increase their sense of safety at transit stops.

4.0 BARRIER RAIL DESIGN

One objective of this study was to develop a prototypical barrier system concept suitable to deter damage at transit stops and injury to transit users. The barrier layouts developed are based on guidelines in the *2011 AASHTO Roadside Design Guide*. The discussion of the barrier layouts is based on the assumption that the reader is familiar with the guide.

The majority of barrier rail systems are continuous and longitudinal in nature. They are laid out, in general, with the concepts depicted in Figure 29.

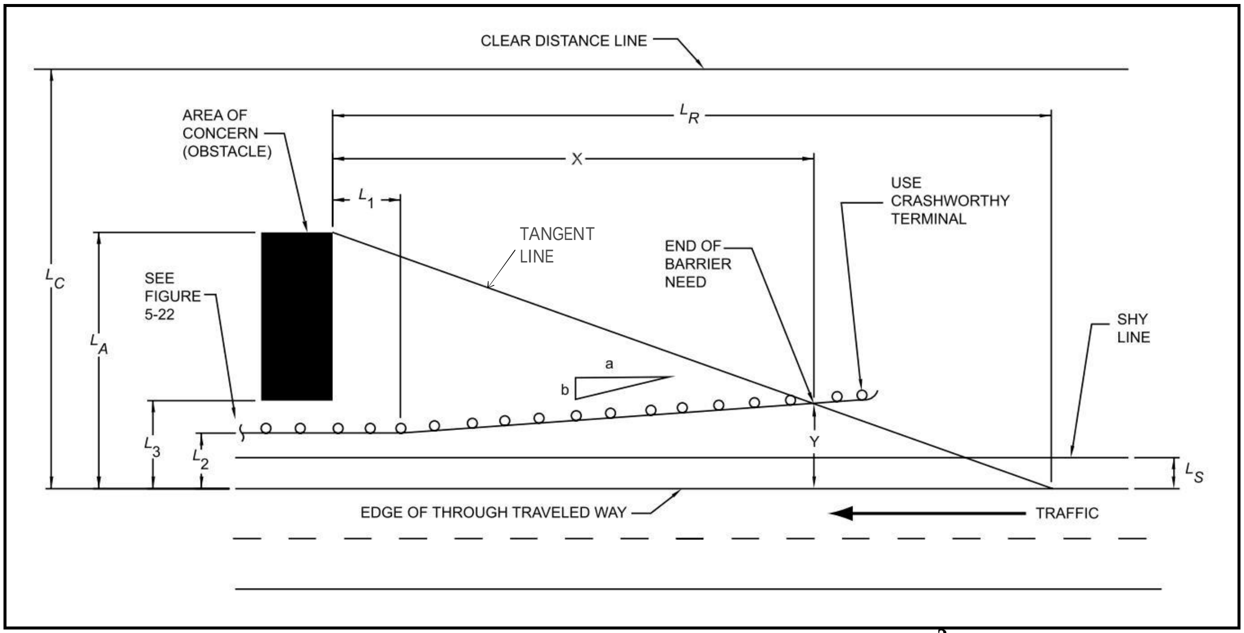


Figure 29: Approach Barrier Layout Variables[2]

The runout length (L_R) is 230 feet for a 50 mph roadway, which equates to a 45 mph speed limit, the most common speed limit along transit routes within the Las Vegas Valley.

The triangular area, located between the "edge of through traveled way" and the "tangent line", is the area where physical barriers can shield the transit stop from a vehicle running off of the roadway. Note: Existing features, such as utility poles and street trees, can shield the transit shelter from oncoming vehicles. However, no protection is provided if the existing features are located behind the sidewalk where the transit shelter is located on the sidewalk.

The required length-of-need (X) is the length of barrier rail needed in advance of the "area of concern" (in this case, a transit shelter) for a straight section of roadway. For a typical transit shelter placed on a 5-foot sidewalk, the length-of-need is approximately 165 feet. However, the standard placement of a transit shelter is typically 70 to 200 feet from the end of the curb return to the nose of the transit shelter. Thus, in many cases, the length-of-need will exceed the available length.

To address this concern, it is necessary to consider the angle of incidence for roadside crashes. Studies indicate that the median angle of incidence for a roadside crash on a city street is about

16°, with a standard deviation of 7.44°, resulting in a range from 8° to 24°. By comparison, the angle of incidence for the tangent line to a shelter located on a 5-foot sidewalk is approximately 1.75°. Therefore, the placement of a longitudinal barrier rail should be site specific to provide the longest length-of-need possible. Additionally, the length may be adjusted if other existing features can provide additional shielding to transit shelters.

In most urban settings, it is impractical to provide a longitudinal barrier of sufficient length to fully protect a transit stop from an errant vehicle. However, providing a combination of barriers in the immediate vicinity of the transit stops can provide the needed protection. Section 4.3 of this document provides conceptual plans for the installation of barriers, low profile barriers, and bollards for the protection of five separate transit stop scenarios.

4.1 Low Profile Barrier

The *2011 AASHTO Roadside Design Guide* identifies a low profile barrier that has been developed for use in urban environments. A low profile barrier is typically an 18-inch to 20-inch high vertical curb and is appropriate where Test Level 2 barrier systems are suitable. Test Level 2 barrier systems are used where the "design vehicle" consists of passenger cars and pickup trucks. Note: As mentioned earlier in this document, the most common vehicle involved in crashes within Clark County are 4-door sedans. Hence, Test Level 2 barrier systems account for this type of vehicle.

The low profile barrier system was tested in 1998 by the Texas Department of Transportation and has subsequently been approved for use by the Federal Highway Administration. Low profile barriers, using various designs, are now in use in Iowa, Florida, California, and Texas:

- Iowa – the barrier section described earlier in the document includes a photo of a low profile barrier in Des Moines, IA. This type of low profile concrete barrier is more aesthetically pleasing than traditional concrete barriers.[18]
- Florida – the state has standard plans for portable precast low profile concrete barrier systems.[36]
- California – the barrier section described earlier in the document includes a photo of Caltrans' "test" low profile barrier. This type of barrier was developed to address design criteria relating to the protection of trees on low-speed highways.[19]
- Texas – in April 1998, the Texas Department of Transportation sponsored a study for compliance testing of an end treatment for the low profile concrete barrier system. The study included a full-scale crash testing of the end treatment and recommended its implementation for Test Level 2 applications, per NCHRP Report 350, for terminals and re-directive crash cushions. The end treatment tested was a tapered concrete element, 15-feet in length, with a 20-inch maximum height and a 4-inch minimum height. Figure 30 illustrates the geometry of the low profile end treatment. Note: The *2011 AASHTO Roadside Design Guide* recommends that where end treatments are used, the curb and gutter should be terminated in advance of the end treatment, which is not practical at urban bus stop locations. However, there is an allowance to install a modified curb-to-barrier end transition on lower speed urban roadways. Therefore, the RTC would need to

determine the appropriate curb-to-barrier end treatment allowed if barrier protection is implemented.

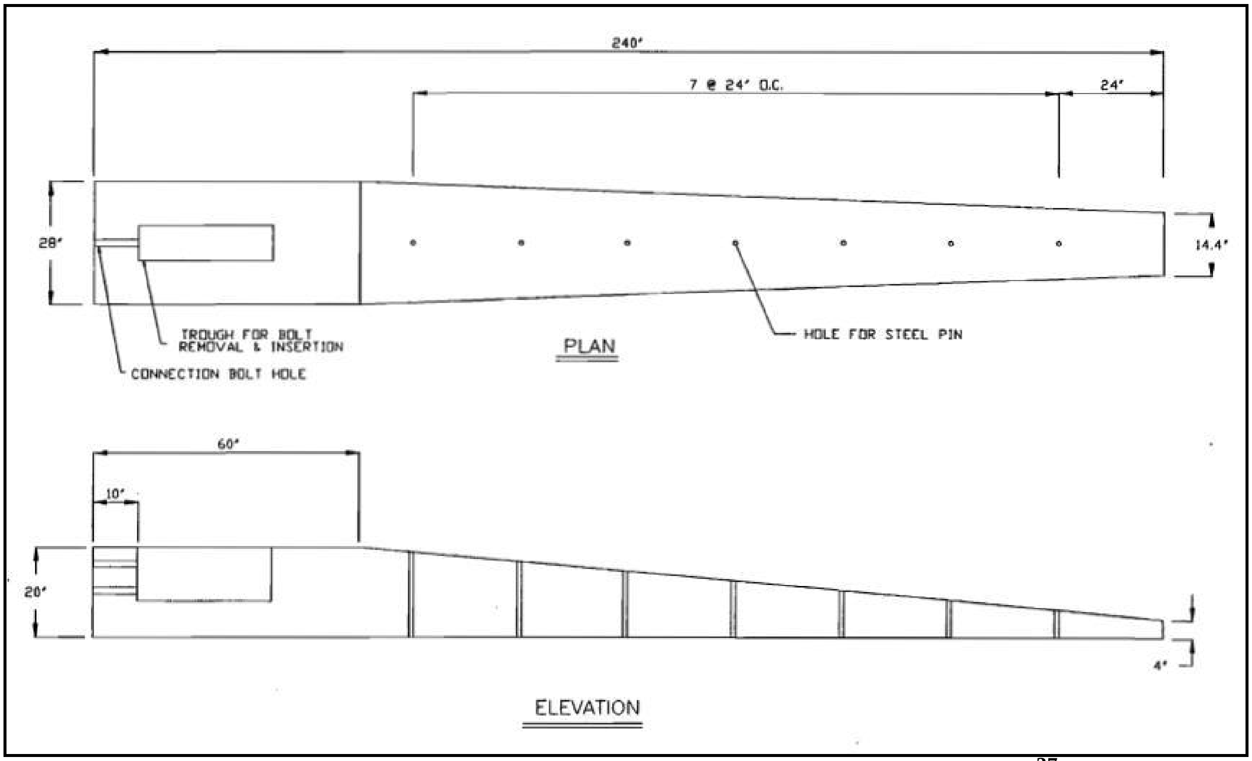


Figure 30: Geometry Of Low Profile End Treatment In Texas[37]

4.2 Conceptual Transit Stop Barrier Designs

Prototypical barrier system concepts have been developed for transit shelters with five different site conditions:

- Shelter located on 5-foot sidewalk (see Exhibit 1)
- Shelter located behind 5-foot sidewalk (see Exhibit 2)
- Shelter located on 5-foot sidewalk with 5-foot landscape buffer (see Exhibit 3)
- Shelter located behind 5-foot sidewalk with 5-foot landscape buffer (see Exhibit 4)
- Shelter located at bus turnout (see Exhibit 5)

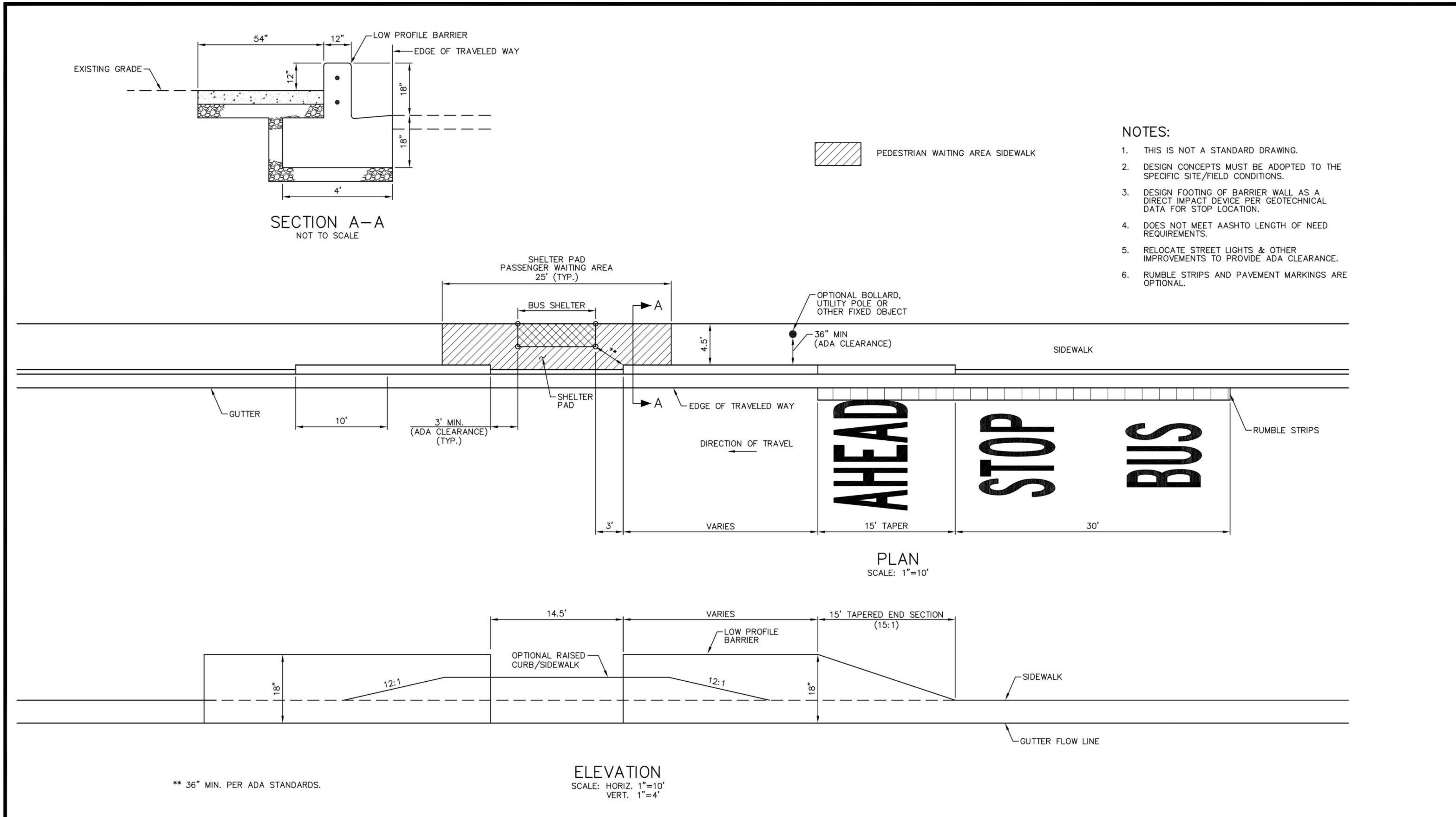
The development of these conceptual barrier plans were designed using concepts and criteria included in the *2011 AASHTO Roadside Design Guide*. The designs are based on a typical vehicle that leaves the roadway at a speed of 45 mph. Specific site conditions will necessitate adjustments to the design for each site.

4.3 Conceptual Transit Stop Barrier Cost Estimates

Cost estimates for the five different site conditions were performed. The cost estimates are based on the assumption that one shelter stop will be done per construction contract. The improvements involve a variety of trades, pavement markings, concrete placement, saw cutting, traffic control, etc.; each of which require different equipment and skilled labor. Due to the small quantities involved for many of the bid items, historical cost data is often unavailable.

The unit price for installing pavement markings on a typical arterial roadway project is about $10 per square foot. However, this unit price is for projects installing thousands if not tens of thousands of square feet of markings at one time. For example, the cost to install 68 feet of "BUS STOP AHEAD" is driven more by the time it takes the crew to prepare and clean up than it does for the actual placement of the markings. Because of this, you will notice that the unit prices vary between estimates for many of the items. The unit prices are marked up to include the estimated cost of labor and equipment traveling to and from the contractor's yard.

Each cost estimate is based on the existing shelter configuration, in other words, the cost of additional right-of-way to move the transit shelter was not included. (Table 6 corresponds with Exhibit 1; Table 7 corresponds with Exhibit 2; Table 8 corresponds with Exhibit 3; Table 9 corresponds with Exhibit 4; and Table 10 corresponds with Exhibit 5.)



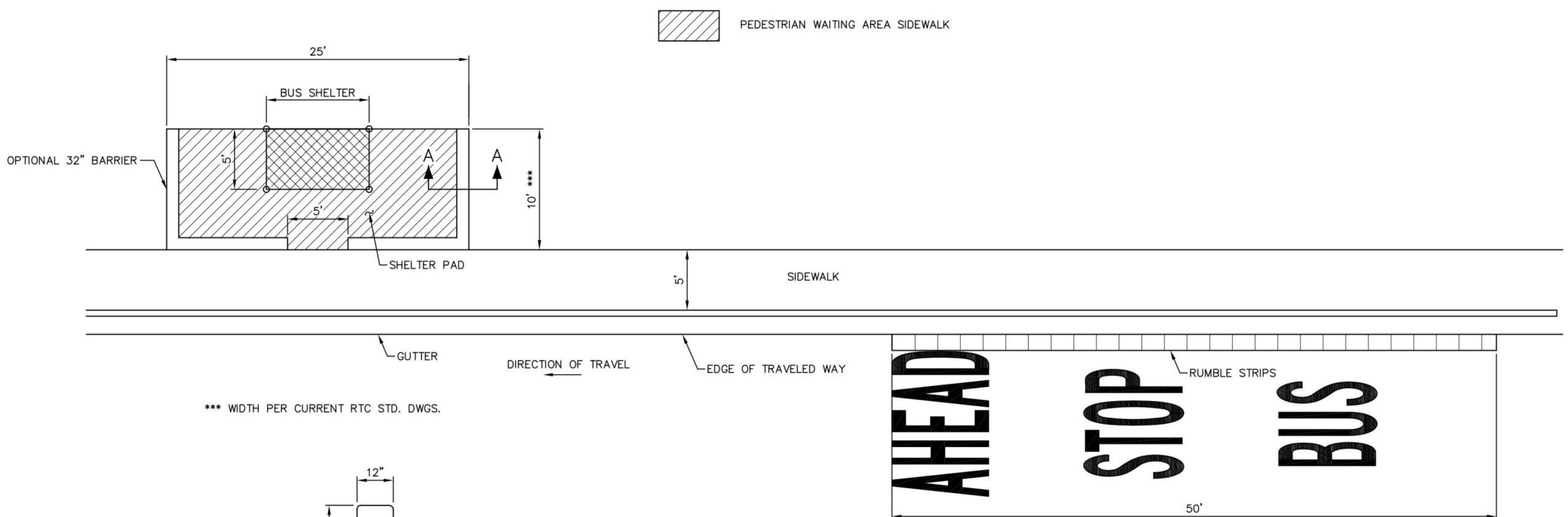
PARSONS BRINCKERHOFF

TRANSIT STOP SAFETY STUDY UPDATE

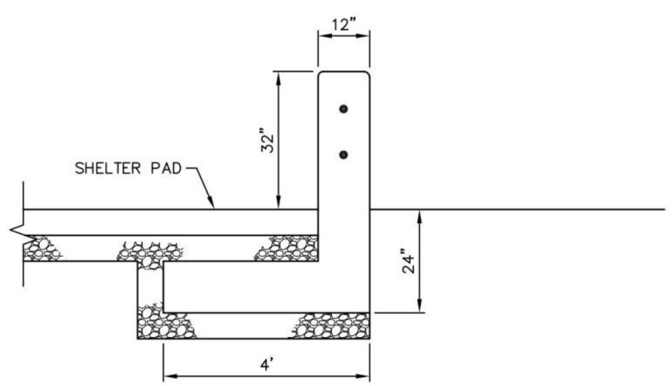
SHELTER LOCATED ON 5-FOOT SIDEWALK
AASHTO LOW PROFILE BARRIER

EXHIBIT - 1

TABLE 6: COST ESTIMATE FOR SHELTER LOCATED ON 5-FOOT SIDEWALK				
ITEM DESCRIPTION	**UNIT**	**QUANTITY**	**UNIT COST**	**AMOUNT**
REMOVAL OF CONCRETE SIDEWALK	SY	39	$15.00	$585.00
REMOVAL OF CURB AND GUTTER	LF	70	$12.00	$840.00
REMOVE AND RESET BUS SHELTER	EA	1	$2,000.00	$2,000.00
SAWCUT OF CONCRETE SIDEWALK	LF	10	$25.00	$250.00
MILLED RUMBLE STRIP	LF	45	$40.00	$1,800.00
SAFETY BOLLARD	EA	1	$1,200.00	$1,200.00
LOW PROFILE BARRIER W/GUTTER - 18 INCH	LF	40	$70.00	$2,800.00
CURB - 12 INCH	LF	14	$25.00	$350.00
LOW PROFILE BARRIER TAPER	LF	15	$65.00	$975.00
CONCRETE SIDEWALK	SY	30	$50.00	$1,500.00
AGGREGATE BASE (TYPE II) (CLASS B)	CY	11	$100.00	$1,100.00
PAVEMENT MARKING (BUS STOP AHEAD)	SF	68	$20.00	$1,360.00
TRAFFIC CONTROL	LUMP SUM	1	$5,000.00	$5,000.00
CONSTRUCTION SUBTOTAL				$19,760.00
30% CONTINGENCY				$5,928.00
TOTAL				**$25,688.00**



PLAN
SCALE: 1"=10'



SECTION A—A
NOT TO SCALE

NOTES:

1. THIS IS NOT A STANDARD DRAWING.
2. DESIGN CONCEPTS MUST BE ADOPTED TO THE SPECIFIC SITE/FIELD CONDITIONS.
3. DESIGN FOOTING OF BARRIER WALL AS A DIRECT IMPACT DEVICE PER GEOTECHNICAL DATA FOR STOP LOCATION.
4. DOES NOT MEET AASHTO LENGTH OF NEED REQUIREMENTS.
5. RELOCATE STREET LIGHTS & OTHER IMPROVEMENTS TO PROVIDE ADA CLEARANCE.
6. BARRIER HEIGHT 32" TO 42".
7. RUMBLE STRIPS AND PAVEMENT MARKINGS ARE OPTIONAL.

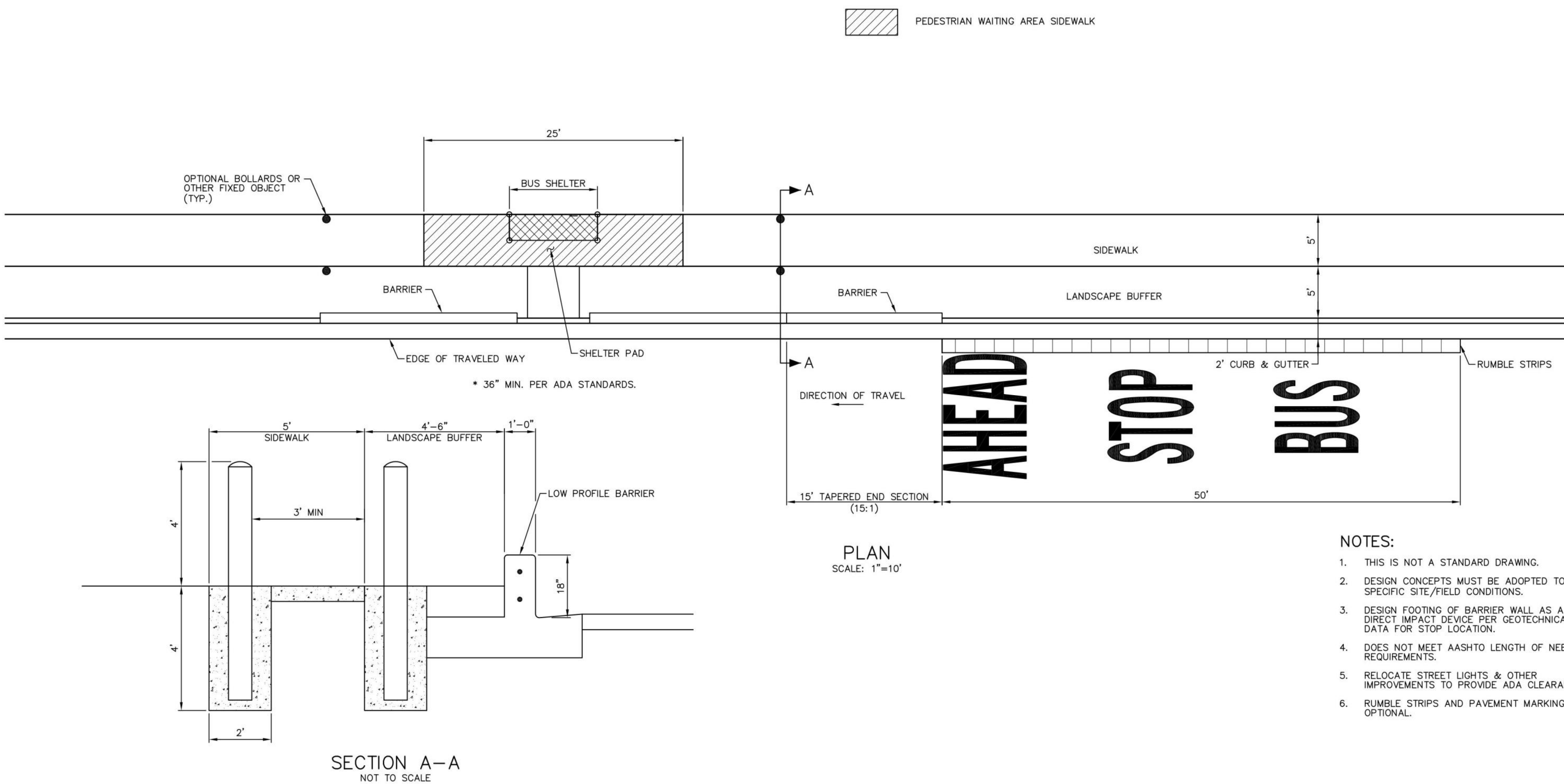
PARSONS BRINCKERHOFF

TRANSIT STOP SAFETY STUDY UPDATE

SHELTER LOCATED BEHIND 5-FOOT SIDEWALK

EXHIBIT - 2

TABLE 7: COST ESTIMATE FOR SHELTER LOCATED BEHIND 5-FOOT SIDEWALK				
ITEM DESCRIPTION	**UNIT**	**QUANTITY**	**UNIT COST**	**AMOUNT**
REMOVAL OF CONCRETE BUS PAD	SY	17	$200.00	$3,400.00
SAWCUT CONCRETE BUS PAD	LF	29	$25.00	$725.00
MILLED RUMBLE STRIP	LF	50	$40.00	$2,000.00
BARRIER - 32 INCH	LF	40	$70.00	$2,800.00
AGGREGATE BASE (TYPE II) (CLASS B)	CY	3	$100.00	$300.00
PAVEMENT MARKING (BUS STOP AHEAD)	SF	68	$20.00	$1,360.00
TRAFFIC CONTROL	LUMP SUM	1	$5,000.00	$5,000.00
CONSTRUCTION SUBTOTAL				$15,585.00
30% CONTINGENCY				$4,675.50
TOTAL				**$20,260.50**

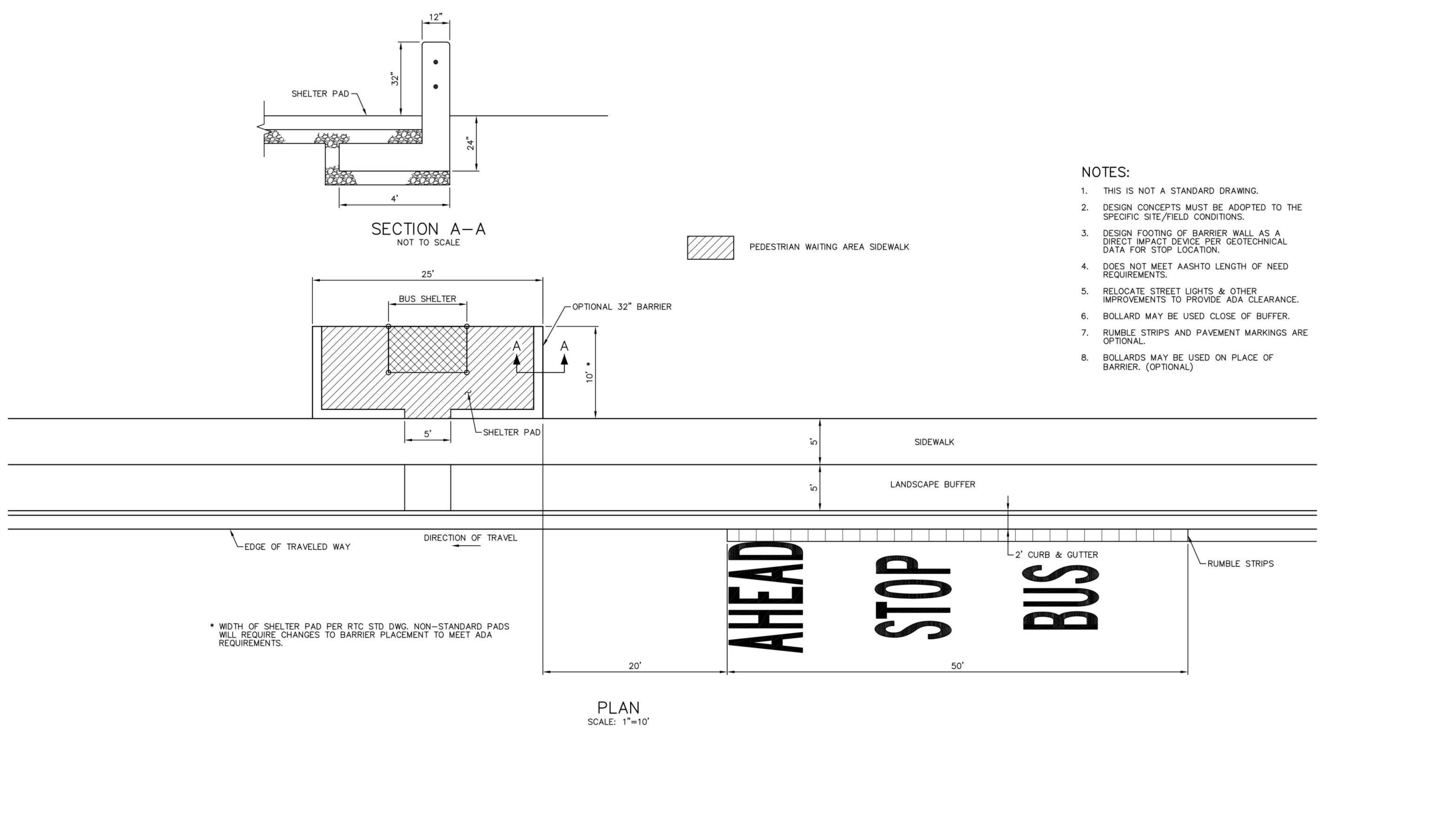


NOTES:

1. THIS IS NOT A STANDARD DRAWING.
2. DESIGN CONCEPTS MUST BE ADOPTED TO THE SPECIFIC SITE/FIELD CONDITIONS.
3. DESIGN FOOTING OF BARRIER WALL AS A DIRECT IMPACT DEVICE PER GEOTECHNICAL DATA FOR STOP LOCATION.
4. DOES NOT MEET AASHTO LENGTH OF NEED REQUIREMENTS.
5. RELOCATE STREET LIGHTS & OTHER IMPROVEMENTS TO PROVIDE ADA CLEARANCE.
6. RUMBLE STRIPS AND PAVEMENT MARKINGS ARE OPTIONAL.

PARSONS BRINCKERHOFF	TRANSIT STOP SAFETY STUDY UPDATE **SHELTER LOCATED ON 5-FOOT SIDEWALK WITH 5-FOOT LANDSCAPE BUFFER**	RTC	**EXHIBIT - 3**

TABLE 8: COST ESTIMATE FOR SHELTER LOCATED ON 5-FOOT SIDEWALK WITH 5-FOOT LANDSCAPE BUFFER				
ITEM DESCRIPTION	**UNIT**	**QUANTITY**	**UNIT COST**	**AMOUNT**
REMOVAL OF CURB AND GUTTER	LF	55	$12.00	$660.00
MILLED RUMBLE STRIP	LF	50	$40.00	$2,000.00
SAFETY BOLLARD	EA	4	$1,200.00	$4,800.00
LOW PROFILE BARRIER W/GUTTER - 18 INCH	LF	40	$70.00	$2,800.00
LOW PROFILE BARRIER TAPER	LF	15	$65.00	$975.00
AGGREGATE BASE (TYPE II) (CLASS B)	CY	4	$100.00	$400.00
PAVEMENT MARKING (BUS STOP AHEAD)	SF	68	$20.00	$1,360.00
TRAFFIC CONTROL	LUMP SUM	1	$5,000.00	$5,000.00
CONSTRUCTION SUBTOTAL				$17,335.00
30% CONTINGENCY				$5,200.50
TOTAL				**$22,535.50**



PARSONS BRINCKERHOFF

TRANSIT STOP SAFETY STUDY UPDATE

SHELTER LOCATED BEHIND 5-FOOT SIDEWALK WITH 5-FOOT LANDSCAPE BUFFER

EXHIBIT - 4

TABLE 9: COST ESTIMATE FOR SHELTER LOCATED BEHIND 5-FOOT SIDEWALK WITH 5-FOOT LANDSCAPE BUFFER				
ITEM DESCRIPTION	**UNIT**	**QUANTITY**	**UNIT COST**	**AMOUNT**
REMOVAL OF CONCRETE BUS PAD	SY	17	$200.00	$3,400.00
SAWCUT CONCRETE BUS PAD	LF	29	$25.00	$725.00
MILLED RUMBLE STRIP	LF	50	$40.00	$2,000.00
BARRIER - 32 INCH	LF	40	$70.00	$2,800.00
AGGREGATE BASE (TYPE II) (CLASS B)	CY	3	$100.00	$300.00
PAVEMENT MARKING (BUS STOP AHEAD)	SF	68	$20.00	$1,360.00
TRAFFIC CONTROL	LUMP SUM	1	$5,000.00	$5,000.00
CONSTRUCTION SUBTOTAL				$15,585.00
30% CONTINGENCY				$4,675.50
TOTAL				**$20,260.50**

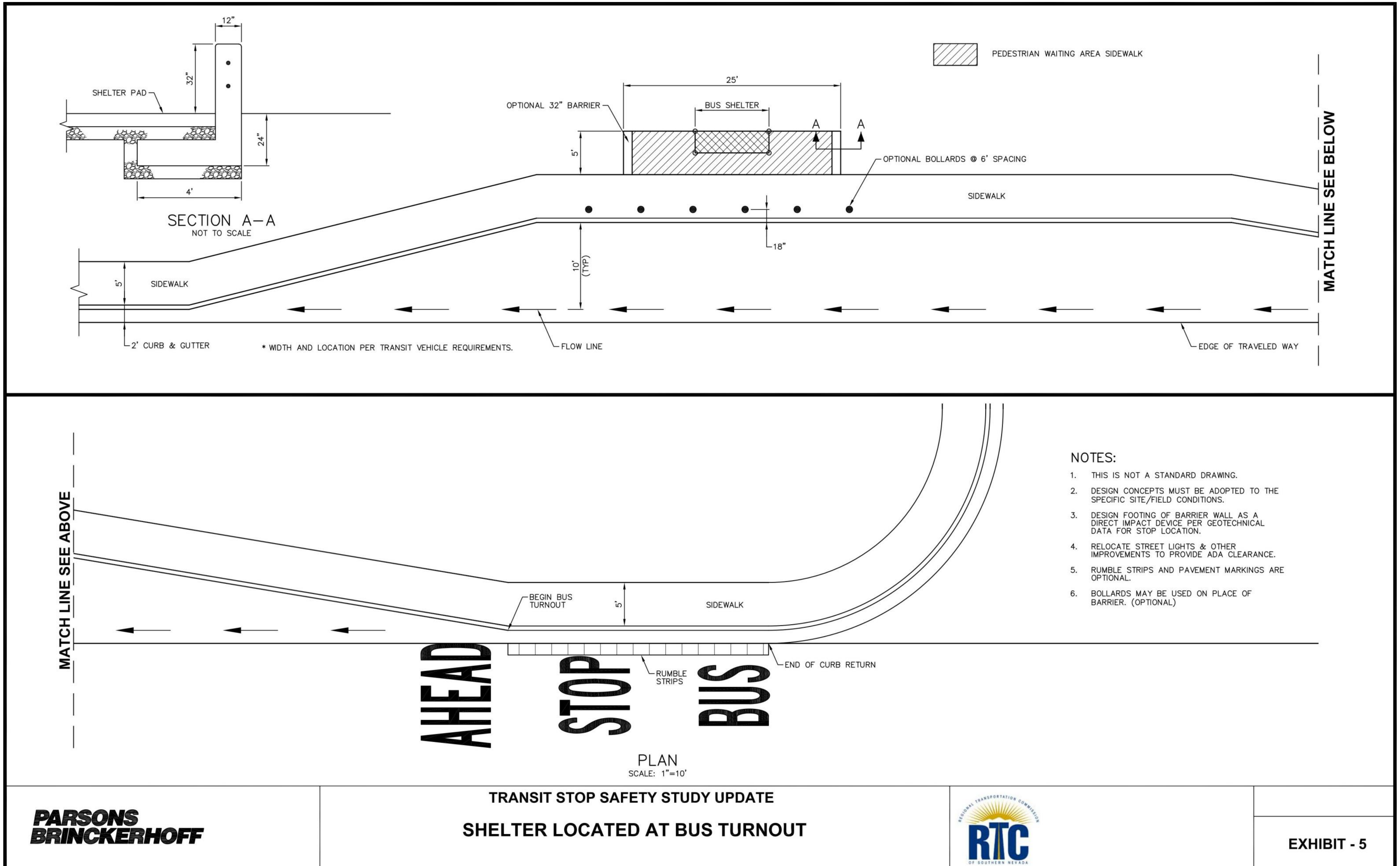

12"
32"
SHELTER PAD
24"
4'
SECTION A–A
NOT TO SCALE
PEDESTRIAN WAITING AREA SIDEWALK
25'
BUS SHELTER
OPTIONAL 32" BARRIER
A
A
5'
OPTIONAL BOLLARDS @ 6' SPACING
SIDEWALK
18"
10' (TYP)
5'
SIDEWALK
2' CURB & GUTTER
* WIDTH AND LOCATION PER TRANSIT VEHICLE REQUIREMENTS.
FLOW LINE
EDGE OF TRAVELED WAY
MATCH LINE SEE BELOW
MATCH LINE SEE ABOVE
NOTES:
1. THIS IS NOT A STANDARD DRAWING.
2. DESIGN CONCEPTS MUST BE ADOPTED TO THE SPECIFIC SITE/FIELD CONDITIONS.
3. DESIGN FOOTING OF BARRIER WALL AS A DIRECT IMPACT DEVICE PER GEOTECHNICAL DATA FOR STOP LOCATION.
4. RELOCATE STREET LIGHTS & OTHER IMPROVEMENTS TO PROVIDE ADA CLEARANCE.
5. RUMBLE STRIPS AND PAVEMENT MARKINGS ARE OPTIONAL.
6. BOLLARDS MAY BE USED ON PLACE OF BARRIER. (OPTIONAL)
BEGIN BUS TURNOUT
5'
SIDEWALK
RUMBLE STRIPS
END OF CURB RETURN
AHEAD
STOP
BUS
PLAN
SCALE: 1"=10'
PARSONS BRINCKERHOFF
TRANSIT STOP SAFETY STUDY UPDATE
SHELTER LOCATED AT BUS TURNOUT
EXHIBIT - 5

TABLE 10: COST ESTIMATE FOR SHELTER LOCATED AT BUS TURNOUT				
ITEM DESCRIPTION	**UNIT**	**QUANTITY**	**UNIT COST**	**AMOUNT**
REMOVAL OF CONCRETE SIDEWALK	SY	8	$15.00	$120.00
REMOVAL OF CONCRETE BUS PAD	SY	5	$200.00	$1,000.00
SAWCUT	LF	46	$10.00	$460.00
MILLED RUMBLE STRIP	LF	30	$40.00	$1,200.00
SAFETY BOLLARD	EA	6	$1,200.00	$7,200.00
LOW PROFILE BARRIER - 18 INCH	LF	10	$58.00	$580.00
CONCRETE SIDEWALK	SY	7	$50.00	$350.00
AGGREGATE BASE (TYPE II) (CLASS B)	CY	1	$200.00	$200.00
PAVEMENT MARKING (BUS STOP AHEAD)	SF	68	$20.00	$1,360.00
TRAFFIC CONTROL	LUMP SUM	1	$5,000.00	$5,000.00
CONSTRUCTION SUBTOTAL				$17,470.00
30% CONTINGENCY				$5,241.00
TOTAL				**$22,711.00**

5.0 RECOMMENDATIONS

After analyzing numerous options, Parsons Brinckerhoff has developed recommendations for the RTC to consider. These options are ranked in categories of their importance and are described below.

5.1 Primary Strategies

The "Primary Strategies" category includes options that should be thoroughly considered to increase the safety of transit riders and pedestrians at and around transit stops. Implementing just one of these options will increase the safety at transit stops, however it is recommend that a combination of the options will be considered.

The RTC is already implementing most of these measures as part of the adopted *Uniform Standards* and annual construction projects. Ideally, all of the options listed in this section will be implemented, which will greatly improve the safety at transit stops. The "Primary Strategies" options include:

- Move shelters behind the sidewalk
- Implement a pedestrian buffer
- Implement a bus turnout
- Conduct a Public Service Announcement Campaign

5.2 Primary Strategies But Needs Collaboration

The "Primary Strategies But Needs Collaboration" category includes options that should be thoroughly considered, however the RTC would need to collaborate with other agencies in order to follow through with the improvements. Similar to the "Primary Strategies" category, implementing just one of these options will increase the safety at transit stops. Ideally, both of the options will be implemented which will greatly improve the safety at transit stops. The "Primary Strategies But Needs Collaboration" options include:

- Implement Complete Streets design concepts including evaluating the reduction of speed limits on arterials with transit routes, where appropriate
- Implement random sobriety checkpoints on all arterials with transit routes

5.3 Secondary Strategies

The "Secondary Strategies" category includes options that will improve the safety at transit stops, however not as much as the previous two categories. It is recommended to consider the options in this category, on the other hand it is much more important to implement the options listed in the "Primary Strategies" and "Primary Strategies But Needs Collaboration" categories. The "Secondary Strategies" options include:

- Implement concrete planters with trees planted inside
- Relocate shelters adjacent to block walls

- Add solar powered LED shelter lighting
- Raise curbs at transit stops to allow for level boarding

5.4 Secondary Strategies If Other Measures Cannot Be Implemented

The "Secondary Strategies If Other Measures Cannot Be Implemented" category contains options that need to be considered if previous options mentioned are not feasible. These options will improve the safety at transit stops, however they may not be necessary if previous options are implemented. The "Secondary Strategies If Other Measures Cannot Be Implemented" options include:

- Implement a low profile barrier
- Implement high containment curbs
- Add "Bus Stop Ahead" pavement markings
- Add shoulder rumble strips
- Brightly paint the curb next to the transit stops
- Brightly paint the transit shelters
- Install a reflective coating on the outside of the transit shelters
- Install rear facing transit shelters

5.5 Last Resort

The "Last Resort" category consists of options that could improve the safety of transit riders at transit stops, however they could also introduce additional safety hazards that do not currently exist. These options should be considered only if all other options are not feasible. The "Last Resort" options include:

- Implement a bollard system
- Implement reinforced concrete trash receptacles
- Implement a handrail system
- Move the transit shelter to a side street

6.0 POLICY & GUIDELINES

The RTC should evaluate existing stop locations and implement the measures and strategies mentioned in this report where appropriate. The expanded range of measures provided will accommodate a variety of site conditions and facilitate policy and site design decision making.

7.0 CONCLUSION

The RTC has already incorporated most of the measures that are recognized as primary safety enhancement strategies and best practices. The findings and recommendations of this report will provide the RTC additional options to continue to improve transit stop safety and provide a positive experience for our transit community. These efforts, along with other programs for Complete Streets and safety awareness are what make the RTC a leader in the nation.

REFERENCES

[1] Schoenmann, Joe. *Accident Pushes Concerns About Bus Stop Safety Back Into Spotlight.* http://www.lasvegassun.com/news/2012/sep/14/accident-pushes-concerns-about-bus-stop-safety-bac/ Published 14 September 2012. Accessed 19 November 2012.

[2] *AASHTO Roadside Design Guide*. 4th Edition. Published 2011.

[3] *America Walks' Position Statement: Speed: A National Pedestrian Safety Issue*. www.americawalks.org/wp-content/upload/Speed2.pdf Accessed 19 November 2012.

[4] Organisation For Economic Co-operation And Development, European Conference Of Ministers Of Transport. *Speed Management*. www.internationaltransportforum.org/Pub/pdf/06Speed.pdf Published 2006. Accessed 19 November 2012.

[5] *Demonstration Projects On Setting And Enforcing Rational Speed Limits*. http://safety.fhwa.dot.gov/speedmgt/eng_spd_lmts/ Accessed 19 November 2012.

[6] *Traffic Calming*. http://en.wikipedia.org/wiki/Traffic_calming Accessed 19 November 2012.

[7] Monash University Accident Research Centre. *The Impact Of Lowered Speed Limits In Urban And Metropolitan Areas*. Published January 2008.

[8] *Do DUI Roadblocks Make Roads Safer?* http://www.duicheckpoints.org/ Accessed 19 November 2012.

[9] *Research Update: Sobriety Checkpoints Are Effective In Reducing Alcohol-Related Crashes*. http://www.cdc.gov/MotorVehicleSafety/Impaired_Driving/checkpoint.html Published December 2002. Accessed 19 November 2012.

[10] Warner, Charles J. *DUI Checkpoint Dedicated To Family Devastated By Impaired Driver*. http://www.franklintn.gov/index.aspx?page=25&recordid=1247&returnURL=%2Findex.aspx Published 23 January 2012. Accessed 19 November 2012.

[11] *Public Information Program*. http://www.ccrfcd.org/publicinformation.htm Accessed 19 November 2012.

[12] *APTA Standards Development Program, Recommended Practice, Bus Rapid Transit Stations And Stops*. www.aptastandards.com/Portals/0/Bus.../002_RP_BRT_Stations.pdf Published October 2010. Accessed 19 November 2012.

[13] *New Solar-Powered Transit Shelters Make A Debut*. http://www.clarkcountynv.gov/Depts/newsletters/districtc/Pages/DistrictCNewsletterJune2012.aspx Published Summer 2012. Accessed 19 November 2012.

[14] Smith, Trevor. *RTC Making Changes Before Deadly Crash*. http://lasvegas.cbslocal.com/2012/10/03/rtc-making-changes-before-deadly-crash/ Published 3 October 2012. Accessed 19 November 2012.

[15] *Translink Bus Stop Design Guide*. varlamov.me/img/moscow_busstops/busstop-designguide.pdf October 2005. Accessed 19 November 2012.

[16] *Better Boarding: Platform And Bus Design*. http://www.tstc.org/issues/brt/brtshow/boarding4.html Accessed 19 November 2012.

[17] *Road Kerbs & Channels, High Containment Kerb*. http://www.pavingexpert.com/edging5.htm Accessed 19 November 2012.

[18] *FHWA Mitigation Strategies For Design Exceptions, Chapter 7, Case Study 3 – State Route 99 Reconstruction, Low-Profile Barrier*. http://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/chapter7/7_lowbarrier.htm Published July 2007. Accessed 19 November 2012.

[19] *California Department Of Transportation, Development And Testing Of A Low-Profile Barrier*. http://www.dot.ca.gov/newtech/operations/roadsidesafety/low_profile_barrier/index.htm Published 20 April 2012. Accessed 19 November 2012.

[20] Palm Tran. *Transit Design Manual.* August 2004.

[21] Land Transportation Authority. *Safety Bollards.* http://www.onemotoring.com.sg/publish/onemotoring/en/on_the_roads/road_safety/safety_bollards.html Published 20 February 2012. Accessed 9 January 2013.

[22] Miami-Dade County. *Bus Bench And Shelter Cylindrical Post Protection Feasibility Study.* Published 31 August 2007.

[23] *Removable Bollards Offer "Flexible" Streetscapes*. http://landscapeonline.com/research/article/12514 Accessed 19 November 2012.

[24] Interclamp. *Handrails: Pedestrian Road Safety Barrier With Mesh Infill*. http://www.interclamp.com/en/gallery1-3 Accessed 9 January 2013.

[25] *Nitterhouse Concrete Planters*. http://www.nitterhouse.com/masonry/products/site_amenities/planters.php Accessed 19 November 2012.

[26] *Modrono, Native Plants Through A Modern Lens, Stormwater Infiltration Sidewalk Planters*. http://www.madrono.org/san-francisco-landscape/water/stormwater/stormwater-infiltration-sidewalk-planters.html Published 19 November 2012. Accessed 19 November 2012.

[27] Elysian Custom Concrete Products. *Concrete Landscape Products for Schools, Parks and Institutions*. http://www.elysianproducts.com/school-products.htm Accessed 9 January 2013.

[28] *Smart Growth America, Making Neighborhoods Great Together, National Complete Streets Coalition*. http://www.smartgrowthamerica.org/complete-streets/complete-streets-fundamentals/complete-streets-faq Accessed 19 November 2012.

[29] *Rumble Strip*. http://en.wikipedia.org/wiki/Rumble_strip Accessed 19 November 2012.

[30] *KSA, Community, High Street Crosswalks*. https://ksacommunity.osu.edu/mckee518osuedu/blog/2012/10/high-street-crosswalks Published 13 October 2012. Accessed 19 November 2012.

[31] http://dttocs.smugmug.com/photos/359850988_Xedxm-M.jpg Accessed 19 November 2012.

[32] http://rogerkramercycling.org/blog/wp-content/uploads/2010/12/021_21.jpg Accessed 19 November 2012.

[33] Marshalls. *Bus Stop Kerbs*. http://www.marshalls.co.uk/select/kerb Accessed 9 January 2013.

[34] Massachusetts Bay Transportation Authority. *Key Bus Route Improvement Program.* http://www.mbta.com/about_the_mbta/t_projects/default.asp?id=19047 Accessed 9 January 2013.

[35] *Metshelter Bus Shelter System*. http://www.metshelter.com/Gallery.php Accessed 19 November 2012.

[36] *2008 FDOT Design Standards, Low Profile Barrier*. www.dot.state.fl.us/rddesign/DS/08/IDx/412.pdf Accessed 19 November 2012

[37] Beason, W. Lynn; Menges, Wanda L.; Ivey, Don L. *Compliance Of An End Treatment For The Low-Profile Concrete Barrier*. d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/1403-S.pdf Published April 1998. Accessed 19 November 2012.

- Advance Transit. *Hanover Bus Stop Feasibility Study*. December 2008.

- Albuquerque, Sicking, and Stolle. *Roadway Departure And Impact Conditions*. 15 November 2009.
- APTA Standards Development Program. *Bus Stop Design And Placement Security Considerations*. 26 June 2010.
- APTA Standards Development Program. *Crime Prevention Through Environmental Design (CPTED) For Transit Facilities*. 24 June 2010.
- APTA Standards Development Program. *Fencing Systems To Control Access To Transit Facilities*. October 2009.
- Arlington Virginia. *Transit Development Plan: Fiscal Years 2011-2016*. 14 December 2010.
- ART – Arlington Transit. http://www.arlingtontransit.com/ Accessed 9 January 2013.
- Auckland Regional Transport Authority. *Bus Stop Infrastructure Design Guidelines*. May 2009.
- BC Transit. *Infrastructure Design Guidelines*. November 2010.
- BC Transit: British Columbia Transit Service. http://www.transitbc.com/ Accessed 9 January 2013.
- Brett Landscaping. *Kassel – Specialist Bus Boarding Kerb For Safe And Easy Passenger Access*.
- Caltrans. *Informing A Pedestrian Safety Improvement Program*. 14 December 2009.
- Caltrans. Pedestrian Accessibility *Guidelines For Highway Projects*. 18 August 2010.
- Caltrans. *Traffic Manual, Chapter 7, Traffic Safety Systems*. January 2012.
- Chicago Transit Authority. http://transitchicago.com/ Accessed 9 January 2013.
- City Of Peoria. *Bus Stop Design Standards*. June 2010.
- City Of Raleigh. *Passenger Amenity Guidelines & Transit Design Standards*. March 2011.
- City Of Toronto. *Accessibility Design Guidelines*. 2004.
- Civic Voice. *Street Pride Briefing 3: Bollards*. April 2010.

- Designing With Transit. *Making Transit Integral To East Bay Communities.* 2004.
- El Dorado County Transit Authority. *Transit Design Manual*. 9 November 2007.
- EPA. *Water Security: Security Product Guides: Passive Security Barriers.* 5 December 2012.
- Fairfax County. *Bus Stop Guidelines.* July 2004.
- FEMA. *Site and Urban Design for Security.* December 2007.
- Florida Department of Transportation. *District 4, Transit Facilities Guidelines, Version 3*. October 2007.
- Frederic County, Maryland. *Transit-Friendly Design Guidelines.* Marcy 2009.
- Geissler, Rebecca. *Mapping Safe Crossings And Bus Stops: A Case Study In Chicago To Improve Pedestrian Safety*. 30 March 2012.
- Georgia Department Of Transportation. *Design Policy Manual, Complete Streets Design Policy*. 21 September 2012.
- Georgia Department Of Transportation. *Georgia Bicycle And Pedestrian Safety Action Plan.*
- Institute Of Transportation Engineers. *Design And Safety Of Pedestrian Facilities*. 1998.
- LA Metro. http://www.metro.net/ Accessed 9 January 2013.
- Los Angeles County Metropolitan Transportation Authority. *Corporate Safety Report*. 2012.
- Los Angeles County Metropolitan Transportation Authority. *2012 Metro Transit Service Policy*. 2012.
- Massachusetts Bay Transportation Authority. http://www.mbta.com/index.asp Accessed 9 January 2013.
- Metro Transit. http://metro.kingcounty.gov/ Accessed 9 January 2013.
- Metropolitan Transit. *Bicycle And Pedestrian Connections To Transit Infrastructure Study*. 12 February 2009.

- National Capital Planning Commission. *Designing And Testing Of Perimeter Security Elements*.

- National Cooperative Highway Research Program. *Report 500, Volume 6: A Guide For Addressing Run-Off-Road Collisions*. 2003.

- National Cooperative Highway Research Program. *Report 500, Volume 10: A Guide For Reducing Collisions Involving Pedestrians*. 2004.

- National Cooperative Highway Research Program. *Report 500, Volume 14: A Guide For Reducing Crashes Involving Drowsy And Distracted Drivers*. 2005.

- National Cooperative Highway Research Program. *Report 500, Volume 16: A Guide For Reducing Alcohol-Related Collisions*. 2005.

- National Cooperative Highway Research Program. *Report 500, Volume 23: A Guide For Reducing Speeding-Related Crashes*. 2009.

- National Cooperative Highway Research Program. *Report 537, Recommended Guidelines For Curb And Curb-Barrier Installations*. 2005.

- National Cooperative Highway Research Program. *Report 612, Safe And Aesthetic Design Of Urban Roadside Treatments*. 2008.

- New Jersey Transit. http://njtransit.com/ Accessed 9 January 2013

- New Jersey Transportation Planning Authority. *Pedestrian Safety At And Near Bus Stops Stud*y. June 2011.

- New York City Department of Transportation. http://www.nyc.gov/html/dot/html/home/home.shtml Accessed 9 January 2013.

- New York City Department Of Transportation. *School Safety Engineering Project*. April 2004.

- New York City Department Of Transportation. *The New York City Pedestrian Safety Study & Action Plan*. August 2010.

- NDOT. *Nevada Traffic Crashes, 2007-2009*. 2010.

- NDOT. *Nevada Traffic Crashes, 2010*. 2011.

- Omnitrans. http://www.omnitrans.org/ Accessed 9 January 2013.

- Omnitrans. *Bus Stop Design Guidelines*. 4 October 2006.
- Omnitrans. *Transit Design Guidelines.*
- Orange County Transportation Authority. http://www.octa.net/Index.aspx Accessed 9 January 2013.
- Orange County Transportation Authority. *Bus Stop Safety And Design Guidelines*. 24 March 2004.
- Pace Suburban Bus Service. http://pacebus.com/ Accessed 9 January 2013.
- Pima County Department Of Transportation. *Transit Guidelines For Roadway Design And Construction*. January 2009.
- Regional Public Transportation Authority. *RPTA Bus Stop Program And Standards.* March 2008.
- Regional Transportation District. *RTD Transit Access Guidelines*. January 2009.
- *San Francisco Better Streets Plan.* December 2010.
- San Francisco Municipal Transportation Agency. http://www.sfmta.com/cms/home/sfmta.php Accessed 9 January 2013.
- Sound Transit. *Design Standards And Guidelines For Transit Projects: Sounder & ST Express Passenger Facilities*. 22 January 2007.
- *South Los Angeles Transportation Master Plan*. April 2009.
- Southeastern Pennsylvania Transportation Authority. http://www.septa.org/index.html Accessed 9 January 2013.
- State Of Florida Department Of Transportation. *From Bus Shelters To Transit Oriented Development*. March 2004.
- State Of Florida Department Of Transportation. *Integrating Transit Into Traditional Neighborhood Design Policies – The Influence Of Lane Width On Bus Safety*. June 2010.
- State Of Florida Department Of Transportation. *Safer Stops For Vulnerable Customers*. March 2003.

- State Of Florida Department Of Transportation. *Transit Facility Handbook*. 11 October. 2007.

- State Of Oregon. *Toolkit For The Assessment Of Bus Stop Accessibility And Safety*. August 2011.

- The City and County of Honolulu. http://www.honolulu.gov/government/ Accessed 9 January 2013.

- The Institute Of Transportation Engineers Traffic Engineering Council. *Lower Speed Limits*.

- Titan High Containment Concrete Kerb System. http://www.marshalls.co.uk/select/kerb/high-containment/titan-kerb Accessed 19 November 2012.

- Toronto Transit Commission. http://www.ttc.ca/ Accessed 9 January 2013.

- Toronto Transit Commission. *Transit City Bus Plan*. August 2009.

- Transit Cooperative Research Program. *Report 46, The Role Of Transit Amenities And Vehicle Characteristics In Building Transit Ridership: Amenities For Transit Handbook And The Transit Design Game Workbook*. 1999.

- Transit Cooperative Research Program. *Report 125, Guidebook For Mitigating Fixed-Route Bus-And-Pedestrian Collisions*. 2008.

- Transport. *State Transit Bus Infrastructure Guide*. July 2011.

- Transportation Alternatives. *Rethinking Bollards: How Bollards Can Save Lives, Prevent Injuries, And Relieve Traffic Congestion In New York City*. July 2007.

- Transportation For America. *Dangerous By Design: Solving The Epidemic Of Preventable Pedestrian Deaths*. 2011.

- Transportation Research Board. Chapter 4, Curb-Side Factors. onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_19-c.pdf Accessed 19 November 2012.

- Trimet. *Bus Stops Guidelines*. July 2010.

- Trimet. *Pedestrian Network Analysis*.

- TriMet: Public Transit in the Portland Area. http://trimet.org/ Accessed 9 January 2013.

- Truong, Long Tien; Somenahalli, Sekhar V.C. *Using GIS To Identify Pedestrian-Vehicle Crash Hot Spots And Unsafe Bus Stops*. 2011.

- U.S. Department Of Transportation, Federal Transit Administration. *Transit Security Design Considerations*. November 2004.

- U.S. Department Of Transportation Federal Highway Administration, Institute Of Transportation Engineers. *Toolbox Of Countermeasures And Their Potential Effectiveness For Intersection Crashes*. September 2007.

- Utah Transit Authority. http://www.rideuta.com/ Accessed 9 January 2013.

- Valley Metro. http://www.valleymetro.org/ Accessed 9 January 2013.

- Washington Metropolitan Area Transit Authority. Bus Stop Design, Information, And Placement. 19 November 2009.

- Washington Metropolitan Area Transit Authority. *Guidelines For The Design And Placement Of Transit Stops For The Washington Metropolitan Area Transit Authority*. December 2009.

- WSDOT. *Design Manual, Transit Facilities*. June 2009.

- World Health Organization. *Road Safety Is No Accident*. November 2003.

APPENDIX

Vehicle to Transit Shelter Crashes

- Table
- Map

Detailed Bollard Findings

Vehicle to Transit Shelter Crashes – Table

VEHICLE TO TRANSIT SHELTER CRASHES						
#	LOCATION	FATAL	INJURED	SIDEWALK?	ROW?	DESCRIPTION
SHELTERS HIT 2007						
1	WB TROPICANA W/O RAINBOW NS			On sidewalk	No ROW	
2	NB RAINBOW N/O CHARLESTON ES			On sidewalk		Moved behind sidewalk
3	STEPHANIE/WARM SPRINGS			On sidewalk	ROW	Stop closed
4	NB BOULDER HWY S/O RUSSELL ES			On sidewalk	ROW	
5	WB BONANZA W/O MOJAVE SS			On sidewalk	No ROW	
6	SB MARYLAND PKY S/O DI WS			On sidewalk	No ROW	Bench
7	WB MARYLAND E/O CASHMAN CTR NS			Behind sidewalk		
8	WB PASEO VERDE W/O PALOMINO NS			On sidewalk		Stop closed
9	WB DI W/O SANDHILL NS			On sidewalk	No ROW	
10	WB MEADOWS .2 MILE W/O VALLEY VIEW NS			On sidewalk	No ROW	Asked for easement - no
11	EB LAKE MEAD BLV E/O DECATUR SS			On sidewalk	No ROW	
12	WB CHEYENNE W/O MICHAEL WAY NS			On sidewalk	No ROW	
13	SB PARADISE S/O TROPICANA WS			On sidewalk		Stop closed
14	EB SAHARA E/O FT APACHE SS			On sidewalk		BRT Station
15	WB SAHARA W/O RANCHO NS			On sidewalk		BRT Station
16	CIMARRON / TROPICANA			On sidewalk	No ROW	
17	SB LVB S/O OAKEY WS			On sidewalk	No ROW	
18	NB LVB N/O 4TH ST ES			On sidewalk	No ROW	Stop closed
19	WB CHARLESTON @ PECOS NS			On sidewalk		Moved behind sidewalk
20	NB MLK N/O ALTA ES			On sidewalk	No ROW	
21	SB VALLEY VIEW S/O ALTA WS			On sidewalk		Moved behind sidewalk
22	EB LAKE MEAD BLV. E/O CIVIC CENTER SS			Behind sidewalk		Turnout
23	EB WASHINGTON E/O MLK SS			On sidewalk	No ROW	
24	SB MLK S/O BULZAR WS			On sidewalk	No ROW	
SHELTERS HIT 2008						
1	NB CIVIC CENTER N/O MCDANIELS ES			Behind sidewalk		
2	WB CHEYENNE E/O MIRAMAR NS			On sidewalk	No ROW	
3	NB ARROYO GRANDE N/O WIGWAM ES			On sidewalk		Stop Closed
4	SB MLK S/O GOWAN WS			On sidewalk	No ROW	
5	SB PECOS S/O LAKE MEAD BLV WS			On sidewalk	PUE	
6	SB LVB S/O SILVERADO RANCH WS			On sidewalk	No ROW	9' sidewalk
7	WB SAHARA W/O ATLANTIC NS			On sidewalk	ROW	BRT Station
8	WB PASEO VERDE W/O CORP CTR ENTRANCE			On sidewalk	No ROW	Stop Closed
9	SB RANCHO S/O MICHAEL WAY (N OF CHEYENNE)			On sidewalk	No ROW	
10	SB RAINBOW S/O ALTA WS			On sidewalk	PUE	
11	SB BOULDER HWY S/O 95 ENTRANCE WS			On sidewalk		Stop Closed
12	SB LAMB S/O OWENS WS			Behind sidewalk		
13	WB TROPICANA W/O JONES NS			On sidewalk	PUE	
14	SB RAINBOW S/O CHARLESTON WS			On sidewalk	ROW	
15	WB LAKE MEAD BLV W/O MLK NS			On sidewalk		Turnout
16	WB TROPICANA W/O MTN VISTA NS (repaired shelter)			On sidewalk	No ROW	
17	WB FLAMINGO W/O DUNEVILLE NS (charles pulled)			On sidewalk	No ROW	
18	SB RANCHO S/O SANTE FEE WS (charles pulled)			On sidewalk	ROW	
19	EB CHARLESTON E/O PALM SS			On sidewalk	No ROW	
20	NB BOULDER HWY N/O GLEN ES (city removed??)			On sidewalk	ROW	Stop Closed
21	SB EASTERN S/O BONANZA WS			On sidewalk	No ROW	
22	NB BOULDER N/O LAKE MEAD ES			On sidewalk	ROW	Stop Closed
23	WB TROPICANA W/O PARADISE NS			On sidewalk	No ROW	Airport Property
24	NB BOULDER HWY N/O FLAMINGO ES (1 fatility)	1	1	Behind sidewalk		BRT Station
25	SB LVB N/O BONANZA WS			On sidewalk	No ROW	
26	EB TROPIANA E/O MOJAVE SS	0	1	On sidewalk	PUE	
27	SB BOULDER HWY N/O LAKE MEAD PKY WS			Behind sidewalk		no curb
28	WB CHEYENNE W/O PECOS NS (CALIFORNIA SHELTER			Behind sidewalk		
29	WB SPRING MTN W/O JONES NS			On sidewalk	No ROW	
30	WB SPRING MTN W/O VALLEY VIEW NS			On sidewalk	No ROW	
SHELTERS HIT IN 2009						
1	EB CRAIG W/O BERG SS (E/O Losee)			On sidewalk	No ROW	
2	EB LAKE MEAD BLV. E/O LOSEE SS			On sidewalk	ROW	
3	SB RAINBOW S/O DEWY WS (100 YD N/O RUSSELL)			On sidewalk	No ROW	
4	WB SAHARA W/O SANDHILL NS			On sidewalk	No ROW	

Vehicle to Transit Shelter Crashes – Table

VEHICLE TO TRANSIT SHELTER CRASHES						
#	**LOCATION**	**FATAL**	**INJURED**	**SIDEWALK?**	**ROW?**	**DESCRIPTION**
5	WB CHARLESTON W/O PALMHURST NS			On sidewalk	No ROW	
6	EB SUNSET E/O ATHENIAN SS			On sidewalk	No ROW	
7	WB CHEYENNE W/O RANCHO NS			On sidewalk	PUE 3'	Phase III
8	SB PARADISE S/O GUS GIUFFRE WS			On sidewalk	No ROW	Airport Property
9	WB SUNSET W/O MTN. VISTA NS			On sidewalk	No ROW	
10	WB TROP E/O NELLIS NS			On sidewalk	No ROW	Bench
11	EB LAMB E/O BOULDER HWY SS			On sidewalk	No ROW	
12	NB STEPHANIE N/O SANTIAGO ES			On sidewalk	ACA	8.5' sidewalk. Low ridership
13	NB RAINBOW N/O PALMYRA ES (CC)			On sidewalk	No ROW	
14	SB LVB N/O PECOS WS			On sidewalk		Closed
15	SB RANCHO S/O BONANZA			On sidewalk		City planning turnout
16	SB TORRY PINES S/O LAKEMEAD			Beind Sidewalk		Closed
17	NB BOULDER HWY S/O LOWES ES			On sidewalk	ROW	Phase I
SHELTERS HIT IN 2010						
1	EB SAHARA E/O TORREY PINES SS			On sidewalk		BRT Station
2	NB LVB S/O WALNUT ES			On sidewalk	ROW	Stop Closed
3	WB CRAIG RD W/O WALNUT NS			On sidewalk	No ROW	
4	EB CHARLESTON W/O JONES SS			On sidewalk		Partial pad
5	NB RANCHO N/O LAKEMEAD BLVD ES	0	3	On sidewalk	No ROW	Talked to hotel
6	NB DECATUR N/O OAKEY ES			On sidewalk	PUE	Breakdown lane
7	SB EASTERN N/O WARM SPRINGS			On sidewalk	PUE	
8	NB EASTERN N/O WASHINGTON			On sidewalk	No ROW	9/5' sidewalk
SHELTERS HIT IN 2011						
1	EB WASHINGTON AVE E/O MINNESOTA			On Sidewalk	No ROW	Breakdown Lane
2	WB LAKE MEAD BLV W/O BUFFALO DRIVE NS			Behind Sidewalk		
3	SB GREEN VALLEY PARKWAY LA MESA DRIVE WS			On Sidewalk		
4	EB CHARLESTON BLVD E/O DURANGO DRIVE SS			On Sidewalk	No ROW	
5	EB CAREY AVE E/O LVB SS			Behind Sidewalk		
6	EB SPRING VALLEY PKY W/O RAINBOW BLVD SS			On Sidewalk	PUE	Low Ridership
7	EB FLAMINGO RD E/O JONES BLV SS			On Sidewalk	PUE	Phase III
8	EB TROPICANA AVE E/O SEPUVEDA SS			On Sidewalk	No ROW	
9	NB MARYLAND PKY N/O ROCHELLE AVE ES			On Sidewalk	No ROW	
10	NB VAN WAGENEN N/O PACIFIC ES			On Sidewalk	No ROW	
11	EB TROPICANA AVE E/O BOULDER HWY SS			On Sidewalk	No ROW	
12	SB RAINBOW BLV S/O SMOKE RANCH RD WS			On Sidewalk	No ROW	
13	SB JONES BLV S/O EUGENE AVE WS			Behind Sidewalk		
14	WB FLAMINGO RD W/O BOULDER HWY NS			On Sidewalk	No ROW	
15	NB RAINBOW BLV N/O ALTA DR ES (LVMPD 111110-0340)			Behind Sidewalk		Phase I
16	WB SAHARA AVE W/O SLOAN LANE NS			Behind Sidewalk		Turn Lane
17	SB MLK BLV N/O VEGAS DRIVE WS			On Sidewalk		Phase I
SHELTERS HIT IN 2012						
1	EB TROPICANA AV E/O MARYLAND PKY SS #1			On Sidewalk		Phase III
2	EB TROPICANA AV E/O MARYLAND PKY SS #2			On Sidewalk		Phase III
3	WB SPRING MTN RD W/O EL CAMINO RD NS	0	1	On Sidewalk	PUE	Phase III
4	WB CHARLESTON BLV W/O DECATUR BLV			Behind Sidewalk		Turn Lane
5	NB 13TH ST N/O STEWART AVE ES			Behind Sidewalk		
6	WB TROPICANA W/O SPENCER NS			On Sidewalk	No ROW	
7	SB NELLIS BLV S/O SAHARA AVE WS			On Sidewalk	No ROW	Turnout
8	EB LAKE MEAD BLV E/O TORREY PINES DR SS			Behind Sidewalk		Turn Lane
9	NB MLK BLV N/O GOWAN			On Sidewalk	No ROW	Block Wall
10	WB SPRING MOUNTAIN RD W/O ARVILLE ST NS			On Sidewalk	No ROW	
11	EB TROPICANA AVE E/O ARVILLE ST SS			On Sidewalk	No ROW	
12	SB EASTERN AVE S/O OWENS WS	0	3	On Sidewalk	No ROW	
13	WB CHARLESTON BLV W/O RAINBOW BLV NS			Behind Sidewalk		Phase II
14	EB CHARLESTON E/O LAMB SS	0	1	On Sidewalk	No ROW	
15	EB SPRING MOUNTAIN E/O DECATUR SS	4	8	On Sidewalk	No ROW	
16	EB Craig E/O Clayton	0	0	Behind Sidewalk		3' pad
	TOTAL	**5**	**18**			

Vehicle to Transit Shelter Crashes – Map

Detailed Bollard Findings

OMNITRANS – DRAFT Transit Design Guidelines (November 2012)

The uses of bollards in the Transit Design Guidelines are outlined as follow:

- Used as a physical separator between Dedicated Bus-Only Lanes and mixed-flow traffic. (pg. 156)
- Physical security feature that enhances patron and personnel security. Barriers/bollards can be used to provide: safety; theft deterrence; asset protection; pedestrian vs. vehicle separation; pedestrian control; and traffic control. Properly designed and installed barriers are effective in controlling both pedestrian and vehicular movement inside a facility, within a facility's perimeter, or gaining access to the exterior of the facility. (pg. 175)

Tri-County Metropolitan Transportation District of Oregon (TriMet) – Bus Stop Guidelines (July 2010)

- Figure 23 shows a detail of Bollard design and Figure 24 shows Bollard Installation details. According to the bollard installation detail, the bollard is mainly used as a separation between a bus shelter and a parking area behind it. No further write-up regarding bollard use or any other application for bollards was discussed in the literature.

APTA Standards Development Program – Recommended Practice - APTA SS-IS-RP-008-10 "Bus Stop Design and Placement Security Considerations" (2010) – *This Recommended Practice provides guidance on the security concerns to transit agencies when considering the design and placement of bus stops.*

- At high-consequence locations as identified in the agency's risk assessment, the use of bollards and other barriers such as planters to assist in buffer zone protection and stand-offs to mitigate vehicle encroachment and enhance pedestrian safety should be considered.

USDOT/FTA – Transit Security Design Considerations (November 2004)

This document provides an overview of the major assets of transit systems—bus vehicles, rail vehicles, and transit infrastructure and communications—as well as a preliminary assessment of the vulnerabilities to various methods of attack inherent in each asset. In addition, this document addresses the topics of access management, systems integration, and communications—all crucial to the protection of transit assets. Although many of the subject areas are addressed discretely in the document, users of the resource must recognize the interconnectivity of the considerations and hardening strategies that are presented. For this reason, consulting the sections on both infrastructure and access management will provide additional value when developing a strategy for protecting and hardening a maintenance facility or rail terminal.

Developed by the Federal Transit Administration in collaboration with transit industry public and private sector stakeholders, these design considerations provide actionable steps that transit agency staff can select from to create a security strategy.

- Bollards are identified as a fabricated/structural barrier in many situations within the literature. It could be used as:
  - Perimeter-control barrier – establish a secure boundary around an area, and limit access to and from that area to admission-control points. They may be designed to prevent some types of movement while permitting others and barriers can be placed to direct passenger flow and deter access to isolated or hidden locations.
  - Passive vehicle barrier – can be used on inbound and outbound roadways to control vehicle speed and low incoming vehicles before they reach the facility gate/active barrier so that security personnel have adequate time to respond to unauthorized activities. Barriers protect facilities, critical infrastructure, and people from both errant and terrorist vehicle attacks. Other applications of barriers are outlined below:
    - Asset Protection – barriers can protect assets from intentional or unintentional ramming by vehicles. For example, bollards can be used around fueling stations, around guardhouse entrances to protect guards and equipments, or at station entrances to protect pedestrians.
    - Vehicle Speed – barriers can limit vehicle speeds on facility approaches using speed controls.
    - Vehicle Stops – barrier can stop unauthorized vehicles from proceeding through vehicle checkpoints/entryways.
    - Vehicle Restriction – barriers can be used to restrict vehicle entry, limiting access to agency vehicles only.
    - Traffic Direction – barriers can channel traffic at an approach or within a facility.
    - Revenue Collection – barriers can enforce revenue collection at parking lots and garages.
    - Theft Deterrence – barriers can deter theft at parking lots and garages.

New York City Department of Transportation (NYCDOT) – School Safety Engineering Report General Mitigation Measures – Final Report (April, 2004)

This report is a general discussion of traffic safety measures that could be used in the vicinity of schools. The mitigation measures presented in this document offer a range of actions - from simple programs to more costly capital investments—that can be taken to achieve the desired goal of improving a child's safety as he or she travels to and from school. The report enumerates different applications of bollards and is discussed below:

- NYCDOT Design Considerations for Neckdowns, Geometric and Construction Requirements – Bollards, planters, or other street furniture may be included in the neckdown. The design and placement of street furniture shall not impede pedestrian flow, present a trip hazard, or interfere with "day-lighting" the intersection, emergency operations, or sight lines. A sign, bollard, or other vertical device shall be placed on the neckdown to alert drivers to the presence of the neckdown. The design placement of the device shall not obstruct emergency operations or sightlines.

- Chapter 4: Passive Traffic Calming – These elements do not force a change in driver behavior, but provide visual or other cues that can encourage drivers to travel at slow speeds.
  - Streetscape Improvements
    - Bollards – are a form of rigid traffic barrier used to prevent vehicles that leave the roadway from hitting a pedestrian or hitting an object that has a greater crash severity potential than the bollard itself. Because bollards are a source of crash potential themselves, their use must be carefully considered. The NYCDOT policy for bollards are given below:
    - Purpose – the purpose of rigid bollards is to protect pedestrians from collisions with motor vehicles, usually at location with unusual roadway geometry. This is accomplished by: redirecting or decelerating errant motor vehicles away from pedestrians; preventing motor vehicles from entering sidewalks o other off-street locations where frequent unlawful incursions occur; defining appropriate locations for vehicles to travel and for pedestrians to assemble.
    - Consideration – bollards should be considered:
      - There is a need to better manage vehicular movements;
      - Accidents analyses demonstrate a safety issue involving off-street impacts with pedestrians;
      - There are a substantial number of pedestrians present;
      - The bollards would not create a significant roadway hazard to motor vehicles;
      - Alternatives to bollards (e.g. guide rail, planters, crash cushions) have been explored and found unsuitable.
      - Additional factors need to be considered in the placement of bollards: loading and unloading of goods and passengers; access for fire, ambulance, police or other emergency vehicles; sidewalks access for persons parking their vehicles; bus stops; fire hydrants, utility access and other street furniture.
    - Design Issues
      - Bollards should only be installed off-street on sidewalks or raised median refuge areas.
      - Bollards should be set back from the curb from 18” to 24”.
      - When installed on curves, bollards should be installed on the outside of the horizontal curve of the roadway.
      - Bollards should not interfere with access to pedestrian ramps.
      - A minimum distance of 60” should be provided between bollards if the pedestrian path moves between the bollards or 48” where additional impact resistance must be provided.
      - Bollards should not adversely affect pedestrian level of service (i.e., maintain LOS B or better).
      - Bollards may be used in conjunction with other rigid barriers including raised planters and seating.
    - Construction and Installation Issues
      - The height of the bollard should be from 30” to 42”.

  - Bollards may be made of metal, stone, or a combination.
  - Bollards may be of an energy-absorbing design.
  - Bollards should be configured as a post, inverted U, or bell-shaped.
  - Bollards should have a pleasing appearance appropriate to their surroundings.
  - Bollards should be set into the ground with permanent footings.
  - Maintenance agreements and revocable consent agreements should be established for installation of non-DOT bollards.
- Recommendation
  - Bollards may have application as a school safety measure. Potential uses include placement perpendicular to the curb to delineate driveways where school buses or other vehicles may enter school property.

Civic Voice – Street Pride Campaign – Briefing Note 3 – Bollards, United Kingdom (April 2010)

Street Pride is Civic Voice's national campaign supporting local action to help rid streets of unnecessary clutter. Street Pride is focused on the four most widespread sources of street clutter: bollards; signs; posts (including lampposts and traffic lights) and guard rails.

According to the campaign pamphlet, bollards are primarily used to protect a footway area from access by vehicles. This may be to prevent parking, to guide moving vehicles and protect pedestrians at a tight junction or crossover, or just to highlight an informal pedestrian crossing. They may also be used as part of traffic calming or cycle priority measures. Bollards are used more out of expediency than design as pavements tend not to be constructed sufficiently strongly to support over running vehicles. Many towns and cities have wide pavements in areas of parking control, and highway authorities will use bollards to prevent pavement parking either on the pavement itself, or on the forecourts behind them.

Street Pride suggests that bollards should be avoided if possible, and, if used, should be part of a coordinated street furniture design, and even then, only in moderation. Highway authorities have powers to erect bollards under the Highways Act 1980. Town and parish councils do not have express powers to erect bollards though they have a power to maintain footways. Parking on private forecourts is legitimate however access to such parking space is usually illegally across a footway and prevention of this often involves bollard installation. Bollards are not erected at any regulated or standard distances, though they should be clear of the main carriageway, usually 450 mm minimum from the kerb.

Street Pride mentions that there should be a presumption against installing bollards unless absolutely necessary. Strengthening pavements and improving pavement parking enforcement should be reviewed first. Bollards might be retained where they prevent access to the pavement where there is a high probability of pavement parking or casual over-run that might endanger a pedestrian, particularly those with mobility impairment. Removing bollards is justifiable where the circumstances of vehicle overrun are substantially reduced only occasional, and where the likelihood of conflict with the pedestrians is or can be made negligible.

The first steps for alternative are to see if the vehicle control can be carried out in another way. This means reviewing whether the highway might be altered to accommodate more parking, or improving parking enforcement. Reinforced paving slabs are now available that allow occasional vehicular over-run on the footway, for use where street clutter reduction is a priority. Other traffic control methods include:

- Raising the kerb height to dissuade vehicle over-run
- Raising the pavement height using a double kerb
- Using cycle racks and lamp posts instead.

Shared surface pedestrian zones are often cluttered with bollards to delineate a vehicle track. There are plenty of pedestrian schemes that do not use bollards that show this is not necessary. Where bollards are used, alternatives to standard functional types can add character to the street. Regeneration schemes are excellent opportunities to provide bollards that are locally distinctive and provide an opportunity for public art.

United States Environmental Protection Agency (EPA) Water Security Product Guides – Passive Security Barriers

One of the most basic threats facing any facility is from intruders accessing the facility with t he intention of causing damage to its assets. These threats may include intruders actually entering the facility, as well as intruders attacking the facility from outside without actually entering. One of the most effective ways to counter the threat of intruders accessing a facility or the facility perimeter is to install security barriers around the facility's perimeter. Security barriers (bollards or security planters) can be used along the facility perimeter to establish a protective buffer area between the facility and approaching vehicles.

Passive security barriers are typically used in areas where access is not required or allowed – such as long building perimeters on in traffic control areas. Passive security barriers are typically large, heavy structures that are usually several feet high, and they are designed so that even heavy-duty vehicles cannot go over or through them. Therefore, they can be placed in a roadway parallel to the flow of traffic so that they direct traffic in a certain direction, or perpendicular to traffic such that they prevent a vehicle from using a road or approaching a building or area.

- Bollards – cylindrical barriers that are place at discrete intervals in a traffic area such that they block vehicles from passing between then, while allowing pedestrians through. The concept behind a bollard barrier system is to obstruct the part of the pathway of a vehicle. The bollards are typically placed 4-5 feet apart so that vehicles cannot pass between them without hitting the bollards. Bollards are typically at least 3 feet high (some may be 7 feet tall or higher) so that vehicles cannot go over them without becoming stuck or damaging their transmissions. Typical bollards are 1-2 feet in diameter, and many are specifically designed to withstand vehicular impacts without crumbling or breaking off. Thus, even if a vehicle hits a bollard directly, it cannot pass over or through it.

  Bollards can be fixed in place, removable or retractable. Fixed bollards can be constructed from any type of material. They are anchored in place as needed, and are typically used along sidewalks or in areas where traffic can be blocked permanently. These types of bollards are anchored by imbedding them into the ground/driveway surface using some type of anchoring material. Some bollards have side pins that extend out from the bollard's base into the imbedding matrix. These pins can provide extra impact stability to the bollard. Typical applications of fixed bollards are for roadways and sidewalks. The advantage of fixed bollards is that it can be spaced to prevent vehicles from passing them and minimal maintenance after installation. The disadvantage is that once installed, fixed bollards cannot be moved to adapt to changing security needs.

The San Francisco Better Streets Plan, sfbetterstreets.org – (December 2010)

San Francisco's policies encourage the design and development of 'Better Streets' sometimes referred to as 'Complete Streets,' that work for all users. The San Francisco Better Streets Plan, adopted in December 2010, states:

> Better Streets are designed and built to strike a balance between all users regardless of physical abilities or mode of travel. A Better Street attends to the needs of people first, considering pedestrian, bicyclists, transit, street trees, stormwater management, utilities, and livability as well as vehicular circulation and parking.

Street furnishings provide important amenities for pedestrians by adding functionality and vitality to the pedestrian realm. They announce that pedestrians are welcome and that the street is a comfortable place to be. These amenities provide functional service to the pedestrian and provide visual detail and interest. Pedestrian amenities should be considered a requisite public expenditure just as other necessary elements of the street, such as traffic signals and signage. Improved street vitality has been shown to improve public safety and comfort, health of local businesses, local real estate value, and transportation habits.

Bollard is a short vertical post or similar structure that can define areas in the streetscape and provide an attractive design element. Bollards are primarily a safety element often used to separate pedestrians or streetscape elements from vehicles. By placing them in a line, bollards are used to prevent motor vehicles from encroaching on pedestrian space such as sidewalks or plazas. Attractively designed bollards add color and interest to streetscapes, help define pedestrian spaces, and provide a spot to lean on or rest at.

Location of Bollards:

- Bollards should be used at sidewalk locations where vehicles attempting to park are damaging sidewalk structures, trees or plantings, furnishings, or adjacent private property, especially on narrow streets.
- Bollards should be considered for installation on median islands, curb extensions (except transit bulb-outs), and mid-block curb extensions, where there is a risk of danger to pedestrians due to proximity of travel lanes.
- Attractive bollards can also be used in special locations, including pedestrian-oriented spaces such as shared public ways or pedestrian-only streets, to designate unique spaces. Lighted bollards can create a special pedestrian environment, and may be particularly useful to provide additional pedestrian lighting in median refuges.

- Removable bollards should be placed at entrances to streets that are closed to vehicles for pedestrian use, to alert drivers to the changed nature of the street. Similarly, removable bollards can define the outside edge of Parklets where the space has been converted to pedestrian use.
- Bollards should be placed 18 inches from the back of the curb. If there is no parking in the bollard placement area, the bollard may be installed immediately adjacent to the back of the curb.
- Standard bollard spacing is approximately 10 feet on center, but may need to be reduced where there is a need to block vehicular traffic. Spacing should vary to sync with the rhythm of lighting fixtures, trees and landscaping, and other elements in the streetscape.

Design of Bollards:

- Bollards typically range in size from 4 to 10 inches in diameter; decorative bollards can be larger and vary in form.
- Bollards should have articulated sides and tops to provide design detail. Bollards should be painted in colors other than gray to be easily seen by the visually impaired, in colors that complement other streetscape elements.
- Bollards should be designed within a ‘family’ of streetscape elements.
- In circumstances where bollards are used to temporarily close a street or flexible parking space, removable bollards should be designed with long sturdy pipe projections from the bottom that fit into a hole in the ground. Removable bollards should be designed and installed such that, when in place, they are sturdy and look permanent. Electronic retractable bollards that can be lowered into the roadway to selectively allow vehicles to pass, should be considered where streets are closed to allow emergency vehicle access.

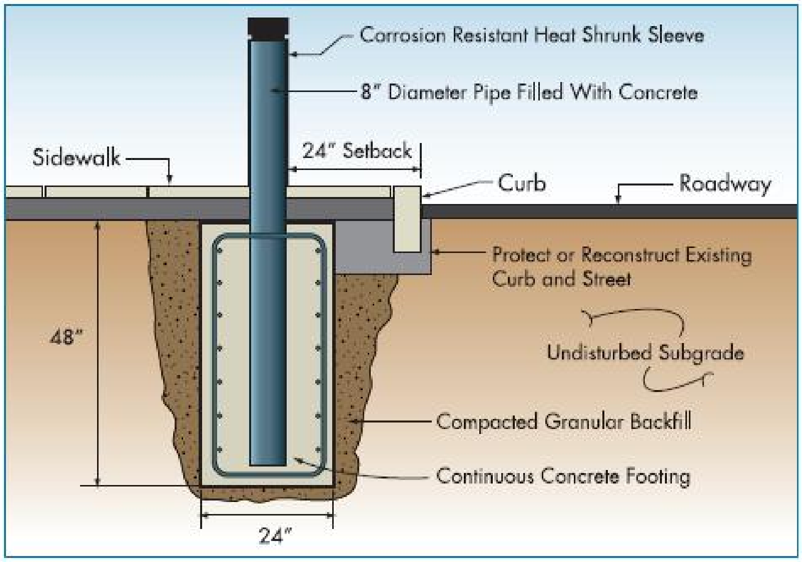
Federal Emergency Management Agency (FEMA) – Site and Urban Design for Security: Guidance against Potential Terrorist Attacks – FEMA 430 (December 2007)

This publication has been developed to provide information and design concepts for protection of buildings and occupants, from site perimeters to the faces of building. The main objective of this manual is to reduce physical damage to buildings and related infrastructure through site design, the purpose of FEMA 430 is also to ensure that security design provides careful attention to urban design values by maintaining or even enhancing the site amenities and aesthetic quality in urban and semi-urban areas.

Chapter 4 discusses the general issues of barrier system design, with emphasis on striking a balance between security needs and the preservation of the amenity and day-to-day functions of the site. This section ends with a description of the present barrier crash test standards. This chapter also describes and illustrates the various types of passive and active barriers that are currently available and in use.

Fixed Bollards – identified as a passive vehicular barrier consisting of a cylinder, usually made of steel and filled with concrete placed on end in a deep concrete footing in the ground to prevent vehicles from passing, but allowing the entrance of pedestrians and bicycles. Bollards are also constructed of steel sections and reinforced concrete. An anti-ram bollard system must be designed to effectively arrest vehicle and its cargo as quickly as possible and not create an opening for a second vehicle.

Figure 1: bollard installation. To illustrate concept only: dimensions and reinforcing will vary.



A typical fixed anti-ram bollard consists of a ½-inch thick steel pipe, eight inches in diameter projecting about 30 inches above grade and buried about 48 inches in a continuous strip foundation (Figure 1). The bollard shown in Figure 1 would be capable of stopping a 4,500-lb vehicle traveling at 30 mph. Rated bollards are also a available that would provide protection up to DOS K12 level.

Bollards can be specified with ornamental steel trim attached directly to the bollard or with selected cast sleeves of aluminum, iron, or bronze that slip over the crash tube. Bollards can be galvanized against corrosion and fitted with internal illumination for increased visibility. Figure 2 shows a number of decorative bollards with high-performance ratings. Bollards may be custom designed for an individual project to harmonize with the materials and form of the building, but to ensure adequate protection, they would need to be tested by an independent laboratory.

Figure 2: Decorative bollards with high-performance ratings.

Commonly used decorative bollards without deep foundations do not have anti-ram capacity, though they may provide some deterrence value by making the building look more protected than it is.

Bollards are by their nature an intrusion into the streetscape. A bollard system must be very thoughtfully designed, limited in extent and well integrated into the perimeter security design and the streetscape in order to minimize its visual impact

The visual impact of bollards can be reduced by limiting height to no more than 2 feet 6 inches. However, the height of the curb and its position relative to the bollard also relates to the bollard height. This and other site specific conditions such as road surface grade, may help to maintain an effective bollard for impact while making the bollard appear visually less obtrusive. In addition, the design basis threat, in terms of vehicle size and speed, also influences bollard height. In no case should bollards exceed a height of 38 inches inclusive of any decorative sleeve.

A bollard reduces the effective sidewalk width in a pedestrian zone by the width of the curb to bollard (typically 24 inches, plus the width of the bollard). In several high-pedestrian and narrow-sidewalk areas of a central business district, the reduction in effective sidewalk width can prove critical.

Other bollard system guidelines are:

- Spacing between 36 and 48 inches depending on the kind of traffic expected and the needs of pedestrians, people with strollers and wheel chairs and the elderly must be considered.

- In long barrier systems, the bollards should be interspersed with other streetscape elements such as hardened benches, light poles, or decorative planters.
- They should be kept clear of ADA access ramps and the corner quadrants at streets.
- They should be arranged in a linear fashion in which the center of the bollards is parallel to the center line of existing streets.

Palm Tran Transit Design Manual (August 2004)

This manual is intended for use by developers, planners, and engineers who recognize that designing for Transit from project inception leads to better transit, rider convenience, safety, traffic mitigation and other socio-economic benefits. It is a design guide to be used with FDOT and Palm Beach County standards as they exist or are amended.

Street side infrastructures are those features street side of the Bus Stop usually associated with the bus operations interface with a Bus Stop. Bus berths are off-site facilities that offer safer, more convenient locations for riders to leave their automobiles and travel to their destinations. One of the designs, called saw tooth design offers the advantage of appearing more like a formal Transit facility and discourages unauthorized parking. It does require more depth and improved sight distances than the parallel design. It also precludes bus queuing.

Transit facility designs incorporating saw tooth designs or other types of designs that direct errant vehicular traffic toward pedestrian-occupied areas should include provisions for positive separation between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area. Typically bollards are placed at the forward ends of saw tooth bus parking spaces. A single bollard is designed to stop a 36,600-pound vehicle traveling 4 MPH. Three bollards of concrete-filled, 8-inch diameter, heavy wall steel pipe should be used at each parking space. The pipe is set vertically in a 6-foot, auger-drilled hole, and retained by reinforced concrete.

Curbside infrastructure are those features curbside of the bus stop and are usually associated with the Rider's off-board interface with the bus stops. Bus stops should be located so as to limit conflicts with pedestrians and other activities. Because bus stops are commonly placed near parking lots, bollards and/or raised curb would prevent cards from damaging bus facilities (benches and shelters) or interfering with bus activities and riders.

APTA Standards Development Program – Recommended Practice - APTA SS-IS-RP-007-10 (June 2010)

Crime Prevention through Environmental Design (CPTED) for Transit Facilities - This *Recommended Practice* provides guidance for the application of CPTED principles to enhance safety and security, while reducing risk to people, operations and assets at public transit facilities.

Crime prevention through environmental design (CPTED) is the application of designing safety and security into the natural environment of a specific area. Specifically, CPTED concepts and strategies use the three interrelated principles of natural surveillance, natural access and territoriality, plus activity support and maintenance. By using the behavior of people, knowledge of crime generators, the physical environment, and the space of an area, CPTED can provide benefits of safety and security if applied in the conceptual, design and planning stages of a project. Planning the use of a facility, such as a bus and/or parking garage, transit center, intermodal terminal or a park and ride lot, should also encompass details for providing users with safety and security. CPTED can be the solution to many transit agencies security issues. Additionally, the concepts and strategies of CPTED have been applied for years and incorporated into the designs of several facilities not related to transit. However, there is belief that its principles can assist transit in increasing ridership through a sense of system safety and security.

An excerpt from the *Recommended Practice* indicates the use of bollards to prevent vehicle ramming.

	STRATEGIES FOR TRANSIT STOPS
	Site layout: ☐ Physical barriers such as bollards and fencing are provided to prevent ramming, or to prevent unauthorized access if the stop has a segregated transit way.

Since this recommended practice focus on crime prevention, it does not outline any information for using bollards at transit stops for pedestrian safety from errant vehicles.

National Capital Planning Commission – Designing and Testing of Perimeter Security Elements

The National Capital Planning Commission is the central planning agency for the federal government in the National Capital Region. The purpose of this document is to identify different security barriers surrounding federal buildings in Washington, D.C. Different security element designs that can enhance streetscapes and also serve as vehicle barriers are as follows:

- Walls, terraces and raised planting beds
- Trees and planters
- Knee walls and fencing
- Gatehouses
- Bollards

In developing security design solutions, the plan recognizes that one size does not fit all. Landscape architects, architects, and urban designers should be consulted during the design development of streetscape elements to ensure that a scheme is appropriate to the setting and security needs of a specific building or site. The physical elements described in this section can be designed to both enhance streetscapes and serve as vehicle barriers.

> Bollards - Curbside bollards can provide security against vehicular attacks. Through careful design and placement, bollards can guide pedestrian circulation, meet accessibility requirements, and enhance the character of the streetscape.

The context of the surrounding streetscape should be considered when designing security measures. Security components can include a wide range of elements beyond walls, planters, and bollards. Through proper design and engineering, a variety of attractive elements and landscape features can serve as anti-ram barriers to stop a moving vehicle. Such elements should foster a sense of openness by allowing for easy pedestrian and bicycle access.

NCPC's National Capital Urban Design and Security Plan encourage designers to consider how ordinary street furniture can be hardened to provide effective security. Utilizing elements typically found along a streetscape—e.g., benches, lamp posts, drinking fountains—helps to prevent clutter and make security appear seamless. Hardening these elements can be as simple as incorporating vehicle anti-ram barriers with decorative sleeves. Items such as newspaper stands, bus shelters, and lampposts can all be designed with sleeves that fit over reinforced bollards or posts to stop a moving vehicle. Bike racks, benches, and drinking fountains also have the potential to serve as perimeter security.

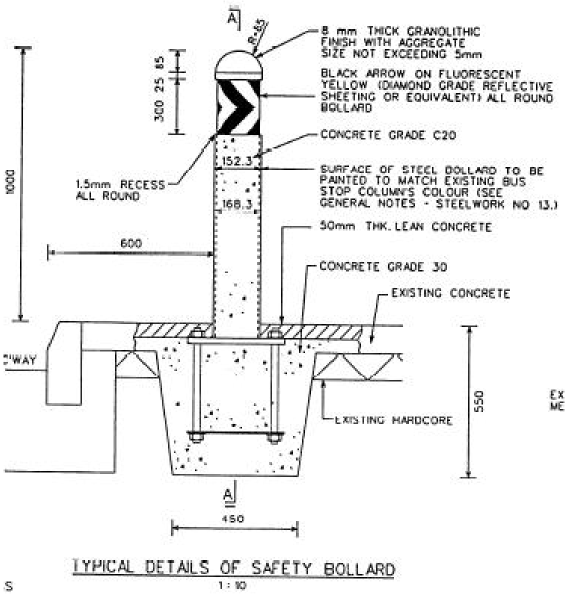
Land Transportation Authority – Singapore Government

The Singapore government through the Land Transportation Authority is committed to ensuring the safety and security of motorist and commuters at all times. LTA, who are responsible for planning, operating, and maintaining Singapore's land transport infrastructure and systems, has safety initiatives for pedestrians which includes the use of safety bollards.

The safety bollards are located at bus stops along high speed roads. The main function is to reduce the severity of impact from errant vehicles. They also alert drivers to the presence of bus stops, especially during night time, and this protect commuters at bus stops. The photo below shows the bollards being used at bus stops in Singapore. According to LTA, safety bollards have proven to be effective in deterring impact from errant vehicles that mount into the bus stop. Singapore has first installed safety bollards at bus stops in 1999.

Left: Bollard installed at bus stops in Singapore.

Right: Excerpt from Standard Detail of Road Elements – Bollard (2001)



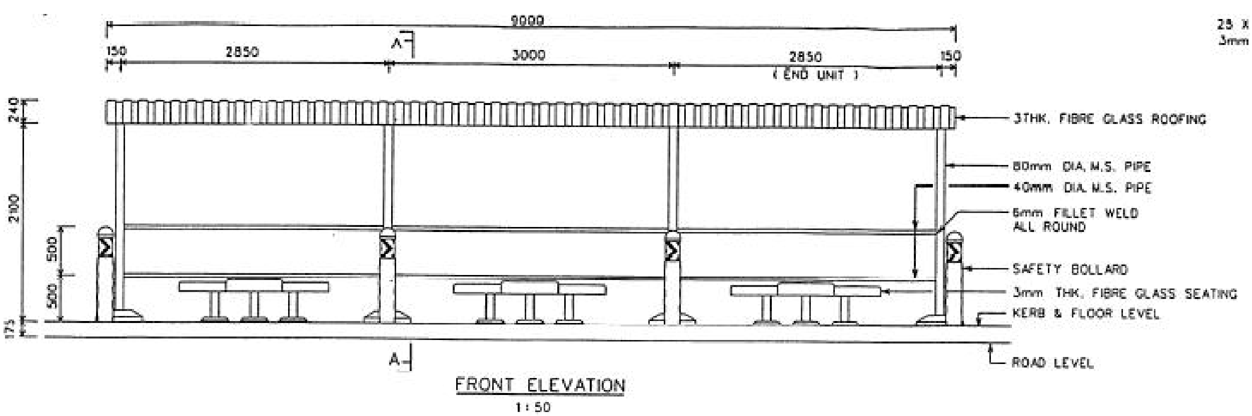
According to One Monitoring, the online portal for LTA, as of December 2011, 2.659 out of 4.600 bus stops have been provided with safety bollards.

A blog post in SG Forum, May 2007 titled "More Bus Stops May Get Safety Bollards" (May, 2007), discussed the efforts of Land Transportation Authority to install safety bollards in all the bus stops. According to the blog, the current LTA guidelines for installation of bollards are:

- At bus stops along roads where the speed limits are at least 60 km/h (37 mph) or above;
- At bus stops located along bends with speed limits of 50 km/h (31 mph);
- At bus stops facing turning traffic from the side the side of road, example, at T-junctions.

About three to four safety bollards are installed at such bus stops. The bollards are about 3 meters apart to sufficiently block any runaway vehicle while still providing adequate space for commuters to board or alight the buses.

Standard drawings for bollards and installation within bus stops can be found in LTA's website and an excerpt from the standard drawing is shown below:



A front view of typical bus shelter with bollards safety bollards

Harbor Freeway - Los Angeles Metropolitan Transportation Authority (February 2012)

On February 22, 2012 an incident occurred on the northbound Metro Silver Line platform during the afternoon. A vehicle struck the northbound platform of the Silver Line (rapid bus transit). The Metro Silver Line bus was not hit by the private truck when it was entering the station. There were 7 passengers who were about aboard the Silver Line bus to Downtown LA as a vehicle struck the platform. The 7 passengers received critical and serious injuries. During the incident, the Metro Silver Line, Metro Express Lines: 450X and 550 were detoured to stop at Figueroa Street/Harbor FWY station entrance. There has never been an incident on the Harbor Transitway ever since it first opened on June 1998. As a result of the incident, Metro's CEO: Art Leahy asked Metro's safety committee to review the station layout and signage of the Silver Line stations on the Harbor Transitway portion. A report was scheduled within 60 days after the incident. The report was complete during April 2012. Bollards were added during early August

2012 at the station. Bollards were also installed at the 37th Street/USC Metro Silver Line Station as well.

Bollards installed at Harbor Freeway, Silver Line Station to enhance pedestrian safety

Transportation Alternatives – Rethinking Bollards (July 2007)

Bollards are suggested as an effective way to calm traffic and protect pedestrians. This report presents examples of how bollards are working at a few select locations in New York City, and makes recommendations for a citywide policy to expand the deployment of bollards and other vertical deflectors to protect all street users. Recommendations for bollard use include the following:

- Experimentation with innovative pedestrian-friendly street designs
- Designation of exclusive pedestrian and bicycle areas
- Preventative safety measures to manage vehicular flow and calm traffic
- Implementation of Bus Rapid Transit (BRT)
- Securing bike lanes, paths & greenways
- Security for government and financial institutions
- Prevention of parking on sidewalks

While bollards have demonstrated efficacy in these and other applications, New York City has been conservative in their use. Currently, the DOT does not have a set policy to guide their prescription, installation or maintenance. A clearly defined city policy and community support for bollards will help the city and local neighborhood interests move forward in installing them. The use of bollards as a preventative safety measure on the City's streets and sidewalks could dramatically reduce the number of people injured and killed by errant motorists.

This report outlines the different bollard designs. New York City agencies use bollards to experiment with new street designs. While temporary bollards or planters will not protect pedestrians from wayward vehicles, they are a powerful tool for testing and demonstrating innovative designs, and ultimately making streets safer for pedestrians and cyclists.

According to the report, Bollards are a simple engineering tool to protect pedestrians and cyclists from vehicles, and designate pedestrian areas by blocking vehicular access while allowing pedestrians and cyclists to enter freely between each bollard. Bollards enforce and manage traffic flow 24 hours a day.

Another aspect of bollard use is to provide a physical barrier to protect pedestrians from encroaching vehicles. But they can also be used as a preventative measure to manage vehicular flow and calm traffic. Used in conjunction with neck downs (a.k.a. bulbouts or sidewalk extensions) and other traffic calming measures, bollards alert drivers to the narrowed roadway, and prevent vehicles from mounting the sidewalk and injuring pedestrians.

Measures for security device are also discussed in the report. Bollards are indentified as an indispensable security device. They can stop a truck at high speeds, and for this reason, they are used at nuclear power plants, embassies, courthouses, the State Department headquarters, the US Supreme Court and military bases around the world. The rapid proliferation of security bollards after September 11th demonstrates the ease of installing them. They City could easily make bollards a standard feature for pedestrian safety, which would respond to another daily threat to public safety.

Several concerns about bollards are discussed and their solutions, according to the report, are outlined below:

- Bollards impede people with visual and mobility impairments.

Bollards can and should be spaced so that wheelchairs may pass but vehicles cannot. Visually impaired pedestrians are, in most cases, equipped with a method of detecting obstacles, such as a guide dog or cane, and are prepared to encounter a bollard. Bollards should be tall enough to prevent a tripping hazard.

- Bollards interfere with snow plowing.

Countries with heavy snowfall such as Canada, Denmark, Norway and Sweden routinely use bollards both on sidewalks and streets. Proper management of areas sectioned off by bollards should be determined and implemented.

- Permanent steel bollards cause damage to vehicles.

While bollards are a boon for pedestrian safety, DOT engineers have limited bollard installation because they perceive them as dangerous to vehicles and their drivers. The DOT's stated fear is that a driver hitting a bollard could cause damage to the car, or even cause injury or death, and the City could be held liable.

As this report demonstrates, there are dozens of successful examples of safe, common sense applications for bollards in New York City. Bollards are no different than street lights, posts or trees that already line our streets. Cars will only come in contact with bollards if they waver out of their lane. Thus, if a bollard is hit, it is preventing injuries and saving lives.

Cars mounting sidewalks is a widely publicized problem in New York City, injuring and killing scores of people each year (see Appendix for articles), and bollards are a proven solution to this problem. According to records kept by the NY State Department of Motor Vehicles, about 10% of New York City pedestrians struck by cars are actually hit off road on the sidewalk or inside their homes.

Reflectors or lights on bollards alert and warn drivers of bollards' location. If a car collides with a fixed bollard, drivers are protected by thousands of pounds of steel. Potential injury to passengers and drivers is much less severe than potential injury to unprotected pedestrians and cyclists who would be struck if there were no bollard.

Where pedestrian safety is not the primary goal of bollard use (such as in lane separation or testing street redesign), plastic bollards, which cause little or no damage to vehicles and their drivers, are used.

- Retractable bollards cause damage to vehicles.

Retractable bollards can cause damage to a vehicle if it passes over the bollard as it rises from the ground. However, the simple installation of an inductive loop in the road prevents a bollard from rising with a vehicle overhead. The coil of wire is embedded in the street surface to detect the presence of a driver above. In addition, the City should also clearly indicate the presence of the bollard, post the time bollards rise if they are set to a timer, and install lights to alert drivers when bollards are about to rise.

Miami-Dade Legislative Report – Item # 072615 Findings of Feasibility Study for the Installation of Cylindrical Posts Between Bus Passenger Benches or Shelters and the Edge of the Road at Bus Stops in Unincorporated Miami-Dade County (September 2007)

This legislative report discussed the findings to the investigation and documentation of the potential benefits, risks, regulatory issues, time and cost of installing cylindrical posts for passenger safety at over 2,300 bus stops throughout Miami-Dade County. The 2,300 bus stops consist of 1,100 bus shelters and 1,200 bus benches. The study includes the investigation of 300 bus stop locations representing the various typical conditions that exist at bus stops with benches or shelters.

According to the legislative report, it was found in the study that most of the bus stops do not have the allowable space required for bollards to be installed and meet Federal, State and County design standards. In nearly all cases, it would not be possible to install bollards in front of bus benches and shelters without violating the standards set in the Florida Manual of Uniform Minimum Standards for Design, Construction and Maintenance of Streets and Highways, also known as the Florida Green Book.

Additional significant findings from the feasibility study are outlined in the legislative report and are as follows:

- Bollards are designed for low speed impact. A high speed collision at bus stop benches or shelters with bollards could result in pedestrians being hit or trapped by a bollard driven out of ground.
- Design for most locations would require a bollard to be installed within four feet of the curb and gutter, or fourteen feet from flush roadways, violating Clear Zone guidelines.
- Objects installed within Clear Zone are designed to bend or break upon impact. Bollards would not bend or break.
- Maintaining 36 inches of clear width for disabled persons restrict bollards from being installed on most sidewalks.
- Bollards can obstruct the driver’s view of traffic at an intersection.
- Large foundations and conflicts with subsurface utilities make designs impractical to implement at most locations.
- Shelter layouts with sufficient distance from roadway are possible locations where bollards can be installed without violating State or County regulations, Based on inventory (in 2007) 11% of bus shelters throughout the county are possible candidates for bollard retrofits. Benches are not recommended.

- The average cost for installation (in 2007) is $22,000. The cost of installation at 121 locations is approximately $2,662,000. Design costs are an average 5% of construction, for a cost of $133,100. Total cost for installation is approximately $2,795,100.
- Design, Permitting and Construction would take approximately 12 months. The County's solicitation of a design consultant and contractor would take approximately 20 months for a total of 32 months.

The report stresses the fact that a bollard specifically designed to withstand high speed collisions may actually increase the risk of a deadly incident as the driver or passenger or the errant vehicle are most likely to suffer serious injury. While the concept of using bollards to protect the patrons of our bus system would at first blush appear to increase public safety, research indicates that it would in all likelihood result in the opposite effect. Therefore, cylindrical posts are not recommended for protection of pedestrians at bus stops against errant vehicles that leave the roadway.

TRANSIT STOP SAFETY STUDY UPDATE

January 2013

Prepared by:

PARSONS BRINCKERHOFF

On Behalf of:

REGIONAL TRANSPORTATION COMMISSION
RTC
OF SOUTHERN NEVADA

Regional Transportation Commission of Southern Nevada