PERSPECTIVES IN PRACTICE

Corner Design For All Users

A review of geometric design practices to improve safety for pedestrians and bicyclists at intersection corners

SUMMARY

Historically, intersections have been designed to facilitate easy turning by infrequent design vehicles. This approach has resulted in countless intersections that are much larger than they need to be; intersections where pedestrians and bicyclists confront long crossings that leave them exposed to turning vehicle traffic moving quickly along large corner radii. Balancing access for more infrequent larger vehicles with the safety needs of vulnerable roadway users is possible and cities across North America have been experimenting with designs for years. This white paper makes the case, with case study examples, for a more thoughtful approach to intersection corner design as communities place greater priority on reducing serious injuries and deaths among vulnerable road users.

Contributors:

Joe Gilpin, Vice-President
Matt Pinder, Senior Designer
Kristie Di Cocco, P.E., Senior Engineering Associate
Derek Abe, Planning Associate
Nataliya Pekar, Engineer in Training

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ALTA

As a global leader in mobility innovation for over 22 years, Alta helps make positive changes in communities to empower all people to live active, healthy lives. We are dedicated to connecting people to places by working across disciplines and scale to address social equity, access, and environmental resilience.

Disclaimer: The design details, recommendations and conclusions in this document are based on interviews with city staff throughout North America, Alta project experience, and industry design guidance. This white paper uses design resources and discoverable original research by various institutions to make conclusions, though it is possible that other research that may be relevant was not identified. Engineering judgment should always be used in roadway design decisions.

CONTENTS


Minneapolis, MN

01 INTRODUCTION

This white paper explores the relationship between intersection corner design and pedestrian and bicyclist safety. Intersection design often involves balancing the needs of larger design vehicles with standards that sometimes conflict with pedestrian and bicycle safety. This white paper outlines the inherent conflicts that exist between turning vehicles and pedestrians/bicyclists, explores the design challenges, and catalogs solutions and lessons learned from cities across the US and Canada.

Background

Cities in the US and Canada have long recognized the relationship between vehicle speed and crash severity for vulnerable road users and many have attempted a variety of solutions to manage this conflict. The inherent problem in intersection design is the need to accommodate a large design vehicle, often a semi truck or large emergency vehicle, through a tight right turn or a left turn (from a one-way street). Designing such corners often has the following results:

- Large vehicles, which compose a small fraction of roadway traffic, are typically provided large corner radii to complete their turns
- Large corner radii can substantially lengthen pedestrian crossings and exposure to vehicular traffic
- Large corner radii enable smaller passenger vehicles, which compose the vast majority of roadway traffic, to make turns at higher speeds
- At higher vehicle turning speeds,
    - Driver reaction time and stopping distance require more space
    - The likelihood of a driver yielding to crossing pedestrians and/or bicyclists is lower
    - Potential for crashes with pedestrians and bicyclists is higher with an increased likelihood of injury or death to the non-motorized user

These relationships will be explored in detail along with various design and policy solutions which will allow large vehicles to complete turns while improving the safety of pedestrians and bicyclists.

Crashes between pedestrians and right turning vehicles are a common pedestrian crash type in most US and Canadian communities.

Engineering Basis

The following section explores design considerations in the geometric design of an intersection corner radius. This section is intended to be technical and utilize North American geometric design guidance and industry technical research to link corner radii size with implications for drivers and pedestrians. The AASHTO *A Policy on Geometric Design of Highways and Streets* 2018 Edition ("Green Book") supports the findings of this white paper and provides in section 9.6.1.4 general recommendations for curb radii of:

- as low as 15 feet (5 meters) to accommodate passenger vehicles
- 40 feet (12 meters) or more to fit the paths of large trucks or buses

This section explores common engineering principles and guidance to explore the relationships between minimum turn radius, stopping sight distance, and reaction time, as well as research on driver speed and yielding behavior in varying conditions.

Relationship between Radius and Speed

The relationship between radius and speed is determined by the balance of forces as a vehicle navigates a curve, where lateral friction results in a centripetal force, and superelevation results in gravitational force. The 2018 AASHTO *Green Book* (Section 3.3.3.3) describes minimum radius of horizontal curvature in design is derived from this relationship and represented by the following equation (Equation 3-8)[2]:

$$R_{min} = \frac{V^2}{15(0.01e_{max} + f_{max})} \quad \textit{(Imperial)}$$

$$R_{min} = \frac{V^2}{127(0.01e_{max} + f_{max})} \quad \textit{(Metric)}$$

Where,

e_{max} - maximum rate of superelevation
F_{max} - maximum side friction factor
V - design speed mph (kph)
R_{min} - radius of curvature ft (m)

The equivalent is found in the TAC GDGCR in Section 3.2.2.6 with Equation 3.2.3.

For the purpose of evaluating urban intersections, superelevation is set to zero, as horizontal curves on low-speed streets are not substantially influenced by it. In reality, there will be some cross slope variation dependent on the amount of crowning present. Lateral friction factors (f) are dependent on a number of variables, including speed, roadway surface, and the type and condition of tires. R_{min} for design is based on e_{max} and f_{max} at the limits of what is comfortable for most drivers. As such, lateral friction factors recommended by AASHTO and TAC are conservative relative to the capabilities of most modern vehicles in order to ensure skidding is avoided. In urban scenarios, drivers are more likely to complete a turn with several stops due to the nature of urban surroundings as opposed to at a constant speed more common in suburban and rural settings.

Using superelevation as zero and design friction factors from AASHTO, the relationship between speed and curve radius is plotted in Figure 1. The equation is to the vehicle's center of gravity. To compensate and estimate curb radii size, 7 feet (1.9 meters) has been subtracted.

The AASHTO equation in Figure 1 produces an estimate of vehicle speed based on radius. A 2004 study by the Texas Transportation Institute[17] looked at vehicle free flow speeds through channelized right turns and found that speed was rarely constant with general deceleration slightly past the midpoint of curvature and then acceleration towards the exiting tangent. The study conducted speed observations in

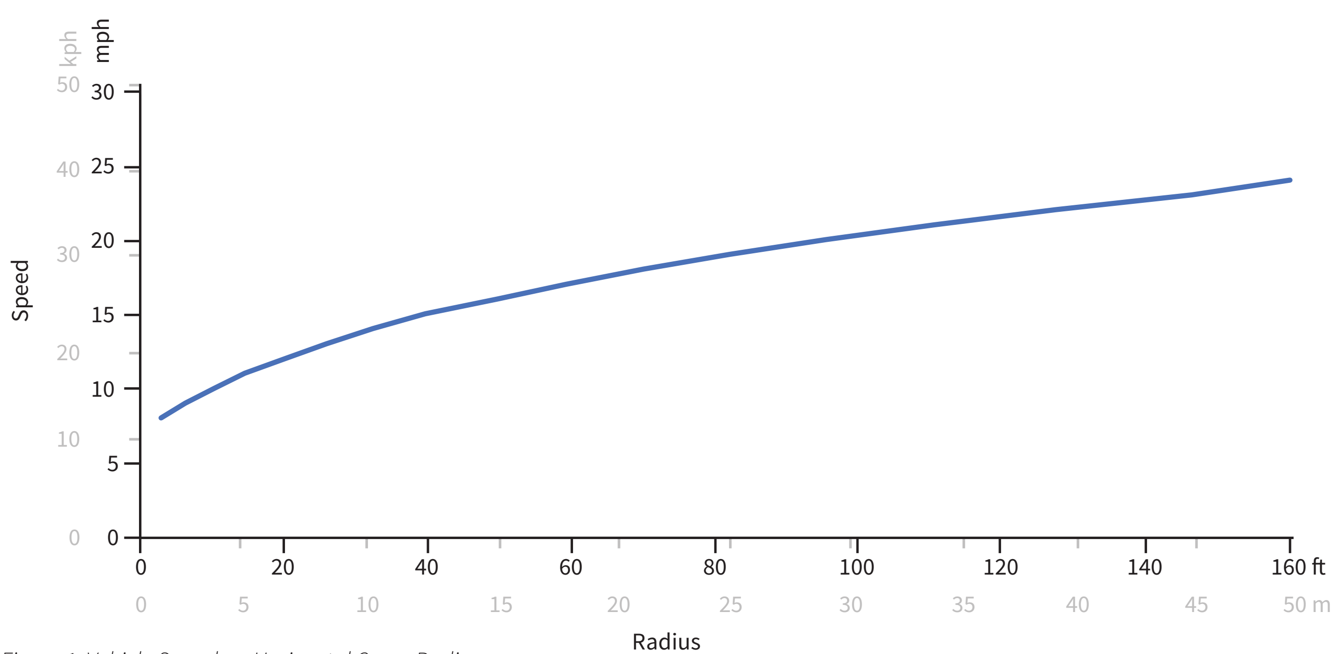


Figure 1: Vehicle Speed vs. Horizontal Curve Radius

19 different channelized turns with curb radii ranging from 27 feet (8 meters) to 86 feet (26 meters). Interestingly, as shown in Figures 2 and 3, observed average midpoint curve speeds matched closely with the AASHTO equation 3-8; however, speeds at the beginning of the curve were higher, as were 85th percentile speeds. This study shows that the AASHTO equation may represent less than half of vehicles traveling through a right turn at the midpoint of the curve, with half of vehicles exceeding the predicted speeds. This makes sense given the conservative friction inputs into the AASHTO equation.

The Texas Transportation Institute study also created equations to approximate the observed data which could be utilized or modified in practice. Many of the variables cited are unique to channelized right turn lanes. The study did discuss the implications of the data on selecting crosswalk locations, suggesting that the middle of the turn would produce the lowest turning speeds. Overall, a designer could conclude from the study that in constant speed scenarios, vehicles are capable of higher turning speeds than the AASHTO equation would predict and a extremely small turning radius would be needed to guarantee low turning speeds.

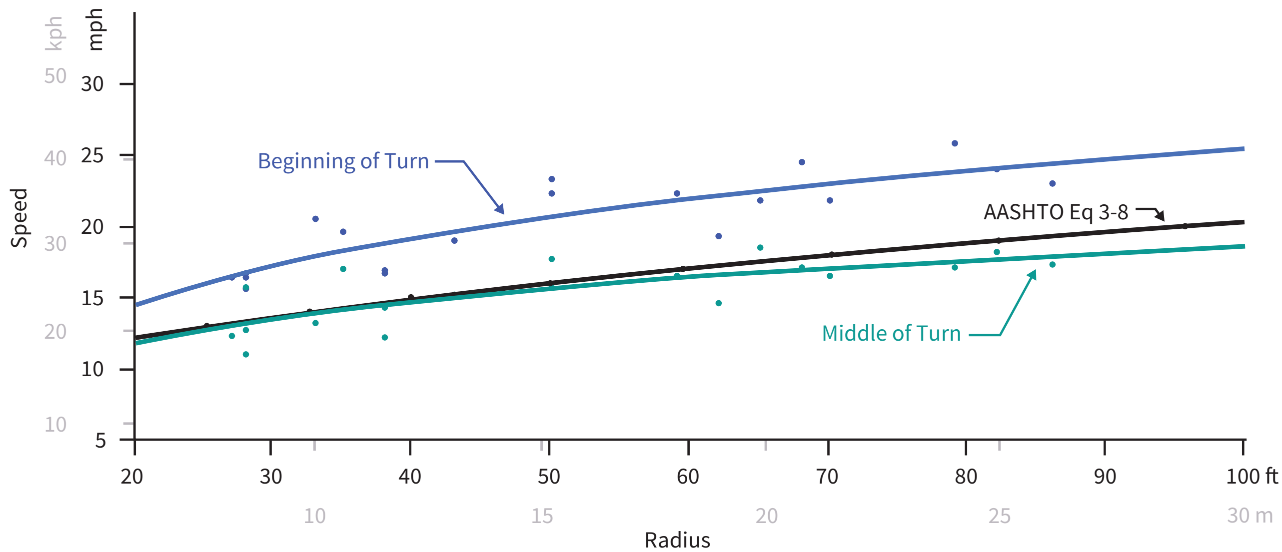


Figure 2: TTI Study Average Speeds

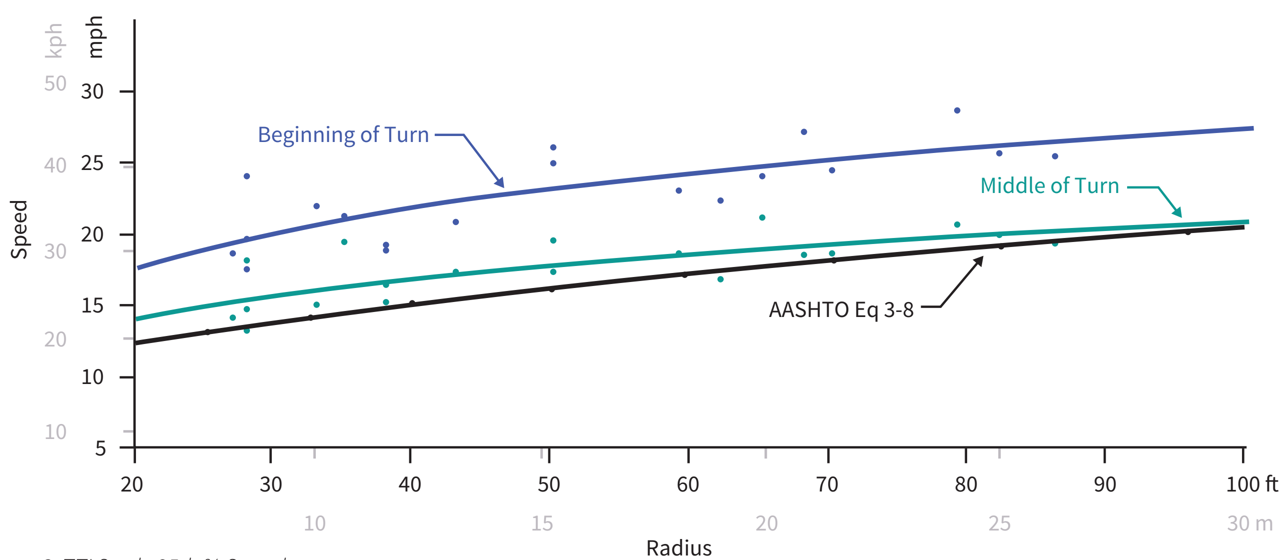


Figure 3: TTI Study 85th % Speeds

Physical vs Effective Radius

There is a distinction between the physical corner radius and the effective radius that a vehicle can exploit given other intersection factors[11]. This distinction is sometimes overlooked in street design and can further exacerbate the potential for high turning speeds through intersection corners. The effective radius can vastly exceed the physical radius if features such as wide travel lanes, bicycle lanes, or parking lanes exist that push the entry and receiving travel lanes further away from the physical curb. Figure 4 illustrates some typical examples.

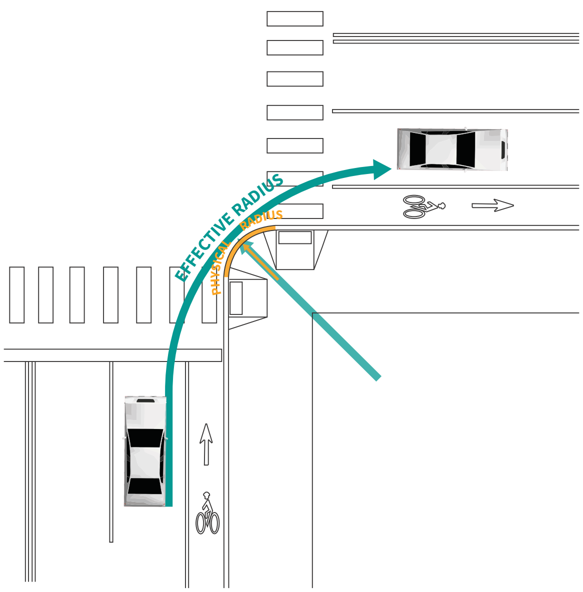


Figure 4: Effective corner radius examples

Relationship between Stopping Sight Distance and Speed

Stopping sight distance is the distance required along a roadway for a driver to identify and react to an obstacle and to come to a complete stop in advance of the obstacle. Drivers turning a corner at an intersection require clear sightlines and enough distance to come to a stop and yield to pedestrians and bicyclists (if applicable). At higher speeds, the distance required to stop safely increases. At larger radii, the potential for increased speeds may result in insufficient distance to perceive and yield to pedestrians given the greater distance covered during reaction time and braking.

The stopping sight distance is a combination of distance until a driver reacts and begins to apply the brakes (braking reaction distance), and the distance required to stop after the brakes have been applied (braking distance). The first component is dependent on reaction time. Reaction times vary widely depending on factors associated with the environment and the driver. For suburban, urban, urban core, and rural town contexts, a reaction time of 1.5 seconds is used per AASHTO. Drivers are also expecting to decelerate at a turn in order to safely navigate and may start to decelerate regardless of the presence of an obstacle. Finally, while 11.2 ft/s^2 is a comfortable/conservative deceleration rate used in design, most drivers decelerate at a rate greater than 14.8 ft/s^2 when confronted with the need to stop for an unexpected object in the roadway (AASHTO). This is reflected below by equation and plotted in Figure 5.

This relationship can be plotted:

$$d = 1.47Vt + 1.075\frac{V^2}{a}$$ *(Imperial)*

$$d = 0.278Vt + 0.039\frac{V^2}{a}$$ *(Metric)*

Where,

a - driver acceleration assumed at

$$11.2\frac{ft}{s^2}\left(3.4\frac{m}{s^2}\right) \text{ and } 14.8\frac{ft}{s^2}\left(4.5\frac{m}{s^2}\right)$$

t - perception-brake reaction time, assumed to be 1.5s

V - initial speed, mph (kph)

d - stopping sight distance, ft (m)

The equivalent is found in the TAC GDGCR in Section 2.5.3 with Equation 2.5.2

As Figure 5 illustrates, stopping distances vary considerably by speed. Figure 6 adds contextual visualization to this relationship and depicts where a vehicle would need to start the reaction and braking processes at various speeds on approach to a right turn with a 25 foot or 7.4 meter physical radius. Even speeds of 20mph (32kph) yield distances that may be unrealistic for a driver to register the need to stop for a pedestrian and be able to do so safely.

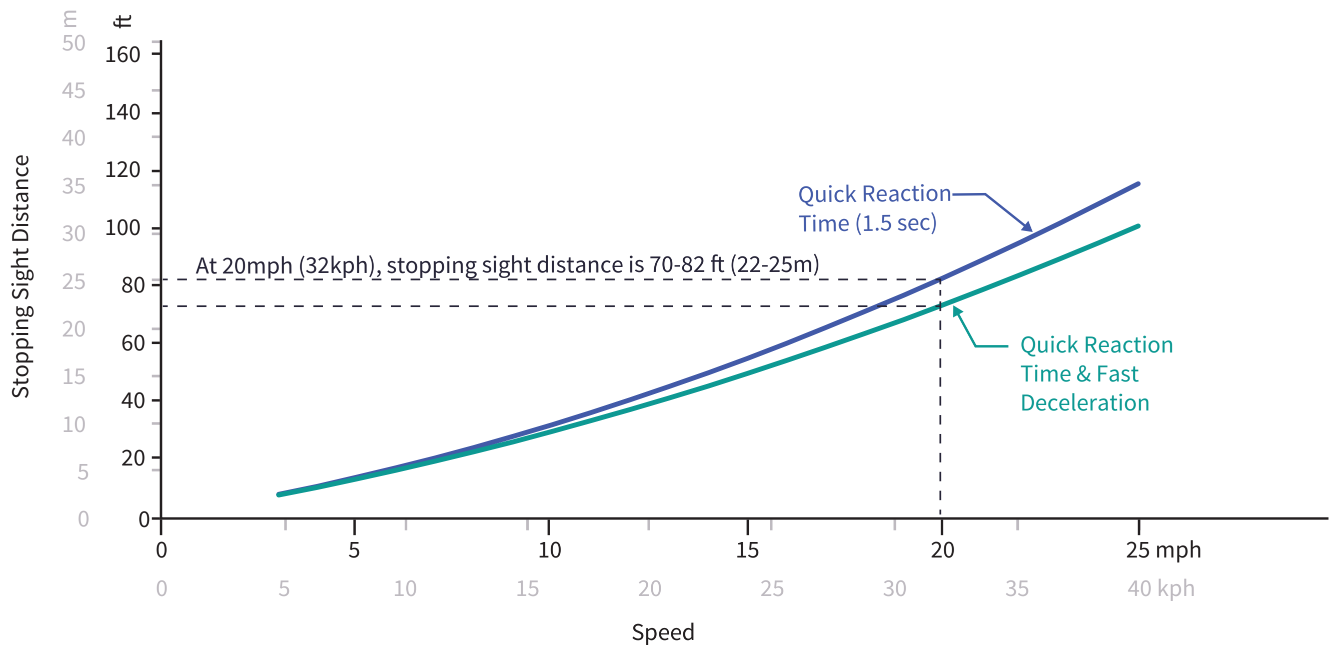


Figure 5: Stopping Sight Distance by Speed

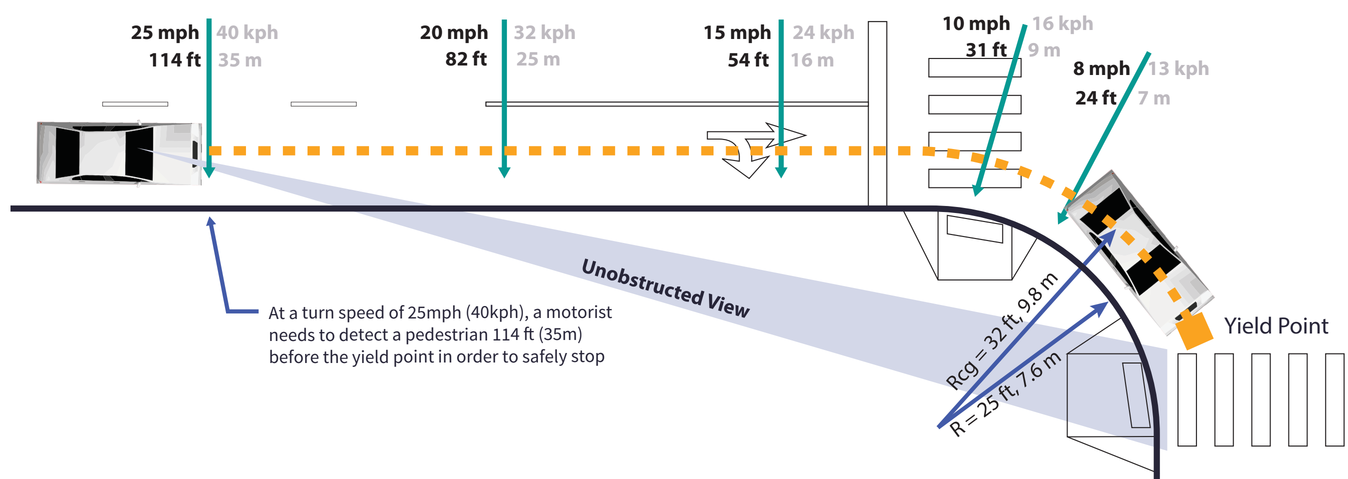


Figure 6: Stopping Sight Distance by Speed

Pedestrian Risk

Numerous studies have shown a direct correlation between vehicle speed and pedestrian crash severity. The probability of a pedestrian being killed by a vehicle traveling at 20 mph (32 kph) is approximately 7 percent. At 32 mph (52 kph) that probability increases to 25 percent, indicating the importance of minimizing vehicle speed at points of potential conflict to improve pedestrian safety. Figure 7 displays the results of a 2011 study which normalized 1990s data analysis from Presusse and Leaf[12] to late 2000s demographics[1] with the shaded areas representing a 95 percent confidence interval.

There are multiple design guidance documents that equate the effective corner radius and potential for vehicle speed to pedestrian safety and exposure. FHWA has multiple publications that draw this reference including their PEDSAFE Countermeasure Selection System under "Curb Radius Reduction", the *Signalized Intersections: Informational Guide*[7], and the Selecting Pedestrian Safety Improvements Library as a treatment for several types of intersection related safety issues.

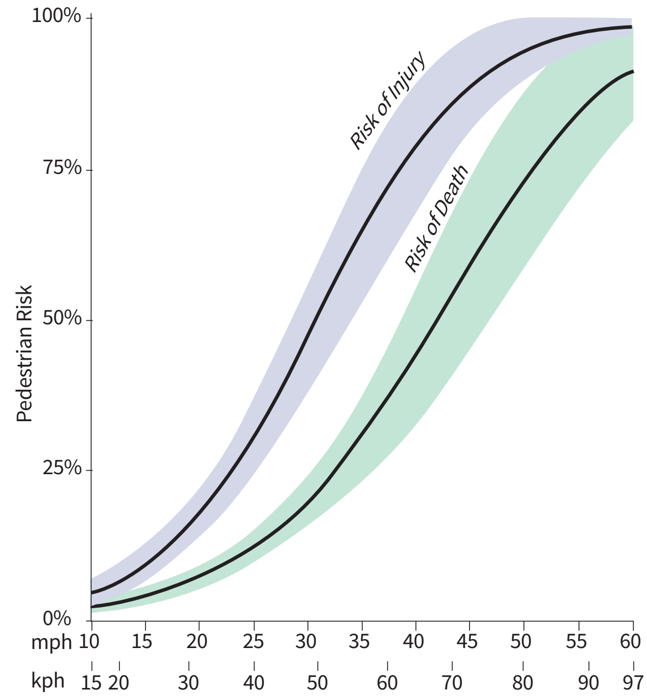
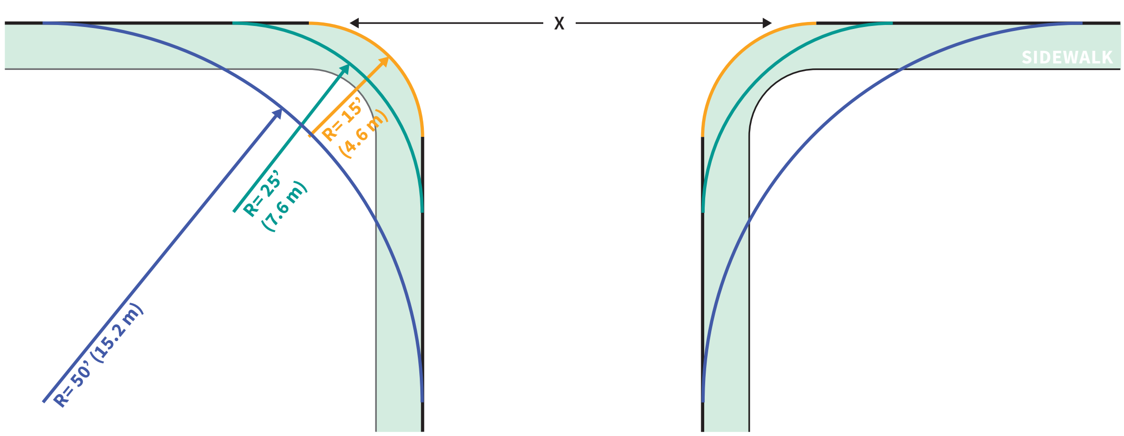


Figure 7: Pedestrian Risk of Injury or Death



Curb Radius (R_1)	Crossing Distance (X)	Crossing Time*	Effective Turning Radius (R_2)**	Vehicle Turning Speed***
15 ft (4.6 m)	37 ft (11.3 m)	10.6 seconds	41 ft (12.5 m)	14 mph (22.5 kph)
25 ft (7.6 m)	50 ft (15.2 m)	14.3 seconds	52 ft (15.8 m)	16 mph (25.7 kph)
50 ft (15.2 m)	89 ft (27.1 m)	25.4 seconds	74 ft (22.6 m)	18 mph (29.0 kph)

*Assumes an average crossing speed of 3.5 fps (3.8 kph)

** Assumes the following widths: 6 ft (1.8 m) bike lane, 10 ft (3.0 m) travel lane, 7 ft (2.1 m) vehicle, 2 ft (0.6 m) clear from corner. $R_2 = v^2/[15(F)]$, where F = 0.32, 0.31, and 0.29, respectively.

*** Average speed in middle of turn

Figure 8: Pedestrian Exposure vs Corner Radii

Pedestrian Exposure

In addition to allowing pedestrians using the crosswalk to come into conflict with faster moving turning vehicles, large turning radii also increase the length of the crosswalk, which lengthens the time required for pedestrians to clear the intersection and increases their exposure to traffic stress and potential conflict.

Driver Yielding Behavior

There has been substantial research into driver yielding at uncontrolled intersections and mid-block crossings over the past several decades, which has been effectively used to better understand countermeasures that affect pedestrian safety and comfort in these contexts. The condition that this white paper is analyzing is very different in that it is examining vehicle right turns and their conflicts with parallel pedestrian crossings.

Little existing literature is present that explores this subject in detail, which is surprising given that right-turn pedestrian crashes are commonplace in North American communities.

A 2013 study on visually impaired pedestrians and driver yielding looked at seven sites across the United States and focused on driver yielding based on the positioning the pedestrian took during the walk signal. Corner radius was not discussed as a variable in the research; however, the study did note in its conclusions that the authors found "no relationships between curb configuration and drivers' responses for yielding when making right turns at a green traffic signal."[3] Vehicle speed was also not observed.

A 2018 evaluation study of San Francisco's first protected intersection at 9th and Division Streets[16], which features mountable corner islands with passenger turning curb radii under 20 feet (6 meters), found that 100 percent of the observed motorists yielded when approaching a pedestrian and 96 percent yielded when approaching a bicyclist. It should be noted that the entry legs of the protected intersection also featured raised crossings.

Substantial work has been done exploring the performance of pedestrian crossings at roundabouts, particularly interactions between visually impaired pedestrians and vehicles. Two studies[9,14] have shown that driver yielding behavior is much higher on roundabout entry, which functions more like a mid-block or perpendicular intersection-based crossing, than on roundabout exit. Roundabout exits are somewhat similar to right turns at intersections in that the pedestrians are in a similar visual position and the driver is in the process of completing a right turn and accelerating out of it. Both studies found a correlation between vehicle speed and yielding; however, other factors (see discussion in the next section), also generated considerable influence.

"Selecting a yield of 90% and the entrylane data from both roundabouts, we calculated that vehicles traveling at 18 mph had a positive predictive value of 0.89. Thus, using 18 mph as a cutoff speed for roundabout entry lanes, a pedestrian could expect that approximately 9 out of 10 drivers would yield. By comparison, at the exit lane, the highest calculated predictive value of 0.6 was associated with a vehicular speed of 10-11 mph. Unfortunately, even at this relatively low speed, the pedestrian has only a 60% chance that a driver will yield. "

The 9th & Division Intersection has various corner designs featuring dual radius truck aprons created with striping and with raised concrete. Credit: StreetsblogSF. Source article

There does seem to be a significant research gap in understanding driver yielding and conflicts with pedestrians during right turns at signalized intersections in the North American context. There are several international studies that do explore this issue, though the applicability is uncertain due to differences in driver culture, training, and pedestrian behavior. Still, one study done in Shanghai China in 2011[19] found that the number of conflicts between right-turning drivers and pedestrians could be expected to be lower with tighter corner radii. Conflicts were also observed to be dependent on the relative flows of vehicles and pedestrians.

Other Factors

The preceding analysis focused on speed control through corner geometry. It should also be stated that geometry alone is only one of several variables that can influence driver yielding and pedestrian safety at intersection corners. Pedestrian assertiveness and pedestrian visibility are two other key variables which have been shown to strongly influence driver yielding behavior under a variety of crossing conditions. One 2020 study[4] on mid-block crossing yielding behavior even suggests that the higher the retail value of the vehicle, the lower the driver was observed to yield to pedestrians. Intersection designs which put a waiting pedestrian in a highly visible location or provide a head start either through geometry or through tools like a Leading Pedestrian Interval (LPI) will also improve yielding behavior and reduce the chance for a crash that could cause serious and fatal injuries.

Table 1: Summary of Variables

EFFECTIVE RADIUS*		AVG VEHICLE SPEED**		85TH% VEHICLE SPEED***		STOPPING SIGHT DISTANCE		RISK OF SEVERE INJURY****	RISK OF DEATH****
10 ft	3m	10 mph	16 kph	12 mph	19 kph	32 ft	9.8m	2-7%	1-4%
15 ft	4.5m	11 mph	18 kph	13 mph	21 kph	36 ft	11m	2-8%	1-4%
20 ft	6m	12 mph	19 kph	14 mph	23 kph	40 ft	12m	3-8%	1-4%
25 ft	7.6m	13 mph	21 kph	14.5mph	23 kph	45 ft	13.7m	4-9%	1-5%
30 ft	9m	14 mph	23 kph	15 mph	24 kph	50 ft	15.2m	5-11%	1-5%
40 ft	12m	15 mph	24 kph	16.5 mph	27 kph	55 ft	16.8m	6-13%	2-5%
50 ft	15.2m	16 mph	26 kph	17.5 mph	28 kph	60 ft	18.3m	7-15%	3-6%
60 ft	18.2m	17 mph	27 kph	18.5 mph	30 kph	65 ft	19.8m	8-18%	3-7%
70 ft	21.3m	18 mph	29 kph	19 mph	31 kph	71 ft	21.6m	10-20%	3-8%
80 ft	24.4m	19 mph	31 kph	20 mph	32 kph	77 ft	23.5m	13-21%	4-8%
95 ft	29m	20 mph	32 kph	21 mph	34 kph	82 ft	25m	14-22%	5-9%

*Not physical radius, this is the inside turning path of the vehicle

**Average speed expected through AASHTO Eq 3-8

***85th Percentile speed expected through data interpolation from TTI Study

****Estimated risk of injury or death from average turning speed

Conclusion

The preceding sections reviewed a number of engineering factors and industry studies. These have shown:

- Average cornering speeds in the middle of the turn roughly equate to the AASHTO horizontal curve equation; however, roughly half the vehicles will exceed this speed
- Smaller effective turning radii will result in lower expected turning speeds
- The potential for crashes involving a pedestrian or bicyclist resulting in serious injuries or death increases dramatically with vehicle speed
- Stopping sight distance for vehicles approaching a turn may not provide sufficient opportunity for a driver to yield at even moderate speeds (20mph / 32kph)
- Smaller effective radii will reduce pedestrian exposure and crossing time
- Driver yielding behavior to pedestrians is complex, but it does show correlation to speed as one variable

Based on these findings, it is reasonable to conclude that **effective corner radii must be extremely small to result in low vehicle speeds which will improve the safety of vulnerable users such as pedestrians and bicyclists.**

Ottawa, ON

02 CORNER DESIGN

This section provides design objectives for corners designed to limit turning speed for passenger vehicles while still allowing larger vehicles to complete the turn. A design that works for both will likely have some form of a truck apron, which creates a tighter effective radius for smaller vehicles while still accommodating large trucks without endangering other road users.

Design Objectives

For a truck apron to be effective, it must:

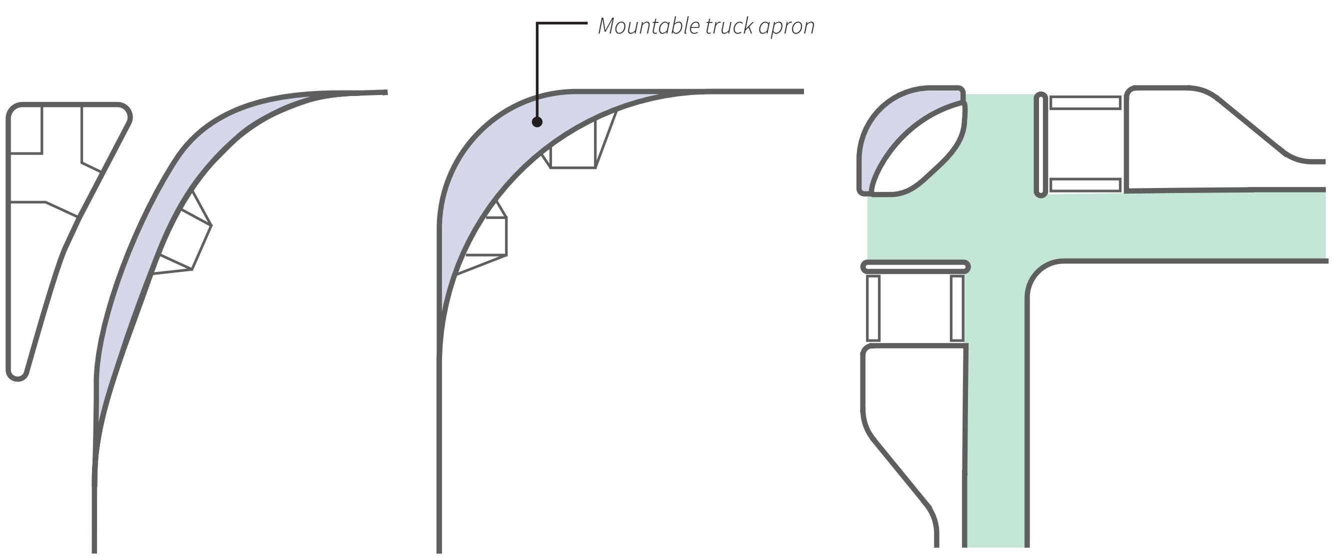
- Deter smaller vehicles from turning across it
- Clearly convey to drivers of larger control vehicles that it is a traversable surface
- Be traversable by large vehicles without threatening stability
- Deter pedestrians and bicyclists from stopping or queuing on it

If an apron fails to meet any of these objectives, its effectiveness as a pedestrian/ bicyclist safety measure may be diminished. Additionally, for cities that experience accumulating snowfall, the ability of the apron to function during and after snow events and its compatibility with snow removal equipment is also a consideration.

Typical Applications

Truck aprons are a fixture of numerous North American cities and are most commonly found in roundabouts. In roundabouts, the design objectives are the same as those stated above: to provide a tighter turning path for passenger vehicles to manage speeds through the roundabout, while providing space for larger vehicles to still navigate through.

This white paper examines how the same concept has been (and can be) applied to the following examples.



Channelized Right Turn *Conventional Intersection Corner* *Protected Intersection Corner*

Vehicle Accommodation

In the 2019 NACTO publication *Don't Give Up at the Intersection*[10], a useful framework is introduced involving three types of vehicles to be planned for in the design of a corner. This framework is similar to those traditionally used by AASHTO and others with the distinction of highlighting the "managed vehicle".

- The **managed vehicle** is the vehicle that will most often be completing the turn. This is typically a personal vehicle. The managed vehicle is capable of high turning speeds, makes up the vast majority of vehicles using the corner, and is the target for corner design measures.
- The **design vehicle** is the largest vehicle that will frequently be completing the turn. This varies significantly by context and can include transit vehicles, delivery vehicles, or single-unit trucks.
- The **control vehicle** is the largest vehicle that is expected to complete the turn on an infrequent basis. Significant allowance can be provided for the turning path of this vehicle (such as straddling the approach lanes and oversteering past the receiving centerline), and very slow or "crawl speed" turns should be the default design condition.

Emergency vehicles require access to all types of roadways and have challenging maneuvering characteristics to allow for in constrained urban environments. In some instances, it may be useful to consider emergency vehicle access as even more permissive than the control vehicle. Austin is allowing emergency vehicles to mount medians, corners, and encroach into pedestrian areas if necessary to complete turns that occur very infrequently. Fire apparatus is permitted to mount raised street features and objects are kept out of these areas of potential encroachment by design.

The design and control vehicles are typically determined using a combination of data and policy (policy examples are discussed in Section 3). Factors typically taken into consideration are:

- Measured turning volumes for different vehicle types
- The classification of the intersecting roadways (local, collector, arterial) and their contexts (industrial, commercial, residential)
- Existing and planned transit networks, truck routes, and emergency vehicle response routes
- Safety and collision data

Within these typical applications the truck apron is provided to slow the managed and design vehicles while accommodating the control vehicle.

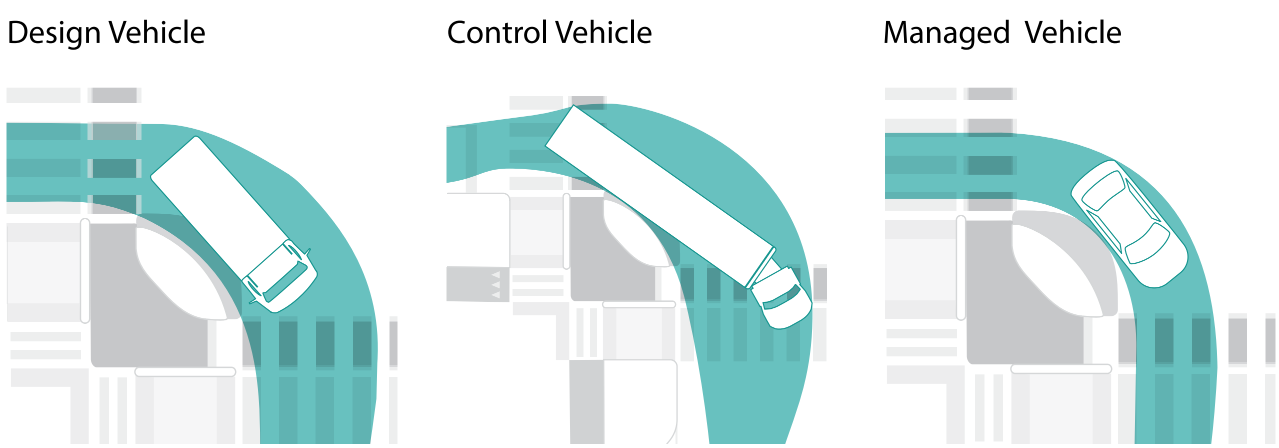


Figure 9: Types of vehicles accommodated at an intersection corner Source: NACTO

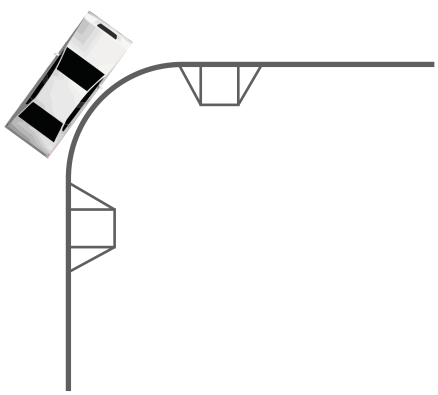
Design Variables

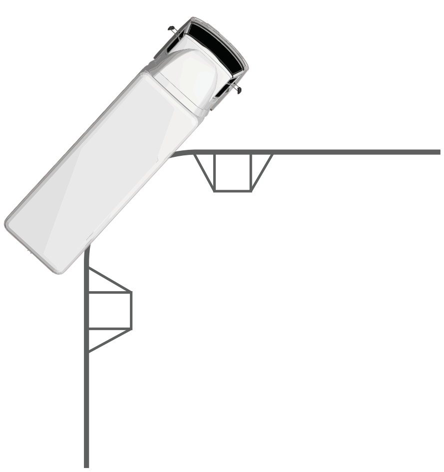
This section explores the various types of corner treatments that have been deployed around North America and classifies them by similar traits.

Type of Accommodation for Design and Control Vehicle

SINGLE RADIUS WITH MOUNTABLE ZONE

This group features a single curb line that is intended to be usable for the vast majority of vehicles (design and managed). Only very infrequent control vehicles (such as fire trucks) are expected to mount the curbs, which are designed to allow mounting by larger vehicles while strongly deterring smaller vehicles. There is no secondary curbline or path defined for the control vehicle. City experience has shown that the mountable zone must be tall enough to deter most drivers from using it. Corners built lower have not been effective at minimizing unnecessary vehicle encroachment.





Examples of a mountable zone include:

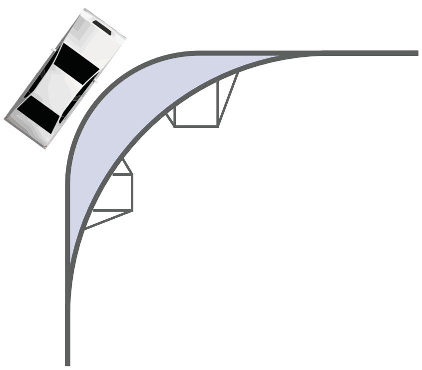
Atlanta, GA

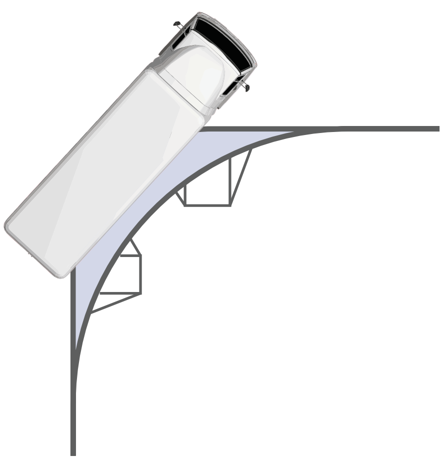
Austin, TX

Salt Lake City, UT

DUAL RADIUS WITH DEFINED APRON AREA

This group features a defined apron area that is intended for encroachment by larger design and control vehicles on a more frequent basis, while providing a tighter radius for managed vehicles. When compared with the single path typology, this type exhibits a more obvious wider curb line for larger vehicles. Managed vehicle compliance in staying out of the apron will depend on the design details discussed in the next section. Pedestrian and bicyclist waiting areas should be designed outside of the truck apron.





Examples of a dual path corner design include:

Curb extension (Ottawa, ON)

Right turn channel (Bend, OR)

Signalized intersection (Portland, OR)

Elevation and Curb Profile

The elevation of a raised apron may be between the existing road grade and the adjacent sidewalk or pedestrian corner area. Many raised aprons use an intermediate height between the two, allowing for a mountable surface while still providing clear vertical distinction from the sidewalk.

For raised aprons, the profile of the edge of the mountable element determines how easily a vehicle can mount it.

- A **traversable** curb is better for the stability of larger design and control vehicles, but may not provide enough deterrence for some managed passenger vehicles.
- A **mountable** curb typically has a steeper bevel, providing more deterrence to passenger vehicles.

Atlanta, Salt Lake City, and Austin use curb profiles with a vertical plus a mountable portion. Less frequent control vehicles should be accommodated with greater vertical portions, to increase the penalty for encroachment. If pedestrians or bicyclists need to cross the apron, traversable curbs may be more suitable.

Elevation and curb profile variations include:

Traversable Curb (St. Louis Park, MN)

Traversable Curb (Mississauga, ON)

Flush with roadway (Ottawa, ON)

Mountable Curb (Salt Lake City, UT)

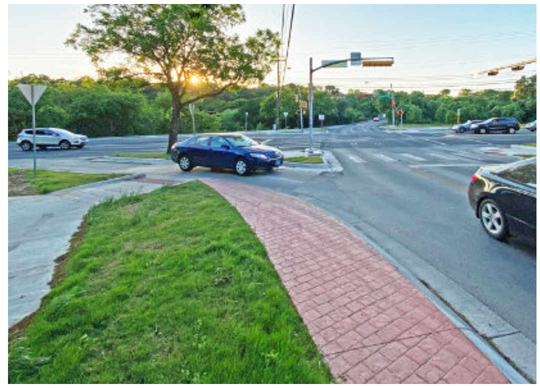
Color and Materials

Color reinforces the distinction between the apron and other road elements. A surface material that is the same color as the sidewalk reinforces the distinction from the roadway for drivers, but may encourage pedestrians to dwell on it, as it may be mistaken as a continuation of the pedestrian area. A more aesthetically enhanced apron distinguishes it from both the roadway and sidewalk, but if the surface finish looks too "nice" it may be unclear to truck drivers that the surface is intended to be driven over.

The City of Austin found that a brick color worked best to distinguish the mountable area from the roadway surface, sidewalk and bikeway. Edge striping can also specifically reinforce the desired turning path. The City of Portland uses edge striping in applications where the turning path may not be clearly conveyed by the apron shape, such as corner speed humps (see ***Rumbles, Humps, and Bumps*** section below).

Color and material variations include:

Pavers with concrete to denote walking path (Atlanta, GA)



Textured, colored concrete (Austin, TX)

Pavers, cobbles or other similar materials (Atlanta, GA)

Gore striping/hatching (Cambridge, MA)

Edge striping (Portland, OR)

Rumbles, Humps and Bumps

Textured surfaces provide a tactile feedback to the managed vehicle driver, making it intentionally unpleasant to drive over the apron. Unlike aprons defined by curbs, textured surfaces do not need to cleanly define a turning path for the managed vehicle; while some cities, including Portland, Oregon, use edge striping to reinforce the desired turning path, New York City has experimented with a box-shaped speed bump area. Experience from New York City and Portland shows that modular speed bumps are an effective retrofit application, requiring no reconstruction of the corners. At the time of publication, New York City has implemented this treatment at over 300 intersection corners. San José's quick-build program took advantage of readily-available pavement reflective markers to create bumps in the apron area.

Cities like Ottawa, Ontario have experimented with rumble strips within the apron, while other cities that do not need to consider snow removal options have installed larger bumps and humps in the apron. Textured or rumble strip options may generate additional vehicle noise, which should be considered in residential contexts.

Variations of rumbles and bumps include:

Rumble strips/surface (Ottawa, ON)

Speed humps/cushions (Portland, OR)

Speed bumps, defined turning path (Portland, OR)

Speed bumps, square area (New York, NY)

Pavement reflective markers as bumps (San José, CA)

Coverage/Extents

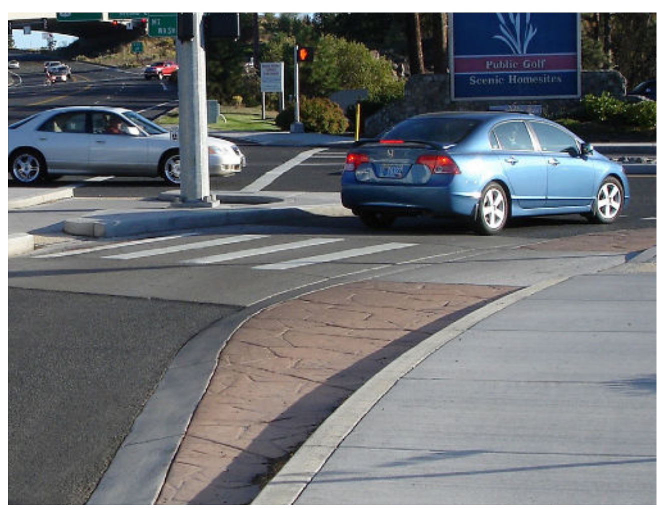
Aprons may pass through the crossing paths of pedestrians and bicyclists or may terminate before and/or after. Detectable warning surfaces should be placed outside of the apron surface so as not to put pedestrians in risk of conflict with a large turning vehicle. One exception to this is Austin, Texas, which allows very infrequent control vehicles (fire trucks) to mount over the area where pedestrians or bicyclists would be expected to dwell. Similarly, stop bars for bicyclists, where applicable, should be set back behind aprons.

Variations in the coverage/extents of aprons include:

Tangent to physical corner, crosswalk painted over apron (Portland, OR)

Between crosswalks (Portland, OR)

Between crossrides (Ottawa, ON)



Crosswalk does not continue across mountable apron (Bend, OR)

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03 POLICY SUPPORT

Implementing corner designs that reduce pedestrian exposure while still accommodating larger vehicles may constitute a different approach to design for many transportation practitioners. Without a supportive policy framework and design guidance, each project could meet a measure of resistance as the design is refined. Many agencies have adopted proactive policies intended to aid designers when considering the needs of different roadway users.

The AASHTO *Green Book* (2018) identifies and addresses the need for design flexibility by stating that "the design criteria presented in this policy are not fixed requirements, but rather are guidelines that provide a starting point for the exercise of design flexibility."[2] In response to the need for design flexibility, AASHTO further identifies three additional resources to aid engineers in applying flexibility where appropriate. Policies can take many forms, but many agencies are building more flexible design principles into their local design standards, leaving no question as to their applicability. The following examples are not intended to be comprehensive, but to serve as inspiration for agencies looking to formalize policies and design standards that permit more flexible intersection design.

Local Agency Examples

The **City of Toronto, Ontario** created a new section in May 2018[18] to supplement its *Road Engineering Design Guidelines* focused on curb radii design. Some key highlights include defining what constitutes frequent truck turns, defining the design and control vehicles for a variety of intersection contexts, and defining optimal turning vehicle speeds for a variety of vehicle types (with a maximum of 10 mph or 15 kph). Large control vehicles are allowed to cross the centerline and use the full width of the receiving roadway in some intersection contexts. Additionally, the City provides the following supplementary resources:

- A Curb Radii Design Worksheet is provided with the recommendation that it should be filled out and kept on file for each project
- Truck and large truck right turning volumes at most major intersections, mitigating the need for field counts for projects
- A series of design tables for a variety of corner configurations, varied by vehicle type, frequency, and lane widths, mitigating the need for AutoTURN analysis for conceptual design

The **City of Edmonton, Alberta** published its *Complete Streets Design Standards* in 2018[5], which includes a section on corner radius (Section 3.6.2). The standard defines the design vehicle based on the classifications of intersecting streets and provides a "design domain" for corner radii to be used as a starting point. Guidance is provided for where design and control vehicles may cross center lines of receiving roadways, and where two-centered curves may be used. The standard also provides a discussion on the use of mountable curbs in combination with truck aprons at intersection corners to accommodate control vehicles (or less frequent design vehicles), and how to integrate them with pedestrian curb ramps.

The **City of Austin, Texas** is updating its *Transportation Criteria Manual* in 2020 to define design and control vehicles, turning path allowances, and encroachment criteria. The Criteria Manual contains the design criteria to support the city's code of ordinances. Austin has many constrained streets and one of the largest challenges has been to accommodate the needs of the larger fire apparatus.

State/Provincial Examples

The **Georgia Department of Transportation** covers large vehicle turns in its *Design Policy Manual*[8] in Section 3.2. It differentiates the design vehicle from the check (control) vehicle which is more infrequent and may utilize "all available space including opposing travel lanes and areas outside of travel lanes designed to accommodate off-tracking." Local context is stressed when selecting design and check vehicles with the use of simulation software recommended to model the paths of both on projects.

The **Florida Department of Transportation** has established guidance on accommodating design and control vehicles on state roadways in the *FDOT Design Manual*, Section 201.6[6]. It has similar definitions of design and control vehicles; however, FDOT allows control vehicles to have minor encroachment onto curbs and areas within the curb return if no critical infrastructure such as traffic signal poles are present.


San Fernando St

04 RECOMMENDATIONS

This white paper has reviewed engineering design principles and behavioral characteristics of drivers and crossing pedestrians as well as potential corner designs that can reduce the risk of a permissive turning collision between a vehicle and a pedestrian or bicyclist. This section outlines a recommended intersection design strategy that can be adopted at any level into an agency's design process.

Identify Vehicles

Alta recommends identifying the relevant types of vehicles that will be using each intersection, which will vary depending on roadway classification and context. For example, a local street intersection with an arterial roadway will have different control vehicles than an arterial intersection with a collector. Similarly, intersections with frequent turning buses will have different considerations than those with no bus service. Projects should be validated to their local conditions. Emergency vehicle access must also be considered (see Section 03 for further discussion). Furthermore, Alta recommends agencies adopt the NACTO definitions of the Managed, Design, and Control vehicles. This framework is extremely useful when selecting which vehicles need to be considered and how they will travel through the corner.

Define Turning Paths

This white paper recommends that each intersection under design be specifically tailored to the design vehicles expected to use it. The important distinction here is to not utilize standard details or to simply consult vehicle turning profile data sheets. Rather, turning software such as AutoTURN should be utilized at each intersection to provide certainty that allocated space is not only appropriate to accommodate vehicle turning needs, but also minimizes pedestrian crossing distance and risk. Some larger control vehicles can be modeled at slower 10 mph (15 kph) or crawl speeds to optimize the design.

Control vehicles should be accommodated utilizing all receiving lanes and in some lower-order streets be allowed to cross the centerline if extremely rare in frequency.

Design vehicles should be allowed to complete their turn by utilizing a mountable apron with waiting pedestrians and bicyclists held outside of this swept path.

Managed vehicles, being the most commonly present vehicle, should be provided a carefully selected effective turn radius that self-enforces the desired design speed. For this to work, the corner must not only take into account the physical radius, but should utilize the "fastest path" methodology commonly used in roundabout design to validate the design speed. Despite a smaller radius, extenuating factors discussed in the section on "physical vs. effective radius" may still allow faster turning than desired, and adjustments to the physical radius may be necessary. The mountable apron should discourage use by the managed vehicles.

Select Materials

The corner typologies and case study examples in this white paper show a variety of possible designs in use throughout North America. No two cities, at the time of writing, are alike. Agencies seeking to adopt mountable corner designs should carefully consider materials, drainage standards and implications, use of accent colors, and use of raised mountable curb profiles to best serve their communities. Standardization should be a local goal, so that new intersections or retrofits use similar materials and treatments to promote uniformity and driver expectancy on the local level.

Monitor Results

Roadway safety is a topic that is supported across the population. Monitoring programs that can quantify the safety benefits will be helpful in allocating funding to improve existing intersection corners. If all cities could show results similar to San Francisco's 100% observed driver yielding to pedestrians, it would be logical that safety funds would be easily prioritized for corner improvements on a large scale.


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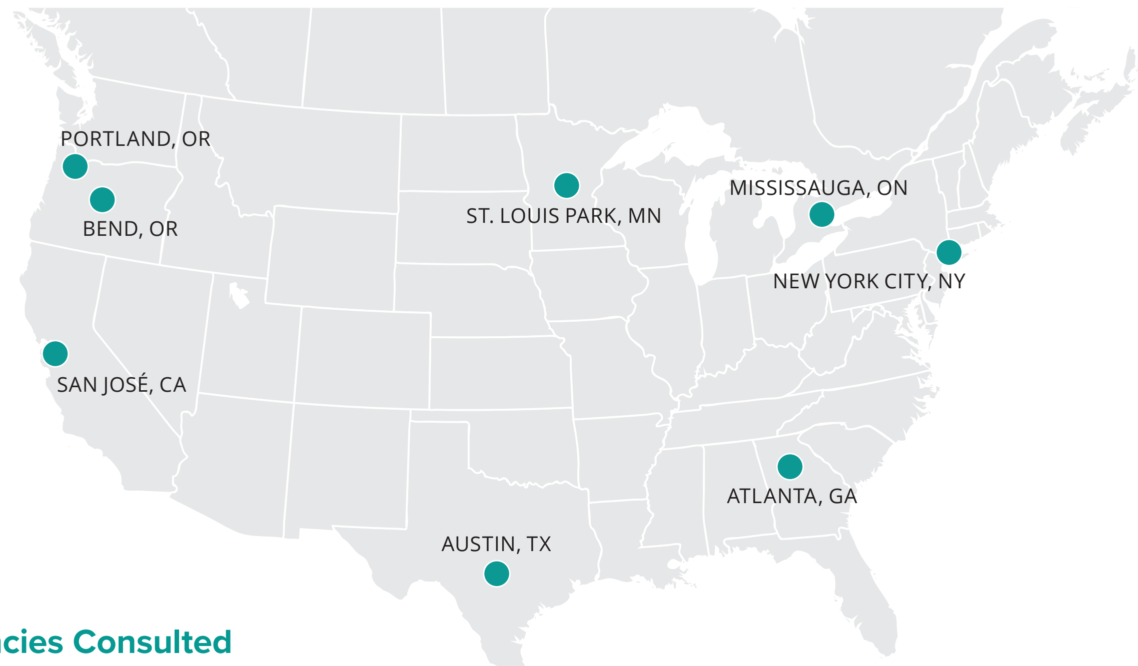
05 CASE STUDIES

To support this white paper, the authors conducted interviews with staff at nine US and Canadian agencies who have implemented some form of truck apron in their corner designs. Each agency has developed locally context-sensitive solutions which differ from each other. Interviews focused on the particular problem being solved, the solution, the efficacy of the designs, and any key takeaways or lessons learned through experience. It is Alta's hope that the information contained within these case studies will help normalize these design principles in everyday intersection design throughout the US and Canada.



Agencies Consulted

City of Mississauga, Ontario, Canada

City of Austin, Texas, USA

New York City Department of Transportation, New York, New York, USA

Upper Westside Improvement District, Atlanta, GA, USA

Atlanta Downtown, Atlanta, Georgia, USA

Portland Bureau of Transportation, Portland, Oregon, USA

City of San Jose, San Jose, California, USA

Oregon Department of Transportation, Region 4, Oregon, USA

Minnesota Department of Transportation, Minnesota, USA

CASE STUDY

MISSISSAUGA, ONTARIO, CANADA

KEY TAKEAWAYS

A traversable curb profile to define the apron appears to work well at deterring passenger vehicles, even with a temporary asphalt surface. This may be due to the large apron radius not imposing significant restrictions on smaller turning vehicles.

EGLINTON AVENUE WEST AT MISSISSAUGA ROAD

Context

Eglinton Avenue West is a major truck route, and Mississauga Road provides the main goods movement connection into the nearby village of Streetsville in Mississauga. Mississauga Road has one receiving lane, so there is little opportunity for trucks to oversteer through the turns when making the westbound right turn movement. As a result, the back wheels of trucks frequently sweep across the pedestrian area and the adjacent boulevard. In 2020, the City of Mississauga added a shared use path along the north side Eglinton Avenue, which triggered an opportunity for design improvements at the intersection.

Problem Solved

The problem was two-fold: the City wanted to provide a legitimate turning path for trucks at this intersection, but with the planned trail project, they were concerned that increasing the physical corner radius would lead to faster vehicle turning speeds, worsening the comfort level for bicyclists and pedestrians.

Solution and Process

A truck apron was proposed as a solution to the problem. The City conducted a peer review and spoke with other agencies, then circulated an internal memo with its proposed design approach. One of the greatest concerns raised through the design development was the potential for pedestrians to stand on the apron surface.

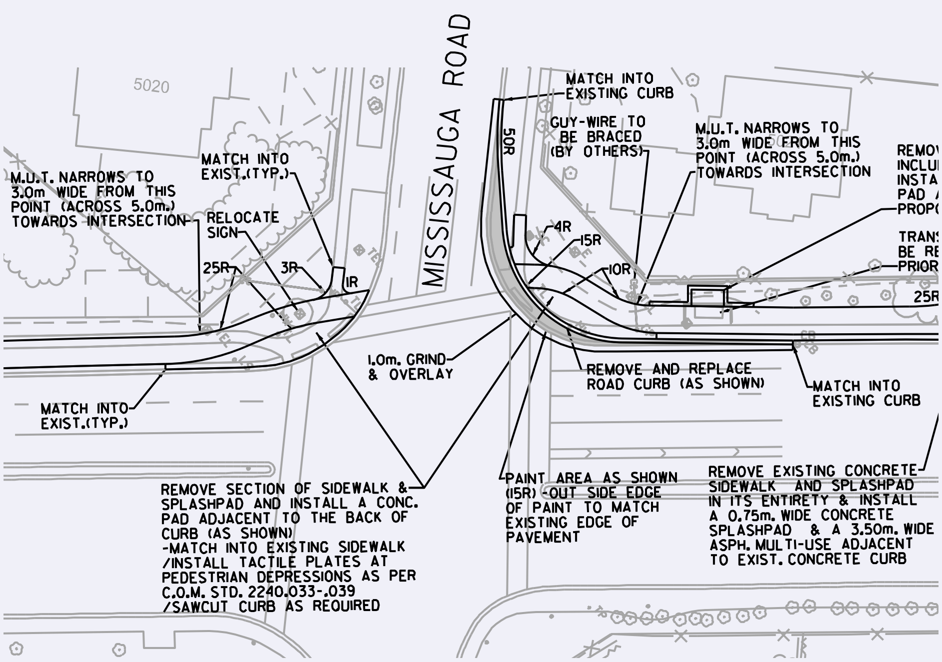
The design solution is an intermediate-height apron with a salmon-colored concrete surface separated from the roadway by a traversable curb. The design vehicle is a WB-20 truck (similar to a WB-67 in the United States); as this is the only vehicle type expected to use the apron. The apron maintains the previous corner radius, while the physical corner radius was adjusted to a two-centered curve to suit the observed truck turning path, and was verified with AutoTURN. When complete, the painted crosswalk and crossride will extend only across the asphalt portion of the roadway, and the apron will be left without pavement markings.

Efficacy

At the time of this writing, the construction was not complete, however the apron path had been implemented with a temporary asphalt surface. The City has visited the temporary condition multiple times and noted that observed compliance is excellent; all passenger vehicles are avoiding the apron, while trucks are using it without encroaching onto the sidewalk. When the project is completed in Summer 2020, including the trail and crossride, the City plans to conduct more substantial field observations.

Typology

Turn type	Signalized intersection
Accommodation Type	Dual path
Elevation and Curb Profile	Traversable (3 inches / 75 mm)
Color and Material	Red painted concrete
Rumbles and Bumps	None
Coverage/Extents	Fully through corner



ABOVE: As of Summer 2020, the corner design is partially complete. The final design will feature a painted red concrete apron surface and a crossride. Credit: City of Mississauga

AT LEFT: Design drawings for the intersection showing the multi-use trail (M.U.T.) that will be added. Credit: City of Mississauga

CASE STUDY

ST. LOUIS PARK, MINNESOTA

KEY TAKEAWAYS

Freeway interchanges are especially likely to require accommodation of large vehicles. When higher pedestrian and cycling volumes are expected, aprons can be effective for accommodating all users.

WOODDALE AVE S AT MINNESOTA HIGHWAY 7 INTERCHANGE

Context

Minneapolis is currently expanding its LRT network to the southwest, into the municipality of St. Louis Park and beyond. To improve connectivity to the future LRT station, a local high school, and support future development, St. Louis Park commissioned the reconstruction of the Wooddale and MN Highway 7 freeway interchange, including the widening of the overpass structure by 12 feet on each side.

Problem Solved

To support walking and cycling comfort in the area, one goal of the project was to minimize the pavement areas of each of the crossings. At the same time, MnDOT required that the intersection corners support the turning movements of WB-65 trucks.

Solution and Process

The reconstructed intersection contains three corners with truck aprons – one regular corner and two yield-controlled right turn channels. Inspired by the effectiveness of truck aprons in roundabouts, the lead consultant for the project proposed the truck apron design approach for the three right turn treatments, and it was approved by St. Louis Park as well as MnDOT.

The chosen design treatment consists of a concrete apron surface at intermediate height, providing an area for the swept path of trucks while restricting passenger vehicles to a tighter path. The apron meets the roadway with a fully-mountable curb profile, and is separated from the sidewalk area by a vertical barrier curb. Flush dropped curbs with tactile surface indicators meet the apron surface at the pedestrian crossings.

Crosswalk markings are provided, but they only extend across the asphalt surface and terminate at the apron edges. Solid white painted lines define the edge of the apron for added visibility.

The control vehicle for the aprons is a WB-65 truck, which was dictated by MnDOT given the context as a freeway interchange. In each of the three corners, the corner angle is skewed and only one receiving lane is available, requiring a large physical corner radius. The apron radii are significantly smaller, leading to large apron areas. The asphalt area of the right turn channel throats is kept to roughly 12 feet or 4 meters for the managed vehicle.

Efficacy

Though a detailed assessment has not been conducted, anecdotally, based on post-construction site visits, the designs appear to be working as intended.

Typology

Right turn Type	Stop-controlled intersection corner (1), yield-controlled right turn channel (2)
Accommodation Type	Dual path
Elevation and Curb Profile	Traversable (3 inches / 75 mm)
Color and Material	Concrete, white painted stripe to delineate apron
Rumbles and Bumps	None
Coverage/Extents	Fully through corner

ABOVE: A road user's view of one of the right turn channels at the interchange with a traversable apron treatment.
BELOW: A close-up view of the same channel showing the traversable curb profile.

CASE STUDY

NEW YORK CITY, NEW YORK

KEY TAKEAWAYS

1. Focus on being as data driven as possible, don't do it on a request basis.

2. Forget the bollards and go right to the rubber speed bumps.

CITY-WIDE PROGRAM

Context

As part of NYC DOT Vision Zero program, the agency wanted to target the high number of collisions due to motorists cutting corners when turning left from a one-way street onto another one-way street. The City's program also includes "Centerline Hardening," where left turns are from a one-way to a two-way street. In New York City, left-turn-related killed or seriously injured (KSI) crashes outnumber right-turn crashes by 3:1 (19% vs 6%). Certain high-injury right-turn pedestrian crash areas have also been treated, though these are much fewer in number.

Problem Solved

NYC DOT's data revealed that left turns pose a greater threat to pedestrian safety than right turns. This is particularly due to the nature of many streets being one-way and that the driver side vehicle pillar limits visibility of pedestrians for drivers turning left. The goal was to develop a scalable design solution to slow down turning vehicles and force turns at closer to a right angle to reduce the probability and severity of collisions between motor vehicles and vulnerable road users.

Solution and Process

Initially NYCDOT experimented with the creation of "corner wedges" using flex post bollards, but these were frequently damaged and became a significant maintenance issue. In recent years the agency has moved to a mountable bolt-in rubber bump solution, placed on the corner between the two roadways.

While many NYCDOT implementations have drawn resistance and opposition, their corner wedges program has been implemented with relative ease and broad acceptance.

Passenger vehicles are used as the managed vehicle for the corner bump areas, and AutoTURN is typically used to validate the turning path. Trucks and buses are expected to turn by driving over the mountable areas.

The corner mountable areas are typically placed between the two crosswalks and are outlined with yellow pavement markings when configured for left turns and white pavement markings when configured for right turns. Black and yellow speed bumps are either placed diagonally within the defined area or along the edges.

For winter maintenance, the speed bumps are typically placed outside of the snowplow sweep path, and after one winter season with a few days of plowing operations, there was minimal damage to the implemented treatments.

The implementation of these interventions is tied exclusively to pedestrian injury data, with high-injury locations being prioritized. The program deliberately does not operate on a public request basis to ensure that the most sensitive locations are targeted first.

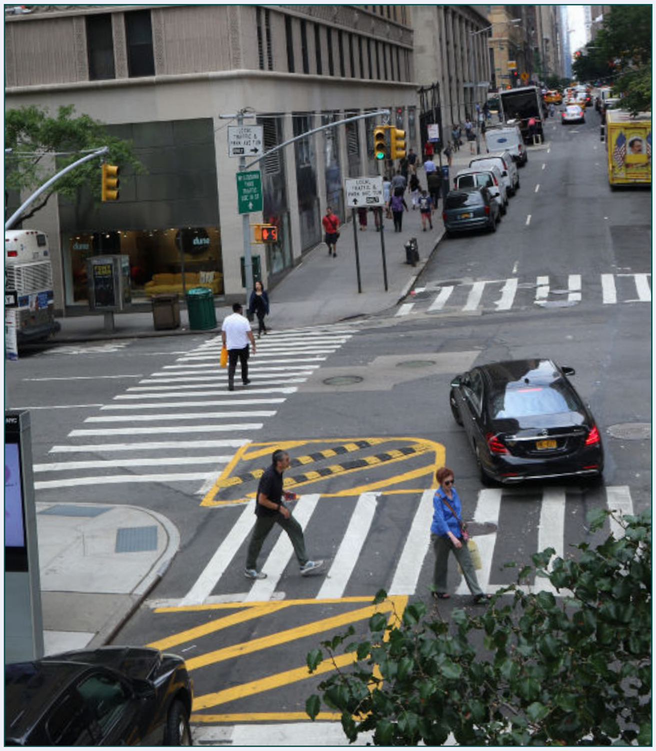
Efficacy

Over 300 locations have been treated as of early 2020. NYC DOT has conducted studies of the effectiveness of these measures and found turning speeds are reduced by up to 40% with the corner wedges, and serious pedestrian injuries are down 30% to 40%.

The agency also reports data on the maintenance of the rubber speed bumps. In an 18-month study period, 55 of 95 locations studied required no repair or replacement, and on average there were 1.15 repair/replacements per location.

Typology

Turn Type	Left turns from a one-way street to another one-way street. Some right turns. Mostly at signalized intersections.
Accommodation Type	Dual path
Elevation and Curb Profile	Flush with roadway
Color and Material	Yellow pavement markings to define turning path and accent the rubber speed bumps
Rumbles and Bumps	Rubber speed bumps
Coverage/Extents	Between crosswalks



ABOVE LEFT: a passenger vehicle turns left at the intersection of two one-way streets, steering around a rounded corner apron with diagonal speed humps. Credit: NYC DOT. ABOVE RIGHT: an example of a square corner apron outlined with speed bumps. Credit: NYC DOT.

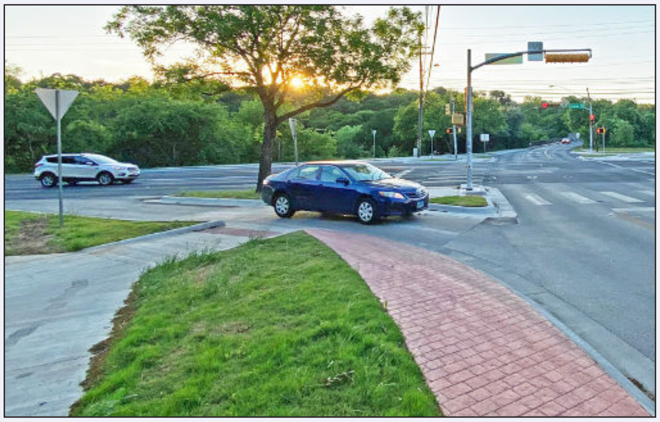
BELOW: a left-turn speed bump design combined with a hardened receiving centerline treatment. Credit: NYC DOT

CASE STUDY

AUSTIN, TEXAS

KEY TAKEAWAYS

1. Work collaboratively with city fire departments
2. Use high-contrast materials to increase visibility of the mountable area and deter passenger vehicles



This Dual Path apron at a channelized turn lane helps slow vehicles through the turn. Credit: City of Austin

CITY-WIDE PROGRAM

Context

The City of Austin is working to design and implement pedestrian safety improvements and separated bikeways in many constrained environments. Many of the city's streets are constrained in width, making improvements for bicycling and walking difficult when accommodating larger vehicle turns. The city desires solutions which do not allow any encroachment from passenger vehicles.

Problem Solved

Austin has developed a mountable curb for bikeways that still accommodates mounting by fire apparatus, but would not be inviting for passenger vehicles. It is also expanding use of mountable dual path corners for more frequent vehicles. Each project is treated as a custom design.

Solution and Process

Given the infrequent passage of fire trucks, it was determined that these vehicles may encroach on the areas of an intersection where pedestrians or bicyclists may queue. Physical corner radii are set based on the design vehicle, and mountable corner elements are provided to allow fire trucks to make turns. Large vehicles are permitted to encroach into the adjacent approach lane by straddling the lane line and can complete their turn through mounting hardscape if needed. Austin has a design process which analyzes the turn path of the largest fire apparatus (the "Quint") with additional modeled extents including the bucket envelope, body envelope, the front and rear tire paths and the overall apparatus path. Doing so ensures that the vehicle can overhang constrained locations without coming into conflict with street furniture and signal equipment during design. These mountable curbs are not seen as appropriate for more frequent large vehicles like buses.

Working with the fire department, Austin Transportation Engineering staff have developed a mountable curb profile which seeks to make the curb undesirable for passenger vehicles, while allowing fire apparatus to access and mount if needed.

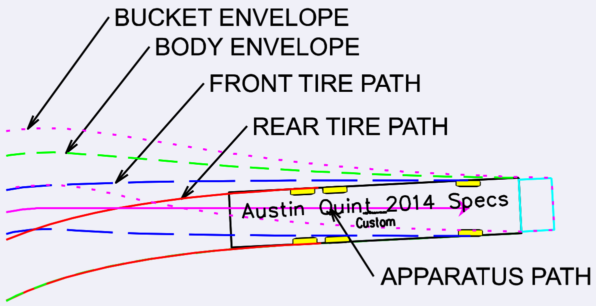
The city has a three-tiered design review process for new projects which features:

1. Internal Transportation Engineering staff geometric review. Designers know which elements have support in various approval positions and have these people on the review team. Design assumptions are defined prior to design. This includes running simulations on:
    a. Passenger vehicle turning at 10 mph (15 kph)
    b. Design vehicles
    c. Control vehicle (Quint)
2. Fire Marshal's office review. The office has an engineering review team which does street design review.
3. Field engineering review during construction to make any adjustments due to site realities.

Efficacy

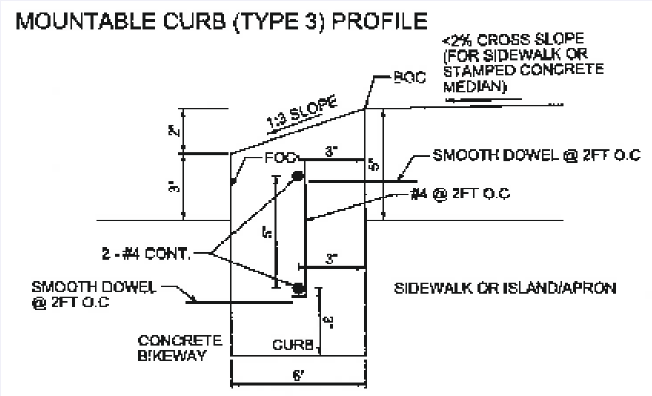
Dozens of locations have been implemented. The city is also now implementing the curb profile at modified channelized turns to provide smart channel geometry with a truck apron. Lessons have been learned by the city through implementation. The color and texture of the raised areas needs to provide substantial visual contrast not only for right turns adjacent to the curbs, but for opposing lefts as well. Early implementations featured standard concrete with asphalt bikeways behind them. Many vehicles began to impact the curbs as they were not visible enough. Several installations were trimmed back or modified to improve contrast. The city has been using a red integrally colored concrete in the bikeway areas behind the curbs with stamped colored concrete in the raised areas to provide visual distinction.

Austin Fire Department "Quint" testing a mountable curb profile. Photo: City of Austin.



Typology

Turn Type	Right turns with protected intersections and channelized right turns
Accommodation Type	Single path and dual path
Elevation and Curb Profile	5 inches (125 mm) mountable curb with 3-inch (75 mm) vertical portion plus 2 inches (50 mm) at a 1:3 bevel
Color and Material	Colored concrete behind beveled curb
Rumbles and Bumps	Stamped concrete
Coverage/Extents	After crosswalk for dual path. Entire corners for areas mountable by fire apparatus



The mountable curb features a 3 inch (75 mm) vertical rise followed by a further 2 inch (50 mm) over 6 inch (150 mm) run for a 1:3 slope. Image: City of Austin.

A more recent implementation of a protected intersection corner that is mountable only to fire trucks. The color helps distinguish this corner to other drivers so as not to hit it.

CASE STUDY

SAN JOSÉ, CALIFORNIA

KEY TAKEAWAYS

1. Wherever possible, field-test the design vehicle to ensure the radius is correct

2. The “bumpy” reflectors are key features in encouraging higher rates of motorists yielding to pedestrians and bicyclists – pavement markings alone aren’t enough

3. Dual turning paths (with aprons) are much more effective

VARIOUS LOCATIONS, CITY-WIDE QUICK-BUILD BICYCLING NETWORK PROGRAM

Context

Since 2017, the City of San José has been implementing quick-build bicycle infrastructure throughout the city, totaling 10 miles (16 kilometers) at the time of the publication of this document. This includes quick-build protected intersections, which have been featured in NACTO’s *Don’t Give Up At The Intersection* guidance document.

Problem Solved

The problem was defined as improving safety at intersections where bicyclists and pedestrians conflict with turning motorists. Specifically, the City wanted to design corners that maximized the rate of yielding between turning motorists and people riding bikes.

Solution and Process

The City’s solution includes setback crossings, tightened corner radii, and a dual turning path design with an apron area. Intersections are completely designed using pavement markings and temporary materials, and no changes are made to signals or curbs.

Removable plastic bollards are used to define the larger vehicle turning path. The second, smaller radius is defined with a painted edge line, and the apron area between is gore striped. In-pavement reflectors are placed along the smaller radius path and across the apron area to introduce bumps and discourage smaller vehicles from turning across the apron.

Passenger vehicles are used as the managed vehicle, and determine the smaller radius. The design vehicle is an SU-30 delivery vehicle, which is expected to turn across the apron area without oversteering. Larger transport trucks are used as the control vehicle, which are expected to oversteer to complete the turn.

In one instance, where the design vehicle was a passenger bus, the radius was field-tested with a test vehicle before installing bollards. The field test indicated that the radius needed to be increased slightly and adjustments were made.

The greatest effort to achieve the design was gaining internal agreement on the principles of the setback bicycle crossing design. After that, work was done to validate that the designs could be implemented without altering signals and curbs. Since several of these have been implemented and field tested, the City is confident in the design approach, and is planning for protected intersection construction using permanent materials when the opportunities arise.

Efficacy

Though a detailed assessment has not been conducted, the designs appear to be working as intended. Anecdotally, motorists are observed to be driving more slowly and paying more attention to pedestrians and bicyclists, with higher yielding rates. Though not designed as such, many pedestrians wait for the signal on the street-side of the bicycle lanes, shortening the crossing distance.

The quick-build materials used are proving to be durable and only minor repairs and replacements have been needed.

One corner of a quick-build protected intersection. A dual turning path is provided, and a passenger car is seen taking the managed vehicle path (smaller radius). Credit: City of San José, Department of Transportation

The City intends to test the rubber speed bumps that NYC DOT uses on some upcoming quick-build intersections.

The City has installed corners with a single turning path as well as corners with dual turning paths. The dual turning paths have emerged as the preferred option and will be the default approach going forward. Many corners initially built with a single turning path are being retrofitted with a dual path.

Typology

Right turn Type	Signalized and unsignalized intersection corners with quick-build bikeways
Accommodation Type	Dual path
Elevation and Curb Profile	Flush with roadway
Color and Material	Painted gore area
Rumbles and Bumps	In-pavement reflectors used as bumps throughout the turn path
Coverage/Extents	Between bicycle crossing markings

CASE STUDY

PORTLAND, OREGON

KEY TAKEAWAYS

1. If aprons are being tested as a pilot, make sure to measure their performance to inform long-term policy decisions.

2. The New York City corner "wedges" model has been effectively replicated in Portland with positive results.

VARIOUS LOCATIONS, CITY-WIDE PROGRAM

Context

The City of Portland has identified left-turn crashes as one of the most common crash types across the city. As part of its Vision Zero program, a pilot was started in summer 2019 to implement "left turn calming" measures at a number of intersections, which also included a smaller number of right turn conflict locations.

Prior to the establishment of the Vision Zero program, in 2009 and 2012, the City also identified two specific locations where right-turning conflicts were high between large vehicles and pedestrians.

Problem Solved

The problem was defined as balancing competing demands at corners: safety for pedestrians, access for freight and transit, and preservation of on-street parking.

Solution and Process

Portland has implemented two types of truck apron designs.

Corner "wedges", made of rubber speed bumps typically placed perpendicular to the corner radius, between the crosswalks, with the managed vehicle radius defined by a painted edge line. These are currently being implemented and evaluated as part of a left-turn calming pilot project under the PBOT Vision Zero program. Though most of the implementation locations are left turns, the same treatment has been applied at a number of right-turn conflict points as well. The program is largely modeled on New York City's program.

Corner speed humps, placed within a flush concrete apron area extending to the tangents of the larger radius, with a raised concrete speed hump at the midpoint of the corner. A white edge line is used to define the managed vehicle turn radius, and crosswalks are painted overtop of the apron area. Two of these were designed and installed in 2009 and 2012. They were based on a review of various corner designs from other jurisdictions including Bend, Vancouver, Snohomish, Davis, and Medford. The apron design was then developed in-house in collaboration with PBOT planning and engineering staff.

Efficacy

The effectiveness of the left turn wedges is being evaluated as part of a pilot project running from Summer 2019 to Summer 2020 to inform the long-term use of these measures. As part of the project, turning speeds, corner cutting, and maintenance requirements will be measured. The turning needs of buses were overlooked in the initial launch of the turn wedges, and some were repositioned after the fact to place them outside of the turning paths of buses to improve passenger comfort.

The efficacy of the corner speed humps was never formally studied, although PBOT staff shared that they seem to work as intended, with vehicles tracking correctly and pedestrians standing outside of the apron area. The PBOT staff shared that if constructed again, they would have designed the raised hump to be higher, with sharper slopes on the edges to increase their effectiveness.

ABOVE LEFT: A corner "wedge" at the intersection of two one-way streets in downtown Portland. ABOVE RIGHT: A concrete corner speed hump as a right turn treatment. Part of the center area of the apron is raised as a deterrent to passenger vehicles. BELOW: A second example of a concrete corner speed hump, with a more pronounced "hump" area.

Typology

LEFT TURN CORNER WEDGES

Turn Type	Left turns, one-way streets onto one-way or two-way streets
Accommodation Type	Dual path
Elevation and Curb Profile	Flush with roadway
Color and Material	Yellow paint to define turning path and accent the rubber speed bumps
Rumbles and Bumps	Rubber speed bumps
Coverage/Extents	Between crosswalks

CORNER SPEED HUMPS

Turn Type	Right turns, one signalized and one non-signalized intersection
Accommodation Type	Dual path
Elevation and Curb Profile	3 inches (75 mm) traversable curb profile outlining speed hump
Color and Material	Concrete, yellow paint used to outline raised area
Rumbles and Bumps	Speed hump
Coverage/Extents	Tangent to corner

CASE STUDY

ATLANTA, GEORGIA

KEY TAKEAWAYS

1. Redesigning a corner as a retrofit can bring unintended consequences and costs.

2. It's all about space. Carve out as much space as possible with the corner design to accommodate pedestrians and cyclists.

TWO LOCATIONS: 10TH NW/BRADY and PEACHTREE CENTER/JOHN PORTMAN

Context

Atlanta's Upper Westside is an older industrial area undergoing a rapid transition into an urban neighborhood. Pedestrian traffic has been steadily increasing at all times of day as restaurants, nightclubs, and residences open in the community. The Community Improvement District for the neighborhood is committed to transforming the community's streets from wide industrial thoroughfares to slower streets that are more walkable. The intersection of 10th NW and Brady was selected by the CID as a target for improvement, with all-way stop control and a bumped-out corner to be added.

From 2015 to 2017, with the help of the Atlanta Downtown CID, the City of Atlanta installed bidirectional cycle tracks on John Portman and Peachtree Center. Where these two streets intersected, a unique design solution was needed to accommodate all of the possible cycling turning movements through the intersection.

Problem Solved

At 10th NW and Brady, the goal of the project was to reduce pedestrian crossing distances and exposure to traffic, and make pedestrians feel welcome in the intersection, while still accommodating the significant volume of freight traffic at the intersection.

At Peachtree Center and John Portman, the problem was creating space for cyclists to queue and complete turning movements between the two bidirectional on-road cycle tracks, while accommodating the large volume of large turning vehicles at the intersection.

Solution and Process

The two featured designs are notably different:

10th NW and Brady: The corner is constructed as a mountable bump-out, with mountable curbs extending from the original radius to create a tighter radius for managed vehicles. The apron is at an intermediate height, with a 2-inch curb reveal between the corner radius and the apron. The detectable warning surface is placed off of the apron, and a concrete curb ramp extends from the warning surface to meet the pavement. The remainder of the apron beyond the curb ramp is surfaced with red pavers.

Peachtree Center / John Portman: On the corner where the bidirectional cycling facilities intersect, a kidney-shaped traffic island was installed. The island is raised, with granite mountable curbs and a granite stone surface. The traffic island is only intended to be mounted by large control vehicles (18-wheelers), and otherwise functions as a two-stage left turn area for bicyclists. A "no left turn on red" restriction is applied at this intersection as well, to ensure that bicyclists waiting next to the mountable median are not placed in conflict with large turning vehicles.

Efficacy

The Upper Westside CID is very pleased with the design and though no formal study has been completed, the CID reported that anecdotally, passenger cars are not seen driving over the apron, and trucks do not have trouble traversing it. The volume of pedestrians crossing at the intersection has significantly increased since the all-way stop control was implemented.

The Atlanta Downtown CID reported that its apron design is generally working as intended, with smaller vehicles avoiding the mountable median and larger vehicles driving over it. One issue has been visibility of the median, both for motorists and cyclists, and a proposal is currently underway to paint it with brighter colors. The CID also reported that if done again, they would strive to create more space for cyclists within the corner, and apply more measures to reduce motor vehicle turning speeds.

ABOVE LEFT: The corner design treatment applied at 10th NW and Brady. The apron is defined by a mountable curb with a significant vertical component. ABOVE RIGHT: The corner design at Peachtree Center and John Portman.
BELOW: Two bicyclists queuing behind the mountable corner apron at Peachtree Center and John Portman.

Typology

10TH NW / BRADY

Turn Type	Right turn, all-way stop-controlled intersection
Accommodation Type	Dual path
Elevation and Curb Profile	4 inches (100 mm) mountable curb
Color and Material	Concrete sidewalk surface for curb ramp, red pavers for rest of surface
Rumbles and Bumps	N/A
Coverage/Extents	Tangent to corner

PEACHTREE CENTER / JOHN PORTMAN

Turn Type	Right turn, one-way to one-way at signalized intersection
Accommodation Type	Single path
Elevation and Curb Profile	Mountable curb, height not specified
Color and Material	Granite curb with granite paver surface with painted white edgeline
Rumbles and Bumps	N/A
Coverage/Extents	Between crossrides

CASE STUDY

BEND, OREGON

KEY TAKEAWAYS

Keep it simple: while aprons and raised crossings can improve the safety of right-turn channels for pedestrians, designers should always consider the trade-offs between pedestrian comfort/safety and vehicular capacity, and the need for channelized right turn lane(s) in the first place.

US-20 AT NORTHWEST MOUNT WASHINGTON DRIVE

Context

In 2006, ODOT Region 4 reconstructed this intersection to add a dedicated southbound right-turn lane and right-turn channel to manage vehicle access into the adjacent conference and convention center. To accommodate the high level of pedestrian activity generated by the convention center, measures were proposed to enhance the pedestrian safety of the turn channel crossing.

Problem Solved

ODOT was seeking to balance the safety of pedestrians and cyclists while accommodating throughput of trucks on the state highway.

Solution and Process

The right-turn channel includes a raised apron to tighten the turning path for managed vehicles, while the physical corner radius accommodated a WB-53. To further reduce turning speeds, a raised concrete pedestrian crosswalk spans the full width of the channel. ODOT used the same design criteria for the apron that Bend uses for the center areas of roundabouts. The apron is lined with a traversable curb and the surface is red stamped concrete.

The process to arrive at the design required significant internal consultation. The existing apron design applied to roundabouts was used as a starting point. It required a collaborative process with central ODOT as well as the persistence of the lead project engineer to gain acceptance for the implemented design.

Efficacy

ODOT reports that the design is functioning as intended and there have not been any issues reported specific to the right-turn channel. In retrospect, it is noted that the right turn lane may not have been necessary, and increases the crossing distance for pedestrians at the intersection.

Because the apron profile is consistent with roundabouts in the area, the apron was compatible with existing winter maintenance and sweeping practices and equipment. At the time of construction it was agreed that the City would be responsible for plowing the turn channel in the winter.

ODOT intends to keep this design as an option for highway interchanges and other intersections with higher levels of pedestrian traffic.

Typology

Turn Type	Right-turn channel at signalized intersection
Accommodation Type	Dual path
Elevation and Curb Profile	Low profile mountable curb, 2 to 3 inches (50-75 mm) height at 1:4 bevel
Color and Material	Red stamped concrete
Rumbles and Bumps	Raised crosswalk fully across turn channel
Coverage/Extents	Tangent to corner

ABOVE: A view of the approach to the right turn channel showing the raised apron surfaced with stamped concrete and lined with a mountable curb.
BELOW: A pedestrian's view of the channel crossing, showing the raised crosswalk and dropped curb.

Bend, OR

06 ENDNOTES

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INTERESTED IN LEARNING MORE?

The range of treatments and design strategies detailed in this white paper can be a transformative toolkit when combined with enabling policy support. Alta Planning + Design offers comprehensive services that can help navigate interdepartmental coordination, establish design standards, and design locally relevant intersection geometry that is optimized to reduce the likelihood of serious injury and fatal crashes with vulnerable road users. We can help you determine which elements are the most appropriate for the context, work with locally applicable design and control vehicles and coordinate installation.

Contact Us

Joe Gilpin | joegilpin@altaplanning.com

Matt Pinder, EIT | mattpinder@altaplanning.com

Kristi Di Cocco, PE | kristidicocco@altaplanning.com

Nataliya Pekar, EIT | nataliyapekar@altaplanning.com

Derek Abe | derekabe@altaplanning.com