

Lecture 15



Intersection Design

Intersections have a disproportionate effect on the overall safety (over 41% of arterial accidents) and capacity of highways.

One reason is that intersections serve a special function in accommodating travel in opposing or conflicting directions.

Major design objects for intersections include

- ☞ Vehicle occupants safety
- ☞ Pedestrian safety and comfort
- ☞ Effective traffic flow
- ☞ Match with surrounding land use
- ☞ Environmental and aesthetic fit

Intersections are frequently focal point for land -development and pedestrian movement - therefore, it is particularly important to consider all functions, not just vehicular function.

Intersection Design

Today's class

- Alignment and Profile at intersections
- Design of turning radius

Next Class

Sight distance at intersection

Horizontal Alignment and Profile

In general, the area of the intersection should be reasonably straight and flat and the angle of the intersecting roads should be close to 90 degrees.

Horizontal Alignment

Angle of Intersection

The angle of intersection should be approximately equal to 90 degrees. An angle of intersection of greater than 60 degrees is considered acceptable

Problems with acute angle include

- Larger pavement area
- Visibility problems (blind spot for trucks, difficult to check for vehicles on cross-road)
- Longer exposure for crossing/veh and ped

Horizontal Alignment

Intersection on **Sharp** Curve

Intersections should not be on sharp horizontal curves

Problems include

- Reduced sight distance
- Operational Difficulties (divided driver attention since driver is concentrating on tracking, less friction available for braking, adverse superelevation for turning)
- Construction and Design Difficulties (matching superelevation to cross-section of intersecting roadway)

Profile

The grade at an intersection should be less than 3% for both intersecting roadways

(San Francisco - grades of 15 to 20% in many cases)

Many problems with >3% grade

- ☞ Reduce discharge rate - affect flow through intersection
- ☞ Greater sight distance needed at intersection (Since acceleration rates decrease)
- ☞ Greater vehicle control problems
- ☞ Construction and design challenge of matching cross-sections

The design of the cross-section in the intersection is achieved by carrying the cross-section of the major road through the intersection

Therefore, the cross-section of the minor road must be transitioned from a normal crown to an inclined cross-section

Radius of Turns

The radius needed is a function of the design vehicle and the desired **speed** of turn and the context.

Three different designs are used

- ☞ simple curve
- ☞ simple curve with taper
- ☞ compound curve

The compound curve provides a much closer fit to the vehicle path and therefore uses much less pavement area.

Curve with taper is not as good a fit as compound curve but sometimes used because it is simpler to design.

Compound curve maybe symmetrical or asymmetrical.

Selecting an Appropriate Design Vehicle

The design radius is determined by the design vehicle selected, the recommended design vehicle for different situations is discussed below

P-design recommended for

Parkways

Local and Major roads where only occasional turns are expected

Two minor roads with low volumes

SU-vehicles recommended

Most rural situations (other than above)

Radius greater than the minimum needed for SU-vehicles should be provided where the turning volume is high and the % of trucks is large

Semitrailer Design

Used where large number of semi-trailer trucks are recommended.

Where this level of design is required, channelization should also be used because of the pavement area needed.

Design Values (AASHTO Green Book)

Exhibit 9-19 give minimum design for different design vehicles and angle of intersection (simple and tapered)

Exhibit 9-20 as in Exhibit 9-19 but for compound curves

Exhibit 9-31 give degree of encroachment for different design vehicles. Two cases, A - start from proper lane - swing wide, B - start wide - swing wide

These three tables can be considered as tools to evaluate the condition for turning at the intersection. These tables are developed for speeds of 10 mph or less. It is important to note that the turning path is dynamic in that it changes with the speed of the turn.

The AASHTO guidelines for turning radii err on the side of ensuring efficient traffic flow, therefore, the minimum values are likely to be excessive for situations with potential for pedestrian travel.

Urban Streets

Generally smaller radii than for corresponding rural roads due to

- Lower speeds
- Space limitations
- Additional available space where there are parking lanes
- Effect of large radius on pedestrian

Most cities use from 1.5 to 9 meters (most common, 3 to 4.5 meters).

With a 3 meter lane, 4.5 meter radius is OK for PC with little encroachment - substantial encroachment for larger vehicles.

Radius greater than 4.5 meters have a noticeable impact on pedestrians.

Many locations use very small radii and bump-outs to make more pedestrian friendly intersections. Example in [DC](#).

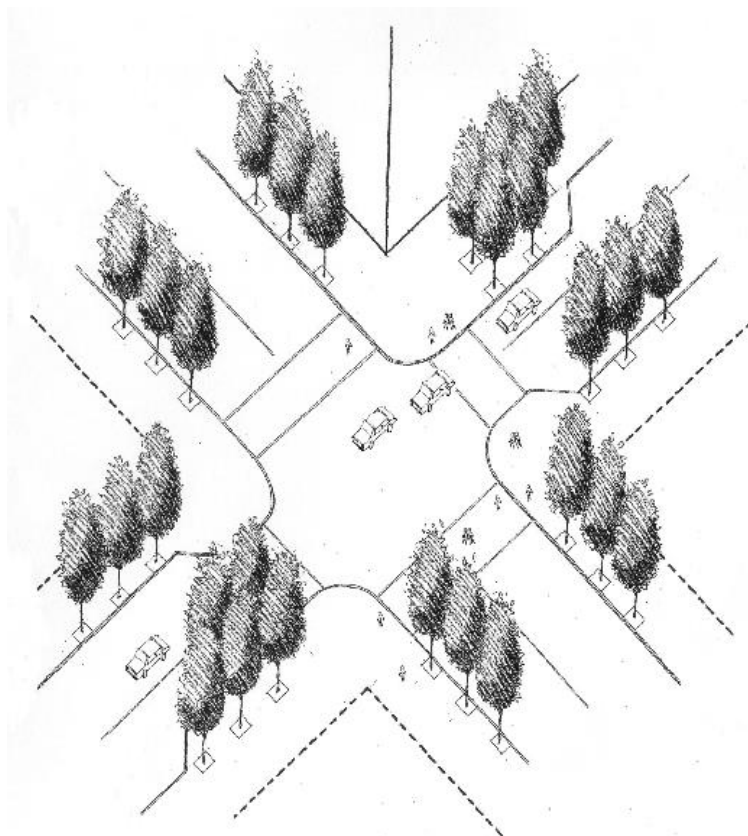


Figure 99 - Important Intersection at F & G Streets Bird's-Eye View

Lecture 16

Intersection Sight Distance

One of the most important design feature at the intersection is the amount of sight distance

There should be enough sight distance for vehicles approaching the intersection and enough sight distance for vehicles already in the intersection

AASHTO uses the concept of sight triangles of assessing the sight distance requirements in the vicinity of an intersection.

The sight triangle maybe either an

- approach sight triangle
- departure sight triangle

See Exhibit 9-50

Approach Sight Triangle

- The approach sight triangle allows vehicle approaching the intersection sufficient time to see the vehicle on the intersecting roadway and to take appropriate action.
- The length of the legs of the triangle is a function of the expected speed on the road in question
- The approach sight triangle is required where the intersection is has no control or a yield control on the minor road. It is not needed where the intersection is controlled by signs or signals.

Departure Sight Triangle

- Provide sufficient distances for the driver on the minor road to depart from a stopped position and to enter or cross the major roadway
- The departure sight triangle is needed at each location where departure is controlled by stop, yield or signal control (for example, if the road is a four-way stop, departure sight triangle is checked for each quadrangle of the intersection)

The AASHTO procedure for determining the type of sight triangle that is applicable depends on the type of control that exists at the intersection

Six different control situations are considered

- Case A - No Control
- Case B - Stop Control on Minor
- Case C - Yield Control on Minor
- Case D - Signal Control
- Case E - All-way Stop
- Case F - Left from Major

Case A - No Control

This design is rarely used - only applicable to very lightly traveled rural roads

For this design we must consider

- Approach Sight Triangle
- Departure Sight Triangle on Minor

Approach Sight Triangle

The distance allowed for each leg is the distance needed during perception and braking. This is similar in concept to SSD but the distance for the sight triangle is less than that the equivalent SSD because the assumptions are slightly different. For example, it is assumed that the vehicles approaching the intersection are traveling at a somewhat lower speed due to presence of intersection.

The distances for the approach sight triangle are given for different design speeds in Exhibit 9-51. (Exhibit 9-52 compares Case A distances to SSD.)

Exhibit 9-53 adjust 9-50 for grade.

No **Departure Sight Triangle** is provided in this situation because of the low traffic volume.

Case B - Stop Control

Departure sight triangle must be considered in this case for three different scenarios

Case B1 - Left Turn from minor road

Case B2 - Right turn from minor road

Case B3 - Crossing major road from minor road

Case B1 - Left Turn

The distance, a , along the minor road is given as 4.4 m (14.4 ft) plus the $1/2$ lane width for vehicles approaching from the left (1 and $1/2$ lane width for vehicles approaching from right). The distance of 4.4 m represents the position of the drivers eye relative to the edge of the road (assuming that the vehicle stops 2.4 m from the road edge).

The distance on the major road for the departure triangle is given in Exhibit 9-54.

The formula is as follows (metric form)

$$ISD = 0.278 V_{\text{major}} t_g$$

Where:

ISD - intersection sight distance

V_{major} - design speed on major road (kph)

t_g - time gap for minor road vehicle to enter major road

The table gives values for the appropriate time gaps including recommendations for

- different types of vehicles
- different types of major highways

Exhibits 9-55 and 9-56 contains the ISD values calculated using the formula above.

Case B2 - Right Turn

The distance, a , is same as above.

The distance on the major road for the departure triangle is determined in exactly the same ways as for B1 but in this case the time gap is less.

The gap values are given in Exhibit 9-57

Design values are given in Exhibit 9-58 and 9-59.

Case B3 - Crossing

The distance, a , is same as above.

In most cases the distances provided by left and right turns is sufficient for crossing. The only situations where crossing sight distance must be checked are

- where turns are not permitted
- where the crossing distance is more than 6 lanes
- where heavy trucks cross on steep grade

Exhibit 9-58 and 9-59 are also used for B3

Case C - Yield Control

Yield control requires provision of an **approach** sight triangle for crossing and a separate **approach** sight triangle for both turns.

Case D - Signal Control

The AASHTO criteria is that the first stopped vehicle on one approach should be visible to the first stopped vehicle on each of the other approaches.

Also, left turning vehicles should have sufficient sight distance to select gaps in oncoming traffic and complete left turn.

Where signal is used in 2-way flashing mode (yellow on major, red on minor), Case B should be used. If right turn on red is permitted, departure sight triangle for Case B2 should be provided.

Case E - Intersection With All-Way Stop

The AASHTO criteria is that the first stopped vehicle on one approach should be visible to the first stopped vehicle on each of the other approaches.

All-way stops should be considered when where sight distance criteria for other types of controls cannot be attained.

Case F - Left Turn from Major Road

Sufficient sight distance is required for left turn from major road across turning traffic. The sight distance is the distance along the major road and is the distance traversed at the design speed using the time gap in Exhibit 9-66.

Lecture 17

Roundabouts

Introduction

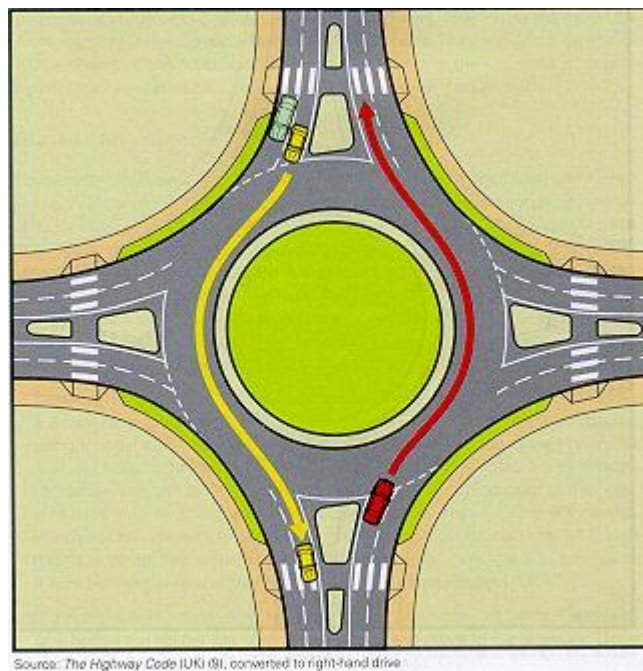
Circular intersections date back to 1905 with the construction of Columbus Circle in NYC.

The design that was favored in the USA enabled high speed merge and weave - the operational and safety experience with traffic circles in the USA provided to be quite negative. They generally had high crash rate and severe congestion problems. Consequently, by the 1950's most agencies in the USA and abroad had stopped building traffic circles.

The modern roundabout was developed in the UK in the 1960's. Superficially they are similar to traffic circles but they are different in key aspects that make them safer and more efficient.

One main difference is the use of the 'give-way' rule where the entering traffic must yield to traffic already in the circle. Since vehicles cannot enter without sufficient gap, this rule prevented the 'lock-up' in the circulatory roadway that was common with the old traffic circles.

The modern traffic circle is also based on use of much smaller circle which serves to reduce entry, circulating and exit speeds.



Urban Two-Lane Roundabout (ref. 1)

Studies in several countries have confirmed that modern roundabouts are substantially better than traffic circles in both operations and safety.

Modern roundabouts are designed to slow down traffic but are still frequently more efficient at moving traffic than signal-controlled intersections. For example, roundabouts used on state highways in Europe have been found to reduce overall delays and queue lengths relative to other intersection types.

According to the Insurance Institute are cheaper and more attractive and much more environmentally friendly. The cost savings is in the money needed for electricity and maintenance of traffic control signals. This savings has been estimated to be up to \$5,000 per year. The environmental benefit comes from the reduction in emissions and fuel consumption since there is much less idle time at roundabouts.

Types of Circular Intersections

Rotaries (Traditional Style Roundabout or Traffic Circle)

Common in the USA before 1960's – very unpopular with drivers and prone to high crash rates and congestion.

Characteristics

- ☞ large diameter > 100m (300ft)
- ☞ Little or no horizontal deflection of path of thru traffic
- ☞ Relatively high speed in rotary > 50 kph (30 mph)
- ☞ Sometimes based on "yield to right" rule (yield to entering traffic)

Neighbourhood Traffic Circles

Use for traffic calming and esthetic improvements at intersection of local streets.

Characteristics

- ☞ Intersection either uncontrolled or stop controlled
- ☞ Channelization for guiding traffic generally not used
- ☞ In some cases, left turns movement is allowed to go clockwise around the intersection

Roundabouts

Developed in the UK in the 1960's. Can be used in a wide variety of different situations – low or high ROW requirements, low or high traffic volumes, situations with pedestrian and bike travel.

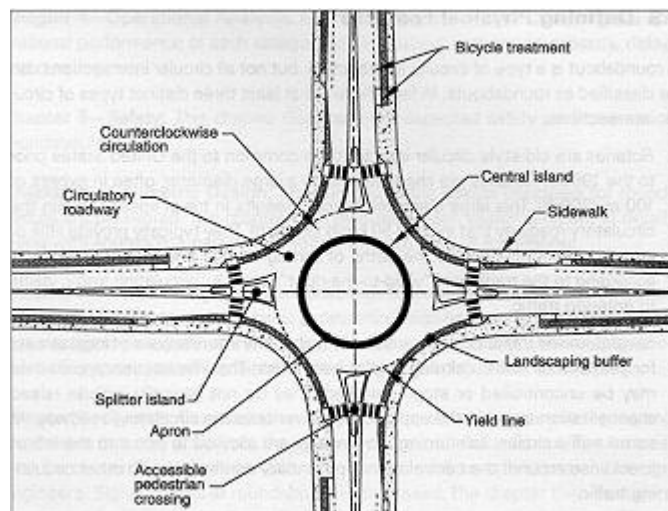
Characteristics

The following features are considered essential for the proper operation of a roundabout

- Yield control for entering traffic - "Yield to Vehicle in Roundabout"
- Channelization on all approach
- Sufficient curvature on entrance, exit and on circulator road to ensure low speeds in the roundabout (speed <30 mph)

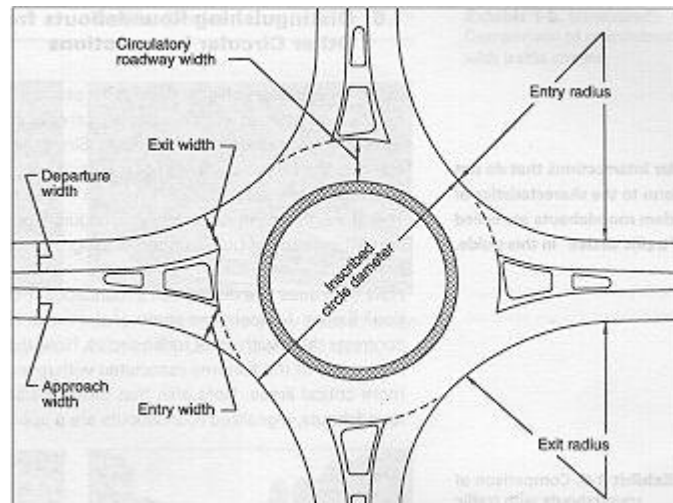
Design of Roundabouts

Features of a Roundabout



1. Central Island
2. Splitter Island
3. Circulatory Roadway
4. Apron
5. Yield Line
6. Pedestrian Crossing
7. Landscape Buffer

Key Dimensions



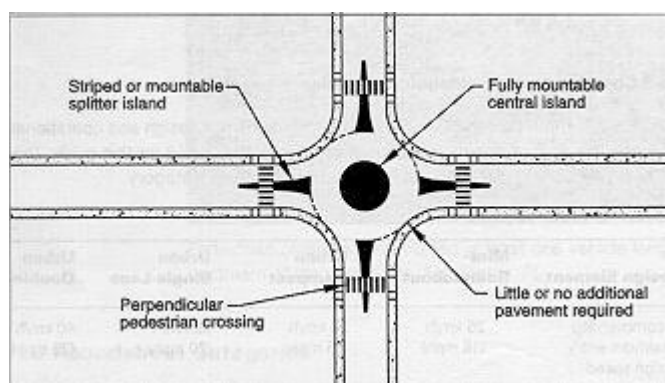
1. Inscribed Circle Diameter
2. Circulatory Roadway Width
3. Approach Width
4. Departure Width
5. Entry Width
6. Exit Width
7. Entry Radius
8. Exit Radius

Roundabout Categories

Based on the size and land-use context.

1. Mini-roundabout
2. Urban Compact
3. Urban Single-lane
4. Urban Double-lane
5. Rural Single-lane
6. Rural Double-lane

Mini-Roundabout



(Ref 1)

Used in low speed urban environment with restrictive ROW availability and where pedestrian friendly environment is a top priority.

Key Features

- Maximum entrance speed – 25kph (15mph)
- One approach lane
- Inscribed circle diameter – 13m (45ft) to 25m (80ft)
- Raised splitter island (if possible) with cut for crosswalk
- Volume – 10,000 veh/day with 4-legs
- Mountable central island (big vehicles may pass over island)



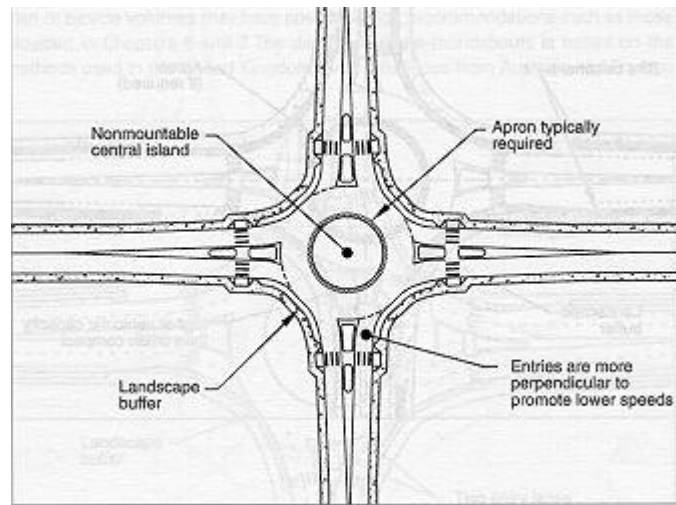
Mini-roundabout in Nottinghill Gate, London, UK (source: N.W. Garrick, July 2000)

note: remember that vehicles travel on the **left** in the UK



Mini-roundabout in Nottinghill Gate, London - Bus pass over center island (source: N.W. Garrick, July 2000)

Urban Compact



Dutch Urban (N.W. Garrick, Aug 2001)

Also considered bike/ped friendly due to relatively low speed of entry. The major design consideration is pedestrian safety, comfort and efficiency. Low speed is enforced by a distinct right turn into or out of the circulatory roadway.

Key Features

- Maximum entrance speed – 25kph (15mph)
- One approach lane
- Inscribed circle diameter – 25m (80ft) to 30m (100ft)
- Raised splitter island with cut for crosswalk
- Volume – 15,000 veh/day with 4-legs
- Non-mountable central island with apron for large vehicle



Roundabout with Truck Apron - Denmark (NW. Garrick AUG 2001)

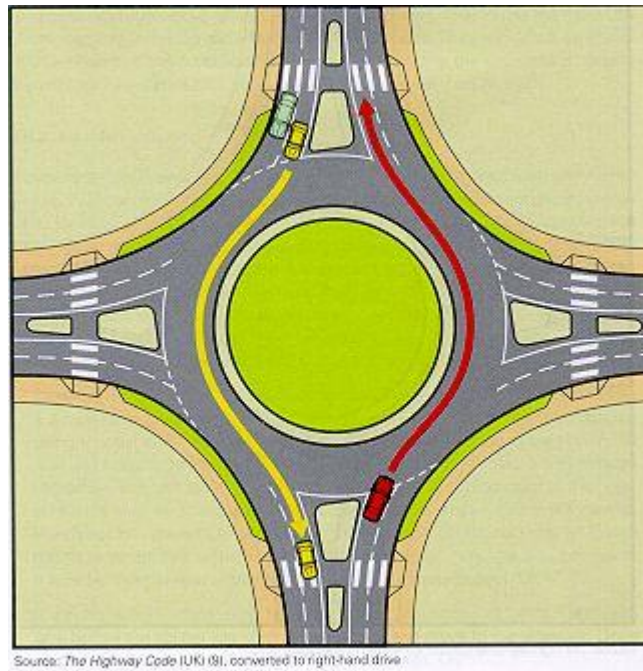
Urban Single-Lane

Less pedestrian friend due to higher speeds – more efficient vehicle flow. Higher speeds and vehicle flow facilitated by larger inscribed circle and more tangential entry and exit.

Key Features

- Maximum entrance speed – 35kph (20mph)
- One approach lane
- Inscribed circle diameter – 30m (100ft) to 40m (130ft)
- Raised splitter island with cut for crosswalk
- Volume – 20,000 veh/day with 4-legs
- Non-mountable central island with no apron

Urban Double-Lane



Rural Single-Lane

Characterized by higher approach speeds than urban roundabouts – 80kph (50mph) to 100 kph (60 mph). Geometric and traffic control treatments are used to slow drivers on approach to roundabout (for example, by use of longer splitter island). Also characterized by larger inscribed diameter and more tangential entry and exit than corresponding urban roundabouts.

Key Features

- Maximum entrance speed – 40kph (25mph)
- One approach lane
- Inscribed circle diameter – 35m (115ft) to 40m (130ft)
- Raised and Extended splitter island with cut for crosswalk
- Volume – 20,000 veh/day with 4-legs
- Non-mountable central island with no apron

Safety of Roundabouts

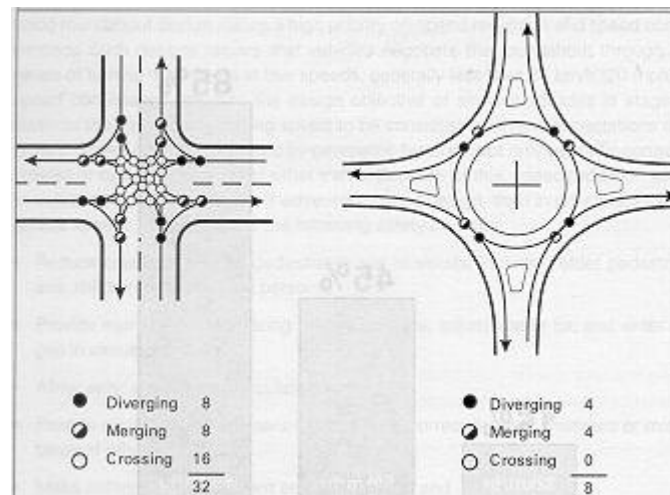
Intersections can be made safer by

- Eliminating or altering the nature of potential conflicts
- Decreasing speed into and thru the intersection
- Decreasing speed differential

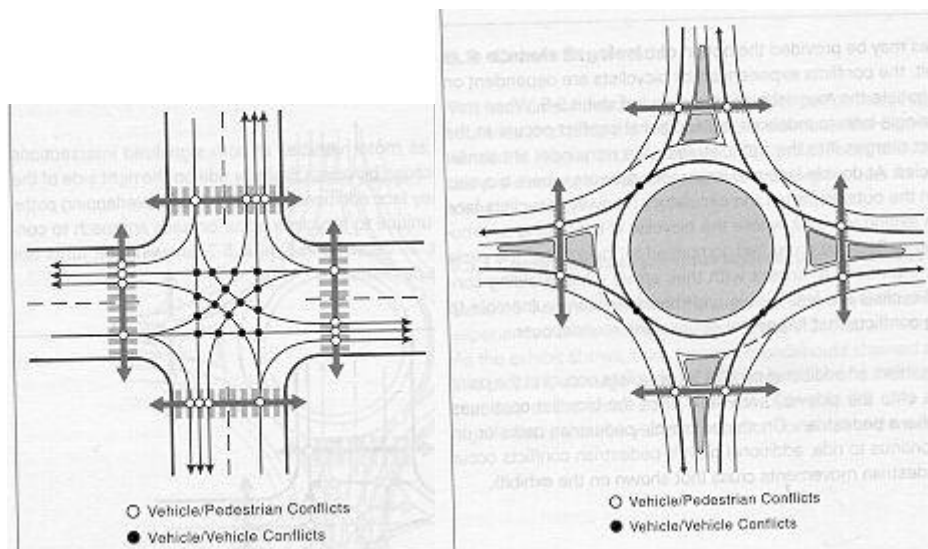
Roundabouts have a positive effect in each of these three areas.

This can be illustrated by assessing the number and the nature of conflict points in a roundabout versus that in a conventional intersection.

Vehicle Conflicts



Pedestrian Conflicts

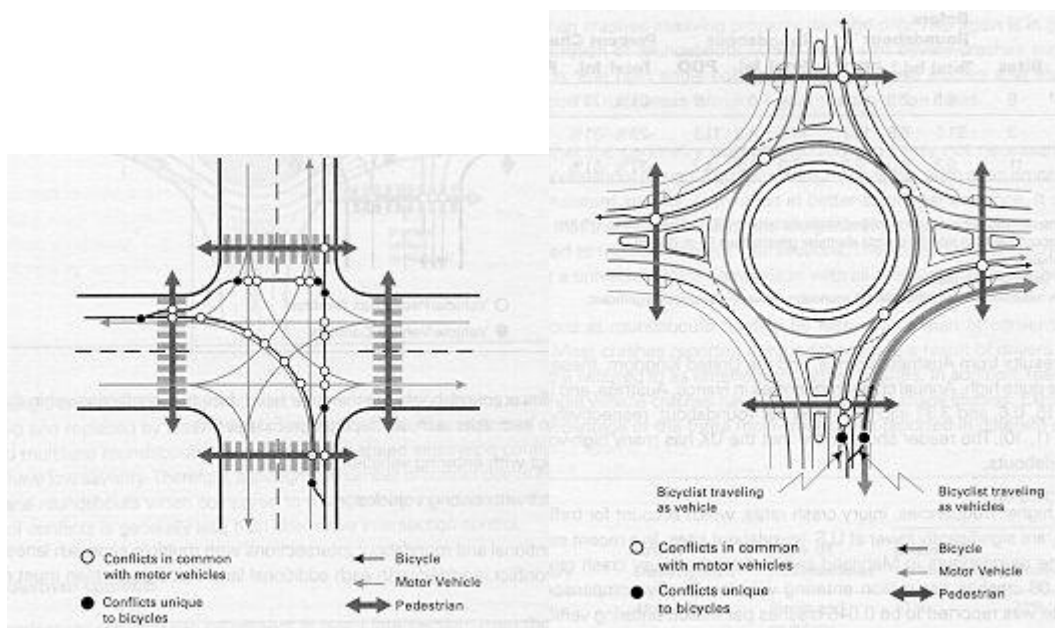




Pedestrian and Bike Crossing (note that the pedestrian and bike crossings are separated from each other) - Dutch Roundabout

(N.W. Garrick Aug 2001)

Bike Conflicts



International Crash Studies

Studies in both the USA and such countries as Australia, France and Germany shows a reduction in crash rate at an intersection after the building of a roundabout. The figures show that the reduction is of the order of about 50%.

The rate for injury crashes are reduced much more dramatically than that for crashes with property damage only. The explanation for this is that the configuration of roundabouts eliminates the more severe types of crashes (left turn, head-on and right angles crashes).

Results from the USA are limited but consistent with the international results. For more details on safety results see the [Insurance Institute Report on Highway Safety](#).

Sources:

1. [Roundabouts: An Informational Guide, USDOT, FHWA, Publication No. FHWA-RD-00-067](#) <<<< go to this site to order a free copy of this report
2. [Roundabouts, Status Report, Insurance Institute for Highway Safety, vol. 35, no. 5, May 13, 2000](#) <<< full report is on-line

For more info with pictures of roundabouts from around the USA go to the [KSU](#) roundabout page

Lecture 18

return to [CE371 Mainpage](#), [Top](#)

Types of Interchanges

Interchanges are used mostly on controlled access roads or on full-access roads to accommodate very high volumes

An INTERCHANGE refers to situation where ramps are provided to connect two roads that are separated by grade

Situations where grade separation maybe used

- ☞ Control Access road
- ☞ Bottleneck location
- ☞ Hazardous location
- ☞ Natural Topography (Fall Creek)
- ☞ Bikeway/Pedestrian way
- ☞ Access to isolated area

Types of Interchanges

Three Main Types of Interchanges

- ☞ Diamond
- ☞ Cloverleaf
- ☞ Directional

The large number of variation of these basic formats are used to fit site specific conditions

other types are used in special circumstances, for example

- ☞ trumpet - *used at T-junction*
- ☞ one-quadrant - *example, Rock Creek*

See [here](#) for Terraserver Image of interchange in downtown Hartford

KURUMI Very interesting site! This site has gives a very good overview of interchange types. The author lives in California but is fascinated with Connecticut roads.... lots of arcane info about Connecticut and its roads

Diamond

Simplest, most common and least costly type of interchange

Generally used to connect freeway to a local road

Off ramp from the freeway terminates with an at-grade intersection at the minor road (not applicable if minor road is limited access)

Inexpensive - little ROW required and only one, simple structure

Visual of Diamond

Variations of Diamond

Split-Diamond

Used because it reduces number of conflict points at the intersection on the minor road

Problem is that a vehicle that exit the freeway cannot directly re-enter - this is not a problem if there is a frontage road

Single Point Diamond (or Single Point Interchange (SPI))

Relatively recent innovation (early 1970s)

Also called Urban Interchange

More efficient for traffic flow (maybe!)

Require relatively narrow ROW but more expensive than typical diamond because of size and complexity of the bridge

Visual of a SPI

A good comparison of the conventional diamond and the SPI is given at this website

Cloverleaf

Consists of slip ramps and loop ramps

How does it differ from diamond?

No at grade crossing, therefore, can be used to connect two controlled access roads

Much more ROW than diamond

Distance traveled to turn left much longer than with diamond
(DS = 40 Loop Distance = 300m, DS = 50 Loop Distance = 500m - note that there is a trade-off between higher speed and distance)

Potential for significant mainline weaving (if total volume on adjacent loops is more than 1000 vph reduction in speed due to weaving becomes a problem)

Collector-distributor road can be used to alleviate weaving problem

Partial Cloverleaves used where left turn at grade is allowed or where some turns are not accommodated

Directional or Semi-Directional

Name implies that travel is directional - towards your destination

Characterized by

- ☞ high speed exit
- ☞ high capacity
- ☞ minimum weaving
- ☞ no indirect movement

Usually used for freeway to freeway connection - connections are all high speed high volume

Requires relatively little ROW (compared to Cloverleaf)

Very high cost - because of multiply level structures

Mostly for urban, high volume situations