Types of Interchanges and At-Grade Intersections

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Section 1 — Definition

Overview

In the field of road transport, an interchange (American English) or a grade-separated junction (British English) is a road junction that uses grade separations to allow for the movement of traffic between two or more roadways or highways, using a system of interconnecting roadways to permit traffic on at least one of the routes to pass through the junction without interruption from crossing traffic streams. It differs from a standard intersection, where roads cross at grade. Interchanges are almost always used when at least one road is a controlled-access highway (freeway or motorway) or a limited-access divided highway (expressway), though they are sometimes used at junctions between surface streets.

Terminology

Grade Separation

Grade separation is a method developed to avoid the disruption of traffic flow at intersections. Grade separation is adopted at junctions where two or more surface transport axes cross with each other. Grade separation is generally achieved by my means of a vertical level. For example, if two roads are intersecting at one point on a ground level, then grade separation is achieved by raising or lowering the profile of one of the roads with respect to ground level. So, the traffic from both roads will never meet and safety aspect stays intact.

Grade separation can be achieved by two types of intersections and they are:

- Overpass
- Underpass

Overpass

When the vertical profile of one highway is raised with the help of embankments and over-bridge arrangement to eliminate intersection with another highway on ground level, then it is said to be overpass. (Refer to Figure 1)

Underpass

Similarly, when the vertical profile of one highway is lowered with respect to ground level in the form of tunnel to avoid intersection with another highway then it is said to be underpass. (Refer to Figure 2)

Interchange

Grade separation eliminates intersection of traffic flow at junctions but it is incomplete without provision for interchanges. Interchanges facilitates the change of direction of traffic from one highway to another highway at intersections.

Figure 1 Underpass

Figure 2 Overpass

Freeway Junction, Highway Interchange (North America), or Motorway Junction (United Kingdom)

A type of road junction linking one controlled-access highway (freeway or motorway) facility to another, to other roads, or to a rest area or motorway service area. Junctions and interchanges are often (but not always) numbered either sequentially, or by distance from one terminus of the route (the "beginning" of the route).

The American Association of State Highway and Transportation Officials (AASHTO) defines an interchange as "a system of interconnecting roadways in conjunction with one or more grade separations that provides for the movement of traffic between two or more roadways or highways on different levels."

System Interchange

A junction that connects multiple controlled-access highways.

Service Interchange

A junction that connects a controlled-access facility to a lower-order facility, such as an arterial or collector road.

The mainline is the controlled-access highway in a service interchange, while the crossroad is the lower-order facility that often includes at-grade intersections or roundabouts, which may pass over or under the mainline.

Complete Interchange

A junction where all possible movements between highways can be made from any direction.

Incomplete Interchange

A junction that is missing at least one movement between highways.

Ramp (NA), Slip Road (UK), or Link (Ireland)

A short section of road that allows vehicles to enter or exit a controlled-access highway.

Ingressing traffic is entering the highway via an on-ramp or entrance ramp, while egressing traffic is exiting the highway via an off-ramp or exit ramp.

Directional Ramp

A ramp that curves toward the desired direction of travel; i.e., a ramp that makes a left turn exits from the left side of the roadway (a left exit). (Refer to Figure 3).

Semi-Directional Ramp

A ramp that exits in a direction opposite from the desired direction of travel, then turns toward the desired direction. Most left turn movements are provided by a semi-directional ramp that exits to the right, rather than exiting from the left. (Refer to Figure 3).

Weaving

An undesirable situation where traffic entering and exiting a highway must cross paths within a limited distance. (Refer to Figure 4).

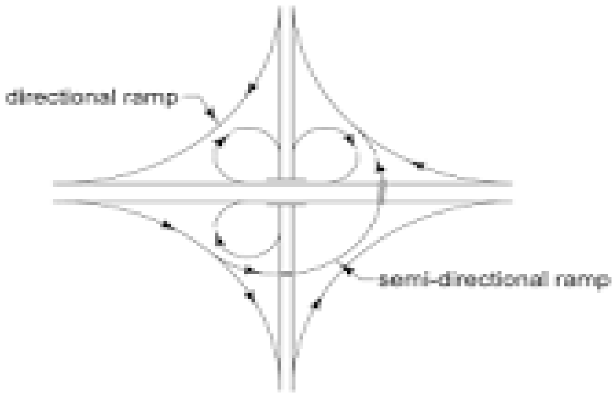

Figure 3 Directional and Semi-Directional Ramps

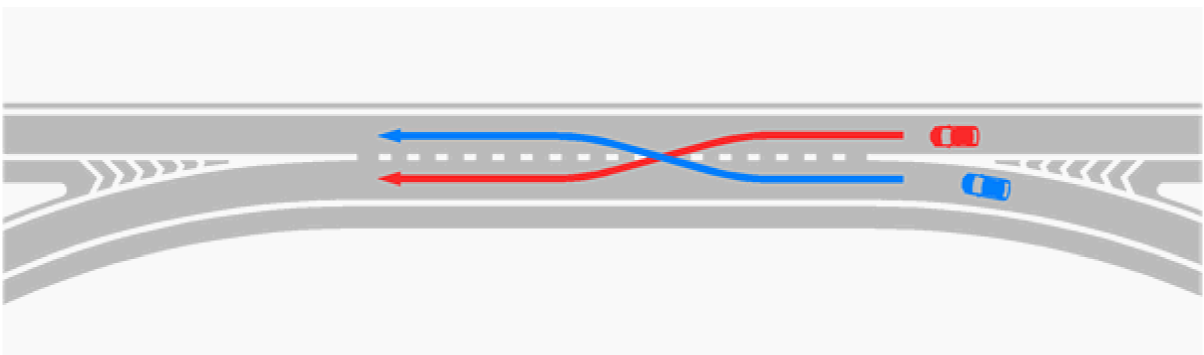

Figure 4 Weaving

Direct, Semi-Direct, and Indirect Interchanges

In the case of direct interchange, the vehicle is diverged into the right side and merged from the right while in case of semi-direct interchange, the vehicle is diverged to its left side and merged from right. In case of indirect interchange, vehicle is diverged to its left and merged from left. All these three are shown in Figure 5.

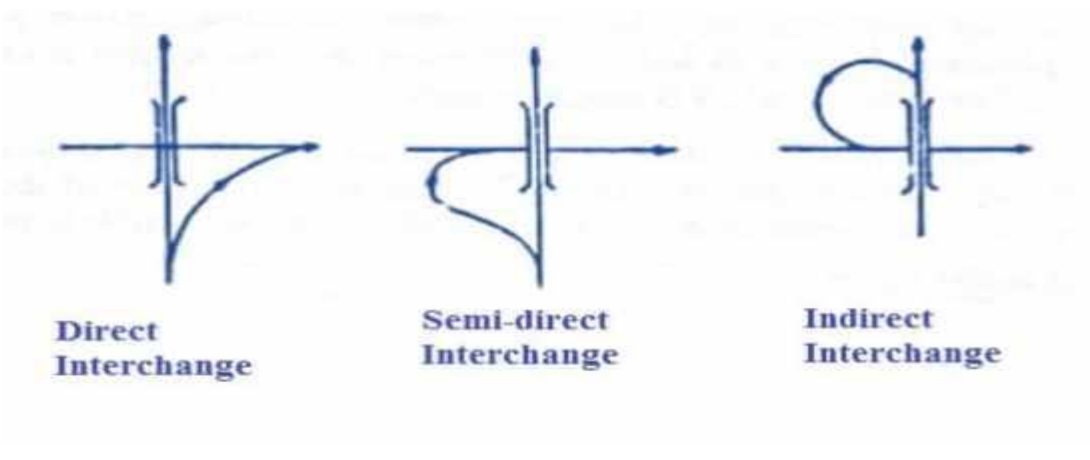

Figure 5 Direct, Semi-Direct, and Indirect Interchanges

History

The concept of the controlled-access highway was developed in the 1920's and 1930's in Italy, Germany, the United States, and Canada. Initially, these roads featured at-grade intersections along their length. Interchanges were developed to provide access between these new highways and heavily-travelled surface streets. The Bronx River Parkway was the first road to feature grade-separations.

Maryland engineer Arthur Hale filed a patent for the design of a cloverleaf interchange on May 24, 1915, though the conceptual roadwork was not realized until a cloverleaf opened on December 15, 1929, in Woodbridge, New Jersey, connecting New Jersey Route 25 and Route 4 (now U.S. Route 1/9 and New Jersey Route 35). It was designed by Philadelphia engineering firm Rudolph and Delano, based on a design seen in an Argentinian magazine.

Section 2 — System Interchange

A system interchange connects multiple controlled-access highways, involving no at-grade signalized intersections.

The System Interchange consists of:

- Three-Legged Interchanges:
  - Trumpet Interchanges
  - T and Y Interchanges
- Four-Legged Interchanges:
  - Full-Cloverleaf Interchanges
  - Stack Interchanges
  - Combination Interchanges (Cloverstack Interchanges)
  - Turbine Interchanges (Whirlpool Interchanges)
  - Windmill Interchanges
  - Braided Interchanges
  - Three-Level Roundabout (Rotary) Interchanges

Three-Legged Interchanges

These interchanges can also be used to make a "linking road" to the destination for a service interchange, or the creation of a new basic road as a service interchange.

Trumpet Interchanges

Trumpet interchanges may be used where one highway terminates at another highway, and are named as such for to their resemblance to trumpets. They are sometimes called jug handles. (Refer to Figure 6).

These interchanges are very common on toll roads, as they concentrate all entering and exiting traffic into a single stretch of roadway, where toll plazas can be installed once to handle all traffic, especially on ticket-based tollways.

A double-trumpet interchange (three-way directional) can be found where a toll road meets another toll road or a free highway. They are also useful when most traffic on the terminating highway is going in the same direction. The turn that is used less often would contain the slower loop ramp. (Refer to Figure 7).

Trumpet interchanges are often used instead of directional or semi-directional T or Y interchanges because they require less bridge construction but still eliminate weaving.

Figure 6 Trumpet Interchange

Figure 7 Three-Way Directional Interchange

T and Y Interchanges

A full Y-interchange (also known as a directional T- interchange) is typically used when a three-way interchange is required for two or three highways interchanging in semi-parallel/perpendicular directions, but it can also be used in right-angle case as well. Their connecting ramps can spur from either the right or left side of the highway, depending on the direction of travel and the angle. (Refer to Figure 8).

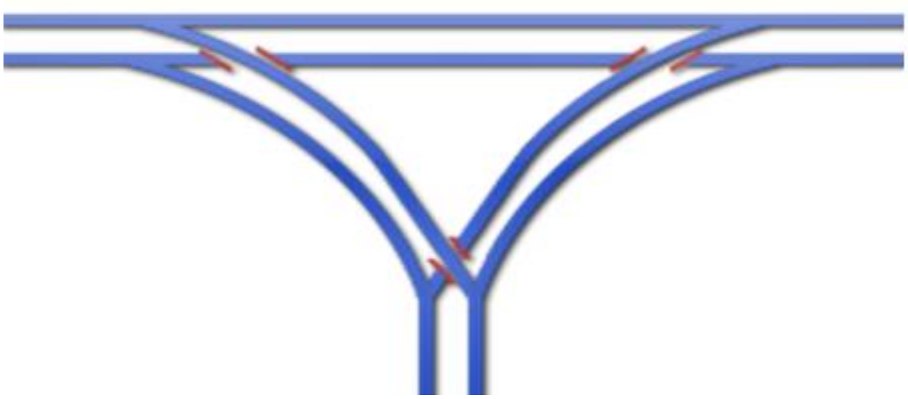

Figure 8 Full Y Interchange

Directional T interchanges use flyover/underpass ramps for both connecting and mainline segments, and they require a moderate amount of land and moderate costs since only two levels of roadway are typically used. Their name derives from their resemblance to the capital letter T, depending upon the angle from which the interchange is seen and the alignment of the roads that are interchanging. It is sometimes known as the "New England Y", as this design is often seen in the northeastern United States, as with the Braintree Split and the northern terminus of MA Route 24, both south of Boston.

This type of interchange features directional ramps (no loops, or weaving right to turn left) and can use multilane ramps in comparatively little space. Some designs have two ramps and the "inside" through road (on the same side as the freeway that ends) crossing each other at a three-level bridge.

The directional T interchange is preferred to a trumpet interchange because a trumpet requires a loop ramp by which speeds can be reduced, but flyover ramps can handle much faster speeds.

The disadvantage of the directional T is that traffic from the terminating road enters and leaves on the passing lane, so the semi-directional T interchange is preferred.

As with a directional T interchange, a semi-directional T interchange uses flyover (overpass) or underpass ramps in all directions at a three-way interchange. However, in a semi-directional T, some of the splits and merges are switched to avoid ramps to and from the passing lane, eliminating the major disadvantage of the directional T.

Semi-directional T interchanges are generally safe and efficient, though they do require more land and are costlier than trumpet interchanges. (Refer to Figure 9).

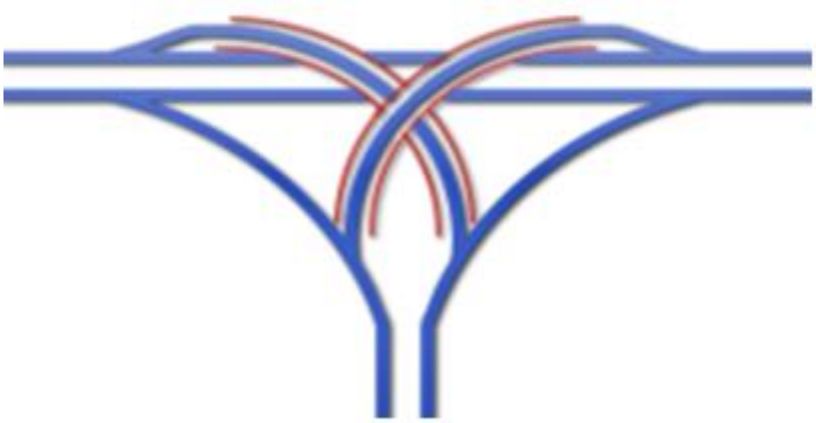

Figure 9 Semi-Directional T Interchange

Semi-directional T interchanges are built as two- or three-level junctions, with three-level interchanges typically used in urban or suburban areas where land is more expensive. In a three-level semi-directional T, the two semi-directional ramps from the terminating highway cross the surviving highway at or near a single point, which requires both an overpass and underpass. In a two-level semi-directional T, the two semi-directional ramps from the terminating highway cross each other at a different point than the surviving highway, necessitating longer ramps and often one ramp having two overpasses. Highway 412 has a three-level semi-directional T at Highway 407 and a two-level semi-directional T at Highway 401.

Four-Legged Interchanges

Full Cloverleaf Interchanges

A cloverleaf interchange is a four-legged junction where left turns across opposing traffic are handled by non-directional loop ramps. It is named for its appearance from above, which resembles a four-leaf clover (Refer to Figure 10). A cloverleaf is the absolute minimum interchange required for a four-legged system interchange. Although they were commonplace until the 1970's, most highway departments and ministries have sought to rebuild them into more efficient and safer designs.

The cloverleaf interchange was invented by Maryland engineer Arthur Hale, who filed a patent for its design on May 24, 1915. The first one in North America opened on December 15, 1929, in Woodbridge, New Jersey, connecting New Jersey Route 25 and Route 4 (now U.S. Route 1/9 and New Jersey Route 35). It was designed by Philadelphia engineering firm Rudolph and Delano, based on a design seen in an Argentinian magazine.

The first cloverleaf in Canada opened in 1937 at the junction of Highway 10 and what would become the Queen Elizabeth Way. The first cloverleaf outside of North America opened in Stockholm on October 15, 1935. Nicknamed Slussen, it was referred to as a "traffic carousel" and was considered a revolutionary design at the time of its construction.

Figure 10 Full Cloverleaf Interchange

A cloverleaf offers uninterrupted connections between two roads, but suffers from weaving issues. Along the mainline, a loop ramp introduces traffic prior to a second loop ramp providing access to the crossroad, between which ingress and egress traffic mixes. For this reason, the cloverleaf interchange has fallen out of favor in place of combination interchanges. Some may be half cloverleaf containing ghost ramps which can upgraded to full cloverleafs if the road is extended. US 70 and US 17 west of New Bern, North Carolina is an example.

Stack Interchanges

A stack interchange is a four-way interchange whereby a semi-directional left turn and a directional right turn are both available (Refer to Figure 11). Usually access to both turns is provided simultaneously by a single off-ramp. Assuming right-handed driving, in order to cross over incoming traffic and go left, vehicles first exit onto an off-ramp from the rightmost lane. After demerging from right-turning traffic, they complete their left turn by crossing both highways on a flyover ramp or underpass.

The penultimate step is a merge with the right-turn on-ramp traffic from the opposite quadrant of the interchange. Finally, an on-ramp merges both streams of incoming traffic into the left-bound highway. As there is only one off-ramp and one onramp (in that respective order), stacks do not suffer from the problem of weaving, and due to the semi-directional flyover ramps and directional ramps, they are generally safe and efficient at handling high traffic volumes in all directions.

Figure 11 Stack Interchange

A standard stack interchange includes roads on four levels, also known as a four-level stack: including the two perpendicular highways, and one more additional level for each pair of left-turn ramps. These ramps can be stacked (cross) in various configurations above, below, or between the two interchanging highways. This makes them distinct from Turbine interchanges, where pairs of left-turn ramps are separated but at the same level. There are some stacks that could be considered five-level; however, these remain four-way interchanges, since the fifth level actually consists of dedicated ramps for HOV/bus lanes or frontage roads running through the interchange. The stack interchange between I-10 and I-405 in Los Angeles is a three-level stack, since the semi-directional ramps are spaced out far enough so they do not need to cross each other at a single point as in a conventional four-level stack.

Stacks are significantly more expensive than other four-way interchanges, due to the design of the four levels. Additionally, they may suffer from objections of local residents, because of their height and high visual impact. Large stacks with multiple levels may have a complex appearance and are often colloquially described as Mixing Bowls, Mixmasters (for a Sunbeam Products brand of electric kitchen mixers), or as Spaghetti Bowls or Spaghetti Junctions (being compared to boiled spaghetti). However, they consume a significantly smaller area of land compared to a cloverleaf interchange.

Combination Interchange (Cloverstack Interchange)

A combination interchange (sometimes referred to by the portmanteau, cloverstack) is a hybrid of other interchange designs (Refer to Figure 12). It uses loop ramps to serve slower or less-occupied traffic flow, and flyover ramps to serve faster and heavier traffic flows. If local and expressways serving the same directions and each roadway is connected right-hand to the interchange, extra ramps are installed. The combination interchange design is commonly used to upgrade cloverleaf interchanges to increase their capacity and eliminate weaving.

Figure 12 Combination Interchange

Turbine Interchange (Whirlpool Interchange)

It is an alternative four-way directional interchange. The turbine interchange requires fewer levels (usually two or three) while retaining directional ramps throughout. It features right-exit, left-turning ramps that sweep around the center of the interchange in a clockwise spiral (Refer to Figure 13). A full turbine interchange features a minimum of 18 overpasses, and require more land to construct than a four-level stack interchange, however, the bridges are generally short in length. Coupled with reduced maintenance costs, a turbine interchange is a less costly alternative to a stack.

Figure 13 Turbine Interchange

Windmill Interchange

A windmill interchange is similar to a turbine interchange, but it has much sharper turns, reducing its size and capacity. The interchange is named for its similar overhead appearance to the blades of a windmill (Refer to Figure 14).

A variation of the windmill, called the diverging windmill, increases capacity by altering the direction of traffic flow of the interchanging highways, making the connecting ramps much more direct. There also is a hybrid interchange somewhat like the diverging windmill in which left turn exits merge on the left, but it differs in that the left turn exits use left directional ramps.

Braided Interchange

A braided or diverging interchange is a two-level, four-way interchange. An interchange is braided when at least one of the roadways reverses sides. It seeks to make left and right turns equally easy. In a pure braided interchange, each roadway has one right exit, one left exit, one right on-ramp, and one left on-ramp and both roadways are flipped (Refer to Figure 15).

Figure 14 Windmill Interchange

The first pure braided interchange was built in Baltimore at Interstate 95 at Interstate 695; however, the interchange was reconfigured in 2008 to a traditional stack interchange.

Figure 15 Braided Interchange

Three-Level Roundabout (Rotary) Interchange

A three-level roundabout interchange features a grade-separated roundabout which handles traffic exchanging between highways.

The ramps of the interchanging highways meet at a roundabout, or rotary, on a separated level above, below, or in the middle of the two highways (Refer to Figure 16).

Figure 16 Three-Level Roundabout Interchange

Section 3 — Service Interchanges

Overview

Service interchanges are used between a controlled-access route and a crossroad that is not controlled-access. A full cloverleaf may be used as a system or a service interchange.

The Service Interchange consists of:

- Diamond Interchanges

- Partial Cloverleaf Interchanges
- Diverging Diamond Interchanges
- Single-Point Urban Interchanges

Diamond Interchanges

A diamond interchange is an interchange involving four ramps where they enter and leave the freeway at a small angle and meet the non-freeway at almost right angles. These ramps at the non-freeway can be controlled through stop signs, traffic signals, or turn ramps (Refer to Figure 17).

Diamond interchanges are much more economical in use of materials and land than other interchange designs, as the junction does not normally require more than one bridge to be constructed. However, their capacity is lower than other interchanges and when traffic volumes are high they can easily become congested.

Figure 17 Diamond Interchange

A double roundabout diamond interchange, also known as a dumbbell interchange or a dogbone interchange, is similar to the diamond interchange, but uses a pair of roundabouts in place of intersections to join the highway ramps with the crossroad (Refer to Figure 18). This typically increases the efficiency of the interchange when compared to a diamond, but is only ideal in light traffic conditions.

In the dogbone variation, the roundabouts do not form a complete circle, instead having a teardrop shape, with the points facing towards the center of the interchange. Longer ramps are often required due to line-of-sight requirements at roundabouts.

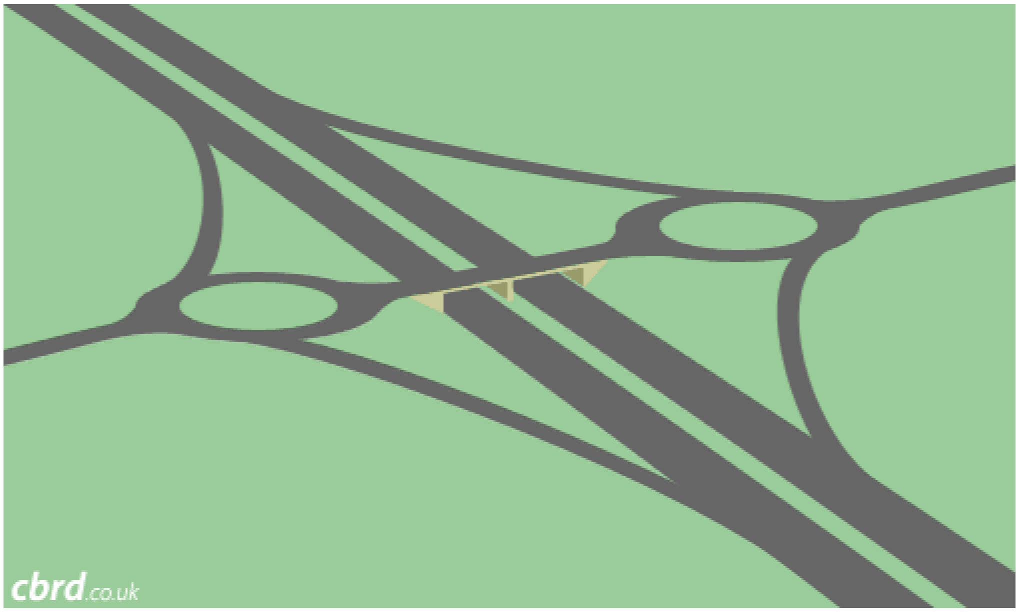

Figure 18 Dumbbell Interchange

Partial Cloverleaf Interchanges

A partial cloverleaf interchange (often shortened to the portmanteau, parclo) is an interchange with loops ramps in one to three quadrants, and diamond interchange ramps in any number of quadrants.

The various configurations are generally a safer modification of the cloverleaf design, due to a partial or complete reduction in weaving, but may require traffic lights on the lesser-travelled crossroad. Depending on the number of ramps used, they take up a moderate to large amount of land, and have varying capacity and efficiency.

Parclo configurations are given names based on the location of and number of quadrants with ramps. The letter A denotes that, for traffic on the controlled-access highway, the loop ramps are located in advance of (or approaching) the crossroad, and thus provide an onramp to the highway. The letter B indicated that the loop ramps are beyond the crossroad, and thus provide an off-ramp from the highway.

These letters can be used together when opposite directions of travel on the controlled-access highway are not symmetrical, thus a parclo AB features a loop ramp approaching the crossroad in one direction, and beyond the crossroad in the opposing direction, as in the example image (Refer to Figures 19, 20, 21, and 22).

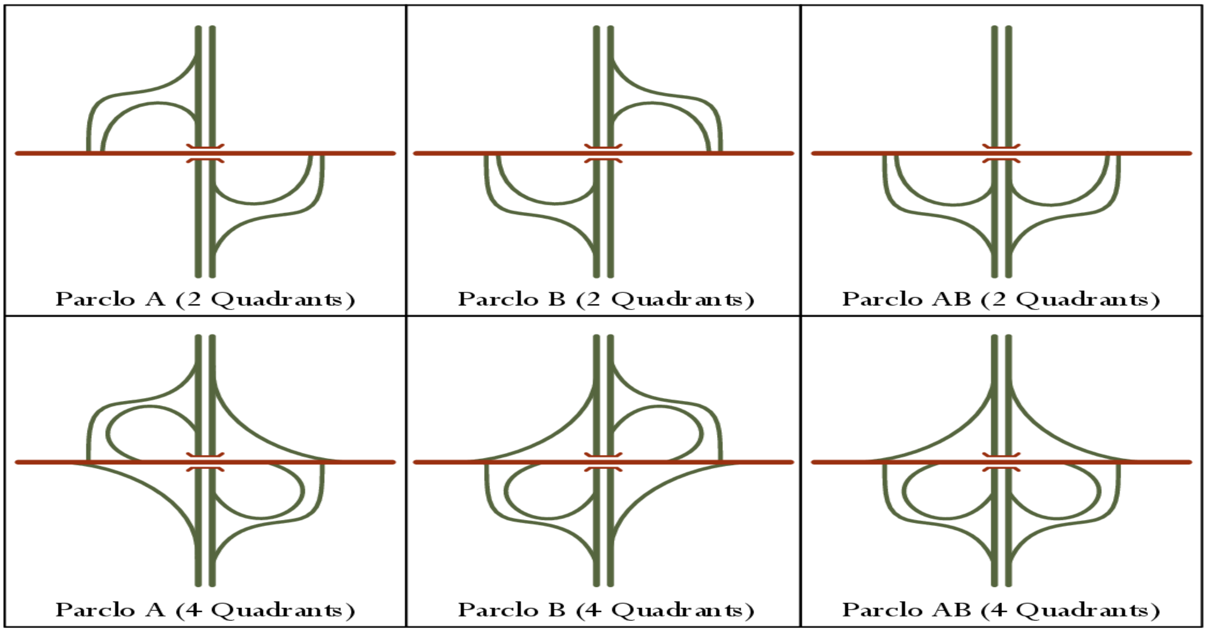

Figure 19 Partial Cloverleaf Configuration

Figure 20 Parclo A Interchange

Figure 21 Parclo B Interchange

Figure 22 Parclo AB Interchange

Diverging Diamond Interchanges

A diverging diamond interchange (DDI) or double crossover diamond interchange (DCD) is similar to a traditional diamond interchange, except the opposing lanes on the crossroad cross each other twice, once on each side of the highway (Refer to Figure 23). This allows all highway entrances and exits to avoid crossing the opposite direction of travel and saves one signal phase of traffic lights each.

The first DDI's were constructed in the French communities of Versailles (A13 at D182), Le Perreux-sur-Marne (A4 at N486) and Seclin (A1 at D549), in the 1970s. Despite the fact that such interchanges already existed, the idea for the DDI was "reinvented" around 2000, inspired by the freeway-to-freeway interchange between Interstate 95 and I-695 north of Baltimore. The first DDI in the United States opened on July 7, 2009, in Springfield, Missouri, at the junction of Interstate 44 and Missouri Route 13.

Figure 23 Diverging Diamond Interchange

Single-Point Urban Interchanges

Single-point urban interchange (SPUI) or single-point diamond interchange (SPDI) is a modification of a diamond interchange in which all four ramps to and from a controlled-access highway converge at a single, three-phase traffic light in the middle of an overpass or underpass (Refer to Figure 24). While the compact design is safer, more efficient, and offers increased capacity—with three light phases as opposed to four in a traditional diamond, and two left turn queues on the arterial road instead of four—the significantly wider overpass or underpass structure makes them costlier than most service interchanges. Since single-point urban interchanges can exist in rural areas, such as the interchange of U.S. Route 23 with M-59 in Michigan, the term single-point diamond interchange is considered the correct vernacular.

Single-point interchanges were first built in the early 1970s along U.S. Route 19 in the Tampa Bay area of Florida, including the SR 694 interchange in St. Petersburg and SR 60 in Clearwater.

Figure 24 Single-Point Urban Interchange

Section 4 — At-Grade Intersections

Overview

An intersection is the area where two or more roadways cross and includes the roadway as well as the roadside components that accommodate traffic movements within the area. Each road that branches out from an intersection is referred to as a leg.

There are four types of roadway crossings: at-grade intersections, grade separations without ramps, grade-separated intersections, and interchanges. Intersections generally have adjacent areas that provide for business and community activities and multiple modes of transportation to share the same travel space. Traffic control devices are placed at intersections that require users to stop or slow down. Therefore, intersections generally have less capacity than other areas of the roadway and are also where most accidents occur. Intersections should be designed to accommodate all modes of travel including automobiles, pedestrians, bicyclists, trucks, and transit. Include not only the roadway pavement, but elements such as sidewalks, bike lanes, and medians in the design.

Types of Intersections

The types of at-grade intersections are three-leg, four-leg, multi-leg, and roundabouts. These intersections can be further described as unchannelized, flared, and channelized intersections. The type of intersections to be designed is based on topography, right of way constraints, number of intersecting legs, modes of the user, traffic volumes, speeds, type of operation, and type of traffic control. Design criteria and the elements of the intersection can be applied once the type of intersection is established. Balance the design of an intersection to accommodate anticipated modes of transportation while also considering the context and community of the project location. Other intersection types include grade-separated, roundabouts, and alternative designs (reduced conflict intersection, median U-turn, bowtie, quadrant, continuous flow, offset, and continuous green -T- intersection).

At-Grade Intersections consist of:

- Three-Legged Intersections:
    - Plain T-Intersection
    - T-Intersection with Right-Turn Lane
    - T-Intersection with Right-Hand Passing Lane
    - T-Intersection with Divisional Island and Turning Roadways
- Four-Legged Intersections
- Multi-Leg Intersections

Three-Leg Intersections

Three-leg intersections are often referred to as -T- intersections. A T-junction is an intersection at which a minor roadway meets a major roadway (Refer to Figure 25). The minor roadway at a T-intersection is almost always controlled by a stop sign, whereas the vehicles on the major roadway continue driving without having to stop.

The types of three-leg intersections are: plain T intersection (Figure 26), T intersection with right-turn lane (Figure 27), T intersection with right-hand passing lane (Figure 28), and T intersection with divisional island and turning roadways (Figure 29). The most common type of three-leg intersection is unchannelized with single-lane approaches.

Generally, this intersection is used for junctions of minor or local roads and minor roads with major roads.

Figure 25 Three-Leg Intersection

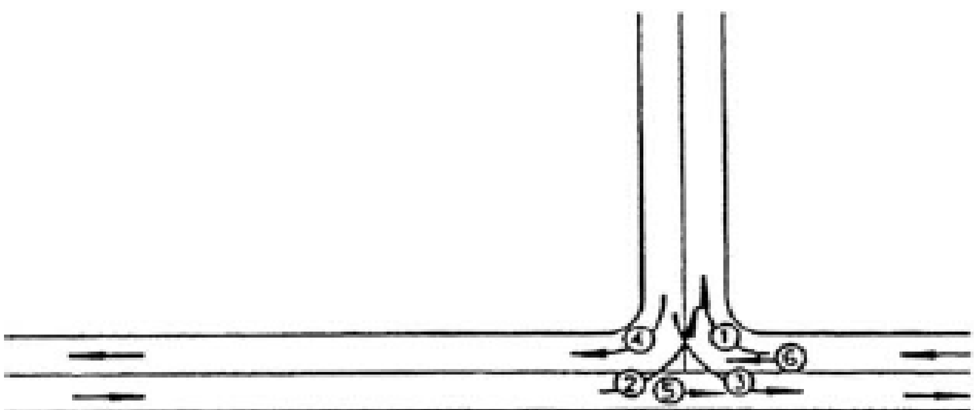

Figure 26 Plain T Intersection

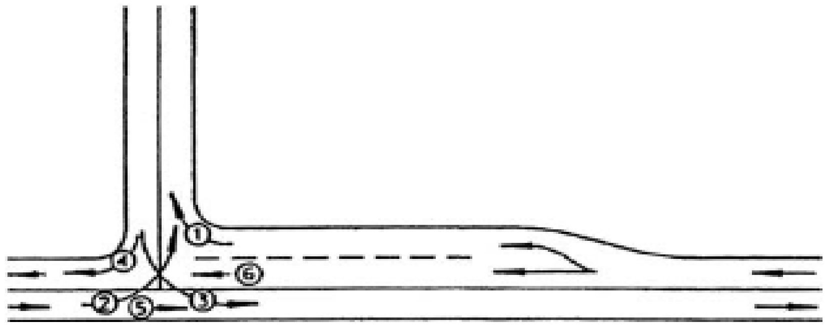

Figure 27 T-Intersection with Right-Turn Lane

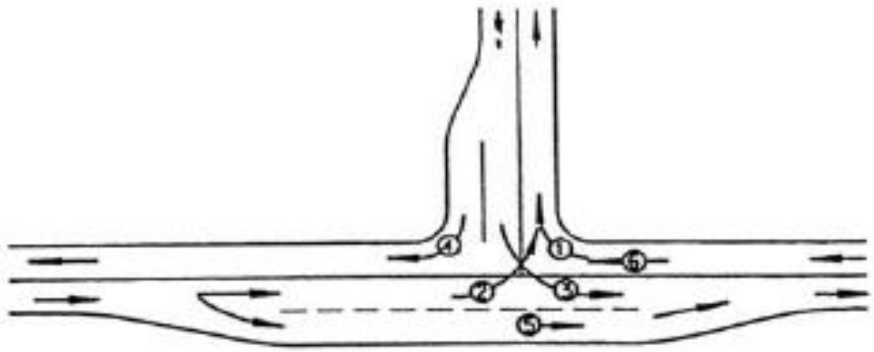

Figure 28 T-Intersection with Right-Hand Passing Lane

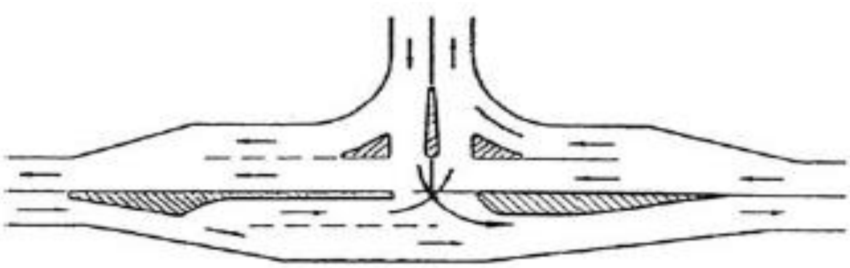

Figure 29 T-Intersection with Divisional Island and Turning Roadways

In areas where speeds or turning movements are high, auxiliary lanes, such as left and right turn lanes, may be used to reduce the frequency of crashes and increase traffic operations and capacity. Channelized three-leg intersections utilize islands to separate turning roadway movements from normal through-lane movements in the intersection. For a channelized right turn movement, the approach roadway could include a right turn lane with a divisional island to separate the right turning movement from the through travel lane. Left turn lanes can be channelized by providing a traditional left turn lane or by transitioning the through lanes to bypass around the left turn lane. Traffic volume, reduction of crashes, and construction costs are factors used in the determination of installing a left turn lane or a bypass lane.

Plain T-Intersections: The intersection shown in Figure 26 is suitable for minor or local roads and may be used when minor roads intersect important highways with an intersection angle less than 30 degrees from the normal. This type of intersection is also suitable for use in rural two-lane highways that carry light traffic.

T-Intersections with Right-Turn Lane: At locations with higher speeds and turning volumes, which increase the potential of rear-end collisions between through vehicles and turning vehicles, usually an additional area of surfacing or flaring is provided, as shown in Figure 27. In this case, the flare is provided to separate right-turning vehicles from through vehicles approaching from the east.

T-Intersections with Right-Hand Passing Lane: In cases where left-turn volume from a through road onto a minor road is sufficiently high but does not require a separate left-turn lane, an auxiliary lane may be provided, as shown in Figure 28. This provides the space needed for through vehicles to maneuver around left-turning vehicles which have to slow down before making their turns.

T-Intersections with Divisional Island and Turning Roadways: Figure 29 shows a channelized T-intersection in which the two-lane through road has been converted into a divided highway through the intersection. The channelized T-intersection also provides both a left-turn storage lane for left-turning vehicles from the through road to the minor road and a right-turn lane on the east approach. This type of intersection is suitable for locations where volumes are high such as high left-turn volumes from the through road and high right-turn volumes onto the minor road. An intersection of this type probably will be signalized.

Four-Leg Intersections

The design principles, island placement, auxiliary lanes, and other aspects of three-leg intersections can be applied to four-leg intersections (Refer to Figure 30). Unchannelized four-leg intersections can be plain or flared and marked with left and right turn lanes. Flared intersections require more pavement and right of way but provide additional capacity for the through and turning movements at the intersection. Channelized four-leg intersections are typically used at major intersections. Channelization for important turning movements such as right turns at intersections can help accommodate large vehicles. Channelized left turns may be utilized at an intersection that carries moderate traffic volumes at high speeds. Auxiliary lanes may be used for storage, speed changes, and maneuvering.

Figure 30 Four-Leg Intersection

Figure 31 shows varying levels of channelization at a four-leg intersection. The unchannelized intersection shown in Figure 31.a is used mainly at locations where minor or local roads cross, although it also can be used where a minor road crosses a major highway. In these cases, the turning volumes are usually low and the roads intersect at an angle that is not greater than 30 degrees from the normal.

When right-turning movements are frequent, right-turning roadways, such as those in Figure 31.b, can be provided. This type of design is also common in suburban areas where pedestrians are present.

The layout shown in Figure 31.c is suitable for a two-lane highway that is not a minor crossroad and that carries moderate volumes at high speeds or operates near capacity.

Figure 31.d shows a suitable design for four-lane approaches carrying high through and turning volumes. This type of intersection is usually signalized.

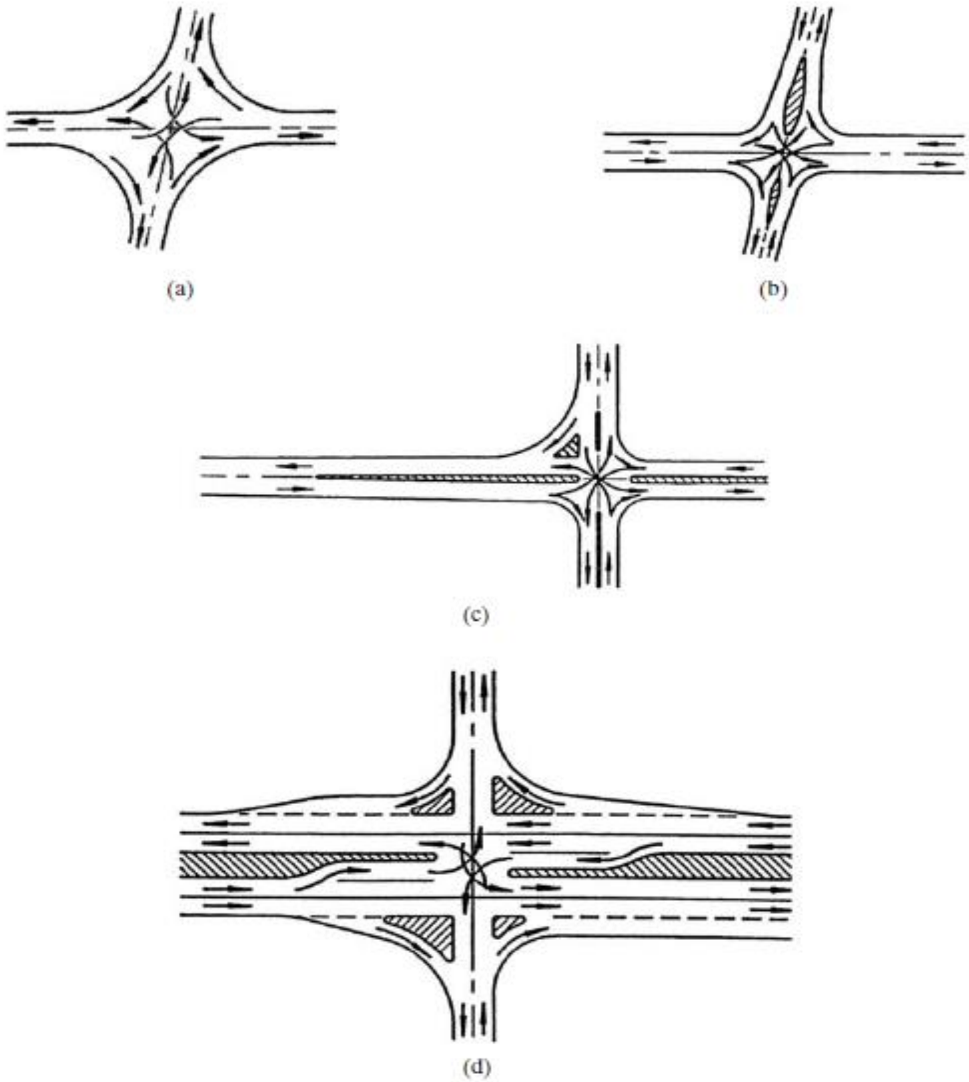

Figure 31 Examples of Four-Leg Intersection

Multi-Leg Intersections

Multi-leg intersections have five or more intersection legs and should be avoided if possible (Refer to Figure 32). Traffic operations can be improved by reconfiguring the intersection so that some minor roadway movements are removed from the major intersection.

Figure 32 Multi-Leg Intersection

Multi-leg intersections have five or more approaches, as shown in Figure 33. Whenever possible, this type of intersection should be avoided. In order to remove some of the conflicting movements from the major intersection and thereby increase safety and operation, one or more of the legs are realigned.

In Figure 33.a, the diagonal leg of the intersection is realigned to intersect the upper road at a location some distance away from the main intersection. This results in the formation of an additional T-intersection but with the multi-leg intersection now converted to a four-leg intersection.

There are two important factors to consider when realigning roads in this way:

- The diagonal road should be realigned to the minor road
- The distance between the intersections should be such that they can operate independently.

A similar realignment of a six-leg intersection is shown in Figure 33.b, resulting in two four-leg intersections. In this case, it is also necessary for a realignment to be made to the minor road. For example, if the road in the right-to-left direction is the major road, it may be better to realign each diagonal road to the road in the top-to-bottom direction, thereby forming two additional T-intersections and resulting in a total of three intersections. Again, the distances between these intersections should be great enough to allow for the independent operation of each intersection.

A roundabout may be a better solution than the reconfiguration of the multi-leg intersection.

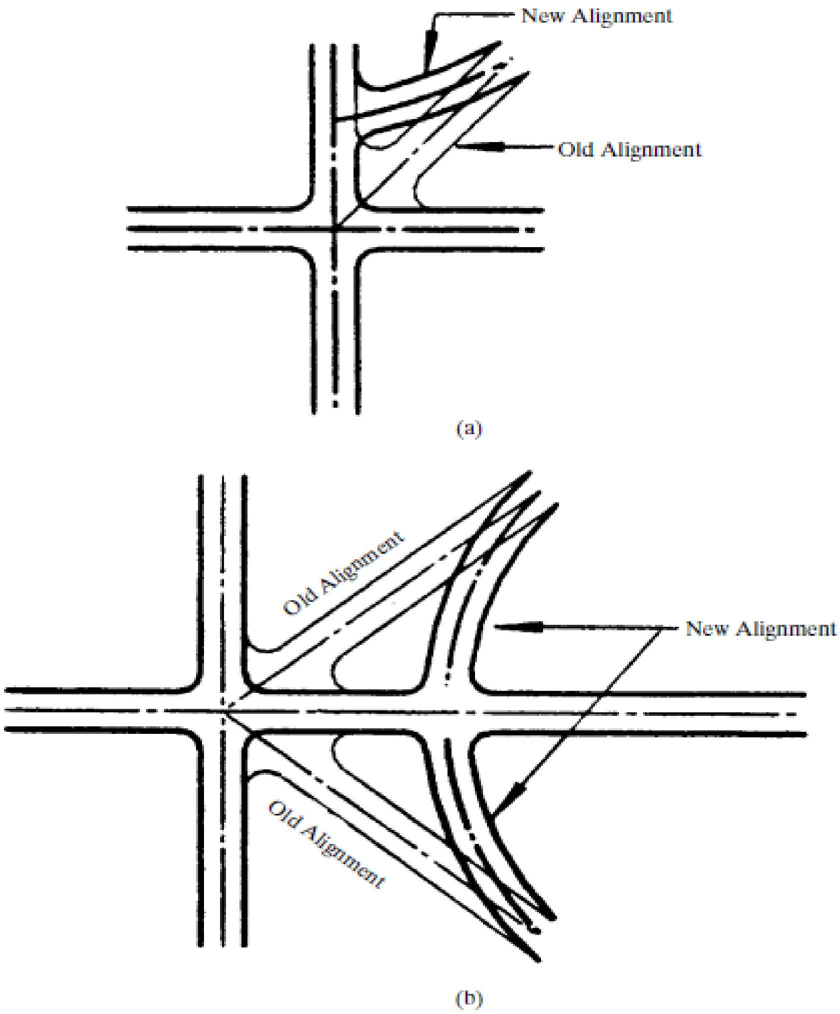

Figure 33 Examples of Multi-Leg Intersection

Traffic Circles

A traffic circle is a circular intersection with a central island that traffic travels counterclockwise around (Refer to Figure 34). Entering traffic must yield to the traffic already in the traffic circle.

Design and traffic control elements of a traffic circlet include yield control, channelized approaches, splitter islands, and curvature within the intersection that allows for speeds less than 30 mph.

Figure 34 Traffic Circle

Traffic circles are classified into three categories based on size and number of lanes:

- Rotaries
- Neighborhood Traffic Circles
- Roundabouts

Rotaries: have large diameters that are usually greater than 300 ft, thereby allowing speeds exceeding 30 mi/h, with a minimum horizontal deflection of the path of the through traffic.

Neighborhood Traffic Circles: have diameters that are much smaller than rotaries and therefore allow much lower speeds. Consequently, they are used mainly at the intersections of local streets, as a means of traffic calming and/or as an aesthetic device. As a rule, they consist of pavement markings and do not usually employ raised islands. Traffic circles may use stop control or no control at the approaches and mayor may not allow pedestrian access to the central circle. Parking also may be allowed within the circulatory roadway.

Roundabouts: have specific defining characteristics that separate them from other circular intersections. These include:

- Yield control at each approach.
- Separation of conflicting traffic movements by pavement markings or raised islands.
- Geometric characteristics of the central island that typically allow travel speeds of less than 30 mi/h.
- Parking not usually allowed within the circulating roadway.

Figure 35 shows the geometric elements of a single-lane modern roundabout.

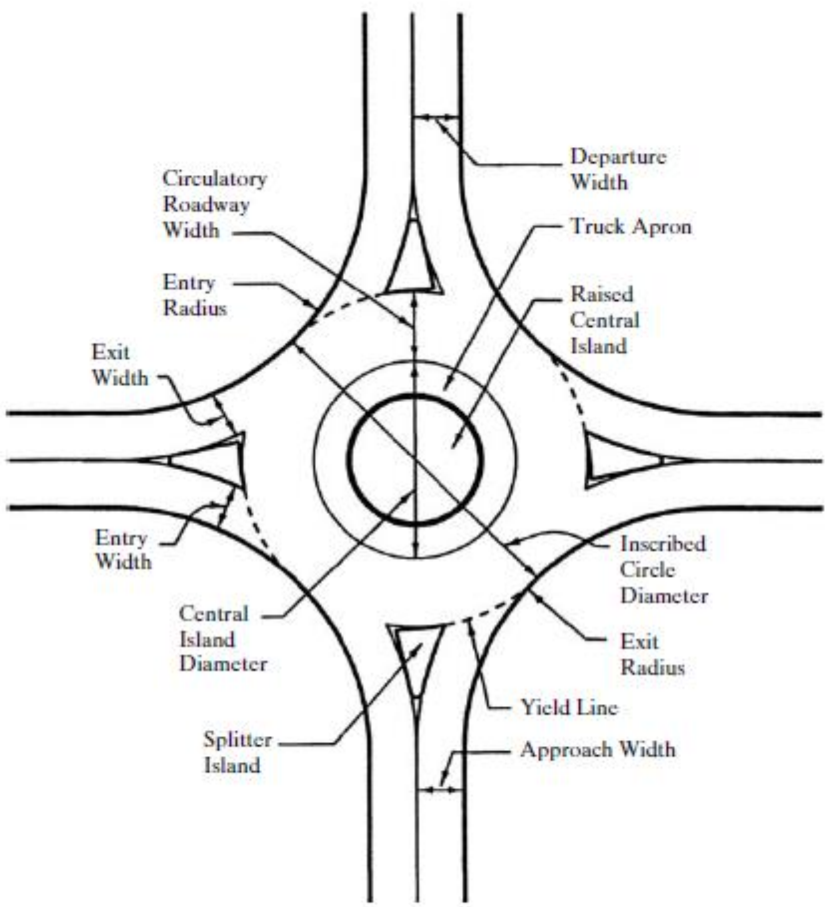

Figure 35 Geometric Elements of a Single-Lane Modern Roundabout

Roundabouts can be further categorized into six classes based on the size and environment in which they are located. These are:

- Mini Roundabouts
- Urban Compact Roundabouts
- Urban Single-Lane Roundabouts
- Rural Single-Lane Roundabouts
- Urban Double-Lane Roundabouts
- Rural Double-Lane Roundabouts

Mini Roundabouts: A mini-roundabout is a type or form of junction control at which vehicles circulate around a white, reflectors, central circular road marking (central island) of between one and four meters in diameter, as shown in Figure 36.

Figure 36 Mini-Roundabout

Mini-roundabouts are small roundabouts used in low-speed urban environments, with average operating speeds of 60 km/h (35 mph) or less. They can be useful in low-speed urban environments in cases where conventional roundabout design is precluded by right-of-way constraints. In retrofit applications, mini-roundabouts are relatively inexpensive because they typically require minimal additional pavement at the intersecting roads-for example, minor widening at the corner curbs. They are mostly recommended when there is insufficient right-of-way for an urban compact roundabout. Because they are small, mini-roundabouts are perceived as pedestrian-friendly with short crossing distances and very low vehicle speeds on approaches and exits. The mini-roundabout is designed to accommodate passenger cars without requiring them to drive over the central island. To maintain its perceived compactness and low speed characteristics, the yield lines are positioned just outside of the swept path of the largest expected vehicle. However, the central island is mountable, and larger vehicles may cross over the central island, but not to the left of it. Speed control around the mountable central island should be provided in the design by requiring horizontal deflection. Capacity for this type of roundabout is expected to be similar to that of the compact urban roundabout. The recommended design of these roundabouts is based on the German method, with some influence from the United Kingdom.

Urban Compact Roundabouts: Like mini-roundabouts, urban compact roundabouts are intended to be pedestrian and bicyclist-friendly because their perpendicular approach legs require very low vehicle speeds to make a distinct right turn into and out of the circulatory roadway. All legs have single-lane entries (Refer to Figure 37). However, the urban compact treatment meets all the design requirements of effective roundabouts.

Figure 37 Urban Compact Roundabout

The principal objective of this design is to enable pedestrians to have safe and effective use of the intersection. Capacity should not be a critical issue for this type of roundabout to be considered. The geometric design includes raised splitter islands that incorporate at-grade pedestrian storage areas, and a non-mountable central island. There is usually an apron surrounding the non-mountable part of the compact central island to accommodate large vehicles. The recommended design of these roundabouts is similar to those in Germany and other northern European countries.

Urban Single-Lane Roundabouts: This type of roundabout is characterized as having a single lane entry at all legs and one circulatory lane. Figure 38 provides an example of a typical urban single-lane roundabout. They are distinguished from urban compact roundabouts by their larger inscribed circle diameters and more tangential entries and exits, resulting in higher capacities. Their design allows slightly higher speeds at the entry, on the circulatory roadway, and at the exit. Notwithstanding the larger inscribed circle diameters than compact roundabouts, the speed ranges recommended in this guide are somewhat lower than those used in other countries, in order to enhance safety for bicycles and pedestrians.

Figure 38 Urban Single Lane Roundabout

The roundabout design is focused on achieving consistent entering and circulating vehicle speeds. The geometric design includes raised splitter islands, a non-mountable central island, and preferably, no apron. The design of these roundabouts is similar to those in Australia, France, and the United Kingdom.

Urban Double-Lane Roundabouts: Urban double-lane roundabouts include all roundabouts in urban areas that have at least one entry with two lanes. They include roundabouts with entries on one or more approaches that flare from one to two lanes. These require wider circulatory roadways to accommodate more than one vehicle traveling side by side. Figure 39 provides an example of a typical urban multilane roundabout.

Figure 39 Urban Double-Lane Roundabout

The speeds at the entry, on the circulatory roadway, and at the exit are similar to those for the urban single-lane roundabouts. Again, it is important that the vehicular speeds be consistent throughout the roundabout. The geometric design will include raised splitter islands, no truck apron, a non-mountable central island, and appropriate horizontal deflection. Alternate routes may be provided for bicyclists who choose to bypass the roundabout. Bicycle and pedestrian pathways must be clearly delineated with sidewalk construction and landscaping to direct users to the appropriate crossing locations and alignment. Urban double-lane roundabouts located in areas with high pedestrian or bicycle volumes may have special design recommendations such as those provided in Chapters 6 and 7. The design of these roundabouts is based on the methods used in the United Kingdom, with influences from Australia and France.

Rural Single-Lane Roundabouts: Rural single-lane roundabouts generally have high average approach speeds in the range of 80 to 100 km/h (50 to 60 mph). They require supplementary geometric and traffic control device treatments on approaches to encourage drivers to slow to an appropriate speed before entering the roundabout. Rural roundabouts may have larger diameters than urban roundabouts to allow slightly higher speeds at the entries, on the circulatory roadway, and at the exits. This is possible if few pedestrians are expected at these intersections, currently and in future. There is preferably no apron because their larger diameters should accommodate larger vehicles. Figure 40 provides an example of a typical rural single-lane roundabout.

Figure 40 Rural Single-Lane Roundabout

Supplemental geometric design elements include extended and raised splitter islands, a non-mountable central island, and adequate horizontal deflection. The design of these roundabouts is based primarily on the methods used by Australia, France, and the United Kingdom. Rural roundabouts that may one day become part of an urbanized area should be designed as urban roundabouts, with slower speeds and pedestrian treatments. However, in the interim, they should be designed with supplementary approach and entry features to achieve safe speed reduction

Rural Double-Lane Roundabouts: Rural double-lane roundabouts have speed characteristics similar to rural single lane roundabouts with average approach speeds in the range of 80 to 100 km/h (50 to 60 mph). They differ in having two entry lanes, or entries flared from one to two lanes, on one or more approaches. Consequently, many of the characteristics and design features of rural double-lane roundabouts mirror those of their urban counterparts. The main design differences are designs with higher entry speeds and larger diameters, and recommended supplementary approach treatments. The design of these roundabouts is based on the methods used by the United Kingdom, Australia, and France. Figure 41 provides an example of a typical rural double-lane roundabout.

Figure 41 Rural Double-Lane Roundabout

Rural roundabouts that may one day become part of an urbanized area should be designed for slower speeds, with design details that fully accommodate pedestrians and bicyclists. However, in the interim they should be designed with approach and entry features to achieve safe speed reduction.

The characteristics of each of these categories are shown in Table 1.

Design Element	*Mini-Roundabout*	*Urban Compact*	*Urban Single-Lane*	*Urban Double-Lane*	*Rural Single-Lane*	*Rural Double-Lane*
Recommended maximum entry design speed	25 km/h (15 mi/h)	25 km/h (15 mi/h)	35 km/h (20 mi/h)	40 km/h (25 mi/h)	40 km/h (25 mi/h)	50 km/h (30 mi/h)
Maximum number of entering lanes per approach	1	1	1	2	1	2
Typical inscribed circle diameter[1]	13 to 25 m (45 ft to 80 ft)	25 to 30 m (80 to 100 ft)	30 to 40 m (100 to 130 ft)	45 to 55 m (150 to 180 ft)	35 to 40 m (115 to 130 ft)	55 to 60 m (180 to 200 ft)
Splitter island treatment	Raised if possible, crosswalk cut if raised	Raised, with crosswalk cut	Raised, with crosswalk cut	Raised, with crosswalk cut	Raised and extended, with crosswalk cut	Raised and extended, with crosswalk cut
Typical daily service volumes on four-leg roundabout (veh/day)	10,000	15,000	20,000	Refer to the source	20,000	Refer to the source

[1]Assumes 90° entries and no more than four legs.

Table 1 Characteristics of Roundabout Categories

Roundabouts can be used in rural, suburban, and urban areas. Mini-roundabouts with a smaller inscribed diameter and fully traversable central island are typically used in urban areas due to right of way constraints, slower speeds, and smaller design vehicles such as a school bus. In areas where alignment, visibility, and cross section details are important due to the higher approach speeds, single-lane roundabouts with a larger inscribed diameter and raised central islands are generally used.

Channelization of At-Grade Intersections

AASHTO defines channelization as the separation of conflicting traffic movements into definite paths of travel by traffic islands or pavement markings to facilitate the safe and orderly movements of both vehicles and pedestrians.

A traffic island is a defined area between traffic lanes that is used to regulate the movement of vehicles or to serve as a pedestrian refuge. Vehicular traffic is excluded from the island area. A properly channelized intersection will result in increased capacity, enhanced safety, and increased driver confidence. On the other hand, an intersection that is not properly channelized may have the opposite effect. Care should always be taken to avoid over channelization since this frequently creates confusion for the motorist and may even result in a lower operating level than that for an intersection without any channelization. When islands are used for channelization, they should be designed and located at the intersection without creating an undue hazard to vehicles; at the same time, they should be commanding enough to prevent motorists from driving over them.

Channelization at an intersection is normally used to achieve one or more of the following objectives:

- Direct the paths of vehicles so that not more than two paths cross at any one point.
- Control the merging, diverging, or crossing angle of vehicles.
- Decrease vehicle wander and the area of conflict among vehicles by reducing the amount of paved area.
- Provide a clear indication of the proper path for different movements.
- Give priority to the predominant movements.
- Provide pedestrian refuge.
- Provide separate storage lanes for turning vehicles, thereby creating space away from the path of through vehicles for turning vehicles to wait.
- Provide space for traffic control devices so that they can be readily seen.
- Control prohibited turns.
- Separate different traffic movements at signalized intersections with multiple phase signals.
- Restrict the speeds of vehicles.

The factors that influence the design of a channelized intersection are availability of right of way, terrain, type of design vehicle, expected vehicular and pedestrian volumes, cross sections of crossing roads, approach speeds, bus-stop requirements, and the location and type of traffic-control device. For example, factors such as right of way, terrain, bus-stop requirements, and vehicular and pedestrian volumes influence the extent to which channelization can be undertaken at a given location while factors such as type of design vehicle and approach speeds influence the design of the edge of pavement.

The design of a channelized intersection also always should be governed by the following principles:

- Motorists should not be required to make more than one decision at a time.
- Sharp reverse curves and turning paths greater than 90° should be avoided.

- Merging and weaving areas should be as long as possible, but other areas of conflict between vehicles should be reduced to a minimum.

- Crossing traffic streams that do not weave or merge should intersect at 90°, although a range of 60 to 120° is acceptable.

- The intersecting angle of merging streams should be such that adequate sight distance is provided.

- Refuge areas for turning vehicles should not interfere with the movement of through vehicles.

- Prohibited turns should be blocked wherever possible.

- Decisions on the location of essential traffic control devices should be a component of the design process.

General Characteristics of Traffic Islands

The definition given for traffic islands in the previous section clearly indicates that they are not all of one physical type. These islands can be formed by using raised curbs, pavement markings, or the pavement edges.

The types of traffic islands are:

- Curbed Traffic Islands

- Traffic Islands Formed by Pavement Markings

- Islands Formed by Pavement Edges

Curbed Traffic Island: A curbed island is usually formed by the construction of a concrete curb that delineates the area of the island, as shown in Figure 42. Curbs are generally classified as mountable or barrier. Mountable curbs are constructed with their faces inclined at an angle of 45 degrees or less so that vehicles may mount them without difficulty if necessary. The faces of barrier curbs are usually vertical. It should be noted, however, that because of glare, curbed islands may be difficult to see at night which makes it necessary that intersections with curbed islands have fixed-source lighting. Curbed islands are used mainly in urban highways where approach speed is not excessively high and pedestrian volume is relatively high.

Figure 42 Curbed Island at an Intersection

Traffic Islands Formed by Pavement Markings: This type of island is sometimes referred to as a flushed island because it is flushed with the pavement, as shown in Figure 43. Flushed islands are formed by pavement markings that delineate the area of the island. Markers include paint, thermoplastic striping, and raised retroreflective markers. Flushed islands are

Figure 43 Island Formed by Pavement Markings (Flushed Island)

preferred over curbed islands at intersections where approach speeds are relatively high, pedestrian traffic is low, and signals or sign mountings are not located on the island.

Islands Formed by Pavement Edges: These islands are usually unpaved and are mainly used at rural intersections where there is space for large intersection curves.

Functions of Traffic Islands

Traffic islands also can be classified into three categories based on their functions:

- Channelized
- Divisional
- Refuge

Channelized Islands: are mainly used to control and direct traffic. The objective of channelized islands is to eliminate confusion to motorists at intersections with different traffic movements by guiding them into the correct lane for their intended movement. This is achieved by converting excess space at the intersection into islands in a manner that leaves very little to the discretion of the motorist. A channelized island may take one of many shapes (f, e, d of Figure 44), depending on its specific purpose. For example, a triangularly-shaped channelized island is often used to separate right-turning traffic from through traffic (see Figure 45) whereas a curved, central island is frequently used to guide turning vehicles (see Figure 44). In any case, the outlines of a channelized island should be nearly parallel to the lines of traffic it is channeling. Where the island is used to separate turning traffic from through traffic, the radii of the curved sections must be equal to or greater than the minimum radius required for the expected turning speed.

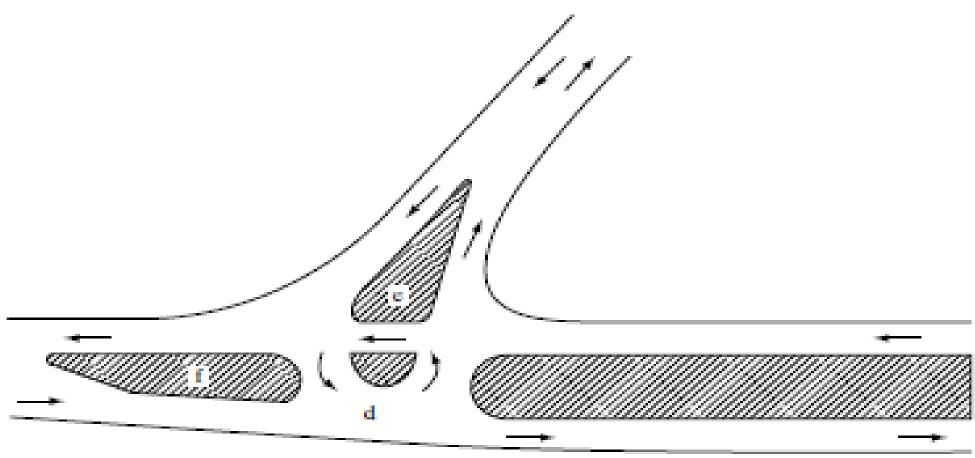

Figure 44 Channelized Islands

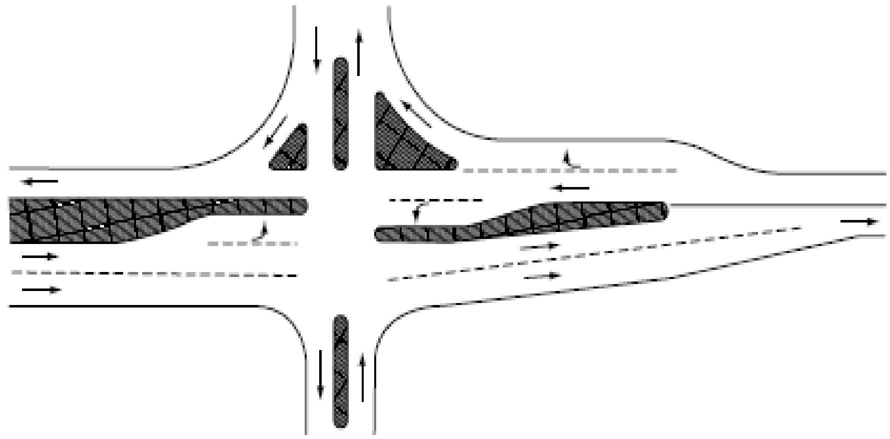

Figure 45 Additional Channelized Islands

The number of islands used for channelization at an intersection should be kept to a practical minimum, since the presence of several islands may cause confusion to the motorist. For example, the use of a set of islands to delineate several one-way lanes may cause unfamiliar drivers to enter the intersection in the wrong lane.

Divisional Islands: are mainly used to divide opposing or same-directional traffic streams. These are frequently used at intersections of undivided highways to alert drivers that they are approaching an intersection and to control traffic at the intersection. They also can be used effectively to control left turns at skewed intersections. Examples of divisional islands are shown in Figure 46. When it is necessary to widen a road at an intersection so that a divisional island can be included, every effort should be made to ensure that the path a driver is expected to take is made quite clear. The alignment also should be designed so that the driver can traverse the intersection easily without any excessive steering.

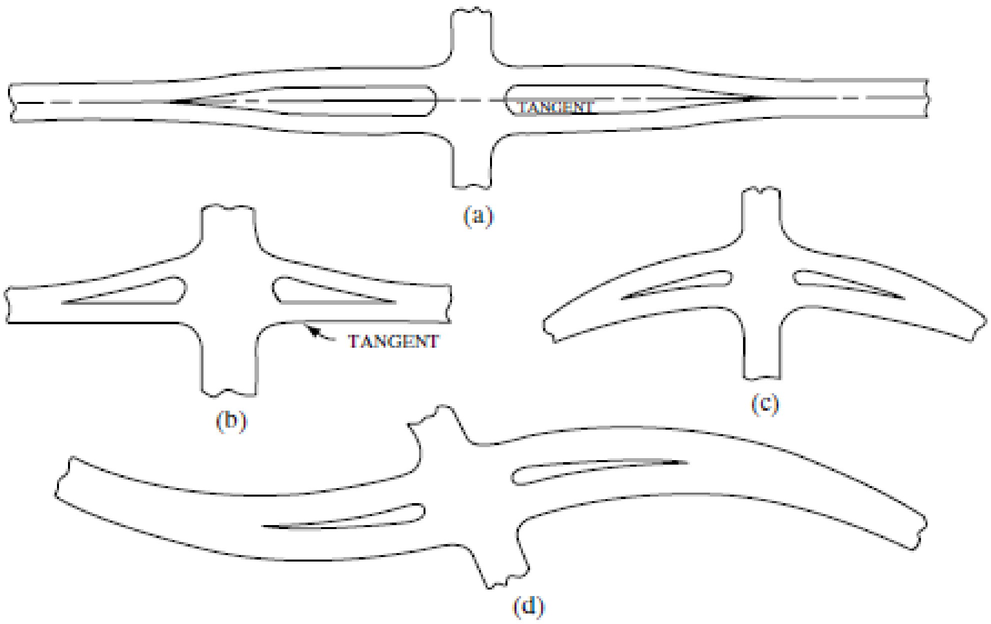

Figure 46 Examples of Divisional Islands

It is sometimes necessary to use reverse curves (two simple curves with opposite curvatures, forming a compound curve) when divisional islands are introduced, particularly when the location is at a tangent. At locations where speeds tend to be high, particularly in rural areas, it is recommended that the reversal in curvature be no greater than 1 degree. Sharper curves can be used when speeds are relatively low, but a maximum of 2 degrees is recommended.

Refuge Islands: are used primarily to provide refuge for pedestrians. Refuge islands, sometimes referred to as pedestrian islands, are used mainly at urban intersections to serve as refuge areas for wheelchairs and pedestrians crossing wide intersections. They also may be used for loading and unloading transit passengers. Figure 47 shows examples of islands that provide refuge as well as function as channelized islands.

In most cases, however, traffic islands perform two or more of these functions rather than a single function, although each island may have a primary function.

Minimum Sizes of Islands

It is essential that islands be large enough to command the necessary attention by drivers. In order to achieve this, AASHTO recommends that curbed islands have a minimum area of approximately 50 ft^2 for urban intersections and 75 ft^2 for rural intersections, although 100 ft^2 is preferable for both.

The minimum side lengths recommended are 12 ft (but preferably 15 ft) for triangular islands after the rounding of corners, 20 to 25 ft for elongated or divisional islands, and 100 ft (but preferably several hundred feet) for curbed divisional islands that are located at isolated intersections on high-speed highways. It is not advisable to introduce

Figure 47 Refuge Islands at Wide Intersections

Figure 48 Additional Example of Refuge Islands at Wide Intersections

curbed divisional islands at isolated intersections on high-speed roads, since this may create a hazardous situation unless the island is made visible enough to attract the attention of the driver.

Islands having side lengths near the minimum are considered to be small islands whereas those with side lengths of 100 ft or greater are considered to be large. Those with side lengths less than those for large islands but greater than the minimum are considered to be intermediate islands.

In general, the width of elongated islands should not be less than 4 ft, although this dimension can be reduced to an absolute minimum of 2 ft in special cases when space is limited. In cases where signs are located on the island, the width of the sign must be considered in selecting the width of the island to ensure that the sign does not extend beyond the limits of the island.

Section 5 — References

- A Policy on Geometric Design of Highways and Streets. American Association of State Highway and Transportation Officials, Washington D.C.