Course Code: CE 455
Course Title: Traffic Engineering and Management

Lecture 6: Grade separation and interchanges

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Outline

- Types of at grade intersection
- Details of 3-leg and 4-leg intersections
- Multi-leg intersection and its factors
- Conflicting movements at intersections
- Grade separated intersection,
- Selection criteria for different interchanges
- Rotary intersection, capacity of rotary intersection
- Geometric elements of rotary intersection
- Design principles of Channelization
- Generalized characteristics of traffic islands

At grade intersection

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

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

Figure 25 Three-Leg Intersection

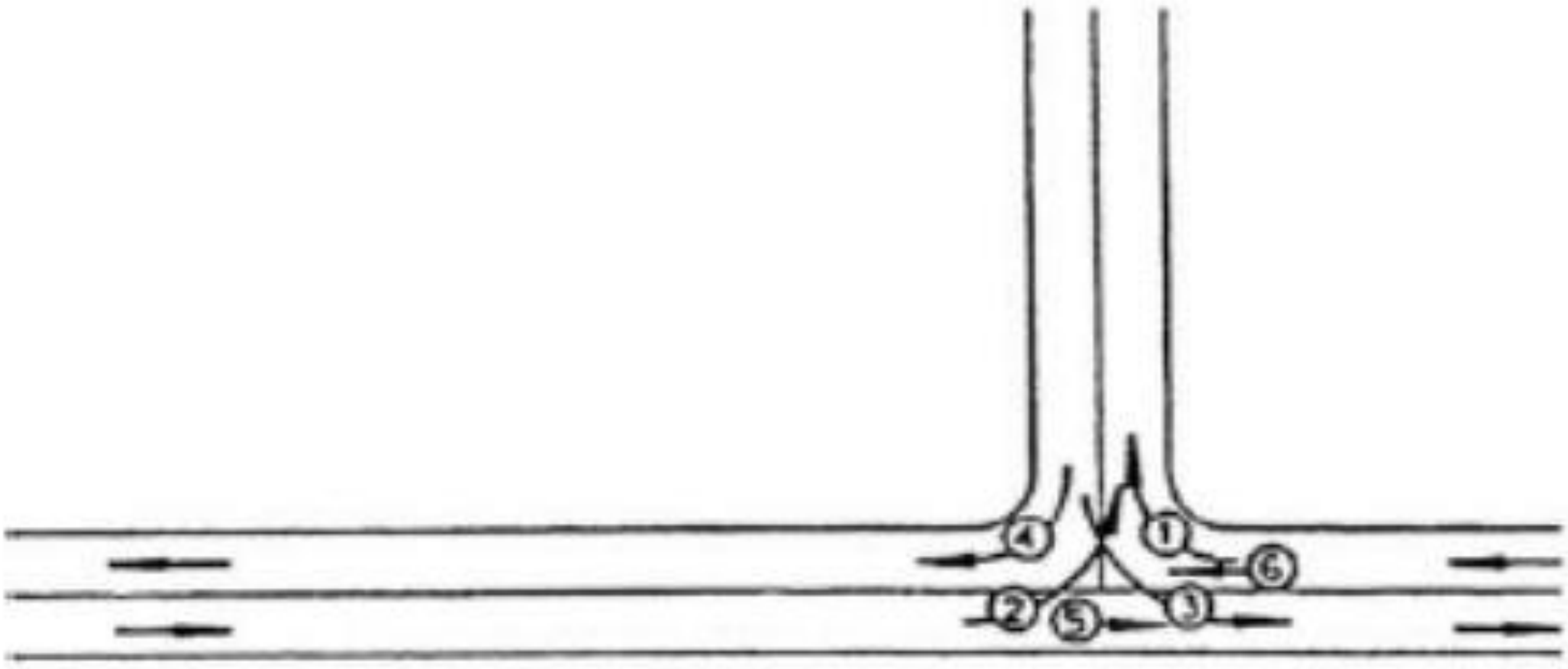


Figure 26 Plain T Intersection

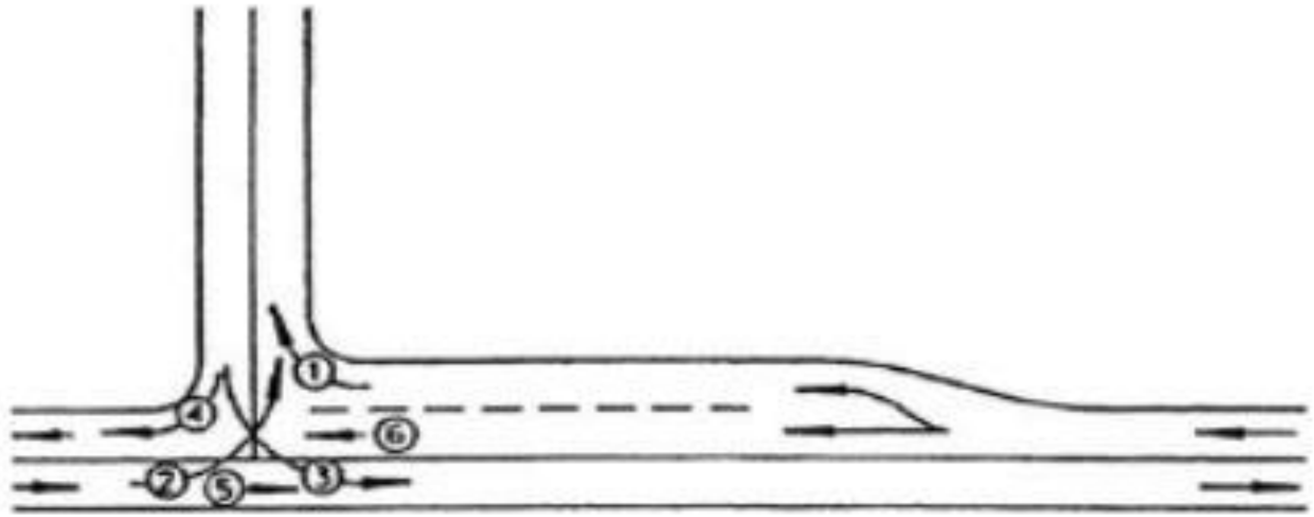
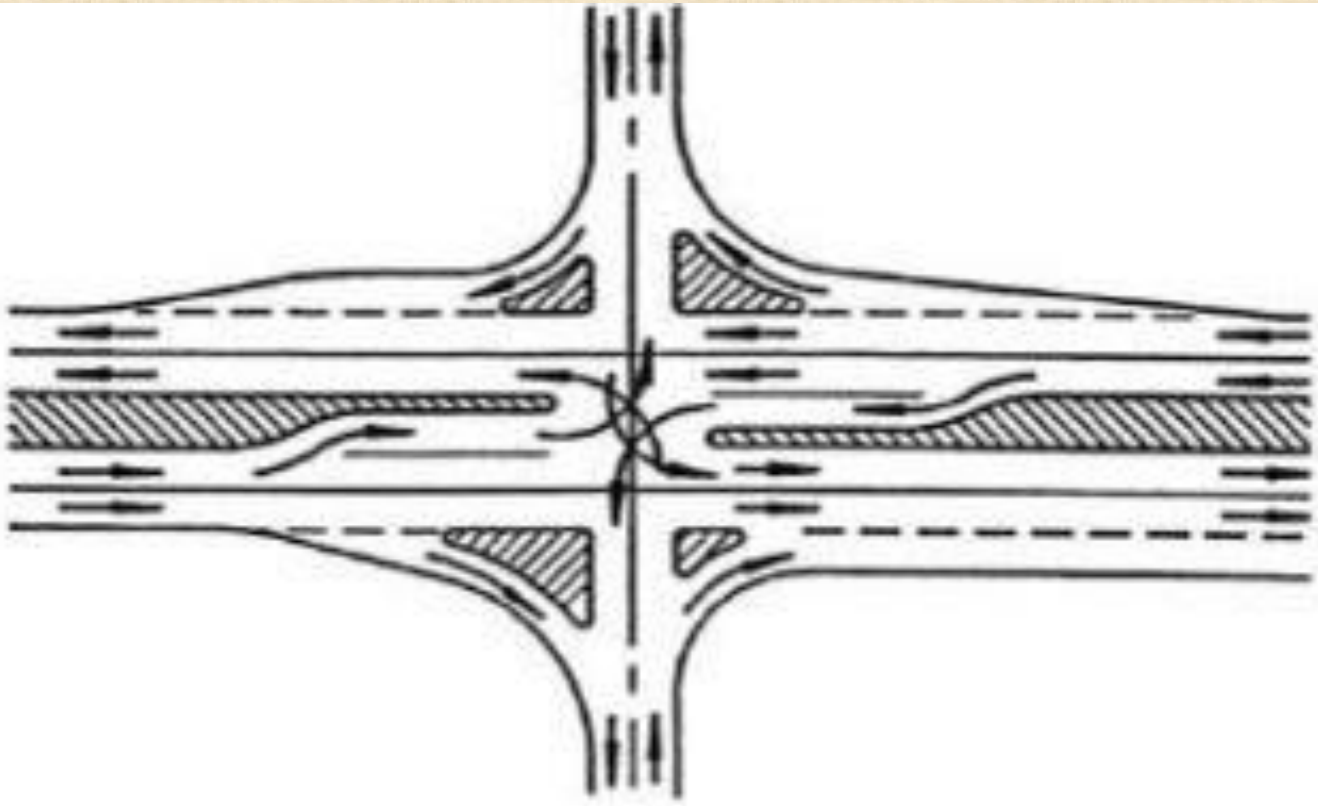


Figure 27 T-Intersection with Right-Turn Lane

Figure 30 Four-Leg Intersection



(d)

Figure 31 Examples of Four-Leg Intersection

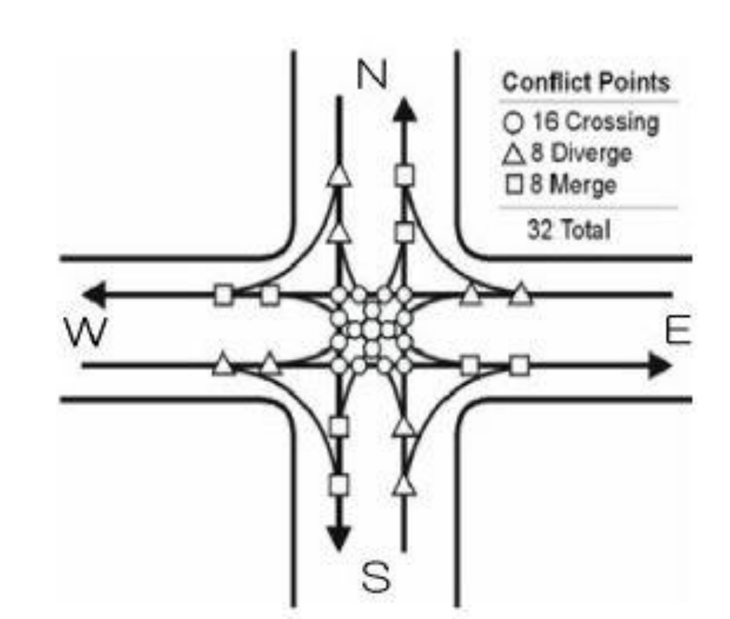
Figure 32 Multi-Leg Intersection

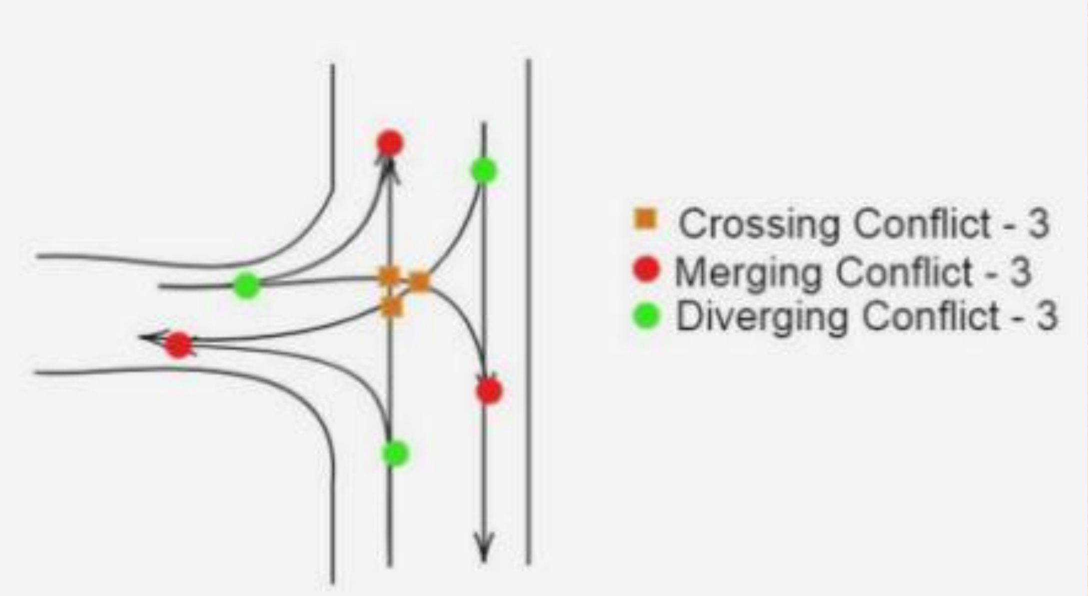
Important factors of multi-leg intersection

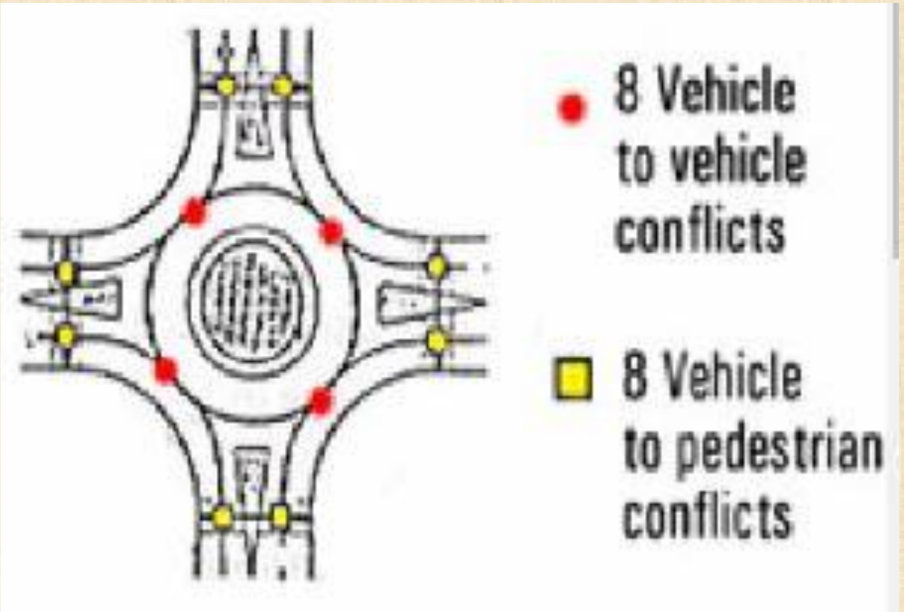
There are two important factors to consider when realigning roads in this way:

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

Conflicting movements at intersections







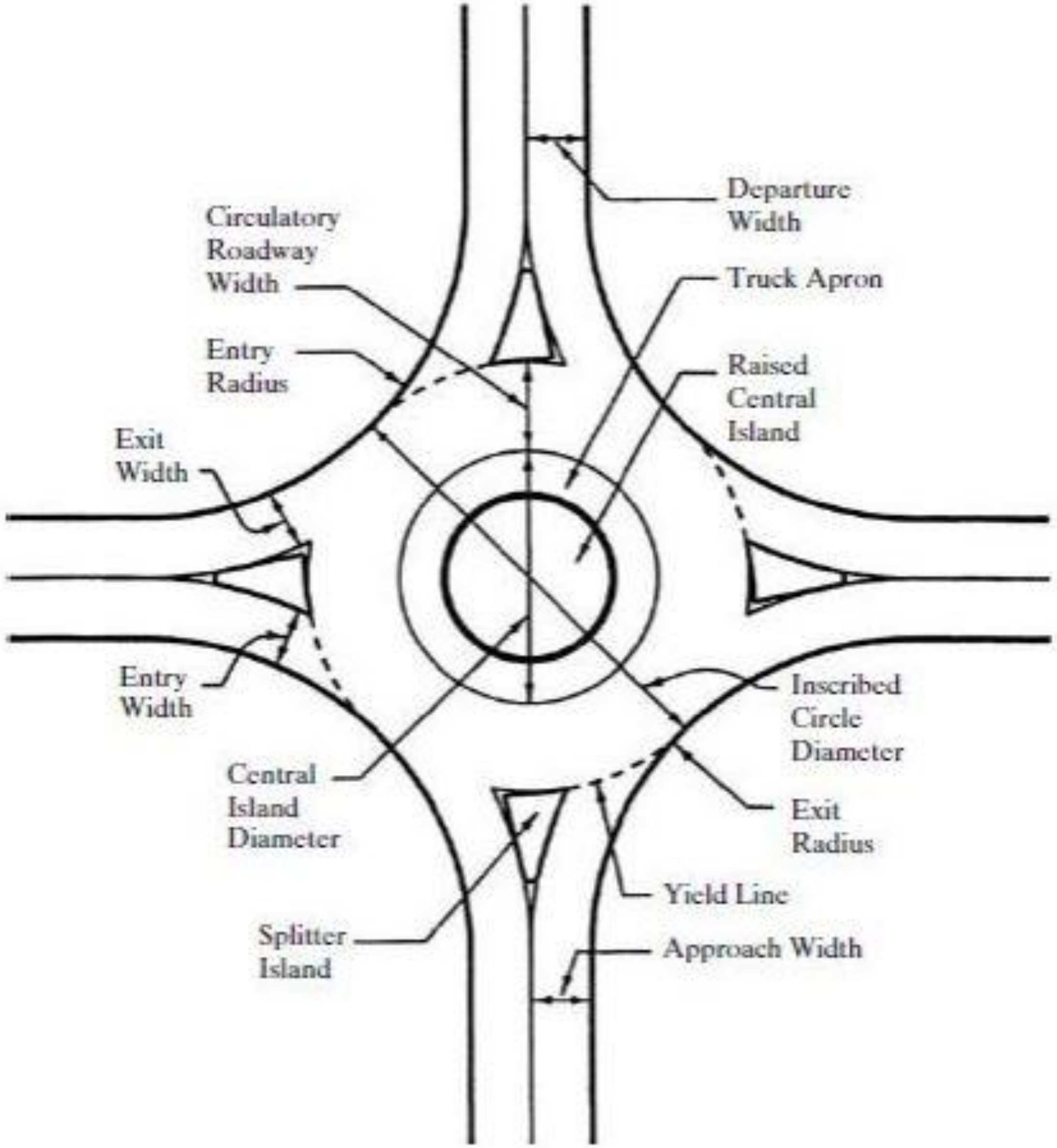
Rotary intersection

Figure 34 Traffic Circle

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.



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

Figure 36 Mini-Roundabout

Figure 41 Rural Double-Lane Roundabout

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

Objectives of Channelization

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.

Design principles of Channelization

- 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.

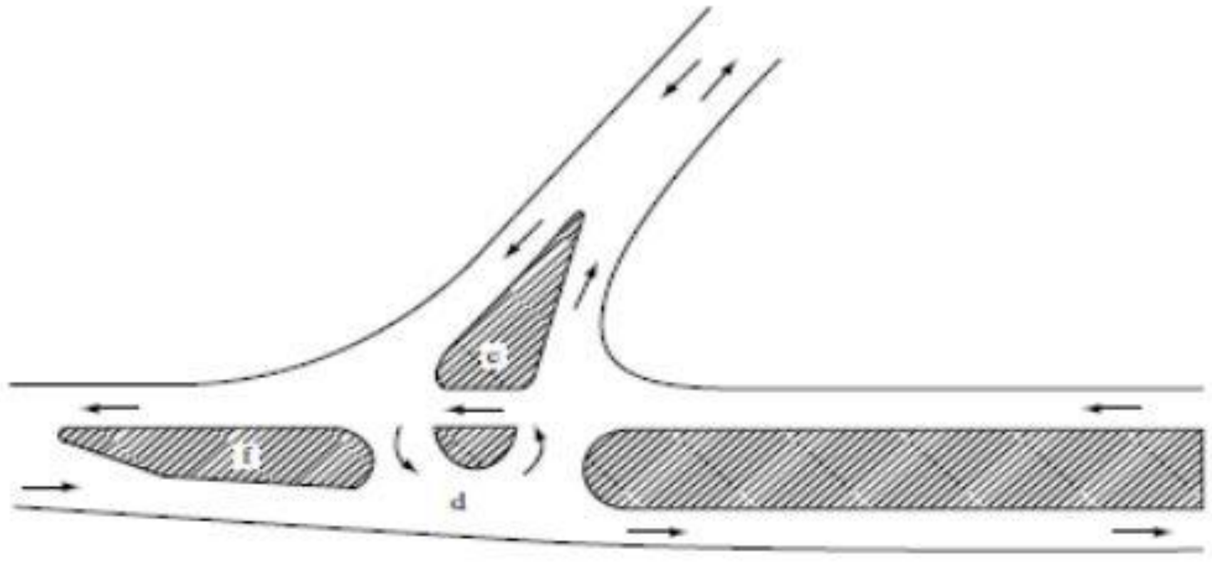


Figure 44 Channelized Islands

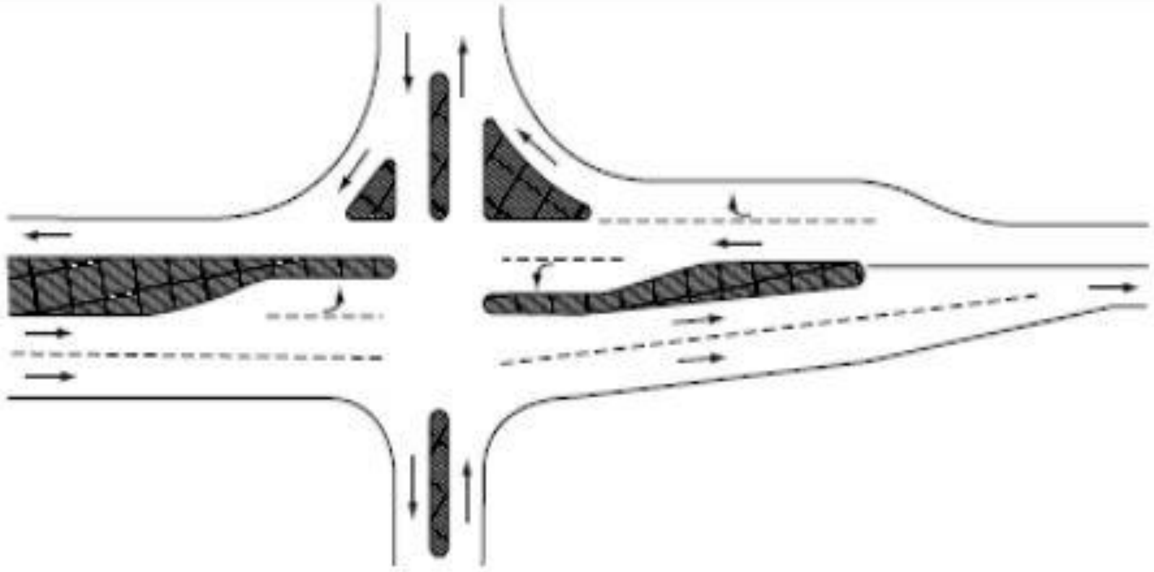


Figure 45 Additional Channelized Islands

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.

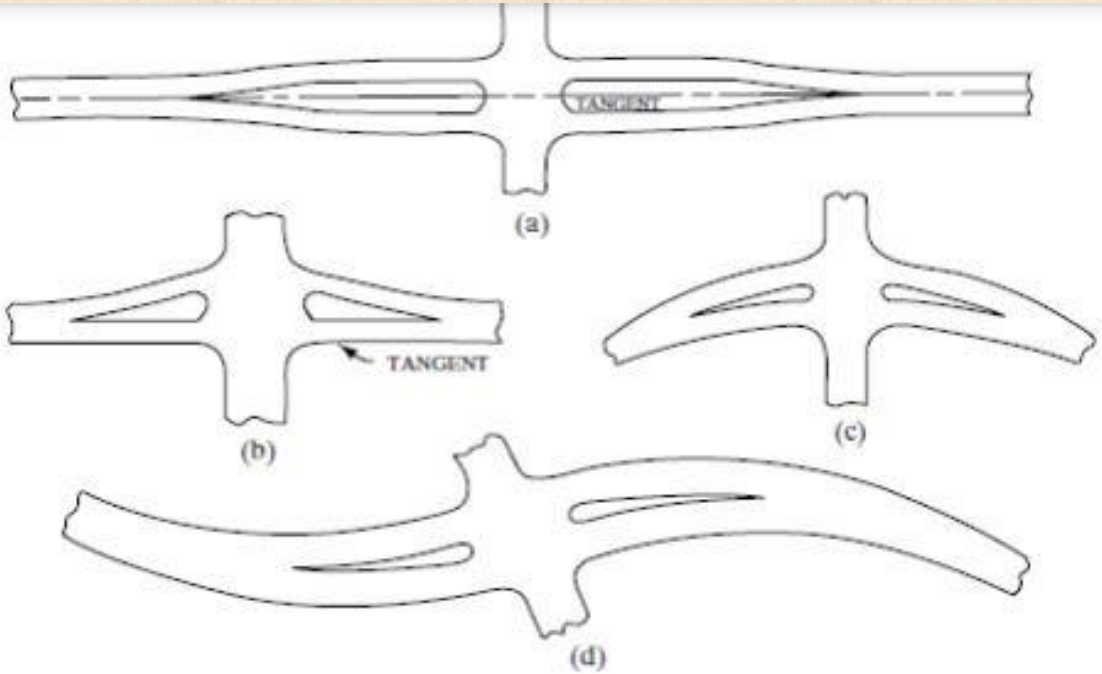


Figure 46 Examples of Divisional Islands

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 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

Figure 6 Trumpet Interchange

Figure 7 Three-Way Directional Interchange

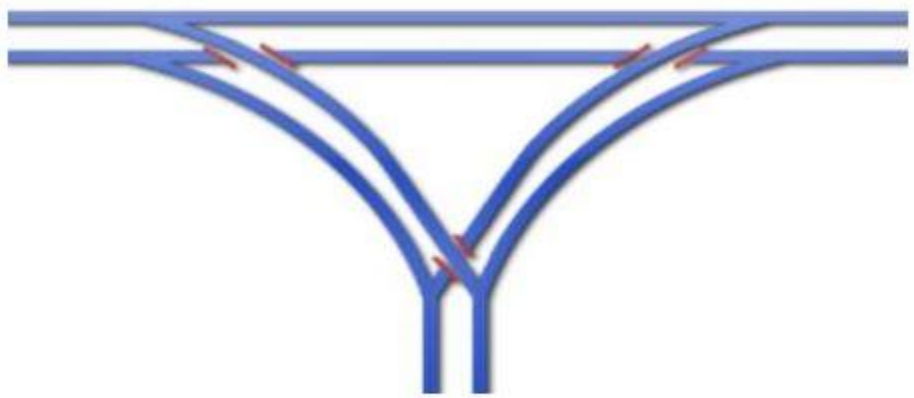


Figure 8 Full Y Interchange

Figure 11 Stack Interchange

Figure 12 Combination Interchange

Figure 13 Turbine Interchange

Figure 14 Windmill Interchange

Figure 16 Three-Level Roundabout Interchange

Figure 17 Diamond Interchange

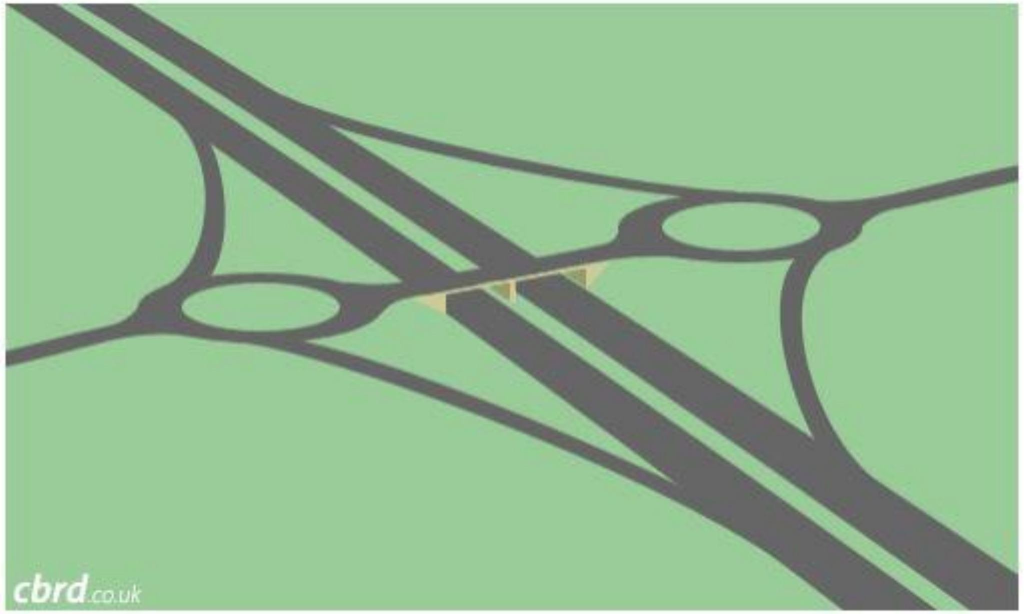


Figure 18 Dumbbell Interchange

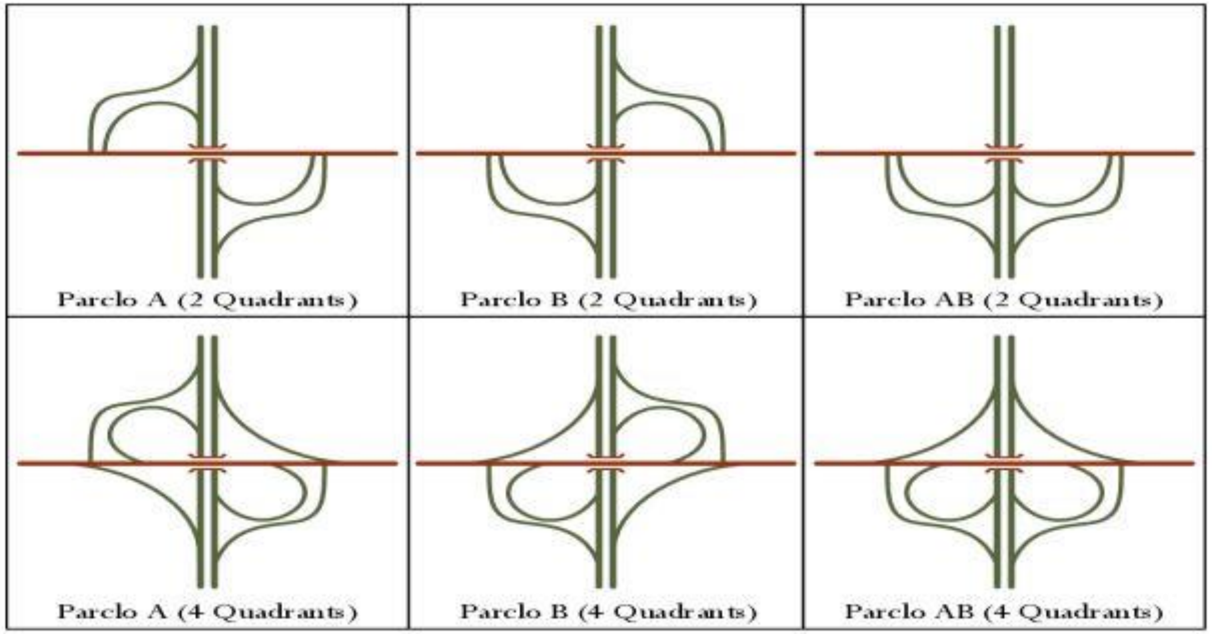


Figure 19 Partial Cloverleaf Configuration

Figure 20 Parclo A Interchange

Figure 23 Diverging Diamond Interchange

Figure 24 Single-Point Urban Interchange

Table 4.1 Approximate Land Requirements of Interchanges in Square Meters

	Category	Approximate land required in square meters
1	Trumpet Interchange	44,000
2	Diamond Interchange	28,000
3	Full Cloverleaf	73,000
4	Bridged Rotary	1,80,000

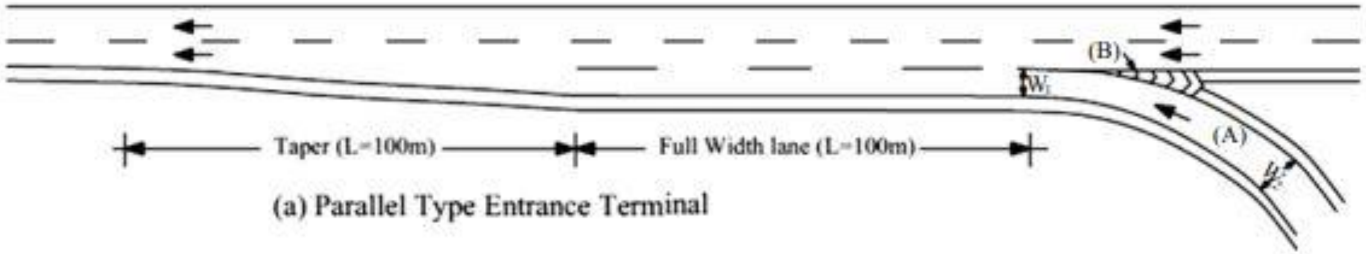
4.2 Interchange Spacing

Interchange spacing is an important consideration in the planning and design of new or modified interchanges. Interchange spacing is the distance measured along the main roadway between the centre lines of the intersecting roadways that maintain ramp access to the through highway. The spacing is intended to minimize the disruption of entering and exiting traffic to the mainline of the highway and to prevent insufficient sign spacing.

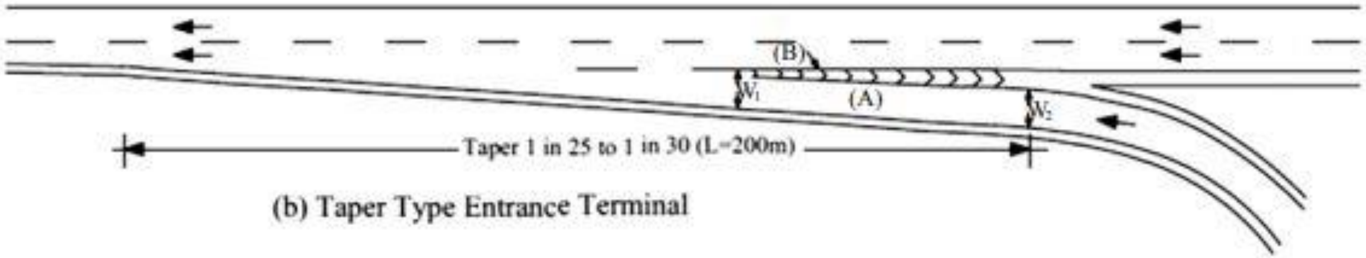
In urban areas, there should be a 1.6 km minimum spacing between interchanges to allow sufficient space for entrance and exit manoeuvres. Closer spacing may require the use of collector-distributor roads to remove the merging/diverging and accelerating/decelerating traffic from the expressway. In rural, undeveloped areas, interchanges should be spaced at more than 4.8 km apart.

6.6.1 *Lateral Clearance*

For underpass roadways, desirably the full roadway width at the approaches should be carried through the underpass. This implies that the minimum lateral clearance (i.e. the distance between the extreme edge of the carriageway and the face of nearest support, whether solid abutment pier or column) should equal the normal shoulder width.



(a) Parallel Type Entrance Terminal



(b) Taper Type Entrance Terminal

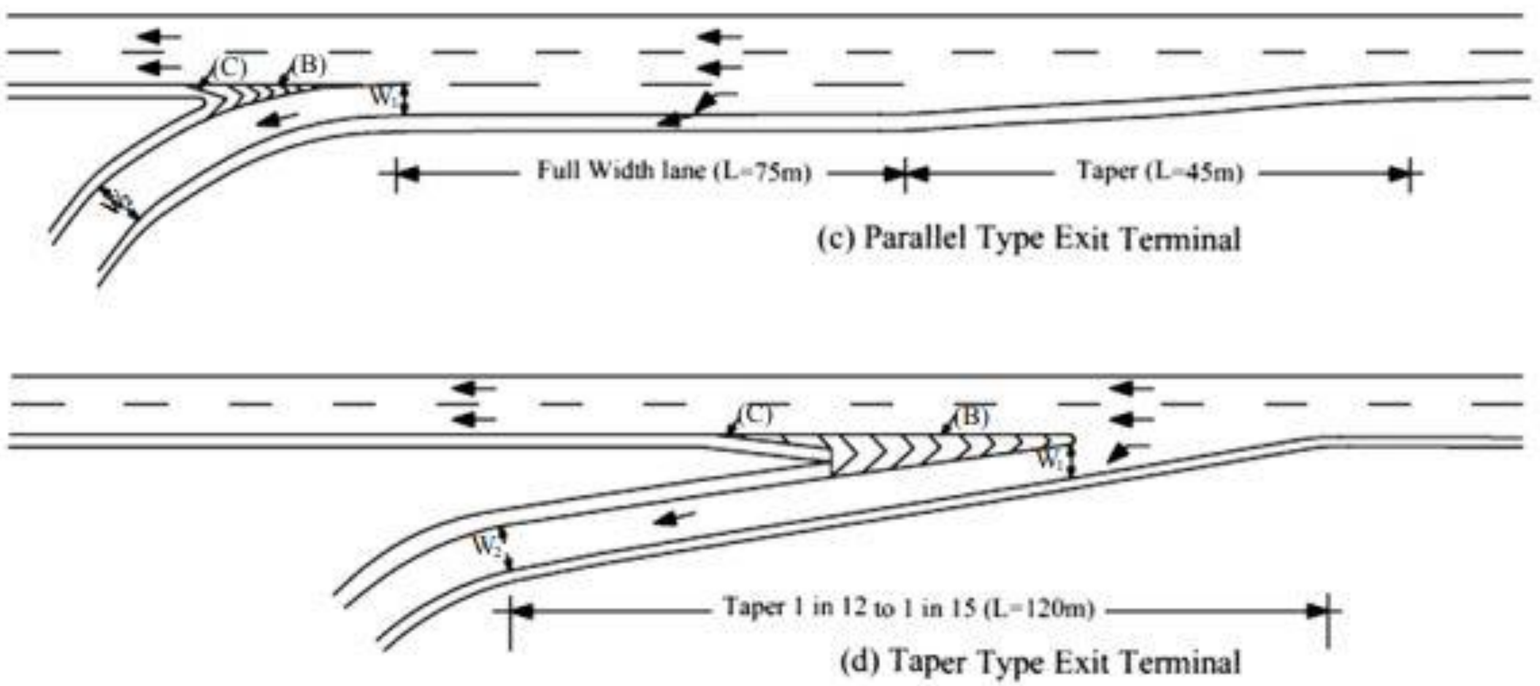


Fig. 6.3 Typical Designs for Entry and Exit Terminals

Notes (i) At locations marked (A) funnel entrance is provided by reducing width of ramp (W_2) to width of lane (W_1)

(ii) The nose area marked (B) should be paved and provided with markings in white paint as indicated.

(iii) At locations marked (C) the through lane should be tapered (1 in 10) for a distance of 20 m)

For overpass structures, the clearances are not that critical as in the case of underpasses since the drivers do not generally get the feeling of constriction. A cross-section with 225 mm wide kerb and open-type parapet will generally be suitable for most cases.

12 NOISE POLLUTION BARRIERS

Noise barriers are used as an effective measure of noise abatement. Different types of "green" noise barriers adapted to the surrounding environment are used. Size and conspicuousness of noise barriers and noise embankments leaves their mark on the environment. An increasing proportion of people's time is spent commuting on highways, and it is therefore an important task to make this time a positive experience through attractive surroundings. Noise screening can constitute an actual physical barrier in a town or housing area. Following principles shall be adhered with while considering noise controlling measures along traffic interchanges:

- Planting of trees and other vegetation so that the noise barrier fits in with its surroundings.

- To allow the noise barrier to bring out the lines and forms of the landscape or town to the roadside.
- Make the noise barrier stand out as a striking and visible addition to its surroundings through a conscious selection of colours and forms.
- Noise barriers constructed could be of different materials, such as steel, brick, concrete, wood and transparent materials.

- The height of a noise screening installation is also important for road users and their possibilities of orientation in the urban area or landscape through which they are passing. Even the erection of a 1.5 m high barrier affects visibility conditions for motorists.

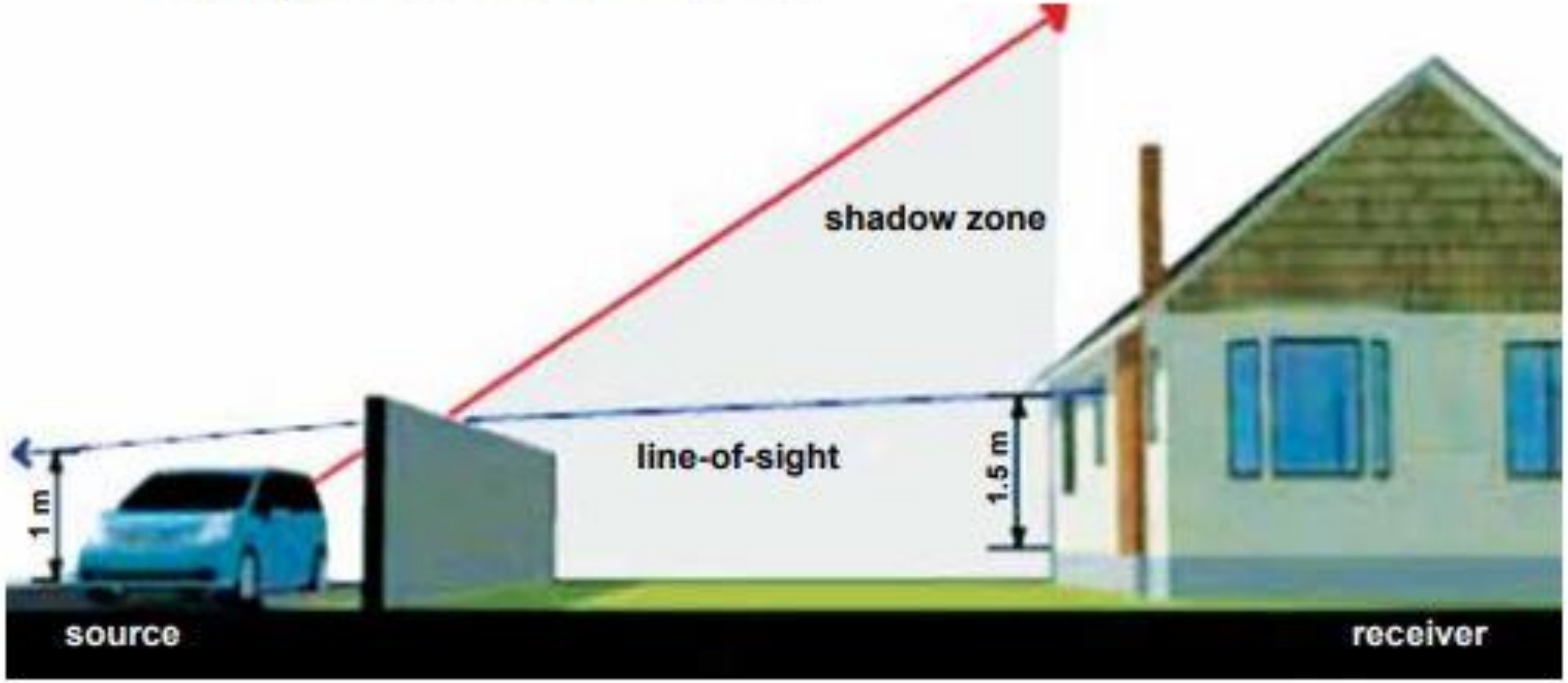
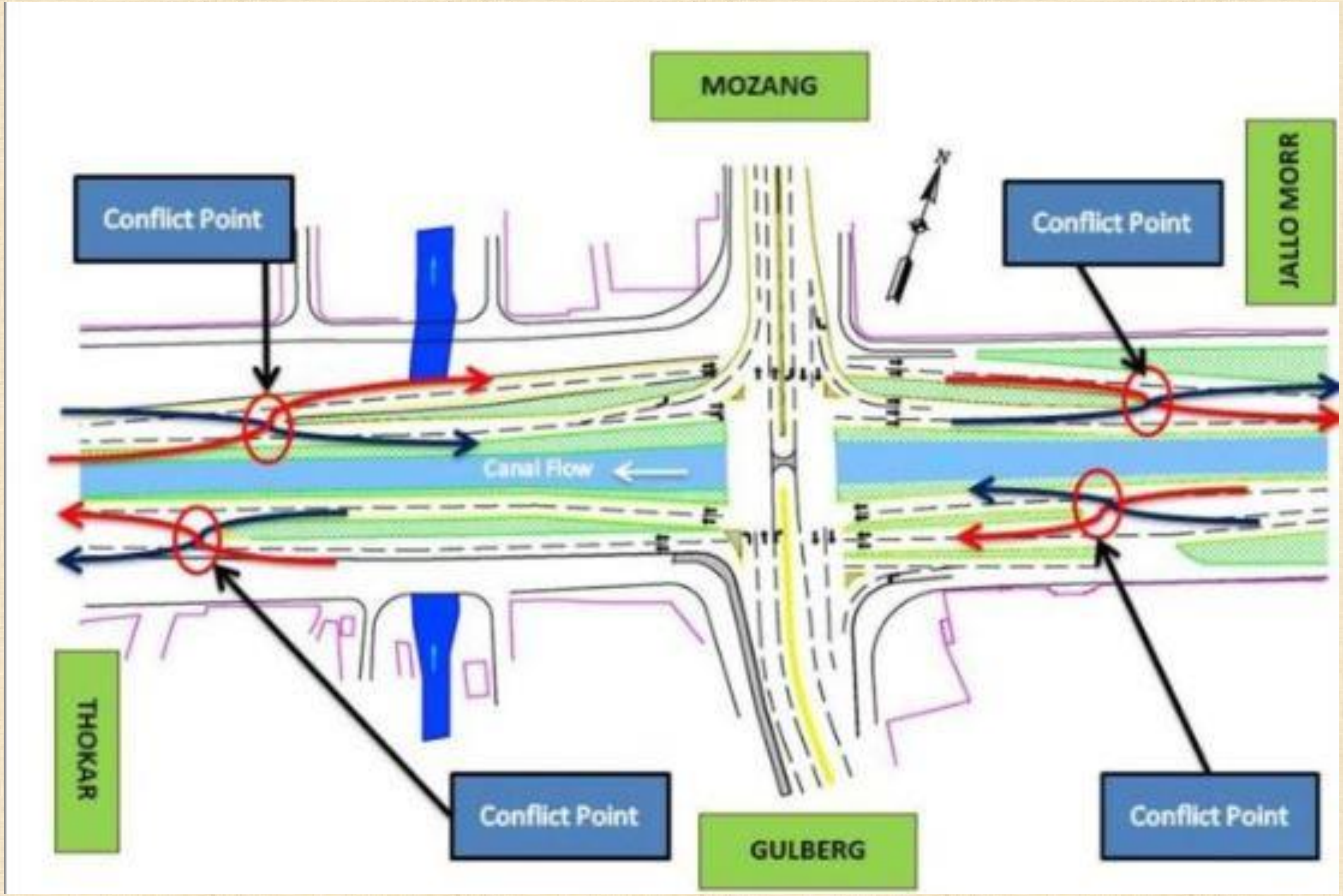


Fig. 12.1 Physical Barrier for Noise Abatement

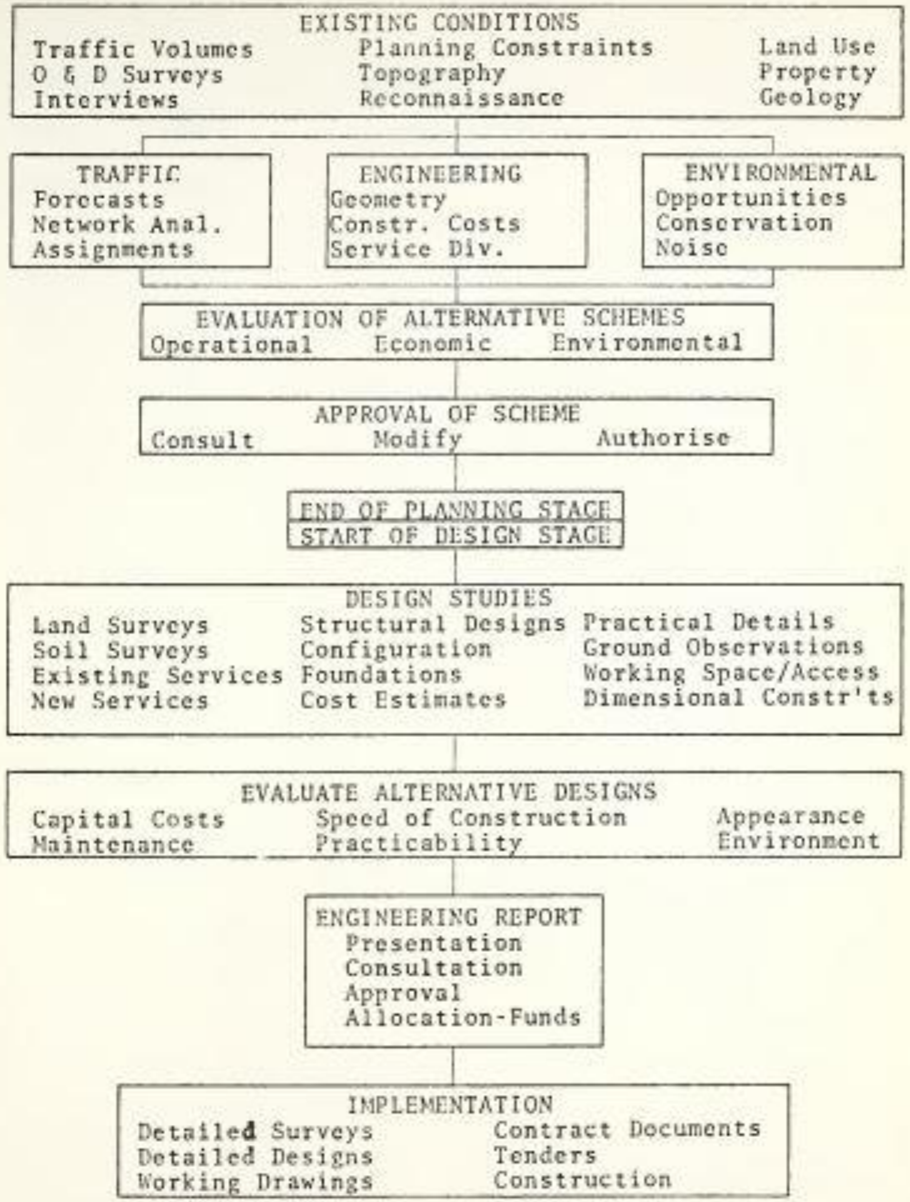
Weaving



MOZANG
JALLO MORR
Conflict Point
Conflict Point
Canal Flow
THOKAR
Conflict Point
GULBERG
Conflict Point

Fites and Jacobs[6] list the following factors which affect the type of interchange selected:

1. Speed
2. Volume
3. Composition of Traffic
4. Number of Intersecting Legs
5. Standards and Arrangement of Local Streets
6. Topography
7. Right-of-way Controls
8. Local Planning Values
9. Proximity of Adjacent Interchanges
10. Community Impact
11. Cost.



Source: 20, p. 43

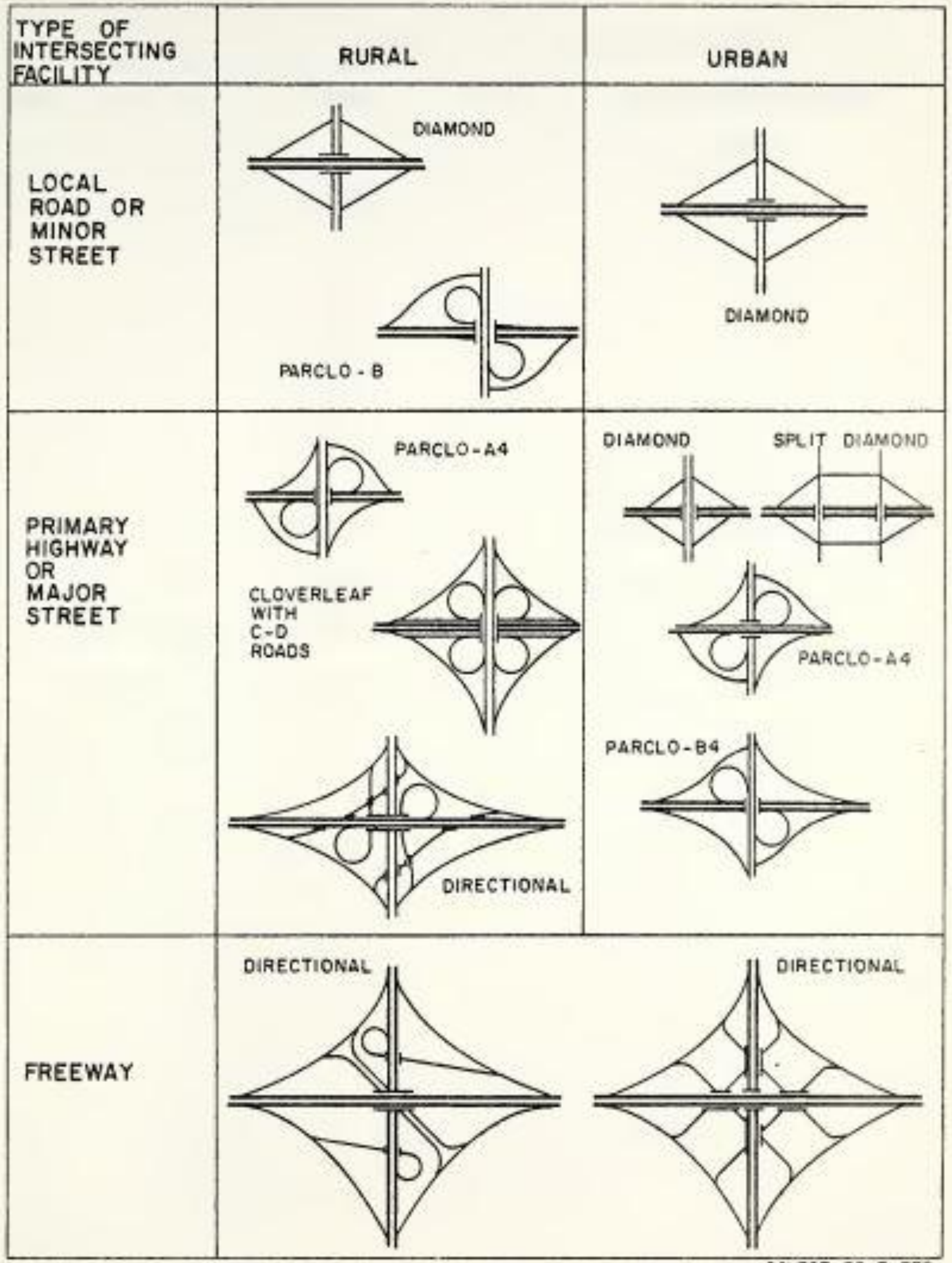
FIGURE 2 FLOW CHART FOR THE PLANNING AND DESIGN OF URBAN INTERCHANGES

TABLE 1

FACTORS TO CONSIDER IN THE COMPARISON OF INTERCHANGE TYPES

Source: 20, p. 45

FACTOR	EVALUATION
<u>Planning</u>	
Properties affected	
Displaced population	
Barrier effect	Mainly subjective aided by numerical data
Noise	
Effect of adjacent areas	
Future land use opportunities	
Landscaping opportunities and costs	
Over-shadowing	
Disturbance of amenity	
<u>Land and Property Costs</u>	
Land	
Demolition	Numerical
Rehousing	
Accommodation works	
<u>Engineering</u>	
Construction costs	
Diversion of services	All numerical with some subjective evaluation of traffic operation and safety
Geometric standards, safety, and design speed	
Lighting costs	
Road heating costs	
Ventilation (if in tunnel)	
Traffic operation characteristics	
Operating costs	
Maintenance	



SOURCE 30, P 372

TABLE 3 CHARACTERISTICS OF LEFT-TURN MOVEMENTS FREE - FLOW INTERCHANGES

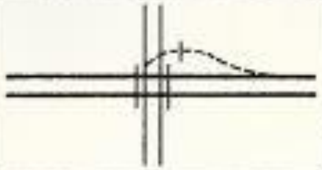
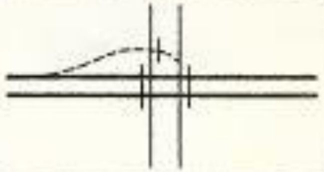
Source: 28, p.178

TYPES	LOOP	CIRCLE	SEMI-A	SEMI-B	DIRECT
					
CAPACITY	LOW	MEDIUM	MEDIUM	MEDIUM	HIGH
SPEED	LOW	MEDIUM	MEDIUM	MEDIUM	HIGH
TRAVEL TIME	HIGH	HIGH	MEDIUM	MEDIUM	LOW
RT. EXIT & ENTRY					
NARROW MED. <60°	YES	YES	YES	YES	YES
WIDE MED. >60°	YES	YES	NO	NO	NO
COSTS					
CONSTR.	LOW	HIGH	MEDIUM	MEDIUM	HIGH
PROPERTY	HIGH	HIGH	MEDIUM	MEDIUM	LOW
WEAVING	LOOPS SEMI A SEMI B	NO	LOOPS SEMI B	LOOPS SEMI A	NO
SKEWED XINGS					
> 90°	POOR	GOOD	POOR	POOR	GOOD
< 90°	POOR	GOOD	VERY GOOD	VERY GOOD	GOOD
ONE EXIT					
NARROW MED.	YES(CD)	YES	YES	NO	YES
WIDE MED.	YES	NO	YES	NO	NO

Selection criteria for right-turn movement free flow interchanges

TABLE 4 ADDITION TO TABLE 3
CHARACTERISTICS OF LEFT-TURN MOVEMENTS

Source: 29

TYPES	STOP - A	STOP - B
		
CAPACITY	VERY LOW	VERY LOW
SPEED	VERY LOW	VERY LOW
TRAVEL TIME	VERY HIGH	VERY HIGH
<u>RT. EXIT & ENTRY</u>		
NARROW MEDIAN	NO	NO
WIDE MEDIAN	NO	NO
<u>COSTS</u>		
CONSTRUCTION	VERY LOW	VERY LOW
PROPERTY	VERY LOW	VERY LOW
WEAVING OCCURS	NO	NO
<u>SKEWED XINGS</u>		
> 90° TURN	GOOD	GOOD
< 90° TURN	GOOD	GOOD
<u>ONE EXIT</u>		
NARROW MEDIAN	YES	NO
WIDE MEDIAN	YES	NO

Basic Interchange Design Principles

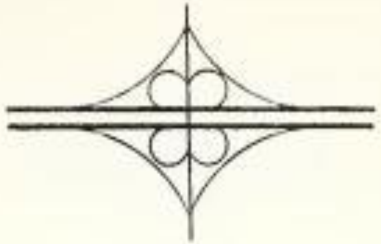
These principles are fundamental to the good design of any interchange and should be thoroughly considered in every interchange design situation.

1. Minimize the Number of Weaving Sections
2. Use No Left Hand Entrances or Exits
3. Design for Flexibility - Design Flexibility and Operational Flexibility
4. The Crossroad is an Important Part of the Interchange
5. Design with Uniformity of On and Off-Ramp Configurations Along a Freeway
6. Simplicity in Design Should be Followed
7. Provide Adequately for All Possible Movements
8. Route Continuity Should be Followed
9. Provide Collector-Distributor Roads with All Cloverleaf Interchanges
10. Interchange types should be Selected Primarily on Traffic Requirements and Not on Costs
11. The Concepts of Lane Balance and Basic Number of Lanes Must be Maintained

12. Aesthetics and Community Impact Must be Considered.
13. Adequate Signing Must be a Consideration.
14. The Construction Scheduling for the Various Freeway Segments in the Completed System Must be Considered
15. The Spacing of Interchanges is Critical to Good Interchange Design

16. External Controls can Affect the Interchange Configuration
17. Safety Must Always be Considered
18. Interchange Configuration Should be a Consideration in the Initial Route Location Process

FULL CLOVERLEAF



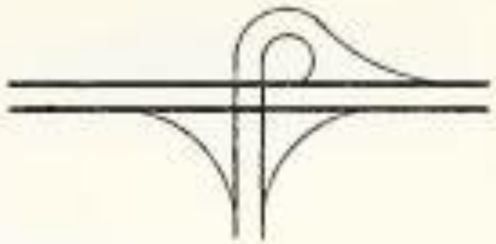
Advantages

1. all movements are free-flow
2. "lowest" type of system interchange
3. no left turn movements on ramps or crossroad

Disadvantages

1. loops have limited capacity
2. tight weave sections on the mainline and on the crossroad
3. takes a large amount of right-of-way
4. should not be used for service interchange
5. free flowing exits often cause problems on the crossroad, especially with weaving to the adjacent intersections
6. requires the additional cost of C-D roads
7. two exits and two entrances
8. indirection in movement
9. high construction and r.o.w. costs

TRUMPET A



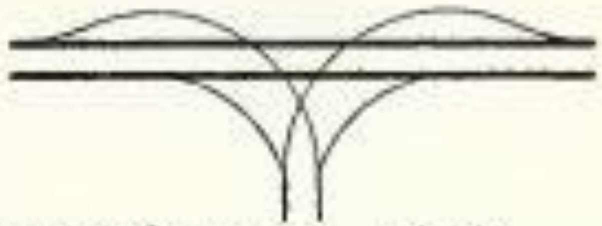
<u>Advantages</u>

1. loop serves as on-ramp to the freeway
2. can handle large directional volumes
3. fits traffic flow pattern

<u>Disadvantages</u>

1. difficult to extend truncated approach if demand develops
2. should not be used for freeway-to-freeway connection
3. minor movement on loop can have an accident problem
4. indirection in movement

DIRECTIONAL T OR Y



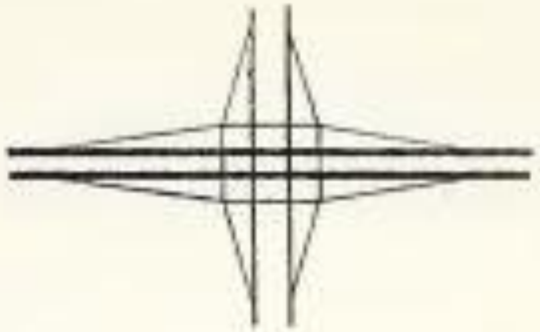
Advantages

1. use for all freeway to freeway interchanges with three approaches
2. can handle large directional volumes

Disadvantages

1. backward movements should be provided
2. left hand ramps usually included
3. signing can be a problem

MULTI-LEVEL DIAMONDS



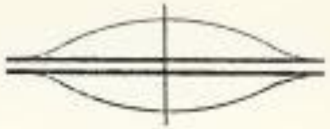
Advantages

1. two phase signals
2. highest diamond capacity
3. turning movements are all separated from the freeway and crossroad
4. used at major crossroads

Disadvantages

1. very expensive
2. a left turn requires a motorist to pass through three traffic signals

SPREAD DIAMOND



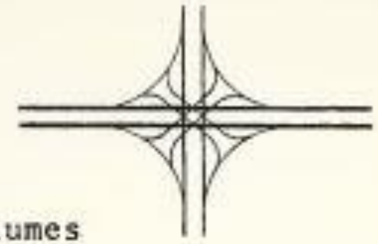
Advantages

1. good sight distance at ramp terminals on the crossroad
2. provides design flexibility; the opportunity to construct loop ramps with the interchange area
3. used where right-of-way is inexpensive - rural areas
4. economical
5. one structure
6. no weaving
7. single exit from freeway
8. simplicity
9. good capacity if ramp terminal flared

Disadvantages

1. requires more right-of-way than tight diamond interchange
2. not suitable for urban areas where right-of-way is restricted
3. stop on crossroad for left turn
4. possibility of wrong way movement
5. at grade intersections at crossroad

4-QUADRANT DIRECTIONAL



Advantages

1. can handle large directional volumes
2. used for system interchanges except where volumes are low and where a 4 quad cloverleaf interchange with C-D roads can be used
3. maintains route continuity
4. minimizes the speed differential between the through lanes and the ramps

Disadvantages

1. high construction and right-of-way costs
2. left hand ramps may be included
3. weaving sections may be developed
4. do not use for service interchange
5. loop ramps may be used for minor flows
6. isolates land adjacent to interchange because of the lack of local access
7. internal service ramps may become a necessity
8. requires a lot of land

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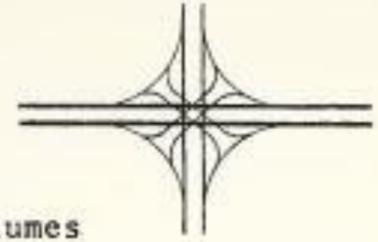

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