2 INTERSECTION DESIGN CONCEPTS

It was pointed out in Chapter 1 that intersection design is founded on an extensive set of design criteria, controls, project parameters and standards. The design process also makes use of several concepts that apply to intersections in general. This chapter identifies the broad considerations that must be understood by designers. Subsequent chapters will provide additional details.

The functional area on the approach to an intersection or driveway consists of three basic elements: (1) perception reaction distance, (2) maneuver distance and (3) queue-storage distance. The maneuver distance includes the length needed for both braking and lane changing when there is a left or right turning lane. In the absence of turn lanes, the maneuver distance is the distance to brake to a comfortable stop.

2.1 INTERSECTION CHARACTERISTICS

The characteristics of an intersection include a set of factors that are involved in some way in the intersection design process. Some characteristics act as controls, while others are the result of design decisions. A summary of these characteristics is presented in Table 2-1.

Table 2-1. Summary of Intersection Characteristics

Physical characteristics	Traveled roadway Curbs Sidewalks Medians Islands Drainage features Physical obstacles
Operational characteristics	Lane configuration and usage Traffic control mode Pedestrian control provisions Lane delineation Turn Prohibitions Crosswalk configuration Signal Phasing and timing Accessibility features
Traffic characteristics	Vehicular volumes Composition Peaking characteristics Pedestrian volumes Bicycle volumes
Site characteristics	Roadway classification Site location Roadside development Institutional proximity (schools, etc.)
Road User Characteristics	Age Special requirements

2.2 RESOLUTION OF CONFLICTS BETWEEN COMPETING MOVEMENTS

In the interest of safety, the conflict between two competing traffic movements must be resolved by a traffic control discipline that gives one movement priority over the other. When some movements are heavy, the priority must be assigned, alternated or distributed in some manner or at least one of the movements will fail.

2.2.1 The Nature of Conflicts

Most conflicts at intersections occur when two vehicles compete with each other for right of way. It is, however, important to recognize the conflicts that occur between two different types of road users. Inter-user conflicts may be characterized as:

- Vehicle-pedestrian conflicts: The Florida Statutes assign the right of way to pedestrians crossing in crosswalks. Pedestrians crossing outside of crosswalks must yield to vehicles. Most pedestrian activity at intersections will be in crosswalks.

- Vehicle-bicycle conflicts: The Florida Statutes consider a bicycle to be a vehicle. In the traveled roadway, a bicycle is always considered as a vehicle. In crosswalks, the Florida Statutes allow the cyclist the option of assuming the rights and duties of a pedestrian. The accommodations for bicycles at intersections must recognize this option.

- Bicycle-pedestrian conflicts: Because they assume the identity of a vehicle, bicycles on roadways are subject to the same rules indicated above for vehicle-pedestrian conflicts. When bicycles are on pedestrian facilities such as sidewalks, crosswalks, etc. they are required to yield to pedestrians.

2.2.2 Traffic Control Disciplines

The method of resolving conflicts between any two movements is referred to as the traffic control discipline. The following traffic control disciplines are commonly employed at intersections:

- Right of Way Rule: The right of way rule applies in the absence of any other traffic control device. Chapter 316.121 of the Florida Statutes assigns the right of way to the first arriving vehicle at an uncontrolled intersection or to the vehicle on the right in cases of simultaneous arrival. Chapter 316.123 states the same rule for all-way stop control (AWSC).

- Fixed Priority: There are two cases of fixed priority covered in the Florida Statutes. Chapter 316.122 assigns right of way to through vehicles in conflict with left turns and Chapter 316.123 governs vehicles on approaches controlled by stop or yield signs.

- Alternating Priority (signals): The assignment of right of way by traffic signals is covered in Chapter 316.075 of the Florida Statutes.

- Weaving Movements: Vehicles proceeding in the same direction may also conflict with each other if their respective origins and destinations cause their paths to cross. Chapter 316.085 of the Florida Statutes places the burden on drivers changing lanes to ensure that the movement may be made in safety. Weaving movements are used by design for resolving conflicts at large traffic circles and some types of freeway interchanges.

- Grade Separation: The conflict between movements is automatically resolved if the movements take place at different levels. Grade separations are typically used to resolve conflicts between major movements at interchanges. It is important to note, however, that, except in the case of extremely complex interchanges, one or more of the other disciplines mentioned above will also be required to resolve some of the conflicts for turning movements.

2.2.3 Traffic Control Modes

A combination of traffic control disciplines will be found at most intersections. It would, however, be very confusing to describe the traffic control at an intersection by enumerating the disciplines that are applied to each set of movements. Instead, the intersection control is characterized by a "mode" that reflects the predominant traffic control discipline for the major movements.

One of the first steps in the intersection design process is to choose the most appropriate control mode from the following alternatives:

- *Uncontrolled:* This is the default mode and the only mode that requires no action to establish. In this case, the right-of-way rule applies. Because of safety concerns, there are very few uncontrolled intersections in Florida, especially on state roadways.

- *Two-way stop control (TWSC):* This mode requires minimal justification and there are no numerical warrants to be applied. The MUTCD suggests that TWSC control may be warranted when one route is clearly more important than the other and when conditions indicate the need.

- *All-way stop control (AWSC):* The justification of this mode is subject to numerical traffic volume warrants presented in the

MUTCD Warrants for Signal Installation

1. Eight-Hour Vehicular Volume
2. Four-Hour Vehicular Volume
3. Peak Hour
4. Pedestrian Volume
5. School Crossing
6. Coordinated Signal System
7. Crash Experience
8. Roadway Network

"The satisfaction of a traffic signal warrant or warrants shall not in itself require the installation of a traffic control signal."

STOP signs shall not be used in conjunction with any traffic control signal except:

- If the signal indication for an approach is a flashing red at all times.
- If a minor street or driveway does not require separate traffic signal control because an extremely low potential for conflict exists.

{MUTCD}

MUTCD. Additional justification categories include locations with high crash rates and locations where traffic signals are warranted but have not yet been installed.

- *Signal:* The MUTCD enumerates eight warrants that may be used to justify the installation of a traffic signal. The MUTCD suggests that a traffic control signal should not be installed unless one or more of the warrants are met and that an engineering study indicates that installing a signal will improve the overall safety and/or operation of the intersection. The MUTCD discourages the installation of a signal if it would seriously disrupt progressive traffic flow.

- *Roundabout:* Roundabouts are gaining popularity in Florida because they have been demonstrated to accommodate moderate traffic volumes with lower delays and improved safety compared to a traffic signal. The Florida Roundabout Guide describes a procedure for justification of a roundabout. It also sets forth the criteria to be used in determining design standards for roundabouts on the State Highway System. The roundabout justification procedure is duplicated in the Florida MUTS Manual.

> Consideration should be given to providing alternatives to traffic control signals even if one or more of the signal warrants has been satisfied.
> {MUTCD}

2.2.4 Intersection Control Mode Selection Procedures

The Florida MUTS manual prescribes justification studies for signals and roundabouts. The MUTCD suggests (as guidance) that vehicular delay and the frequency of some types of crashes are sometimes greater under traffic signal control than under STOP sign control and encourages consideration of alternatives to signalization.

> An engineering study of traffic conditions, pedestrian characteristics and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location. The investigation of the need for a traffic control signal shall include an analysis of the applicable factors contained in the traffic signal warrants and other factors related to existing operation and safety at the study location.
> {MUTCD}

The MUTCD suggests the following alternatives to signalization:

- Installing signs along the major street to warn road users approaching the intersection;
- Relocating the stop line(s) and making other changes to improve the sight distance at the intersection;
- Installing measures designed to reduce speeds on the approaches;
- Installing flashing beacons to supplement STOP sign control or provide advance warning;
- Adding one or more lanes on a minor-street approach to reduce the number of vehicles per lane on the approach;
- Revising the geometrics at the intersection to channelize vehicular movements and reduce the time required for a vehicle to complete a movement;
- Installing roadway lighting if a disproportionate number of crashes occur at night;

> For purposes of signal warrant evaluation, bicyclists may be counted as either vehicles or pedestrians.
> {MUTCD}

- Restricting one or more turning movements, perhaps on a time-of-day basis, if alternate routes are available;
- Installing multi-way STOP sign control if the warrant is satisfied;
- Installing a roundabout and
- Employing other alternatives, depending on conditions, at the intersection.

2.3 ESTIMATION OF CAPACITY

The basic function of a traffic signal is to resolve conflicts between vehicles, cyclists and pedestrians that are competing for time and space at the intersection. The design objective is to ensure that the manner in which the conflicts are resolved provides the desired level of safety, capacity and performance.

The provision of adequate capacity is a primary design objective. It is essential therefore that an acceptable procedure be available for estimating the capacity of any given design. The Highway Capacity Manual (HCM) prescribes capacity estimation procedures for all at-grade facilities. The HCM procedures are based on a combination of traffic modeling, field data and expert consensus. As such, they are widely accepted by transportation professionals and are recognized by the Florida Department of Transportation as the preferred capacity analysis technique. One feature that has contributed to the popularity of the HCM is the availability of publicly supported software that provides a faithful implementation of the procedures.

The following terminology is used to quantify the signal operation:

- Traffic volume, v, (vph);
- Saturation flow rate, s (vphg);
- Flow ratio, y, calculated as v/s;
- Effective green time, g (sec);
- Cycle length, C (sec);
- Green ratio, calculated as g/C;
- Capacity, c, calculated as sg/C;
- Degree of saturation, X, calculated as v/c, i.e., vC/sg and
- Control delay, D, as defined in Chapter 2 (sec/veh), estimated by the procedure prescribed by the Highway Capacity Manual (HCM).

Further complexity is introduced by such features as permitted left turns that must yield to oncoming traffic, shared lanes for through and left turning movements, multi-phase operation, etc. The HCM prescribes procedures to deal with all of these complications. The meticulous nature of the procedures requires software for practical implementation, but fortunately such software is readily available.

2.3.1 Basic Concepts of Capacity Analysis

The *capacity* of a facility is expressed in vehicles per hour (vph). The capacity indicates the level of demand that can be serviced without accumulating long-term queues. The basic capacity of a

single lane of moving traffic depends on the minimum *headway* or time between successive vehicles in the lane that is acceptable to drivers.

Field studies suggest that the minimum headway in a single lane of moving traffic is approximately 2 seconds per vehicle, producing a basic capacity of about 1800 vph. This is referred to as the *saturation flow rate*. The capacity of an approach to an intersection will generally be much lower than the saturation flow rate, because of interruptions in flow due to the traffic control. The saturation flow rate at a signalized intersection is specified in terms of vehicles per hour of green time (vphg). The HCM prescribes procedures for estimating the saturation flow rate and capacity more accurately as a function of site-specific conditions.

The operation of an intersection at full capacity is not a desirable design objective because motorist discomfort increases as the demand approaches capacity. Fully saturated operation is characterized by frequent stops, high delays and short-term periods of queuing. This introduces two new concepts: the *volume/capacity ratio (v/c)* and *level of service (LOS)*. The LOS is a measure of road user acceptance that improves as the v/c ratio decreases. LOS is given a letter grade from A to F, interpreted as follows:

- LOS A and B represent an operation in which vehicles are not affected or only minimally affected, by the presence of other vehicles on the facility;
- LOS C and D represent the operation normally within the range of the design objectives and
- LOS E and F represent the fully saturated and oversaturated operation, respectively.

The HCM defines the criteria and prescribes computational procedures for estimating the level of service on various types of facilities in terms of traffic demand and the facility operating parameters. The Florida Department of Transportation has extended the *level* of service concept for planning analysis of multimodal facilities into the realm of *quality* of service. Separate criteria have been developed for quality of service assessment as perceived by pedestrians, cyclists and public transit users. Unlike the level of service, which is based primarily on considerations of volume, capacity and delay, the quality of service depends more heavily on the condition of the facility, including availability of desirable features and state of maintenance.

2.3.2 Capacity and LOS at Intersections

The procedures for analyzing capacity and LOS differ among control modes. Each of the control modes will therefore be discussed separately.

Signalized Intersections

The capacity, c, of an approach to a signalized intersection is determined by multiplying the saturation flow rate by the proportion of time that the signal controlling the approach is effectively green. *Effective green* is defined as the total phase time for the approach (green + yellow + all-red) minus the *lost time* associated with starting and stopping the movement.

c = sg/C, where

s is the saturation flow rate (vphg);
g is the effective green time per cycle (sec) and
C is the cycle length (sec).

The LOS at a signal is defined in Chapter 9 of the HCM in terms of the average control delay experienced by each vehicle on the approach. Threshold values are provided to distinguish among levels of service.

Stop-Controlled Intersections

The level of service at unsignalized intersections is also defined in terms of control delay, but the thresholds and computational procedures are different than those applied at signal. The movement of traffic at a stop or yield sign is modeled in Chapter 10 of the HCM as a gap acceptance process. The gap acceptance parameters include:

- The *critical gap*, which is defined as the minimum gap in the major street flow that the average driver is willing to accept and
- The *follow-up time*, which is defined as the incremental gap time required by subsequent vehicles entering the same gap.

These two parameters determine the number of vehicles that may enter a gap of a given length. The computation of the approach capacity requires some knowledge or assumptions about the distribution of gaps in the major flow. The HCM sets forth the assumptions and computational procedures for estimating capacity and level of service based on this modeling concept for two-way stop control. Separate procedures are described for all-way stop control.

Roundabouts

Roundabouts represent a newer traffic control mode that is finding increasing acceptance in Florida. Roundabout performance analysis is covered in the Florida and FHWA Roundabout Guides. The HCM provides a method for approximating the capacity of a roundabout as a series of interconnected yield-controlled junctions. A more detailed roundabout gap acceptance model, developed in Australia, uses an empirical procedure to determine the gap acceptance parameters (critical gap and follow-up time) as a function of the roundabout geometrics.

The Australian procedure has been implemented, with some modifications, in a software product called aaSIDRA. The Florida DOT has purchased several aaSIDRA licenses for use in various offices throughout the state.

2.4 INTERSECTION DELAY

Delay is an important measure of performance at an intersection. Delay contributes to the motorist's operating cost and perception of the quality of service. It may be expressed in two ways:

- The *unit delay* (sec/veh), which is related to the motorist's perception of disutility at an intersection.

- The *total accumulated delay* (veh-hours), which is related more to the economic performance of an intersection. One vehicle-hour of delay is accumulated when one vehicle is delayed for a full hour, 3600 vehicles are delayed for one second each, etc.

The total accumulated delay per hour may be determined as the product of the hourly volume times the average unit delay per vehicle.

The unit delay may be divided into four components. Each component is associated with a characteristic that, if eliminated, would eliminate the delay. The four components are:

- *Incident delay:* The additional delay caused by the occurrence of an incident that reduces the capacity of the facility.

- *Control delay:* The delay imposed by the traffic control. This component may be further characterized by the mode of operation, i.e., *signal delay, stop sign delay or roundabout delay.*

- *Traffic delay:* The delay caused by interaction between vehicles in an uninterrupted traffic stream. This is generally mid-link delay caused by a reduction in speed.

- *Geometric delay:* The delay caused by the geometric design feature, generally resulting from reduced speed of vehicles making turning movements.

To avoid overlapping definitions, the delay components are represented above in a hierarchical order. For example, an incident might increase the delay at a traffic signal and increased traffic volumes might increase the delay due to an incident. The hierarchy dictates that all delay that would be eliminated if the incident were eliminated is considered as incident delay. Thus, the unit delay per vehicle may be represented as the sum of these four components.

2.5 COMPONENTS OF INTERSECTION OPERATION

The operation of an intersection may be represented by four interacting components: the road user, the vehicle, the roadway and the traffic control devices, as illustrated in Figure 2-1. Each of these components imposes its own set of requirements and constraints on the designer. Each component will be considered separately in terms of its requirements and constraints.

2.5.1 Requirements and Constraints of Motor Vehicles

The designer must be aware of the roadway space requirements and the performance limitations of a typical vehicle. The following considerations apply to vehicle requirements and constraints:

- *The Design Vehicle:* AASHTO has established a set of ten "design vehicles" with standard physical dimensions. These are used to determine a variety of geometric highway features, such as lane widths, minimum curb and corner radii and minimum turning radius.

- *Acceleration Performance:* The difference in acceleration capability between a large passenger Components of car and a truck is substantial and this is a major cause of inefficiency in mixed traffic streams. Important factors to consider are: distance traveled during acceleration, upgrades and crawl speeds.

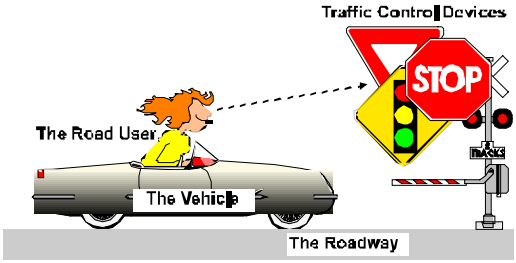


Figure 2-1. Intersection Operation.

- *Braking Performance:* A vehicle's braking performance is one of the most critical factors in highway safety and design and it is related to the vehicle's braking system, type and condition of the tires and the condition and type of roadway surface. Almost every aspect of traffic-system design and operation is determined by the time and distance required to stop a vehicle or so called braking distance. Elements that determine braking distance are: the initial and final speed of vehicle, coefficient of forward rolling or skidding friction and grade. Chapter 316.262 of the Florida Statutes prescribes the performance ability of motor vehicle brakes.

2.5.2 Requirements and Constraints of Road Users

Road user characteristics establish time-critical controls, such as advance placement distances for warning signs. They also influence the need for special accessibility features at intersections. The following considerations apply to road user requirements and constraints:

- *Perception and Reaction Time:* The perception of and reaction to a continuous series of visual and audio cues that are part of the driving task involve four actions on the part of the driver, characterized as: perception, identification, emotion and volition. The time taken by the sequence of these events is commonly referred to as the PIEV time or perception-reaction time and it is defined as the total time taken for the driver to react to a stimulus.

  PIEV time is a function of many factors. For intersection design purposes, a value of 1.0 second is commonly used to account for the driver's reaction to a signal change interval and 2.5 seconds is generally applied to more passive stimuli, such as a fixed warning sign.

- *Visual Acuity and Driving:* Drivers are normally tested only for static visual acuity, that is, the ability to see stationary objects and legend messages. However, this is not the one that most dramatically affects the driving tasks. Other important measures are dynamic visual acuity, depth perception, glare recovery and peripheral vision. The three primary fields of vision that affect the driving task are: the field of clear or acute vision, the field of fairly clear vision and the field of peripheral vision

- *Guidance Task:* Highway design and traffic operations have the greatest effect on guidance. Road user performance can be improved by paying the proper attention to lane placement and road following, car following, overtaking and passing and other guidance activities, (i.e., merging, lane changing, avoidance of pedestrians and response to traffic control devices, etc.).

- *Human Error:* Improper operation and accidents may occur as a result of information-handling errors. These errors can be due to road user deficiencies and situational demands.

- *Cyclist Characteristics:* Knowledge of bicycle dimensions, operating characteristics and requirements is also necessary for providing adequate bicycle facilities. These factors determine acceptable turning radii, grades and sight distances. Some of the measures that need to be considered to enhance the bicycle traffic safety and capacity at an intersection include:

  - Provision of bicycle lanes, either designated or undesignated;
  - Paved shoulders;
  - Wide outside traffic lane if no shoulder is present;
  - Bicycle-safe drainage grates;
  - Manhole covers adjusted to the grade and
  - Maintaining a smooth, clean riding surface.

- *Pedestrian Characteristics:* The safety of pedestrians, especially at intersections, is a very important consideration in the highway design process. Important pedestrian characteristics are: pedestrian crossing volumes, walking speeds and gap acceptance characteristics at crossing locations.

- *Special Needs of Road Users:* Road users with physical, visual or hearing disabilities introduce controls that could modify standards (e.g., clearance time requirement). They also introduce the need for accessibility features in pedestrian detection, displays, etc. These features are covered in more detail in Chapter 4.

2.5.3 Roadway Requirements and Constraints

The roadway has its own set of requirements and constraints that must be considered. The most significant points include:

- Roadway Utilization: *The following sections of the Florida Statutes govern roadway utilization:*

  - 316.081 Driving on right side of roadway;
  - 316.087 Further limitations on driving to left of center of roadway;
  - 316.088 One-way roadways and rotary traffic islands;
  - 316.089 Driving on roadways laned for traffic;
  - 316.090 Driving on divided highways;
  - 316.151 Required position and method of turning at intersections;
  - 316.1515 Limitations on turning around. (i.e., U-turns);
  - 316.1945 Stopping, standing or parking prohibited in specified places;
  - 316.195 Additional parking regulations;
  - 316.1995 Driving upon sidewalk or multi user trail and
  - 316.0765 Lane direction control signals.

  The current version of these sections is available on the Internet.

- *Driveways and Access Control:* AASHTO defines driveways as at-grade intersections and states that they should not be located within the functional boundary of at-grade intersections since accidents are disproportionately higher at driveways than at other intersections. The design and operation of driveways are influenced by:

  - Type of adjoining land use;
  - Dimensions of the property;
  - Trip generation characteristics of the site;
  - Design vehicle(s);
  - Type of highway abutting the driveway and
  - Neighboring driveways and driveways on opposite side of roadway.

  The following conditions may justify access management features:

  - There is a need to provide an organized movement of traffic within an urban area;
  - Access management is required to provide acceptable capacity and safety and
  - Access management is likely to reduce the chance that a highway or artery will need to be relocated or reconstructed.

- *Drainage:* Drainage is usually more difficult and costly for urban areas. There is greater need to intercept concentrated storm water before it reaches the streets and to remove over-the-curb flow and surface water without interrupting traffic flow or causing a problem for vehicle occupants or pedestrians. Critical factors to take into consideration are:

- Runoff volumes;
- Stormwater spread calculations;
- Potential damage to adjacent property by flooding;
- Number of inlets and underground systems needed;
- Location of natural areas of water bodies to receive flood water and
- Problems for bicycles and pedestrians caused by drainage features.

- *Utilities:* It is important to note, by Florida Statutes, that public and privately owned utilities are permitted by the Department to be accommodated within the right-of-way on the State Highway System. The authoritative reference for utilities is the *Utility Accommodation Manual (UAM)*. The intent of this manual is to provide direction, policy, criteria, and regulations for the accommodation of utilities within state transportation facility rights-of-way. In addition, PPM Volume I, Chapter 5 Utilities, provides discussion on utility considerations that must be addressed in the design of state highway facilities.

2.5.4 Requirements and Constraints of Traffic Control Devices

Traffic control devices serve the following purposes:

- Communicating traffic laws and regulations to road users,
- Warning road users of impending hazards,
- Delineating vehicle paths within the roadway,
- Providing information related to destinations, services, etc. and
- Distributing right of way between competing movements.

The following considerations apply to traffic control devices at intersections.

Traffic Control Criteria and Standards

The authoritative reference for traffic control devices is the *Manual on Uniform Traffic Control Devices (MUTCD)*, as described in Chapter 1. Florida Statutes require conformance to the MUTCD for traffic control devices installed at all intersections.

The following statutes define additional requirements and constraints for traffic control devices:

- 316.074 Obedience to and required traffic control devices;
- 316.0745 Uniform signals and devices;
- 316.0747 Sale or purchase of traffic control devices by non-governmental entities; prohibitions;
- 316.075 Traffic control signal devices;
- 316.0755 Pedestrian control signals;
- 316.076 Flashing signals;
- 316.0765 Lane direction control signals and
- 316.077 Display of unauthorized signs, signals or markings.

Traffic control devices are categorized in three groups: markings, signs and signals. Each of these groups is covered in detail in a separate chapter of the MUTCD.

Signal Controller Operation

In theory, a signal controller may be either pretimed or traffic-actuated. Pretimed controllers display fixed phase durations that repeat from cycle to cycle. Traffic-actuated controllers use vehicle presence information from detectors to generate phase durations appropriate to accommodate the demand on each cycle.

As a practical matter modern signal controllers are made up of a group of phase modules, each of which controls one or more traffic movements. Each phase module is capable of traffic-actuated operation. Pretimed phases, where required, are created by imposing constraints on the traffic-actuated features to force a constant duration.

The basic principle upon which traffic-actuated controllers respond to current demand is very simple. The green display is held at first for a prescribed minimum length of time. After the minimum green time has been satisfied, the strategy is to terminate the phase upon satisfaction of the queue of vehicles accumulated on the previous red phase. Maintaining the green display after the queue has been satisfied creates wasted time that could be better used to serve other movements.

The controller uses the length of the gaps between vehicles observed at the detector to determine when the queue has been satisfied. As soon as a gap of a specified length occurs, the controller invokes the phase termination strategy. This promotes the display of green intervals that are appropriate to the vehicular demand on each cycle. During periods of light traffic, phases will be short. As traffic volumes increase, so will the phase durations. Of course, it is also necessary to specify the maximum length of each phase to keep the cycle length to a reasonable level and to stabilize the operation in the event of stalled vehicles or detector failure.

Each phase module therefore requires the following parameters to be specified for basic traffic-actuated operation:

- The minimum time for which the green interval must be displayed regardless of traffic requirements;
- The maximum time for which the green interval may be displayed if there is demand from competing movements and
- The length of a gap between successive vehicles moving on the green phase that will cause the phase to be terminated.

Basic traffic-actuated operation uses fixed values for both the minimum green time and the allowable gap. A more complex traffic-actuated mode causes one or both of these values to vary with traffic demand. The industry has attached the term “volume-density” to these advanced features. Volume-density control is favored regionally for use at isolated intersections with high approach speeds.

Signal Phasing

The signal sequence is controlled by a group of interconnected phase modules, each of which generates the commands to control a single green, yellow, red, walk and don't walk display, with proper transitions between displays. Each module accepts vehicle detector inputs that indicate whether or not a vehicle is present on the approach controlled by the phase. Only one detector input is recognized per phase.

Vehicular presence during the red interval will place a demand for a green signal to be displayed. The detector is ignored during the display of the minimum green interval, but after this interval has expired, the presence of a vehicle will cause the phase to be extended until a gap of the prescribed length has been encountered.

Each phase module also has a single input for pedestrian demand. If vehicular demand is received without pedestrian demand, the phase timing will be as described above. In this case the pedestrian signal will display a constant "don't walk" indication. If pedestrian demand is received, with or without vehicular demand, the phase module will display a "walk" interval of the prescribed duration followed by a "don't walk" interval. After the pedestrian timing has been satisfied, the normal phase extension process will be invoked until a gap in the traffic causes the phase to terminate.

The signal controller consists of a group of these phase modules interconnected to pass control from one to another in an orderly fashion. Two examples of the representation of signal phasing, as presented in the Roadway and Traffic Design Standards (Index 17870), are shown in Figure 2-2 and Figure 2-3. In the simplest form of operation, only one phase module will assume control at any time. The rest will remain in the red state, but will register a demand for their turn whenever they observe vehicular or pedestrian presence.

This simple sequence is known as *single-ring sequential* operation. In its most elementary form, only two phase modules will be involved in the sequence, with each controlling an opposing pair of approaches. Additional modules may be added to a single ring operation to provide exclusive phases for left turns or other minor movements. An example of single ring operation is presented in Figure 2-2, with four phases displayed sequentially as the terminology suggests. Note that each phase module controls two approaches that move simultaneously.

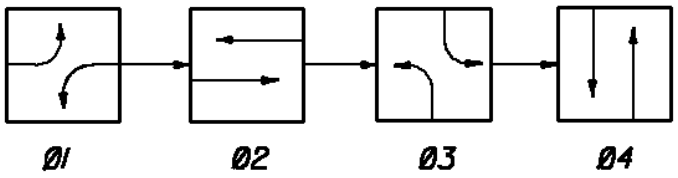


Figure 2-2. Phasing Diagram for Single-Ring Sequential Signal Phasing.

Most traffic-actuated intersections in Florida use a more complex scheme known as *dual-ring concurrent* operation, which is depicted in Figure 2-3. Note that Phases 2 and 5 in the phasing diagram offer two alternatives, only one of which may be displayed on any cycle.

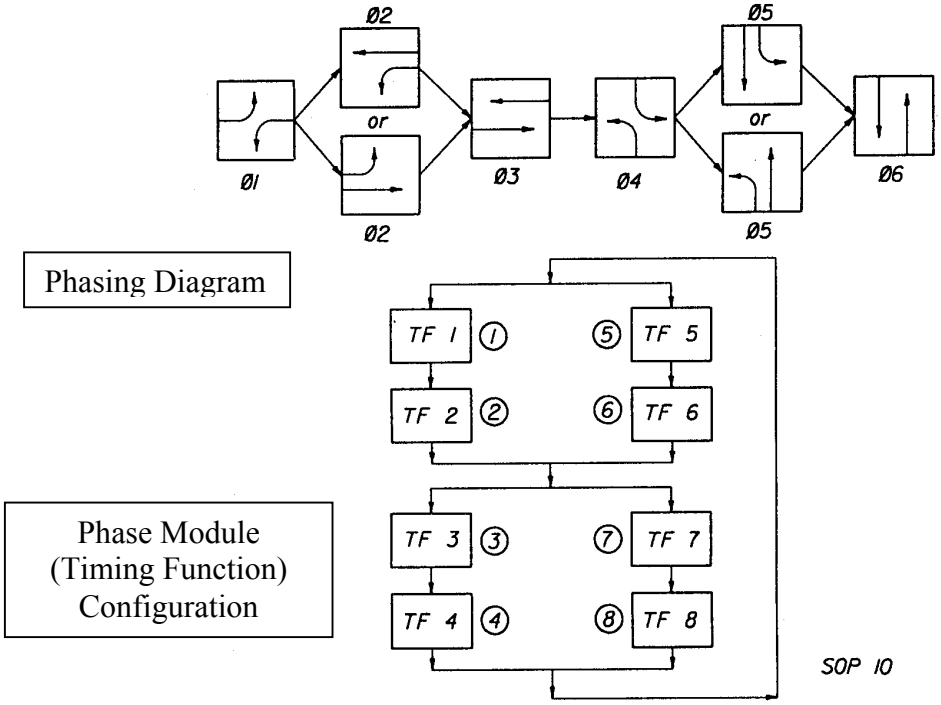


Figure 2-3. Representation of Dual-Ring Concurrent Signal Phasing.

Dual-ring concurrent phasing is generally more efficient than single-ring sequential phasing because it allows the available green time to be distributed with less "slack," i.e., unused green time. Index 17870 refers the phase modules as *Timing Functions* (TF). TF 1-4 constitutes Ring 1 and TF 5-8 constitutes Ring 2. Each timing function controls only one movement. Since two movements can proceed simultaneously without conflict, two of the timing functions (one from each ring) will always have control simultaneously. This process is transparent to the road user.

Signal Timing

Signal timing involves the determination of the appropriate cycle length (i.e., the time required to execute a complete sequence of phases) and apportionment of time among competing movements and phases. The timing apportionment is constrained by minimum green times that must be imposed to provide for pedestrians and to ensure that motorist expectancy is not violated.

Within these constraints, there are three objectives that may be chosen to optimize the timing design:

- Equalization of the degree of saturation (volume/capacity ratio) among competing movements: This design is usually associated with simple manual methods of signal timing

because it is the only approach that can be implemented productively without computer software. It is also the starting point for many software-based procedures.

- Minimization of the aggregate delay to all vehicles using the intersection: This is the only objective that could be considered as a true optimization. The others are based on equalizing driver-perceived disutility. Some procedures consider stops, fuel consumption and operating cost in addition to delay in the optimization process.

- Equalization of control delay among competing movements: While this is not a true optimization, it is popular because the HCM defines level of service in terms of delay to each vehicle. Therefore the equalization of delay results in a more equitable assignment of intersection level of service among all road users.

The software products used for designing signal timing plans are identified in Chapter 4 and the specific parameters to be determined by the signal timing process are discussed.

2.6 OBJECTS AND AMENITIES

All other physical roadside features are referred to in this document as objects and amenities. The principal items in this category include lighting and landscaping. Other miscellaneous items of street furniture, mailboxes, etc. fall under this general designation. The most important requirements and constraints associated with objects and amenities include

- *Intersection Lighting:* Factors that are important in determining the minimum conditions to justify lighting include:

  - Traffic volume, (motor vehicles, pedestrians and bicycles),
  - Speed,
  - Road use at night,
  - Night accident rate,
  - Road geometrics and
  - General night visibility.

  The principal reference governing intersection lighting is "*An Information Guide for Roadway Lighting*," published by AASHTO. More details on intersection lighting are presented in Chapter 6.

- *Landscaping:* According to the AASHTO 1994 edition, the philosophy behind landscape development is based on keeping with the character of the highway and its environment. Improvement programs include: (1) preservation of existing vegetation, (2) transplanting of existing vegetation where feasible, (3) planting of new vegetation, (4) selective clearing and thinning and (5) regeneration of natural plant species and material. The objectives of these programs are to provide vegetation that will:

  - Improve aesthetics and safety;
  - Lower construction and maintenance costs;

- Create interest, usefulness and beauty for the pleasure and satisfaction of the traveling public;
- Mitigate the many nuisances associated with urban traffic and
- Provide a barrier between motor vehicles and other traffic modes

The authoritative references on landscaping include "*A Guide for Transportation Landscape and Environmental Design"* published by AASHTO and "*The Florida Landscaping Guide"* published by the Florida DOT. More detailed information on landscaping will be presented later in Chapter 6.

2.7 DIRECTIONAL ROADWAY UTILIZATION

An undivided roadway is a two way street by default. There are, however, conditions that make other directional utilization schemes desirable. Chapter 316.088 of the Florida Statutes permits the assignment of any part of a roadway for travel in one specified direction part or all of a day. The designer should be aware of the advantages and limitation of one-way streets. The main advantages include:

- Elimination of crashes between vehicles traveling in opposite directions (head-on, left-with-through and sideswipe);
- Increased capacity;
- Improved utilization of streets with an odd number of lanes;
- Simplification of signal phasing through elimination of left-turn conflicts;
- Improved signal progression and
- Improved access at cross streets because of more favorable platoon formation.

On the other hand, one-way streets have some limitations of their own, the most significant of which are:

- Complexity and proliferation of traffic signs;
- Increased circulation requirements;
- Terminal treatment of one-way pairs;
- Loss of public transit curb space and route flexibility;
- Problems of emergency vehicle routing and signal blockage;
- Hazards to crossing pedestrians and cyclists resulting from violation of expectancy and
- Loss of center pedestrian refuge.

2.8 ACCESS MANAGEMENT FOR INTERSECTIONS

Access Management is the practice of controlling the design and placement of access features (such as driveways, side-streets and median openings) in such a way as to enhance the safety and operations of the highway system. Because intersections are a major control of the highway system, it is important to consider the placement and design of driveways, median and median openings especially close to intersections.

Driveways and median openings close to an intersection create a situation where the road user must negotiate conflicts too close to an area that has been designed to manage large volumes of traffic and its own inherent conflicts. Proper driveway placement can also help the business operator because today's traffic queues are so long that traffic exiting driveways may be blocked for long periods of time.

Florida DOT has developed standards and practices to help in the proper access management treatment near intersections. Chapter 3 contains more information on selected access-management topics, including access classification, driveway design and median design.

2.9 DATA REQUIREMENTS FOR INTERSECTION DESIGN

The data requirements will depend on the nature of the design project. The following information will be required for most projects:

- Approach volumes for each intersection approach, typically 24 hour volumes summarized by 15 minute intervals;
- Peak hour turning movement counts;
- Existing geometrics;
- Pedestrian and bicycle volumes, if applicable;
- Distances to other intersections;
- Crash history;
- Institutional locations: schools, etc.;
- Posted speed limits along the intersecting roads;
- Physical and right of way features and limitations;
- Site development features: businesses, driveways, etc. and
- Community considerations: need for parking, landscape character, etc.

In addition, information on the following items may be needed, depending on specific design project objectives:

- Anticipated growth based on governing comprehensive plan;
- Existence of traffic management strategies existing in the area;
- Types of vehicles using the intersecting roadways;
- Transit routes along intersecting roadway;
- Adjacent land uses, especially if the design is proposed as a community enhancement project;
- Access to adjacent properties;
- Compatibility with adjacent intersections;
- Availability of power and lighting and
- The location of existing above-ground and below-ground utilities.

2.10 TYPICAL INTERSECTION LAYOUTS

Typical layouts for an urban intersection and a suburban or rural intersection are illustrated in Figure 2-4, with the principal components labeled. The intersection design process involves choosing or computing values for the various design parameters. The geometric design aspects of this process will be covered in Chapter 3. The traffic operational aspects will be covered in Chapters 4 and 5. Note that the design details shown in this figure are intended for purposes of general illustration and should not be interpreted as specific recommendations.

2.11 DETERMINING THE BASIC INTERSECTION CONFIGURATION

> Adequate roadway capacity should be provided at a signalized location.
> {MUTCD}

The basic intersection configuration is specified in terms of the number of lanes and lane utilization on each approach to the intersection. The basic configuration will be subject to an iterative sequence of changes and refinements as the detailed design procedures described in subsequent chapters of this guide are applied.

The basic configuration begins with the number of through lanes available on the two intersecting streets. Additional lanes will often be necessary to accommodate left and right turns. In some cases a widening of the intersection may be required to accommodate additional through lanes on the approach, with a lane drop on the exit. Multiple left or right turn lanes may be required in addition to channelization for left or right turns.

It is important to consider at the outset the effect of the basic intersection configuration on all modes of travel and for all road users. While the provision of adequate capacity will usually be the principal determinant, the tradeoff between capacity for vehicles and safety for pedestrians and bicyclists cannot be ignored. While this tradeoff is difficult to quantify, the negative effect of added turning lanes on pedestrians and bicyclists is widely recognized. In general, any provision that requires widening of the intersection should be justified on the basis of its demonstrated importance to the capacity of the intersection and mitigation of its adverse effects should be considered.

> Before an intersection is widened, the additional green time pedestrians need to cross the widened roadways should be considered to ensure that it would not exceed the green time saved through improved vehicular flow.
> {MUTCD}

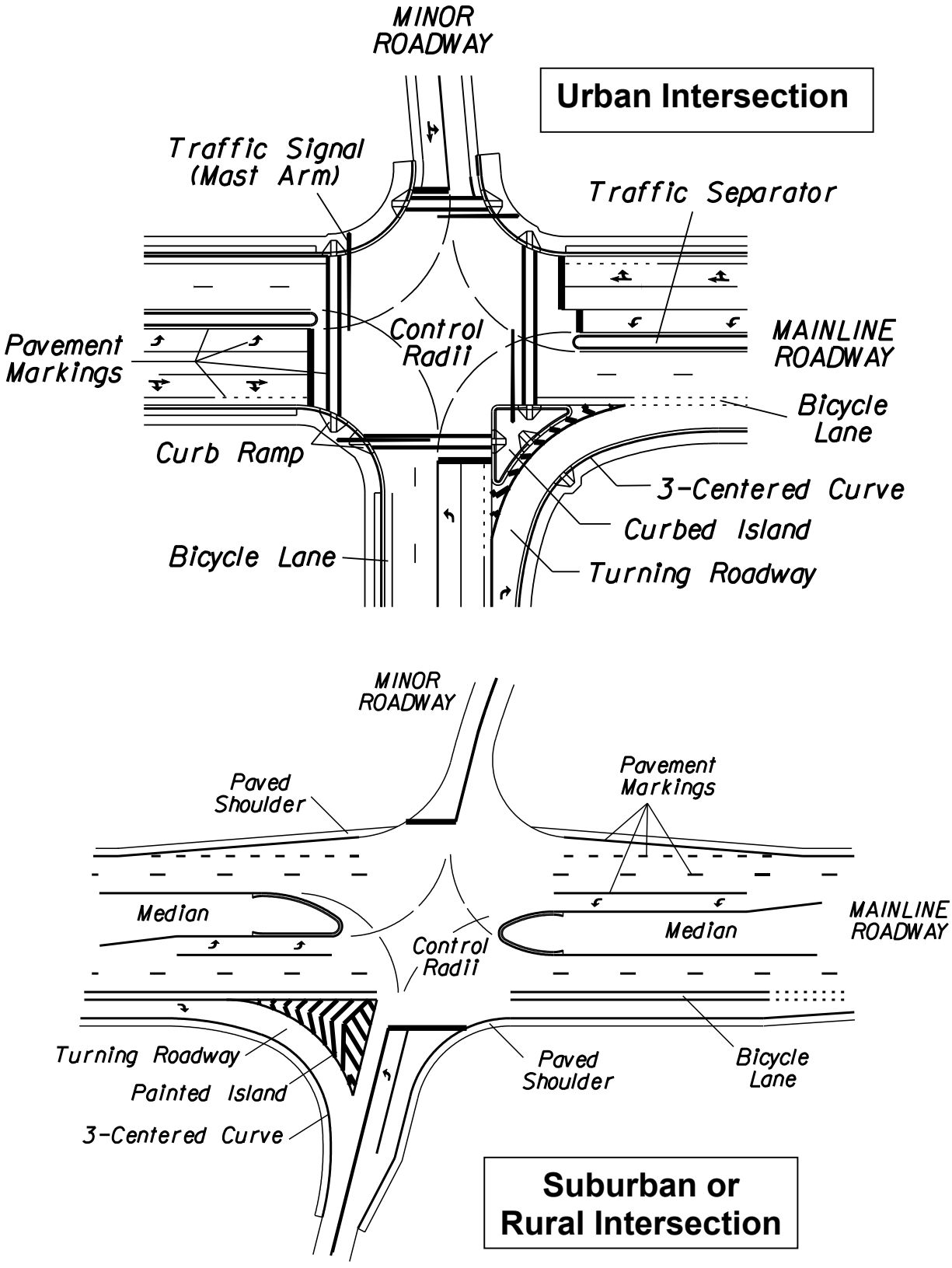


Figure 2-4. Typical Layout for an Urban and Rural Intersection.