Traffic Signal Design

Instructor:
S. M. Mahdi Amiripour

m.amiripour@gmail.com
Introduction

• Intersection is an area shared by two or more roads
• Designated for the vehicles to turn to different directions
• Function to guide and control traffic on a highway
• Ensures safe, smooth and harmonious flow of traffic
Conflicts at an intersection

• A typical four-legged intersection
  ▫ Total 32 different types of conflicts (Vehicle/Vehicle)
  ▫ Total 24 different type of conflicts (Pedestrian/Vehicle)
Intersection Design

- **Main Objectives:**
  - Minimize potential conflicts among different traffic streams (e.g., vehicles of all modes and pedestrians)
  - Provide smooth flow of traffic across the intersection
- The design should incorporate the operating characteristics of both the vehicles and pedestrians using the intersection.
Design Considerations

- **Human**
  - Driving habits, decision/reaction time

- **Traffic**
  - Demand, capacities, turning movements, delay, vehicle speeds, size and types of vehicles

- **Physical**
  - Adjacent property, sight distance, geometric features, control devices, environmental factors, etc…

- **Economic**
  - Cost, benefits, energy consumption
Types of Intersection Controls

- Stop signs
- Yield signs
- Intersection channelizations
- Roundabouts
- Grade Separated Intersections
- Traffic control devices
Stop Signs

- Intersection of a minor road with a major road
- Intersection of a country road, city street with a state highway
- Unsignalized intersection in a signalized area
- Unsignalized intersection where a combination of high speed, restricted view, and serious accident record indicates a need for control by the stop sign
Yield Signs

- On a minor road at the entrance to an intersection
  - Need to assign right-of-way to the major road, but a stop is not necessary
  - Safe approach speed on the minor road exceeds 10 mph
- On a entrance ramp to an expressway
- Separate or channelized right-turn lane without adequate acceleration lane
Intersection Channelization

• Separation or regulation of conflicting traffic movement into definite paths of travel by traffic islands or pavement markings
Rotaries or Roundabouts

- Channelized intersections comprising a central circle surrounded by a one-way roadway
  - Roundabout – unsignalized
- More capacity than stop signs
- Also used for traffic calming
- Good safety record
Grade separated intersections

- Allows the traffic to cross at different vertical levels
- Sometimes the topography itself may be helpful in constructing such intersections
- Otherwise, the initial construction cost required will be very high.
- Usually constructed on high speed facilities like expressways, freeways etc
- Increases the road capacity
- Accident potential is reduced due to vertical separation of traffic
Grade separated intersections

• Flyovers and interchange
• Flyovers
  ▫ Subdivided into overpass and underpass
    • When two roads cross at a point, if the road having major traffic is elevated to a higher grade for further movement of traffic, then such structures are called overpass
    • If the major road is depressed to a lower level to cross another by means of an under bridge or tunnel, it is called under-pass
• Types of interchange
  ▫ Trumpet interchange
  ▫ Diamond interchange
  ▫ Cloverleaf interchange
Grade separated intersections

- Trumpet interchange
Grade separated intersections

- Diamond interchange
Grade separated intersections

- Clover leaf interchange
  - Provides complete separation of traffic.
  - High speed at intersections can be achieved
  - Disadvantage is large area of land is required
Traffic Signal Devices

- One of the most important and effective methods of controlling traffic at an intersection
- Electrically time device that assigns the right-of-way to one or more traffic streams so that these streams can pass through the intersection safely and efficiently
- Suitable for:
  - Excessive delays at stop signs and yield signs
  - Problems caused by turning movements
  - Angle and side collision
  - Pedestrian accidents
History of Traffic Signal Devices

- First traffic signal (1868): London
- First electric signal in the US (1914): Cleveland, Ohio
- First interconnected system of 6 signals (1917): Salt Lake City (manually controlled from a single site)
- First automated electric timer controlled from a central traffic tower (1922): Houston, Texas
- First progressive, pretimed system (1928)
- First actuated controller using pressure detectors (late 20’s)
- First analog computer system (1952): Denver, Colorado
- Pilot study using digital computers (1963)
Purpose of Traffic Signals

- Improve overall safety
- Decrease average travel time through an intersection, hence increase capacity
- Equalize the quality of services for all or most traffic streams
- Factors to considered: justification must be made based on traffic flow, pedestrian safety, accident experience, and the elimination of traffic conflicts
Advantages of Traffic Signals

• Provide orderly movement of traffic
• Flexibility, allocation of right-of-way responding to changes in traffic flow
• Ability to assign priority treatment to some movements or vehicles
• Feasibility of coordinated control along streets or in area networks
• Provision of continuous flow of a platoon of traffic at a desired speed along a given route by coordination
Disadvantages of Traffic Signals

• May increase total intersection delay and fuel consumption (off-peak period)
• Probable increase in certain types of accidents (rear-end collisions)
• Improperly timed, cause excessive delay, increase driver irritation
Type of Left-Turns

• **Permitted left turns**
  ▫ Vehicles are permitted to make a left turn by selecting an appropriate gap in the opposing traffic stream through which to turn.

• **Protected left turns**
  ▫ Vehicles are protected to make a left turn by prohibiting the opposing traffic
  ▫ Need separate signal phases for left turn
Types of Traffic Signals

- **Pretimed**: Repeat a preset constant cycle.

- **Actuated**:
  - Respond to the presence of vehicles and pedestrians
  - Need to use in conjunction with vehicle detectors

- **Semi-actuated**
  - Detectors placed only on the minor approach
  - Major approach is interrupted only if vehicle present at the minor approach

- **Fully actuated**
  - Detectors are installed at all approaches
  - Green time are allocated based on the incoming traffic on each approach
Pre-Timed Control

- Pre-timed operation
  - Cycle length
  - Phase sequence
  - Green time
  - Change interval
Definitions and notations

• **Cycle**
  ▫ A signal cycle is one complete rotation through all of the indications provided

• **Cycle length** C
  ▫ Cycle length is the time in seconds that it takes a signal to complete one full cycle of indications
  ▫ time interval between start of a green till next green for a any approach
Definitions and notations

- **Interval**
  - indicates change from one stage to another

- **Change interval / Yellow / Amber**
  - interval between the green and red

- **Clearance interval / All-Red**
  - after each yellow
  - all signals show red
  - used for clearing off the vehicles
Definitions and notations

- **Green interval** $G_i$
  - Duration the green light of a traffic signal is turned on

- **Red interval** $R_i$
  - Duration the red light of a traffic signal is turned on
Definitions and notations

• **Phase**
  ▫ Green interval + change interval + clearance interval
  ▫ During green interval non-conflicting movements are cleared

• **Lost time**
  ▫ Time during which intersection is not effectively utilized for any movement
  ▫ E.g. reaction time of the first driver in the queue
Signal Design Stages

- Phase Design
- Interval Design
- Cycle Length Determination
- Green Splitting
- Pedestrian Requirements
- Performance Evaluation
Phase Design

• Objective
  ▫ Separate the conflicting movements into various phases
  ▫ Complete separation implies large number of phases
  ▫ So design phases with minimum conflicts or with less severe conflicts
Phase Design

• **Major conflicts**
  - **Through – Through**
    - E.g 1-3
  - **Through – Right**
    - E.g 3-5
  - **Right – Right**
    - E.g 8-5
Phase Design

- Two phase signals
Phase Design

- Four phase signal: Option I
Phase Design

- Four phase signal: Option II
Phase Design

- Four phase signal: Option III
Phase Design

- Four phase signal: All Options
Signal Design Stages

- Phase Design
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Interval Design

• **Change Interval**
  ▫ Yellow time
  ▫ To warn a driver of the end of a green time
  ▫ Given after green time (3-6 Sec)

• **Clearance Interval**
  ▫ All-Read
  ▫ to clear off vehicles already in the intersection
  ▫ Given after Yellow time (2-4 Sec)
- **Change interval**: identical to the intergreen interval (the time between the end of a green indication for one phase and the beginning of a green indication for another)

- **Clearance interval**: identical to the all-red interval (the display time of a red indication for all approaches)
Cycle Time

- Saturation flow

Saturation Headway
Traffic Signals: Terminology

- **Actual Flow Rate**: the design flow rate, or the maximum flow that is expected to use the intersection.
- **All-red interval**: the display time of a red indication for all approaches. In some cases, it is used exclusively for pedestrians crossing very wide intersection.
- **Approach**: the portion of an intersection leg that is used by traffic approaching the intersection.
- **Capacity**: the maximum number of vehicles that can reasonably be expected to pass over a given roadway or section of roadway, in one direction, during a given time period and under the prevailing roadway, traffic, and signalization conditions.
Traffic Signals: Terminology

- **Change interval**: identical to the intergreen interval
- **Clearance interval**: identical to the all-red interval
- **Critical flow ratio**: the flow ratio of the critical lane group within a phase. The actual or design flow rate for the critical movement divided by the saturation flow rate for that movement.
- **Critical movement or lane**: the lane or movement for each phase, depending on how you choose to subdivide you intersection, that requires the most green time.
- **Critical volume**: a volume (or a combination volumes) for a given street that produces the greatest utilization of capacity (e.g., needs the greatest green time) for that street, given in terms of passenger cares or mixed vehicle per hour per lane
Traffic Signals: Terminology

- **Cycle** (cycle length or cycle time): time needed for a complete sequence of signal indications
- **Delay**: the stopped time delay per approach vehicle (sec/veh)
- **Design flow rate**: identical to the actual flow rate
- **Discharge rate**: the rate, in vehicles per hour or passenger car units per hour, at which traffic is entering an intersection.
- **Effective green time**: the green time that is actually used by traffic. Some lost time occurs initially while traffic responds to the green signal and begins to accelerate. Some time is also lost during the intergreen period as vehicles stop in anticipation of the next phase.
- **Flow rate**: the rate, in vehicles per hour or passenger car units per hour, at which traffic is entering an intersection
Traffic Signals: Terminology

- **Flow ratio**: the ratio of the actual flow rate to the saturation flow rate
- **Green interval**: The portion of a signal phase in which the green signal is illuminated
- **Green ratio**: the ratio of the effective green time to the cycle length
- **Green time**: length of green phase plus its change interval (sec)
- **Hourly volume**: the number of mixed vehicles that traverse a given section of lane or roadway during an hour
- **Intergreen (clearance interval)**: the time between the end of a green indication for one phase and the beginning of a green indication for another
Traffic Signals: Terminology

- **Intersection flow ratio**: the sum of all the critical flow ratios—one from each phase
- **Interval**: the part or parts of the signal cycle during which signal indications do not change
- **Lane group**: any group of lanes. Lanes can be combined during the signal timing design process in order to simplify the calculations
- **Legs (intersection)**: the portions of the intersecting streets or roadways that are within close proximity to the actual intersection
- **Level of Service (LOS)**: a measure of the operating conditions of an intersection. See the theory and concepts modules for more detail.
Traffic Signals: Terminology

- **Lost time**: the time during a given phase in which traffic could be discharging through the intersection, but is not. This is the period during the green interval and change intervals that is not used by discharging traffic.

- **Passenger car units**: a unit of measure whereby large trucks and turning movements are converted to passenger cars using multiplication factors. This allows you to deal with mixed traffic streams more accurately than if you had assumed all vehicles were created equal.

- **Peak-Hour**: the hour of the day that observes the largest utilization of capacity, or the hour of the day in which the largest number of vehicles use the intersection approach or lane of interest.
Traffic Signals: Terminology

- **Peak-Hour Factor**: the ratio of the number of vehicles entering an approach during the peak hour to four times the number of vehicles entering during the peak 15 minute period. In the absence of field information, a value of 0.85 is normally used.
- **Pedestrian crossing time**: the time that is required for a pedestrian to cross the intersection.
- **Phase (signal phase)**: the part of a cycle allocated to any combination of traffic movements receiving right-of-way simultaneously during one or more time intervals, consisting green, yellow (amber), and/or all-red.
- **Phase Sequence**: the predetermined order in which the phases of a cycle occur.
- **Queue**: a closely spaced collection of vehicles.
Traffic Signals: Terminology

- **Roadway conditions**: the physical aspects of the roadway, such as lane-width, number of lanes, easements, bike lanes, shoulder width, and any other aspect of the roadway.

- **Saturation flow**: The maximum number of vehicles from a lane group that would pass through the intersection in one hour under the prevailing traffic and roadway conditions if the lane group was given a continuous green signal for that hour.

- **Signalization conditions**: all the various aspects of the signal system, including timing, phasing, actuation, and so on.

- **Split**: a percentage of a cycle length allocated to each of the various phases in a signal cycle.

- **Traffic conditions**: the qualities of traffic, such as traffic speed, density, vehicle types, and traffic flow rate.