Intersection Control

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Outline

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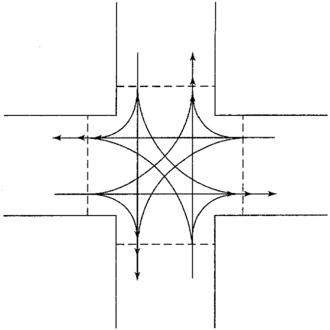
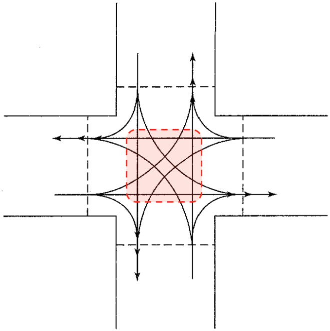
1. Overview
2. Traffic signal control
3. Intersection delay

Overview: Intersection



At a typical intersection of two two-way streets, there are 12 legal vehicular movements (left turn, through, and right turn from four approaches) and four legal pedestrian crossing movements.

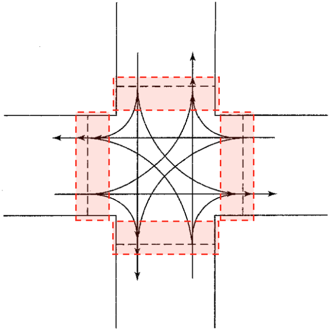
Overview: Intersection



There are a total of 16 potential vehicular crossing conflicts:

- Four between through movements
- Four between left-turning movements
- Eight between left-turning and through movements

Overview: Intersection



There are eight vehicular merge conflicts, i.e., right- and left-turning vehicles merge into a through flow. Pedestrians add additional potential conflicts to the mix.

Overview: Intersection

Thus, the critical task of the traffic engineer is to control and manage these conflicts in a manner that ensures safety and provides for efficient movement through the intersection for both motorists and pedestrians.

Overview: The hierarchy of intersection control

There are three basic levels of control that can be implemented at an intersection:

- **Level I**—Basic rules of the road
  e.g. the left must yield to the right/through
- **Level II**—YIELD or STOP signs

- **Level III**—Traffic signalization

Outline

Traffic signal control: Introduction

The ultimate form of intersection control is the traffic signal. Because it alternately assigns right-of-way to specific movements, it can substantially reduce the number and nature of intersection conflicts.

Traffic signal control: Advantage

If we design the traffic signal appropriately,

- They provide for the orderly movement of traffic
- They increase the capacity of the intersection
- They reduce the frequency and severity of certain types of crashes
- They are coordinated to provide for continuous movement at a definite speed along a given route
- They are used to interrupt heavy traffic at intervals to permit other traffic, vehicular or pedestrian to cross

Traffic signal control: Disadvantage

If we design the traffic signal inappropriately,

- Excessive delay
- Excessive disobedience of the signal indications
- Increased use of less adequate routes as road users attempt to avoid the traffic control signal
- Significant increases in the frequency of collisions (especially rear-end collisions)

Components of a signal cycle

- **Cycle**. A signal cycle is one complete rotation through all of the indications provided. In general, every legal vehicular movement receives a "GREEN" indication during each cycle.
- **Cycle length**. The cycle length is the time (in seconds) that it takes to complete one full cycle of indications. It is given the symbol "C".
- **Interval**. The interval is a period of time during which no signal indication changes. It is the smallest unit of time described within a signal cycle.

Components of a signal cycle

There are several types of intervals within a signal cycle:

- **Change interval**.
  - The change interval is the "YELLOW" indication for a given movement.
  - It is part of the transition from "GREEN" to "RED," in which movements about to lose "GREEN" are given a "YELLOW" signal, while all other movements have a "RED" signal.
  - It is timed to allow a vehicle, which cannot safely stop when the "GREEN" is withdrawn, to enter the intersection legally
  - The change interval is given symbol "y_i" for movement(s) i.

Components of a signal cycle

There are several types of intervals within a signal cycle:

- **Clearance interval**.
  - The clearance interval is also part of the transition from "GREEN" to "RED" for a given set of movements
  - During the clearance interval, all movements have a "RED" signal
  - It is timed to allow a vehicle, which legally enters the intersection on "YELLOW", to safely cross the intersection before conflicting flows are released.
  - The clearance interval is given the symbol "ar_i' (for "all RED") for movement(s) i.

Components of a signal cycle

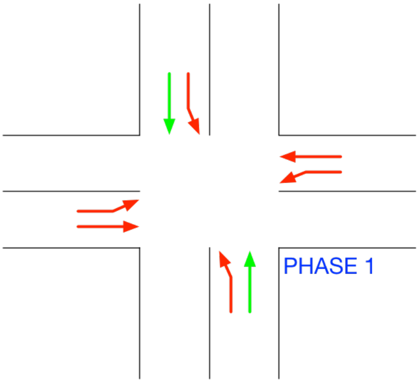
There are several types of intervals within a signal cycle:

- **GREEN interval**.
  - Each movement has one GREEN interval during the signal cycle
  - During a GREEN interval, the movements permitted have a "GREEN" light, while all other movements have a "RED" light
  - The GREEN interval is given the symbol "G_i" for movement(s) i.
- **RED interval**.
  - Each movement has one RED interval during the signal cycle
  - All movements not permitted have a "RED" light, while those permitted to move have a "GREEN" light
  - The RED interval is given the symbol "R_i", for movement(s) i.

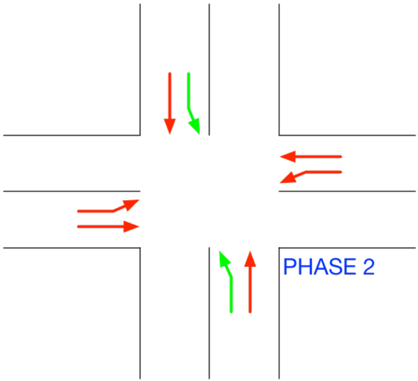
Components of a signal cycle

- **Cycle**.
- **Cycle length**.
- **Interval**.
- **Phase**
  - A signal phase consists of a GREEN interval, plus the change and clearance intervals that follow it.
  - It is a set of intervals that allows a designated movement or set of movements to flow and to be safely halted before release of a conflicting set of movements.

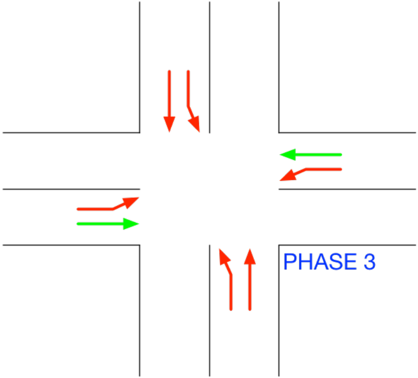
Phase



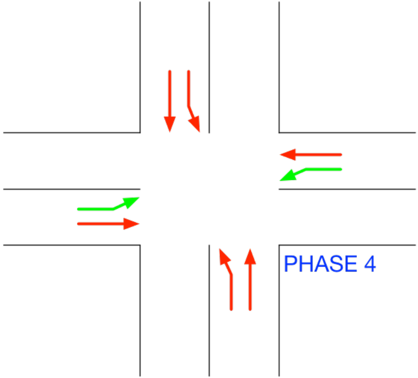
Phase



Phase



Phase



Types of signal operation

Pretimed operation

- The cycle length, phase sequence, and timing of each interval are constant.
- Each cycle of the signal follows the same predetermined plan.
- It is typical to have at least an AM peak, a PM peak, and an off-peak signal timing.

Types of signal operation

Semi-actuated operation

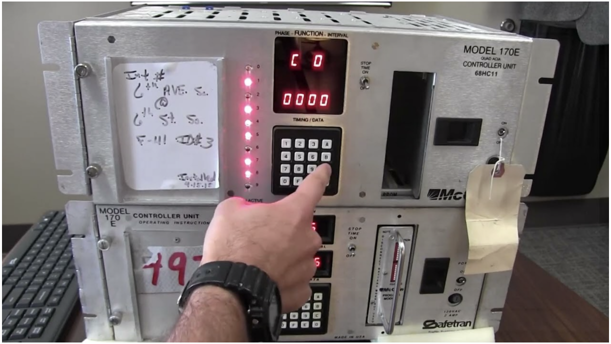
- Detectors are placed on the minor approach(es) to the intersection
- No detectors on the major street
- The light is GREEN for the major street at all times except when a "call" or actuation is noted on one of the minor approaches
- The GREEN returns to the major street when the maximum minor-street GREEN is reached

Types of signal operation

Full actuated operation

- Every lane of every approach must be monitored by a detector
- GREEN time is allocated in accordance with information from detectors and programmed "rules" established in the controller for capturing and retaining the GREEN
- The cycle length, sequence of phases, and GREEN time split may vary from cycle to cycle.

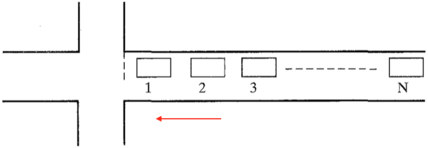
Signal controller



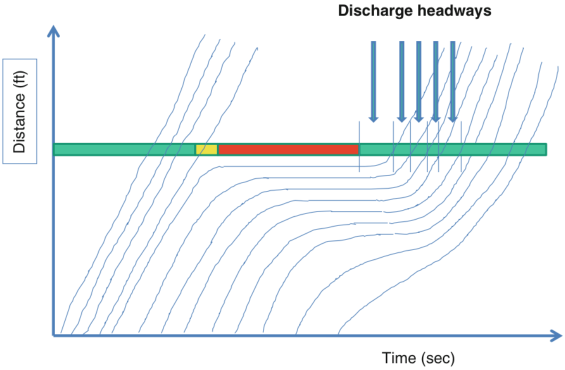
Signal controller

Discharge headways

When the light turns GREEN, there is a queue of stored vehicles that were stopped during the preceding RED phase, waiting to be discharged.

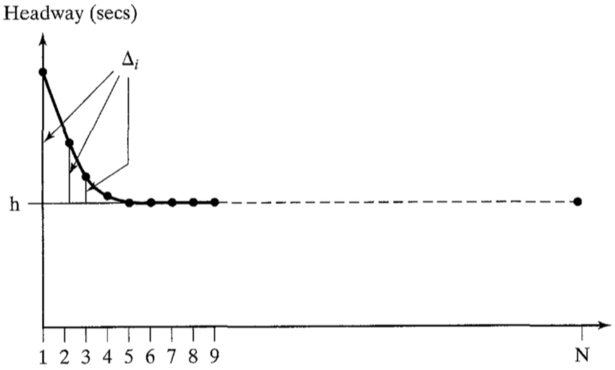


Discharge headways

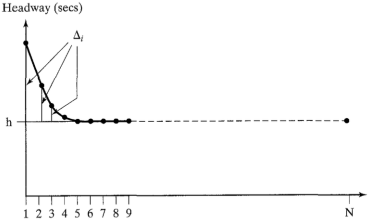


Discharge headways

Average (time) headways departing signal can be plotted as follows,

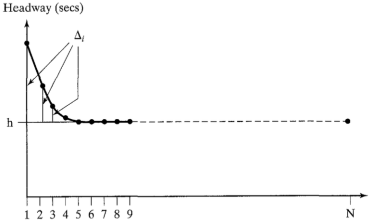


Discharge headways



- The first headway is relatively long, because the driver must go through the full perception-reaction sequence, i.e., move the foot from the brake to the accelerator, and accelerate through the intersection.
- The second headway is shorter, because the second driver can overlap the perception-reaction and acceleration process of the first driver.

Discharge headways



- Each successive headway is a little bit smaller.
- Eventually, the headways tend to level out, and a stable moving queue has been established.
- In general, this occurs from the fourth or fifth headway position. The constant headway h achieved is referred to as the saturation headway.

Saturation flow

If the signal were always GREEN, then s vehicles per hour could enter the intersection:

$$s = 3600/h \tag{1}$$

s is referred to as the saturation flow rate, vehicles per hour of GREEN per lane (veh/h/l);

- Saturation flow rate can be multiplied by the number of lanes provided for a given set of movements to obtain a saturation flow rate for a lane group or approach.
- The saturation flow rate is, in effect, the capacity of the approach lane or lanes if they were available for use all of the time (i.e., if the signal were always GREEN).
- The signal, of course, is not always GREEN for any given movement

Lost time

The lost time is the part of the phase that is essentially NOT used by any movement. It consists of the start-up lost time and the clearance lost time.

- **The start-up lost time** (l_1) is the lost time experienced by vehicles at the beginning of the green, and it includes the driver reaction time before vehicles start to clear the intersection.
- **The clearance lost time** (l_2) is the lost time experienced when vehicles do not use portions of the yellow and all-red intervals.
- Thus, **the total lost time** for a phase is

$$t_L = l_1 + l_2 \tag{2}$$

Effective GREEN time

- The actual signal goes through a sequence of intervals for each signal phase:

  GREEN → YELLOW → ALL-RED → RED

- The YELLOW interval must be provided because vehicles cannot stop instantaneously when the light changes.

- The ALL-RED interval must be provided to clear the intersection

Effective GREEN time

For any given set of movements, effective green time is the amount of time that vehicles are moving. The effective green time for movement i, i.e., g_i, is related to actual green time as follows:

$$g_i = G_i + Y_i - t_{Li} \tag{3}$$

where

- G_i: actual GREEN time for movement i
- Y_i: sum of YELLOW and ALL-RED intervals for movement i
- t_{Li}: total lost time for movement i

Capacity of an intersection lane or lane group

The capacity (c_i) of an intersection lane or lane group (i) is defined as follows

$$c_i = s_i \left(\frac{g_i}{C} \right) \tag{4}$$

where

- s_i: saturation flow (rate) for lane or lane group i
- g_i: effective green time for lane or lane group i
- C: signal cycle length

Outline

Measure of effectiveness

The fundamental element of a signalized intersection is the periodic stopping and restarting of the traffic flow. A number of measures have been used to characterized the operational quality of a signalized intersection, the most common of which are:

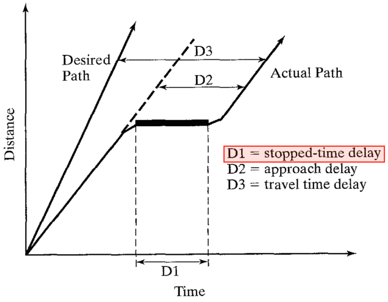
- **Delay** (the most common measure): the amount of time consumed in traversing the intersection
- **Queuing**: the number of vehicles forced to queue behind the stop-line during a RED signal phase
- **Stops**: the percentage or number of vehicles that must stop at the signal

Types of delay

- Stopped-time delay
- Approach delay
- Travel time delay
- Aggregate delay

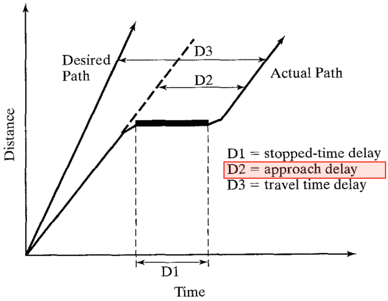
Types of delay

- **Stopped-time delay**: The time that a vehicle is stopped in queue while waiting to pass through the intersection



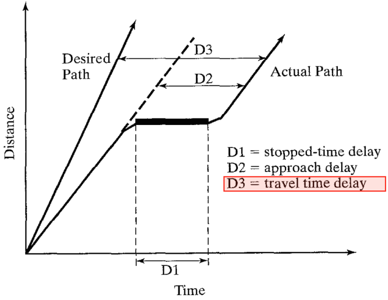
Types of delay

- **Approach delay**: Sum of
  - Stopped-time delay
  - The time loss due to deceleration from the approach speed to a stop
  - The time loss due to reacceleration back to the desired speed



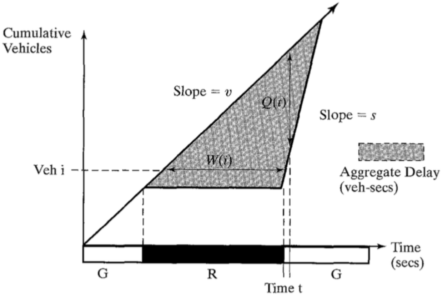
Types of delay

- **Travel time delay**: The difference between the driver's expected travel time through the intersection and the actual time taken.



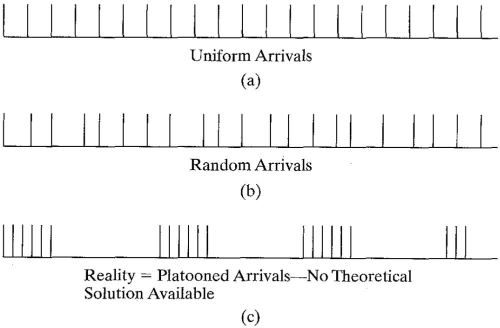
Types of delay

- **Aggregate delay**: An aggregate total delay for all vehicles over a specified time period



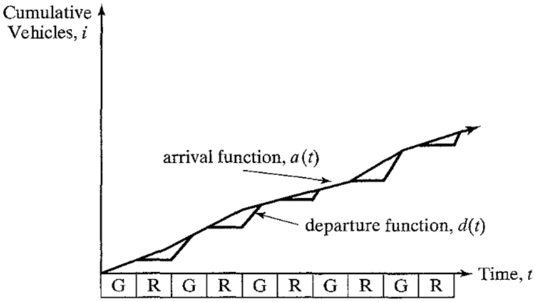
Arrival patterns

- **Uniform arrivals**
- **Random arrivals**: isolated intersections (inhomogeneous Poisson distribution)
- **Platooned arrivals**: more realistic urban intersections



Modeling delay: Stable flow

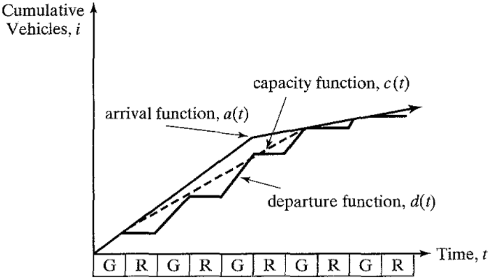
No signal cycle "fails" (i.e., ends with some vehicles queued during the preceding RED unserved).



(a) Stable Flow

Modeling delay: individual cycle failures

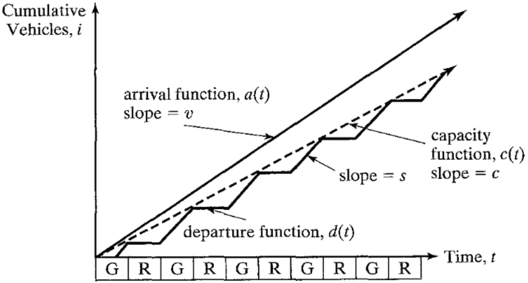
Some of the signal phases “fail”.



(b) Individual Cycle Failures Within a Stable Period

Modeling delay: Demand exceeds capacity significantly

Every GREEN interval "fails" for a significant period of time, and the residual, or unserved, queue of vehicles continues to grow throughout the analysis period



(c) Demand Exceeds Capacity for Significant Period

Thank you!