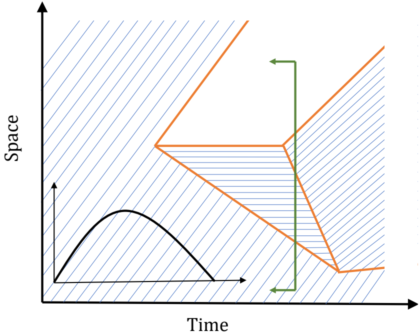
CE 269
Traffic Engineering

Lecture 13

Signalized Intersections

Previously on Traffic Engineering

Consider a signal at junction and assume a fundamental diagram as shown.



How does the density change along the highlighted cross section and where are these points on the fundamental diagram? Can we derive the RH condition using the speed of the shock wave.

Lecture Outline

1. Traffic Control
2. Terminology
3. Design of a Single Intersection

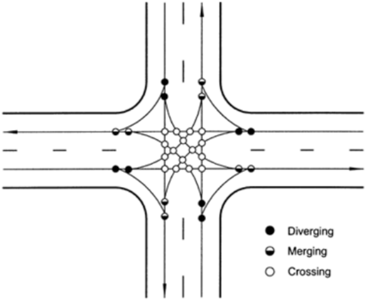
Traffic Control

Traffic Control

Introduction

Traffic control at junctions is usually achieved using stop/yield signs or by signals.

Consider the following 4-way junction. For the unsignalized version, there are 8 merge and 8 diverge conflicts and 16 crossing conflicts.



These reduce the capacity and also make navigating through the junction less safe.

Traffic Control

Warrants

When traffic volumes are low, the intersection can be left unsignalized. The Indian Road Congress (IRC) 93-1985 guidelines prescribe when a junction must be signalized based on a few conditions.

- Minimum vehicular volume

Number of lanes for moving traffic on each approach		Motor vehicles per hour on major street (total both approaches)	Motor vehicles per hour on higher volume minor street approach (one direction only)
Major Street	Minor Street		
1	1	650	200
2 or more	1	800	200
2 or more	2 or more	800	250
1	2 or more	650	250

- Interruption of continuous traffic

Number of lanes* for moving traffic on each approach		Motor vehicles per hour on major street (total of both approaches)	Motor vehicles per hour on higher volume minor street approach (one direction only)
Major Street	Minor Street		
1	1	1000	100
2 or more	1	1200	100
2 or more	2 or more	1200	150
1	2 or more	1000	150

- Minimum pedestrian volume
- Accident experience

Traffic Control

Types of Signals

Signals can also be pre-timed or actuated. Pre-timed plans are usually fixed by time-of-day.

Actuated signals on the other hand can be semi-actuated where sensors are used on minor streets with less traffic or fully-actuated where sensors from all approaches are used to determine green times.

We will first look at isolated intersections and then graduate to handle coordination among signals at a corridor level. Most cities now use area-wide control using optimization or AI-based methods.

Turn movements at signals can be protected/exclusive or permissive. If they are protected/exclusive, drivers have to wait for a dedicated signal as shown in the picture.

If turn movements are permissive, drivers have to take a turn based on the gap sizes in oncoming traffic.

*Right-Hand Traffic

Lecture Outline

Terminology

Terminology

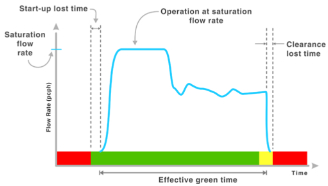
Fixed-time traffic signals operate in cycles. The time for one full cycle is called the *cycle length* C.

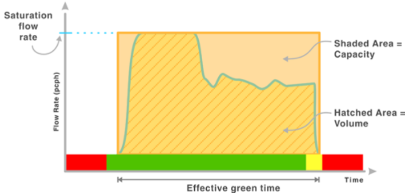
A *phase* is the set of all traffic movements allowed simultaneously. For each phase i, let G_i and R_i indicate the green and red times.

In addition, each phase ends with an *all-red* AR_i phase to allow for residual traffic to clear the intersection. The AR_i duration is set to the width of the intersection/average speed of vehicles clearing the junction.

When signals change from red to green, reaction times of travelers result in *start-up lost time*.

Likewise, when the signal turns amber, vehicles avoid entering the intersection and some time is lost at the end, called *clearance lost time*.



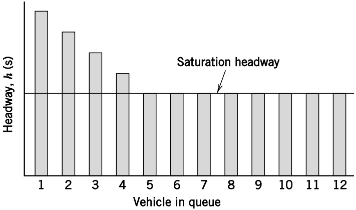


The *effective green* $g_i = G_i + Y_i - t_L$, where t_L is the sum of the above two lost times.

Terminology

Saturation Flow and Capacity

When a signal turns green, the time headways between consecutive vehicles decrease since the vehicles behind the first one will take lesser time to react.



The *saturation flow* is the rate of vehicles that can pass through a movement if it receives a green light throughout.

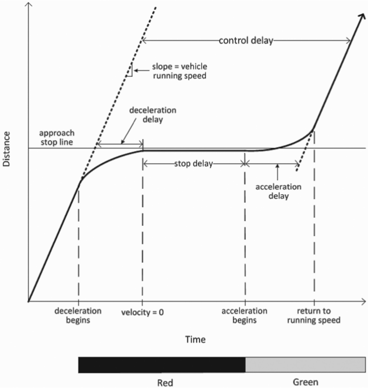
$$s = \frac{3600}{h}$$

s is the saturation flow rate and h is the saturation headway.

Capacity of a lane or approach i can be computed using its saturation flow and effective green time

$$c_i = \frac{g_i}{C} s_i$$

Two types of delay—stop delay and control delay are important in signal design.



Design of a Single Intersection

Design of a Single Intersection

Steps

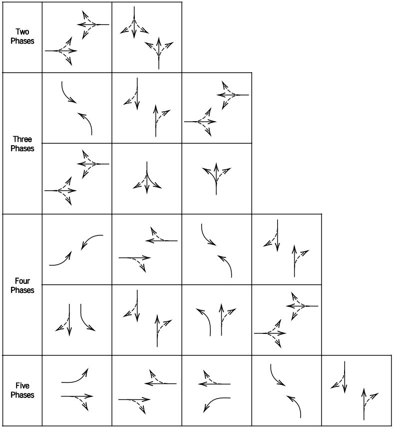
The main steps involved in designing an isolated intersection are:

- Decide the phasing scheme
- Calculate the amber times
- Estimate cycle length
- Distribute green times

Design of a Single Intersection

Phasing

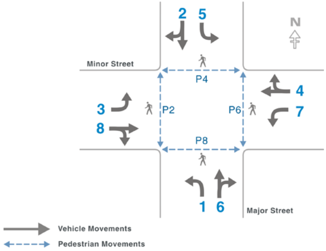
When designing a signal, different types of phasing schemes can be tested to either reduce the overall delay, safety, or the number of conflicts.

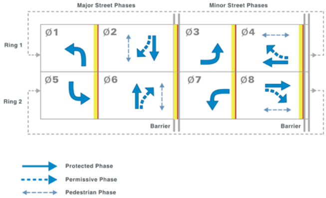


*Right-Hand Traffic

Design of a Single Intersection

Ring-Barrier Diagrams





*Right-Hand Traffic

Design of a Single Intersection

Movement Groups vs. Phases

Number of Approach Lanes	Movements by Lane and Corresponding Lane Groups
1	LT + TH + RT
2	EXC LT TH + RT
2	LT + TH TH + RT
3	EXC LT EXC TH TH + RT
3	EXC LT EXC TH EXC RT

*Right-Hand Traffic

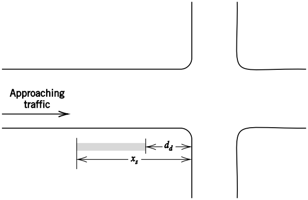
Design of a Single Intersection

Amber Time

The standard practice of setting yellow times is to use the ITE formula

$$Y = t + \frac{v_{85}}{2a + 19.6g}$$

where Y is the yellow time in seconds (rounded up to the nearest integer and is between 3–6 seconds), v_{85} is the 85th percentile speed of approaching vehicles, a is deceleration, and g is grade in decimal.



Drivers in the dilemma zone can leave the intersection during the AR time.

Design of a Single Intersection

Cycle Time Estimation

To estimate the cycle time, we first estimate the *critical flow ratio* v/s of each phase by considering the maximum flow of a through or turn movement in that phase using peak-hour traffic counts.

The minimum cycle length recommended by HCM is

$$C = \frac{NLX_c}{X_c - \sum(v/s)_{ci}}$$

X_c is the critical v/c ratio of the intersection and is typically set to 0.9. It indicates the utilization rate of the intersection.

L is the lost time in seconds, N is the number of phases, $(v/s)_{ci}$ is the critical flow ratio for phase i.

Design of a Single Intersection

Cycle Time Estimation

The Webster's method is similar to this approach and attempts to minimize the delay at an intersection (under some assumptions of uniform arrivals)

$$C_{opt} = \frac{1.5L + 5}{1 - \sum(v/s)_{ci}}$$

X_c is the critical v/c ratio of the intersection and is typically set to 0.9. L is the lost time in seconds, N is the number of phases, $(v/s)_{ci}$ is the critical flow ratio for phase i.

Design of a Single Intersection

Green Splits

Finally, the cycle length is apportioned to each phase based on the ratio of critical lane volumes.

$$g_i = \frac{v_{ci}}{\sum v_{ci}} T_g$$

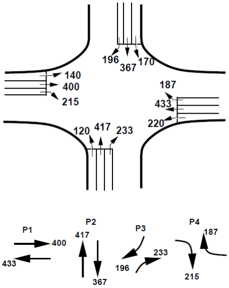
where v_{ci} is the critical lane volume and T_g is the total effective green time which equals $C - Nt_L$.

The actual green time is set to $G_i = g_i - y_i + t_L$.

Design of a Single Intersection

Example

Peak-hour traffic volumes at a four-legged intersection are as shown in the figure. Assuming that the total lost-time per phase is 2.4 s, the saturation headway to be 2.2 s, amber time of 3 s per phase, find the cycle length and the green splits.



Repeat this for a three-phased intersection where P2 and P4 in the above picture are combined.

Additional Reading

Matthew, T. V. (2009) NPTEL Notes on Traffic Engineering. https://nptel.ac.in/courses/105/101/105101087/

FHWA (2008) Traffic Signal Timing Manual FHWA-HOP-08-024. https://ops.fhwa.dot.gov/publications/fhwahop08024/index.htm

Your Moment of Zen