CIVE 440

Traffic Engineering and Simulation – Actuated Traffic Signals

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Faculty of Engineering
Department of Civil Engineering and Applied Mechanics
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SO FAR

We examined traffic signals that are pre-timed using pre-programmed TOD plans:

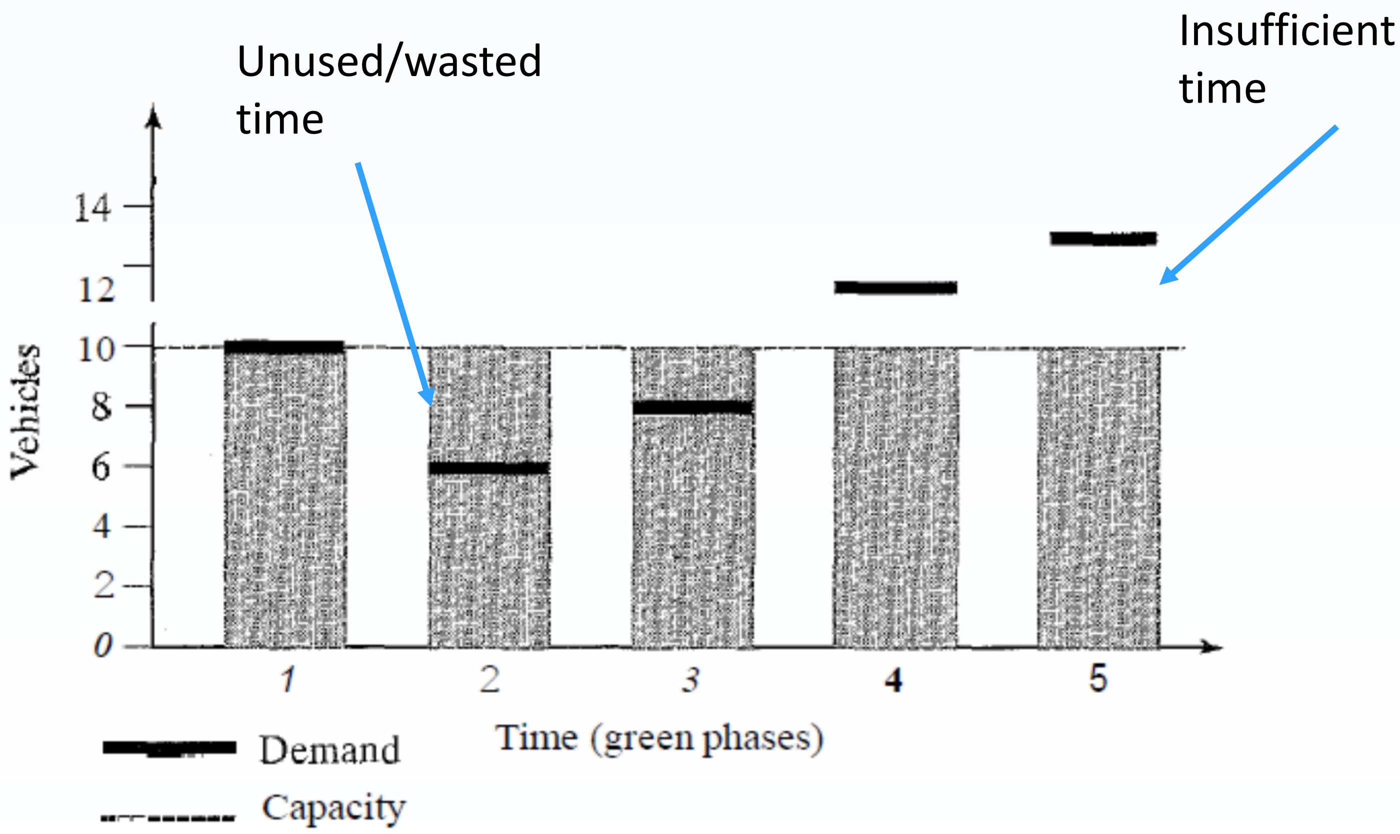
- based on the assumption of relative uniform arrivals throughout the TOD, save for the 15 minute intensity.
- In reality, traffic flow can vary:
    - Cycle to cycle, especially if traffic lights are not synchronized (or poor progression) and demand is generated perfectly randomly.
    - Weekly/daily/hourly variation that breaks trends with expansion factors are uncommon, but still a possibility.
    - Traffic demand can swell unpredictably due to events: traffic incidents, unplanned detours, emptying of sports/entertainment venues, etc.

ACTUATED TRAFFIC SIGNALS

Actuated traffic signals respond dynamically to demand in very basic but reliable ways.

- Actuated traffic signals make use of detectors imbedded in the road surface and present at intersection to gather demand information.
- Actuated signals are the first step in implementing intelligent traffic control devices.
  - Operations are rudimentary but reliable.
  - Traffic lights can still be implemented and operated independently from one another.

DEMAND RESPONSE



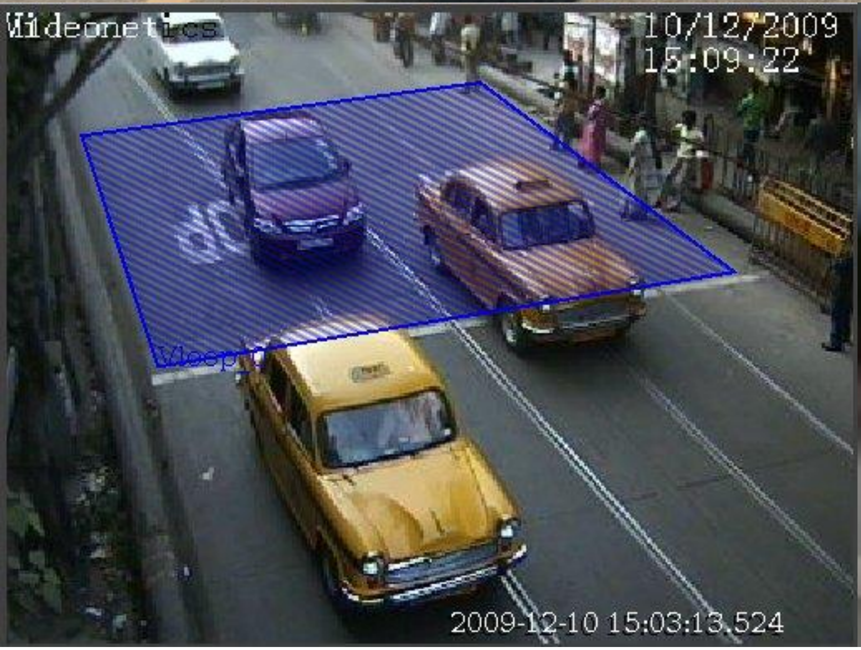
The traffic controller responds dynamically to demand in one or more possible ways:

- Optional phases or variable phase sequences
  - e. g., optional protected LT phases if LT queue in LT lane is detected
- Variable green split for each phase
  - e. g., when critical flow ratios reverse in direction
- Variable cycle length
  - e. g., fluctuation of overall required capacity

However, actuated traffic lights are no silver bullet.

- What issues do you foresee in a traffic grid, particularly as a consequence of the above changes?


SUBARU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PUSH
BUTTON
FOR

Actuated traffic controls are more expensive and require installation of traffic detectors.

Detectors can fail.

- Some detectors cease functioning entirely.
  - Loop detectors are notorious for failing with freeze-thaw cycles or with unplanned road maintenance.
- The detector may not be able to detect certain vehicles or pedestrians with 100% reliability.
- Not all pedestrians use push buttons…

Failure to detect a road user without some form of failsafe can lead them stranded—uncomfortable at best, dangerous at worst.

Failsafes, such as maximum green extension time and best practices such as skipping phases only every other cycle, can address issues with detector failure, but these limit the effectiveness of actuated signals.

Furthermore, road users are creatures of habit. Skipping phases when the driver would normally expect to be next can cause frustration.

- Avoid alternating orders if possible. Except for a few special cases, it provides little benefit.

Finally, varying green split and/or cycle time can ruin synchronisation, unless sophisticated control schemes are purpose-built for the network (e.g. "force-off").

DETECTOR TYPES

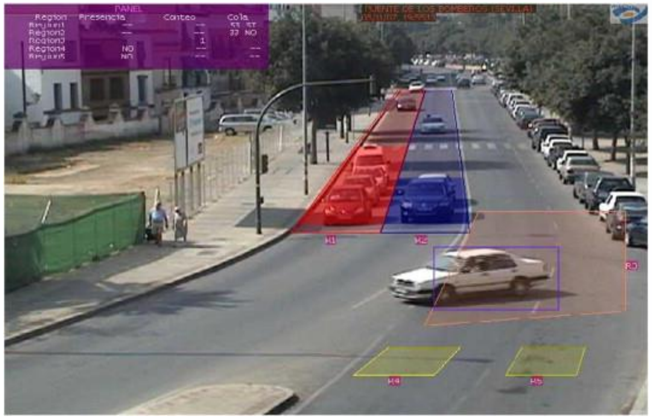
There are two types of detection modes that influence the design and timing of actuated controllers:

- Passage or point detection:
  - In this type of detection, only the fact that the detector has been "disturbed" is noted.
  - The detector is installed at a "point," even though the detector unit itself may involve a short length.
  - The detector is blind to the length of the queue. At best, it can only tell how recently a request has been received.
  - Although it can be used to count incoming demand, it can not be used to determine how many cars have arrived and been served by the intersection at the same time.
    - Therefore, it can't provide true real-time demand analysis.

DETECTOR TYPES

There are two types of detection that influence the design and timing of actuated controllers:

- Presence or area detection:
  - In this type of detection, a significant length (or area) of an approach lane is included in the detection zone.
  - Entries and exits of vehicles into and out of the detection zone are "remembered." Thus, the number of vehicles stored in the detection zone is known.
  - Most presence detection is accomplished using video detectors, a single "long-loop" detector, or using a series of loop detectors covering a significant length of an approach or an approach lane.



Detector	Measuring Capability				Method of Operation	Advantages	Disadvantages
	Count	Presence	Speed	Occupancy			
Loop	Yes [1]	Yes	Yes [2]	Yes	Vehicle passage cuts magnetic lines of flux generated around the loop. Resulting inductance change is detected and transmitted to an amplifying circuit.	• Size and shape of detection zone can easily be set by size of loop • Excellent presence detector • Capable of measuring all traffic parameters • Relatively easy to install • Capable of detecting small vehicles	• Requires sawcutting of pavement • Installation requires closing of traffic lane or lanes for short periods of time
	[1] Short loops may be used to count. Long loops (e.g., 20 ft (6.1 m)) do not count accurately, due to multiple occupancy on the loop. [2] See section 3.2 for speed determination techniques						
Magnetometer	Yes	Yes	No	Yes	Measures change in earth's magnetic field caused by vehicle; makes use of small cylindrical sensing head placed below pavement surface.	• Relatively easy to install • Capable of measuring count or presence • Reliable • Not affected by DC lines in vicinity • Under roadway location and not subject to damage	• Requires closing of traffic lane for installation • May double-count some vehicles due to magnetic material distribution • Poorly defined detection zone
Magnetic, non-directional	Yes	No	No	No	Vehicle passage over wire coil embedded in roadway disturbs earth's lines of flux passing through coil and induces a voltage in the coil; voltage is amplified by high-gain amplifier to operate detector relay.	• Under roadway location and not subject to damage • Relative ease of replacement • Low maintenance	• Non-directional • Difficult to set detection zone • Subject to false calls when located near large DC lines • Cannot detect presence • Necessitates closing of traffic lanes for installation
Magnetic, directional (two-coil version)	Yes	No	No	No	(Same method of operation as non-directional magnetic detector.)	• Directional • Not affected by DC lines in vicinity • Low maintenance • Under roadway location and not subject to damage • Relative ease of replacement	• Requires closing of traffic lane for installation • More expensive than non-directional magnetic detector • Cannot detect presence

Detector	Measuring Capability				Method of Operation	Advantages	Disadvantages
	Count	Presence	Speed	Occupancy			
Pressure	Yes	No	No	No	Weight of vehicle closes metallic contacts to complete a circuit.	• Well-defined detection zone • Rugged construction • Reliable • Capable of detecting all moving vehicles, regardless of speed	• Counts axles, which yields poor count accuracy • Does not measure presence • Installation may disrupt traffic for excessive period of time • Major resurfacing requires the use of a frame extension
Radar/Microwave	Yes	Dependent on design of specific unit	Yes	Dependent on design of specific unit	Passage of vehicle reflects microwaves back to antenna. May use Doppler principle as well as other techniques.	• May not necessitate closing of traffic lanes to install • Non-pavement or roadway invasive	• Requires FCC license to operate • Antenna alignment required
Sonic, active	Yes	Yes	Poor accuracy	Yes	Emits bursts of ultrasonic energy at a rate of approximately 12 to 20 times per second; detects reflected ultrasonic pulse.	• May not necessitate closing of traffic lanes to install • Can be used at locations with unstable pavement • Can classify vehicle by height • Non-pavement or roadway invasive	• Low Pulse Repetition Frequency (PRF) limits accuracy of occupancy and speed • May be difficult to get complete lane coverage and avoid adjacent lane detection • May be sensitive to temperature variations • Cannot be used in certain high wall locations
Video image processing	Yes	Yes	Yes	Yes	TV cameras transmit their images to processor; processor detects vehicles crossing line drawn across lane by analyzing image pixels.	• Provides wide-area detection • Can provide traffic information beyond capability of spot detectors	• May be relatively expensive for simple applications • Subject to phenomenological error sources such as shadows, occlusion and background lighting

DEFINITIONS

Minimum Green time ($G_{\min\_veh_i}$)

- Represents the minimum time allocated on an activation.

Extension Time (Δt)

- Amount of time added to a green phase when an additional activation is received within the interval time.
- Provides sufficient time to allow the vehicle to travel from the detector and to cross the stop line, or the intersection, entirely.

Interval Time (I, sometimes *passage time* PT)

- Represents the max. gap between actuations at a single detector to retain the green by adding Δt. $I < \Delta t$

Maximum Green time (G_{max})

- Absolute maximum green time to allocate, after accounting for green extensions, serves as a failsafe.

Recall settings

- The recall settings determine what happens when there is no demand.
- This permits anticipation of traffic on the most likely approach when there is no traffic demand at all.

Yellow and All-Red (Y, AR)

- Same concepts, purpose, and calculation as with fixed-time signals.

Pedestrian walk time ($G_{\mathrm{min\_ped}_\mathrm{i}}$)

- Minimum green time required for pedestrians to cross intersection, determined as with fixed-time signals.

SEMI- VERSUS FULL ACTUATION

Two types of actuation schema exist:

- Semi-actuated traffic signals place detectors on the minor road or on an infrequently-used left turn lane. The major road has the green light by default until demand is detected on the minor approach.
  - This is most useful when traffic flows are highly polarised between the phases **and** demand on the minor approach is non-uniform.
- Fully-actuated traffic signals place detectors on all approaches.
  - This is most useful when traffic flows are similar between the phases and demand on all the approaches is non-uniform.

In full or near saturation, actuated traffic signals offer no benefit over fixed-time traffic signals. Why?

Few guidelines to formally justify the use of actuated traffic signals or fixed-time signals.

- Typically the case of corrective action, engineering expertise, or even pilot projects.

Consult:

http://mutcd.fhwa.dot.gov/htm/2003r1/part4/part4c.htm

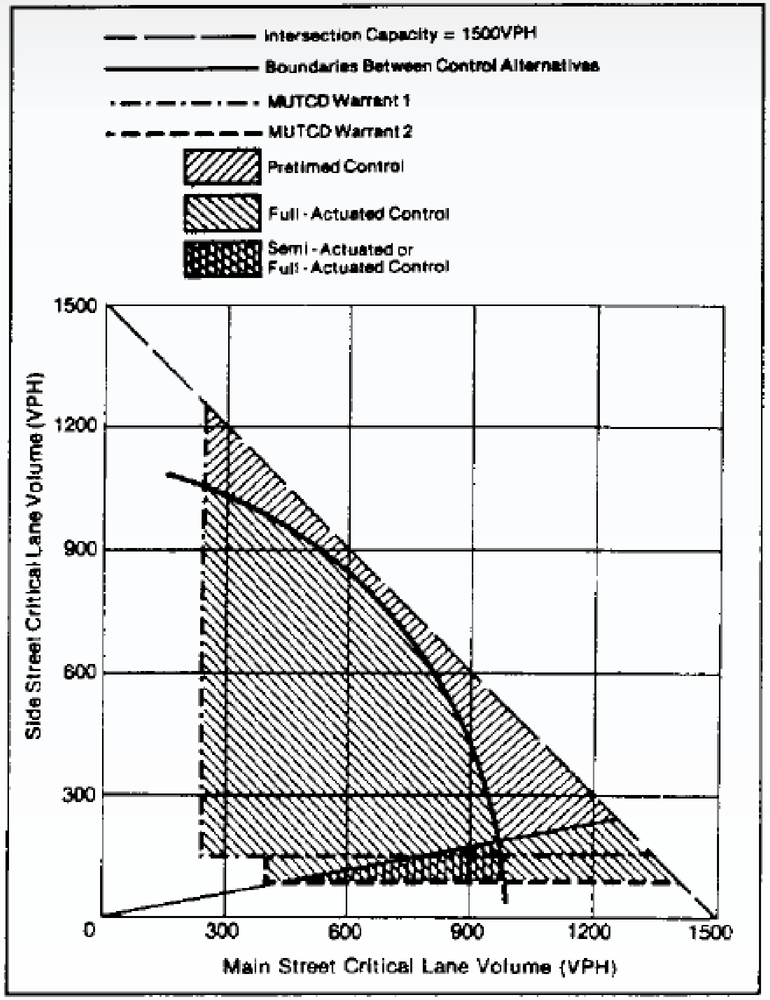
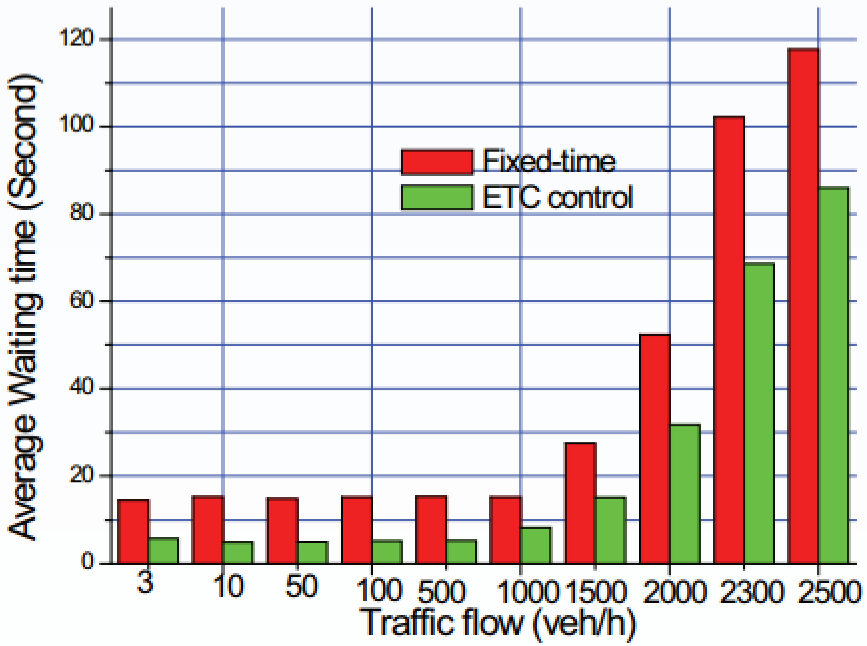
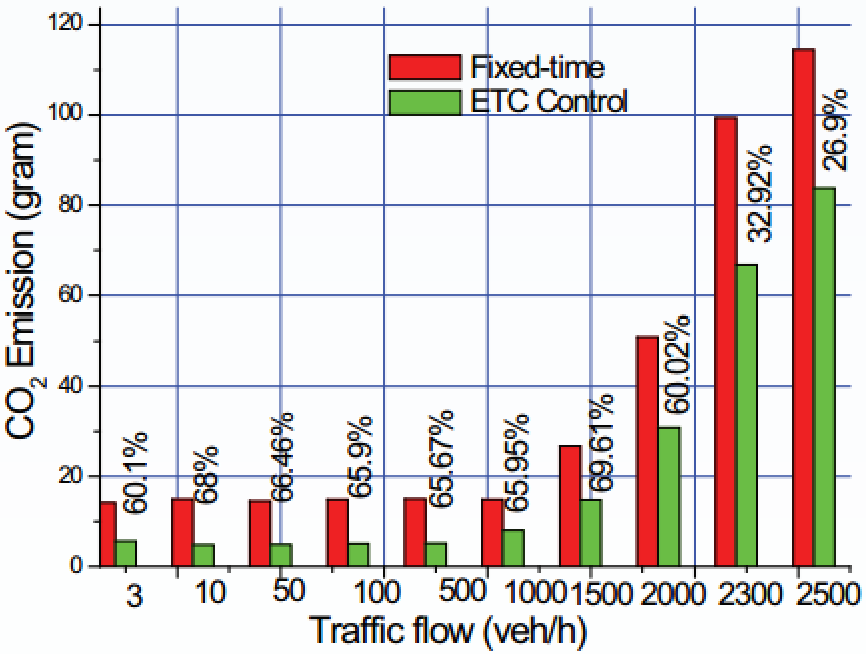


FIGURE 23-5 Determination of type of control: one recommendation.

SOURCE: Tarnoff and Parsonson, "Selecting Traffic Signal Control at Individual Intersections," *NCHRP Report 233*, Transportation Research Board, Washington, DC, June, 1981.

STUDIES





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BASIC OPERATION

Green is initiated on the main phase with:

- enough time to let pedestrians cross,
- enough time to dissipate the initial queue, if it exists and can be estimated or measured,
- and usually one unit extension time to kickstart the detection of additional cars.

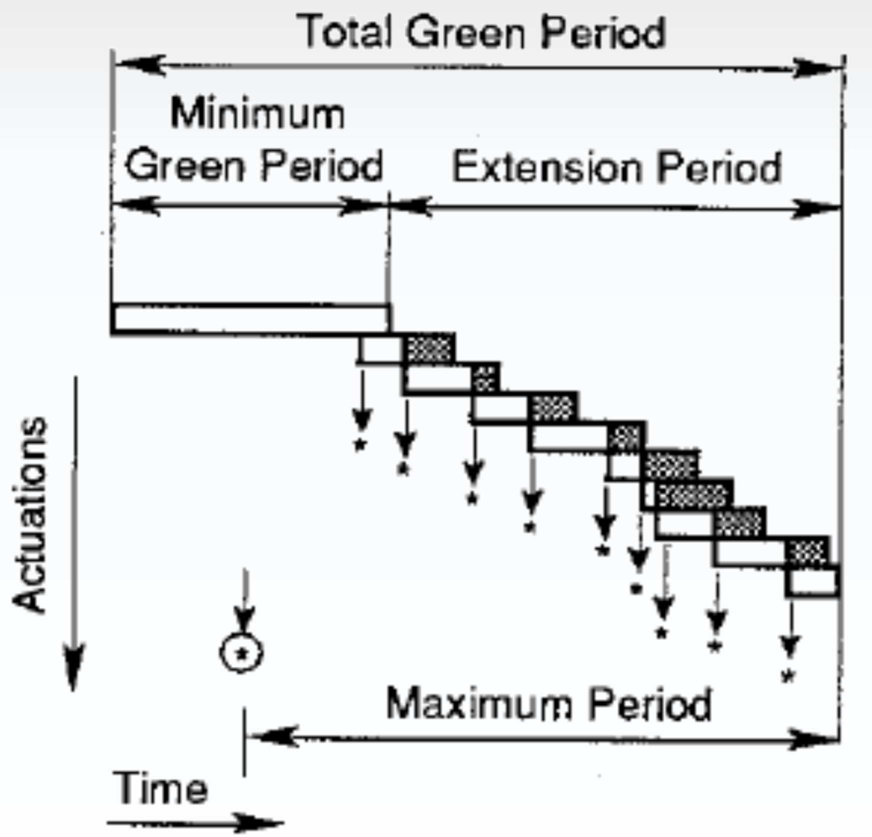
$$G_{min_i} = \max\left(G_{min\_veh_i}, G_{min\_ped_i}\right) + \Delta t$$

If no additional detections are made, the phase changes (“gap-out”).

If a detection is made within the interval time I, additional extension time Δt is added to the green time G_i.

- I is the threshold defining a pack of cars progressing together. If I is too large (greater than headway) the density is too low and priority is given to an alternative phase that may be waiting.
- I can equal Δt, though it tends to be smaller so as to reduce issues with dilemma zones.

Once G_i hits G_{max_i}, the controller switches phases regardless of detection state: this is the failsafe engaging (“max-out”).



Legend

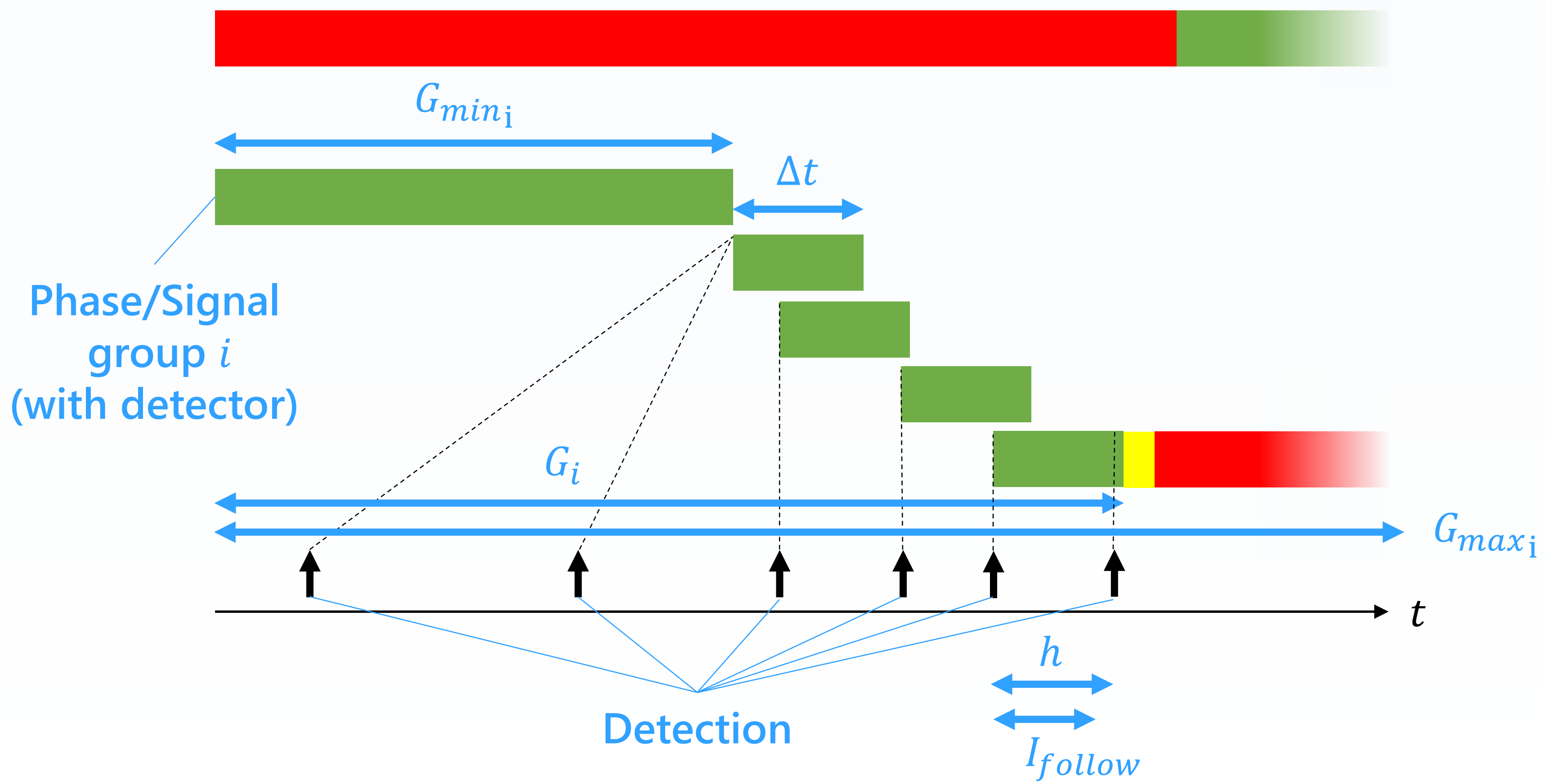
↓ * Detector actuation on phase with right-of-way

⊙ Detector actuation on a conflicting phase

▓ Unexpired portions of vehicle intervals

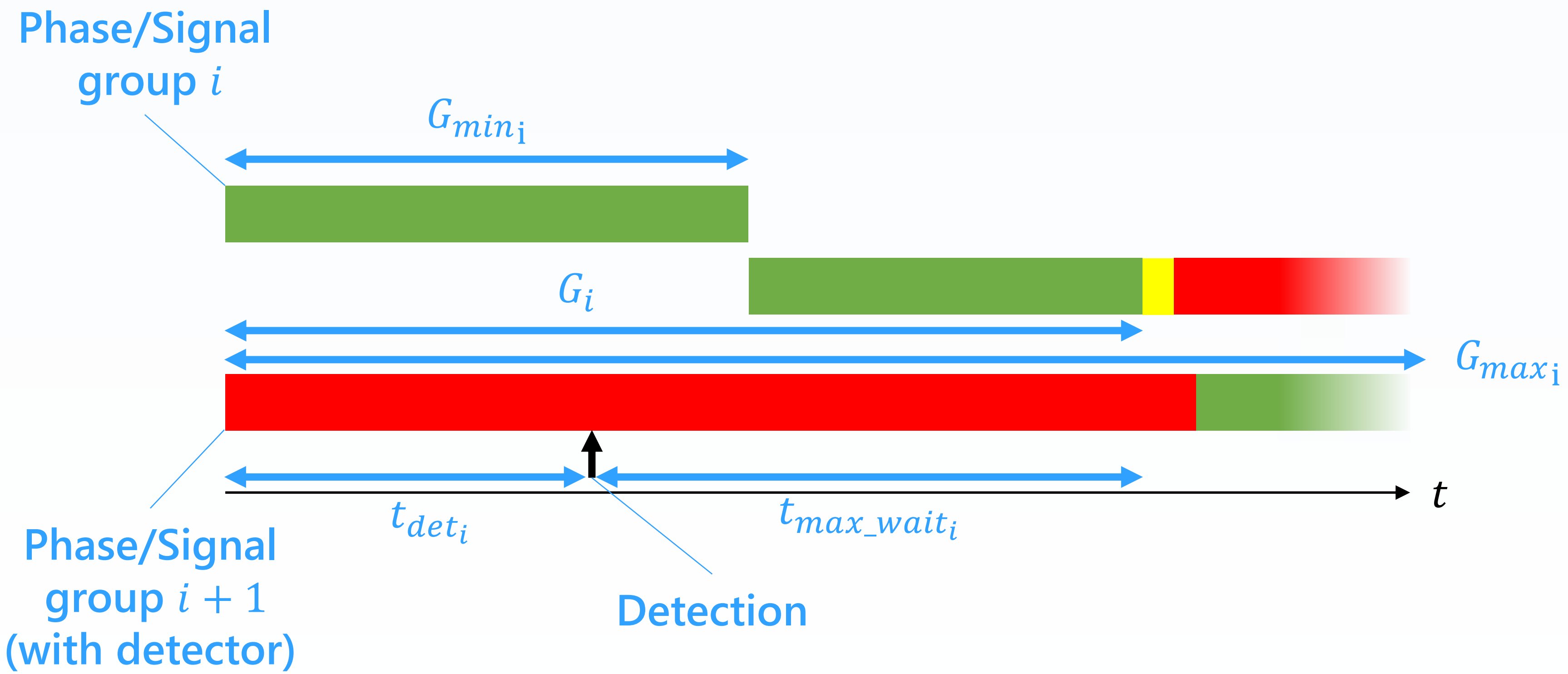
DETECTION FOR CURRENT PHASE

For semi- and fully-actuated traffic signals.



DETECTION FOR NEXT PHASE

For semi-actuated traffic signals only.



MINIMUM GREEN TIME FOR VEHICLES

In addition to $G_{min\_ped_i}$ (calculated as with fixed time) $G_{min\_veh_i}$ is time required to dissipate the average queue that might form between the detector and the intersection.

$$G_{min\_veh_i} = 3.7 + 2.1n \qquad \text{if } n > 5$$

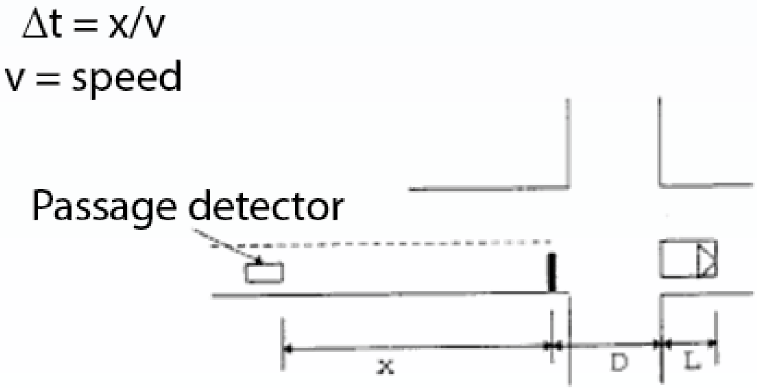
$$G_{min\_veh_i} = 4 + 2n \qquad \text{else}$$

where $n =$ number of vehicles in queue

EXTENSION TIME

The extension time Δt is the time required for a detected car to clear the intersection from the point of detection.

- $\Delta t = \frac{x}{v}$ with an intersection-engaging policy
- $\Delta t = \frac{(x+D+L)}{v}$ with an intersection-clearing policy (the case with the MTQ)

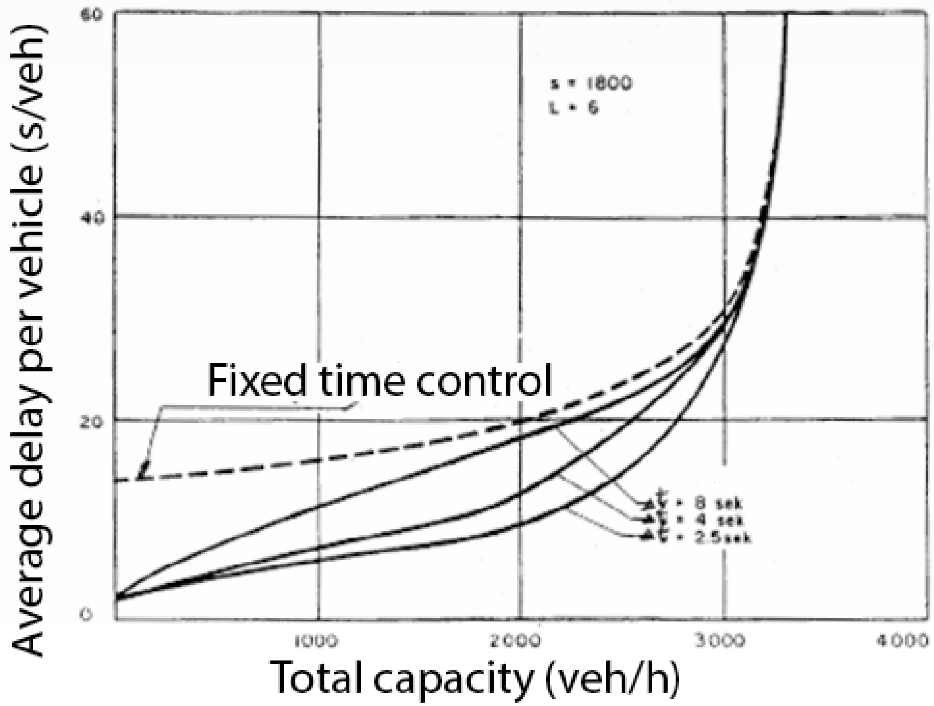


Highly dependant on location of detector x.

Typically, $I = \Delta t$.

- I can also be set to $I \leq \Delta t$ to increase safety
- I should never be set to $I \geq \Delta t$

A very long or very short I will either lead to maximum detections or no detections, and thus functionally equivalent to a fixed time.



MAXIMUM GREEN TIME

Multiple approaches, mostly empirical or practical:

- $C_{max} \leq 120\ s$
- $G_{max_i} = G_{min_i} + t_{max\_wait_{i+1}}$
- $G_{max_i} = G + X$
  - where G is the ordinary green time as calculated for fixed-time signals and X is an arbitrary duration, usually between 5 and 10 seconds.
- $G_{max_i} = G \times f$
  - where f varies between 1.25 and 1.5 (McShane method)
- $G_{max_i} \approx 1.5n\ \times\ \Delta t$
  - where $n =$ average number of vehicles per cycle

ACTUATION LOGIC

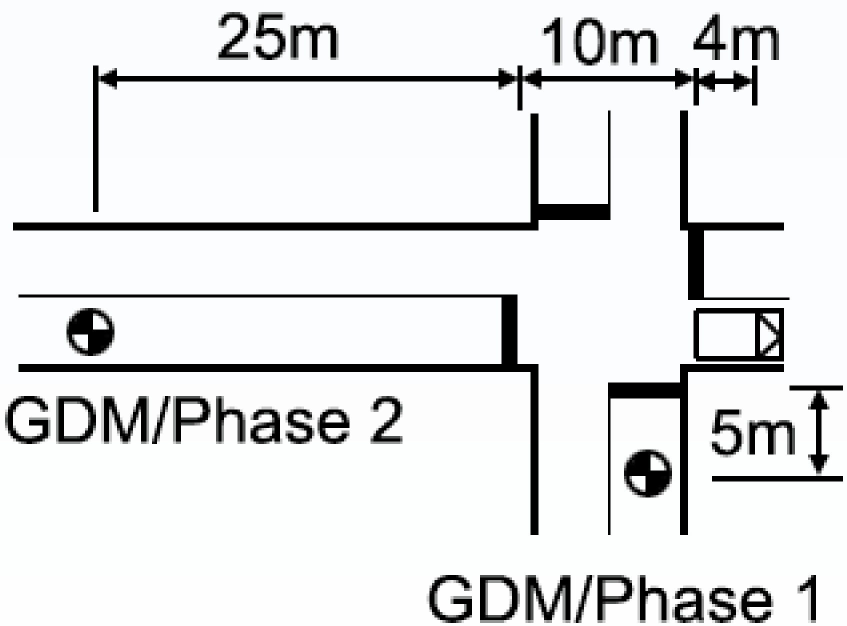
Pseudo-code, where h_j is the elapsed time since the detection of the previous car $j - 1$:

$$
\begin{aligned}
&\textit{while True:}\\
&\qquad if\left(G > G_{min}\ and\ h_j < I\ and\ G < G_{max}\right)\\
&\qquad\qquad then\ G = G + \Delta t\\
&\qquad\qquad continue\\
&\qquad else\\
&\qquad\qquad phase\ change
\end{aligned}
$$

EXERCISE

Average of 13 arrivals on G_1 and 14 arrivals on R_1

v = 60 km/h



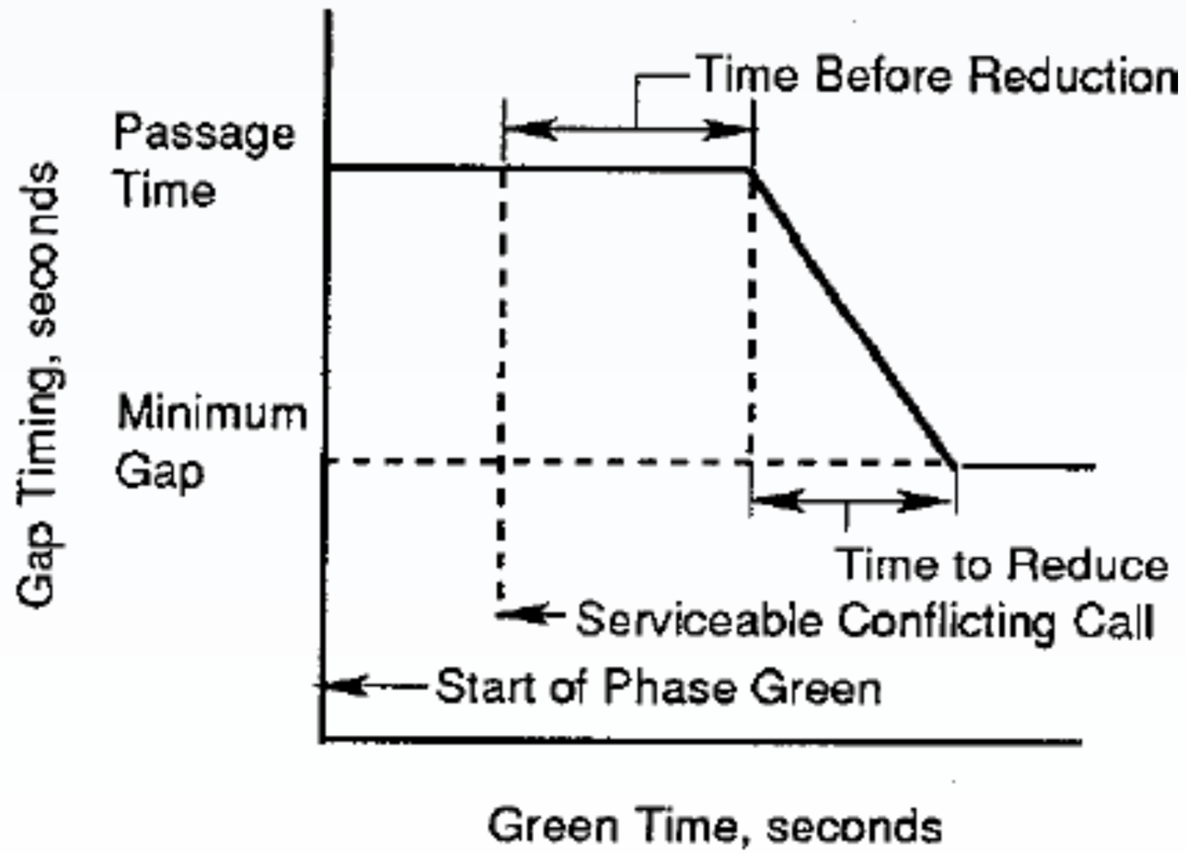
$$G_{min\_ped_1} = 10s$$

Vehicle	Detection (s) Phase 1	Detection (s) Phase 2
1	0	
2	3	
3	4.5	
4	6	
5		6.5
6	7.5	
7		8
8	14	
9	18	
10	19.5	

REAL-TIME SIGNALS

Real time traffic signals function similarly to ordinary actuated signals, but:

- necessarily have queue size detection (full presence detection) and
- vary extension and interval time (I and Δt) over the cycle and according queue sizes on the opposing phases.
  - This is to “close-in” on a phase change to limit excessive delay of the opposing movement.
- In addition, default cycle times and green split may be calculated instantly (at the start of the cycle) from real-time traffic counts using the optimal cycle time methodology from the previous chapters.


Time Before Reduction
Passage Time
Minimum Gap
Gap Timing, seconds
Time to Reduce
Serviceable Conflicting Call
Start of Phase Green
Green Time, seconds

NETWORKED SIGNALS

Most large municipalities are slowly moving towards fully networked and integrated traffic control grids.

- Data link with a centralized server or substations.
  - CAT5 or fiber; wireless in very special cases, but limited reliability
  - Remote control of the signal state
  - Traffic data transmission if available: counts and video feed
  - Issues of network timing—a delay of a few milliseconds can throw off an entire plan or coordination scheme over several cycles
  - Other issues of reliability with networking (even wired)
- Therefore, the system is still operated by a local microcontroller, a backup microcontroller, and a failsafe "flashing red" mechanism.

A fair amount of overlap with computer science and electrical engineering.

Networked signals are typically deployed using fully integrated commercial management solutions.

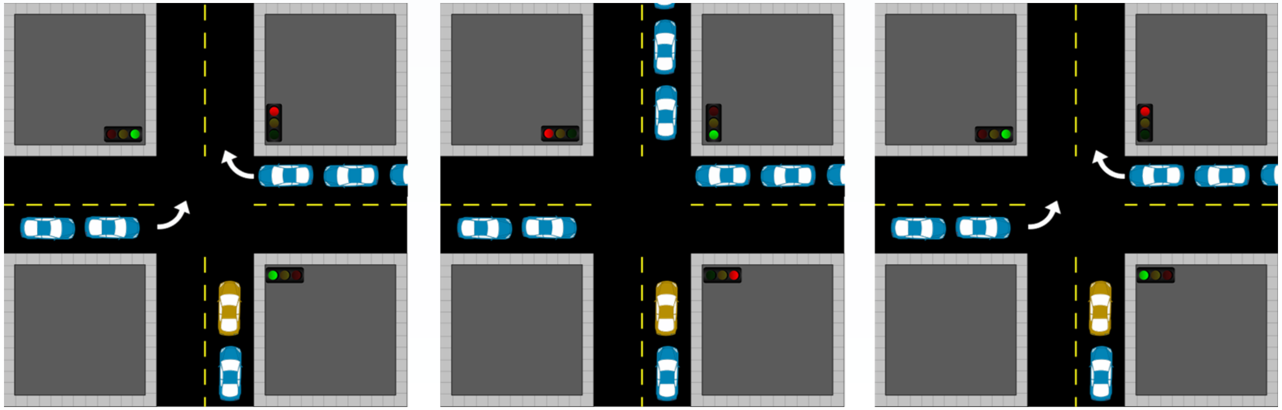
- Traffic signal optimisation
- Actuated control-schemes
- Real-time traffic demand analysis
- Signal coordination

The earliest systems: **S**ydney **C**oordinated **A**daptive **T**raffic **S**ystem (SCATS, 1982), SCOOT

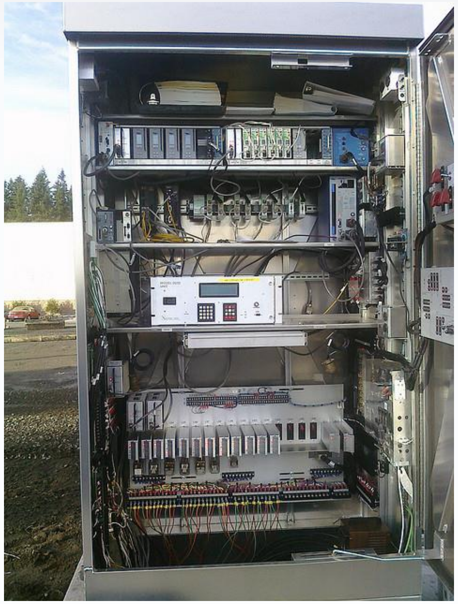
ADVANCED TOPICS

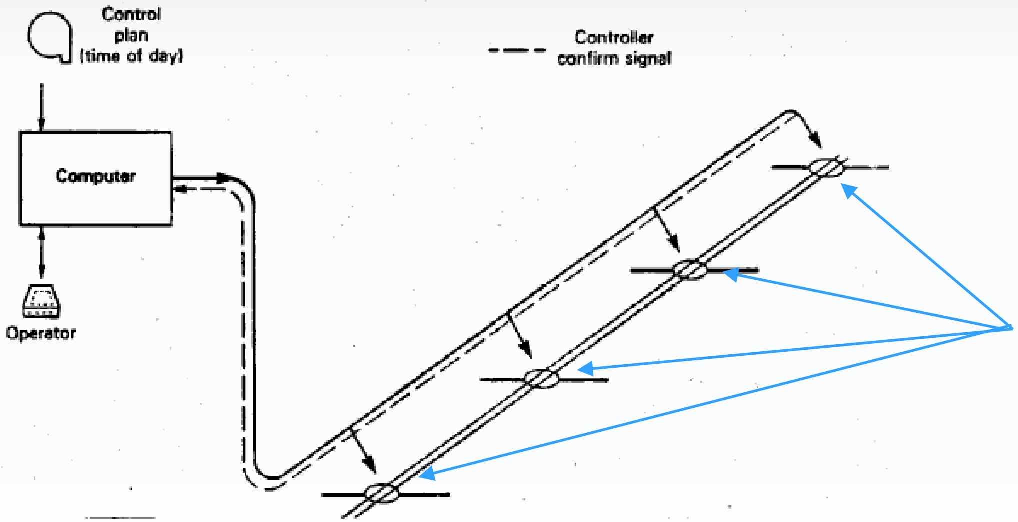
In addition to the previous functions, networked signals offer the possibility of implementing more advanced schemes:

- Communicate and anticipate demand for nearby signals
- Network load balancing (simple or game theory)
- Resolve issues with resonant cycling



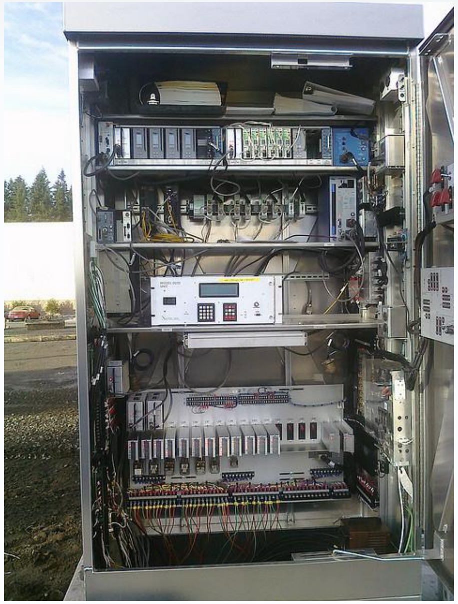
Basic (fix-time) system (~$40 000)

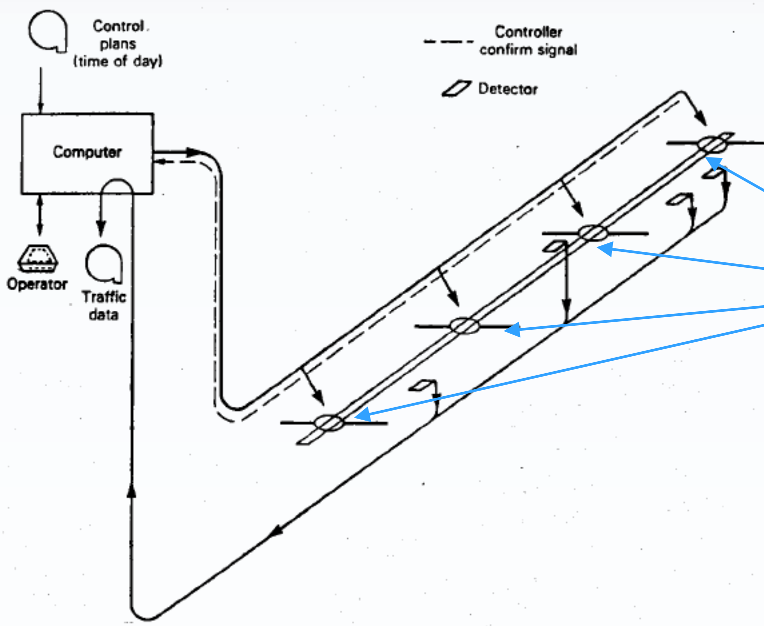




- No retro-action
- Cheap and reliable
- Signal plans do not adapt to non-uniform traffic demand
- Signal plans generated in TOD blocks according to demand history

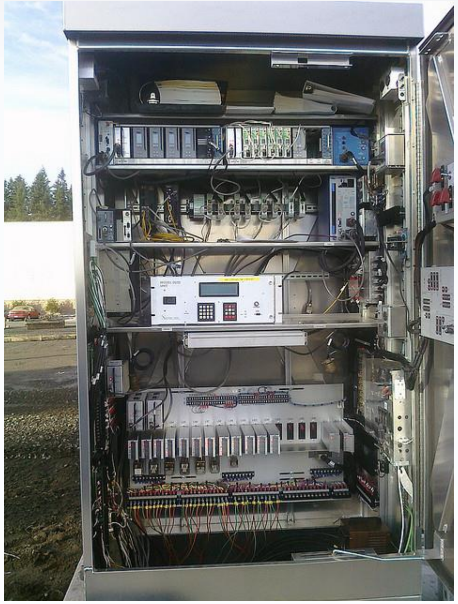
Actuated signal control (~$45 000)

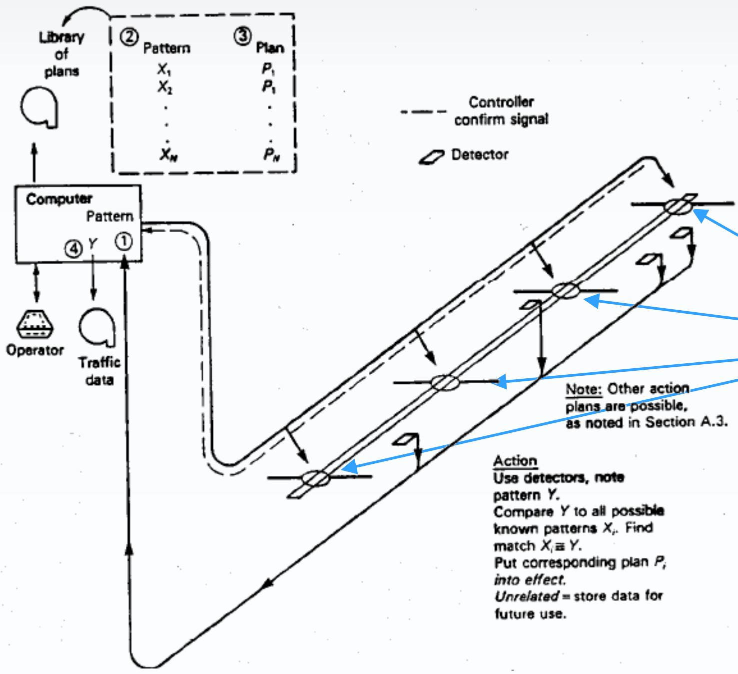




- No retro-action
- Moderate cost, but subject to issues of reliability
- Signal plans can adapt to non-uniform traffic demand
- Signal plans generated in TOD blocks according to demand history

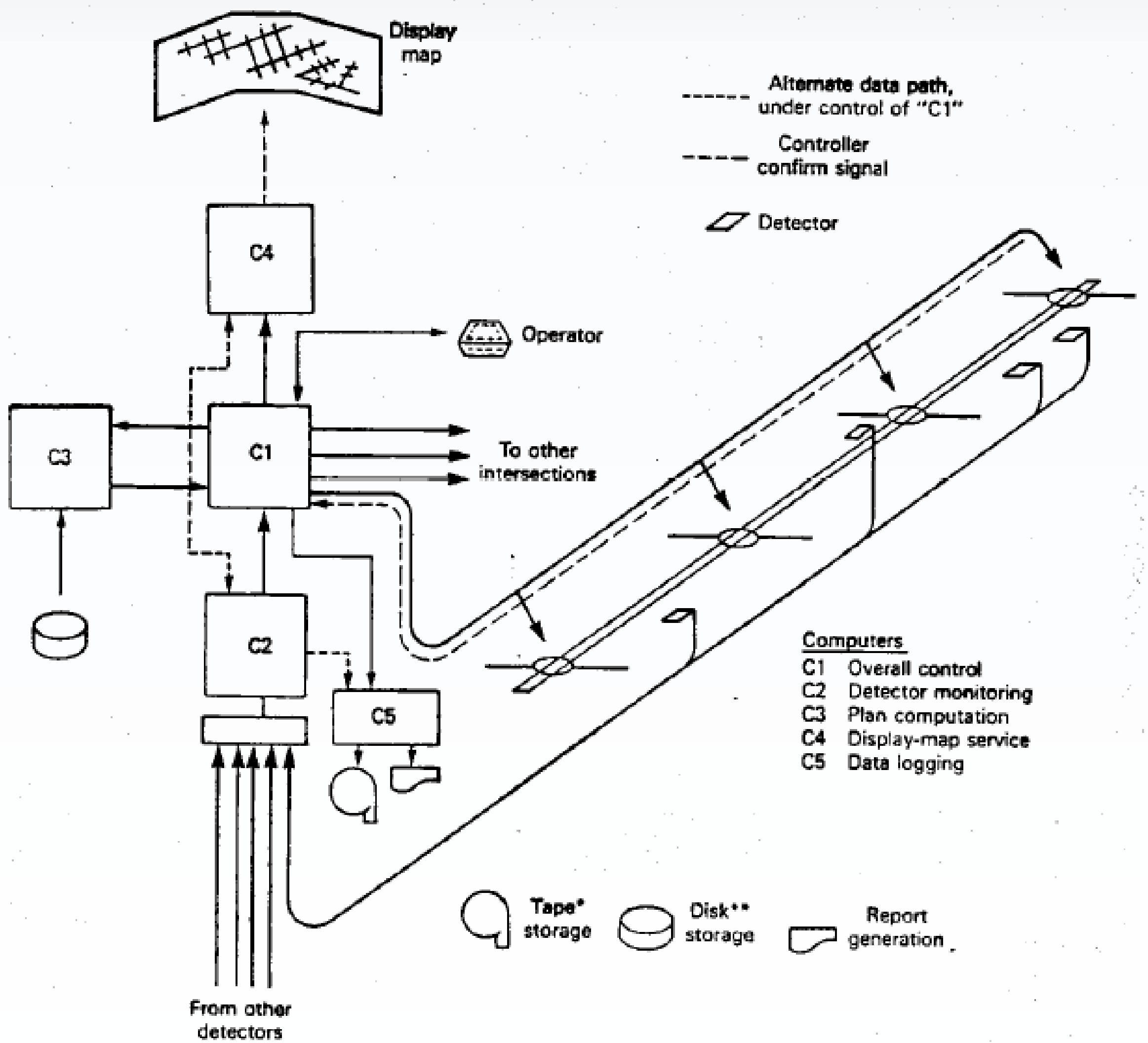
Real-time control (~$50 000)





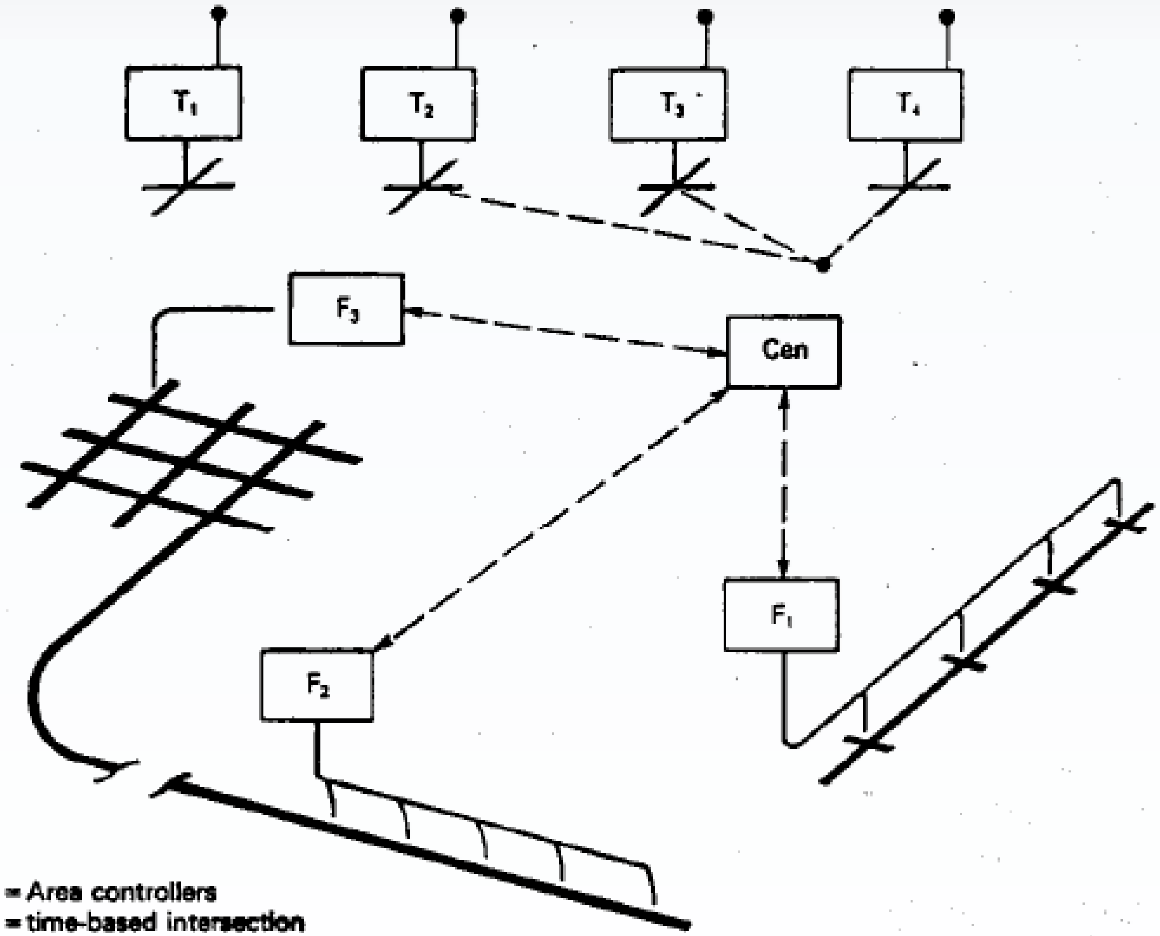
- Expensive and subject to issues of reliability
- Signal plans can adapt to non-uniform traffic demand and to queue length
- Signal timings generated on the fly (or every 2 to 15 min) based on recent and local detector data
- Signal phases from a library of options suited for demand

Centralised system



*Intent is lower access speed. **High speed: algorithms needed by "C3" is one example.

Decentralised system



F1, . . . F3 = Area controllers
T1, . . . T4 = time-based intersection controllers, with radio link
Cen = central control

(Limited) communication of trends, deviations,

LEVEL-OF-SERVICE

Procedure is essentially the same as with fixed-time signals (HCM 2010), except where mentioned otherwise.

- Expect less delay and better LOS overall as green time is actuated on-demand.
- Approaching saturation, actuated and real-time traffic control isn't appreciably more effective than simple fixed-time control. At this stage, network load balancing becomes much more important.

ACTUATED YELLOW

A special application of signal actuation is actuation of the yellow signal in order to avoid the dilemma zone.

- A detector is placed in such a way as to cover the entire length of the dilemma zone.
- Upon normal phase change, if a vehicle is detected traveling within the dilemma zone, the green time may be extended to allow the vehicle to pass safely.
- Benefits are limited in congested flows where the controller may not be able to find a gap larger than the dilemma zone.
- Primarily justified in high-speed zones.

D-50-1

Le panneau D-50-1 doit être installé en amont d'une intersection lorsque les deux conditions suivantes sont présentes :

- la vitesse affichée est de 80 km/h ou moins;
- la distance permettant de voir les feux de circulation est inférieure à la distance indiquée au tableau 3.9–1.

Ce panneau doit également être installé pendant un mois suivant l'installation de nouveaux feux de circulation.

Tableau 3.9–1
Distance de visibilité des têtes de feux

Vitesse affichée (km/h)	Distance mesurée depuis la ligne d'arrêt (m)
30	50
50	100
60	150
70	200
80	250
90	300
100	400

3.10 Préparez-vous à arrêter

Les panneaux « Préparez-vous à arrêter » (D-60-1 à D-60-4), ainsi que les feux de circulation associés dans le cas du panneau D-60-1, doivent être munis d'un système de relève afin de s'assurer que le fonctionnement des clignotements ou des phases programmées se fait normalement.

Le panneau « Préparez-vous à arrêter » (D-60-1) indique, à l'avance, la proximité d'une intersection comportant des feux de circulation et, par le clignotement des feux jaunes, que ces feux passeront au rouge.

D-60-1

Le clignotement alterné des deux feux du panneau D-60-1 doit débuter avant la fin de la phase verte des feux de circulation et se prolonger pendant toute la durée de la phase rouge de l'approche signalée.

Le début du clignotement doit être calibré de façon à permettre à l'usager de la route arrivant à la hauteur du panneau, juste avant que les feux clignotent, d'atteindre le carrefour, en respectant la vitesse affichée, avant le début de la période de dégagement des feux de circulation.

Le panneau « Préparez-vous à arrêter » (D-60-2) indique, à l'avance, la proximité d'un passage à niveau et, par le clignotement des feux jaunes, que les feux lumineux, au passage à niveau, clignotent.

D-60-2

Contenu réglementaire

Contenu normatif

That's all for today!