

CIVE 440

Traffic Engineering and Simulation – Coordination



McGill

Faculty of Engineering

Department of Civil Engineering and Applied Mechanics

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BENEFITS

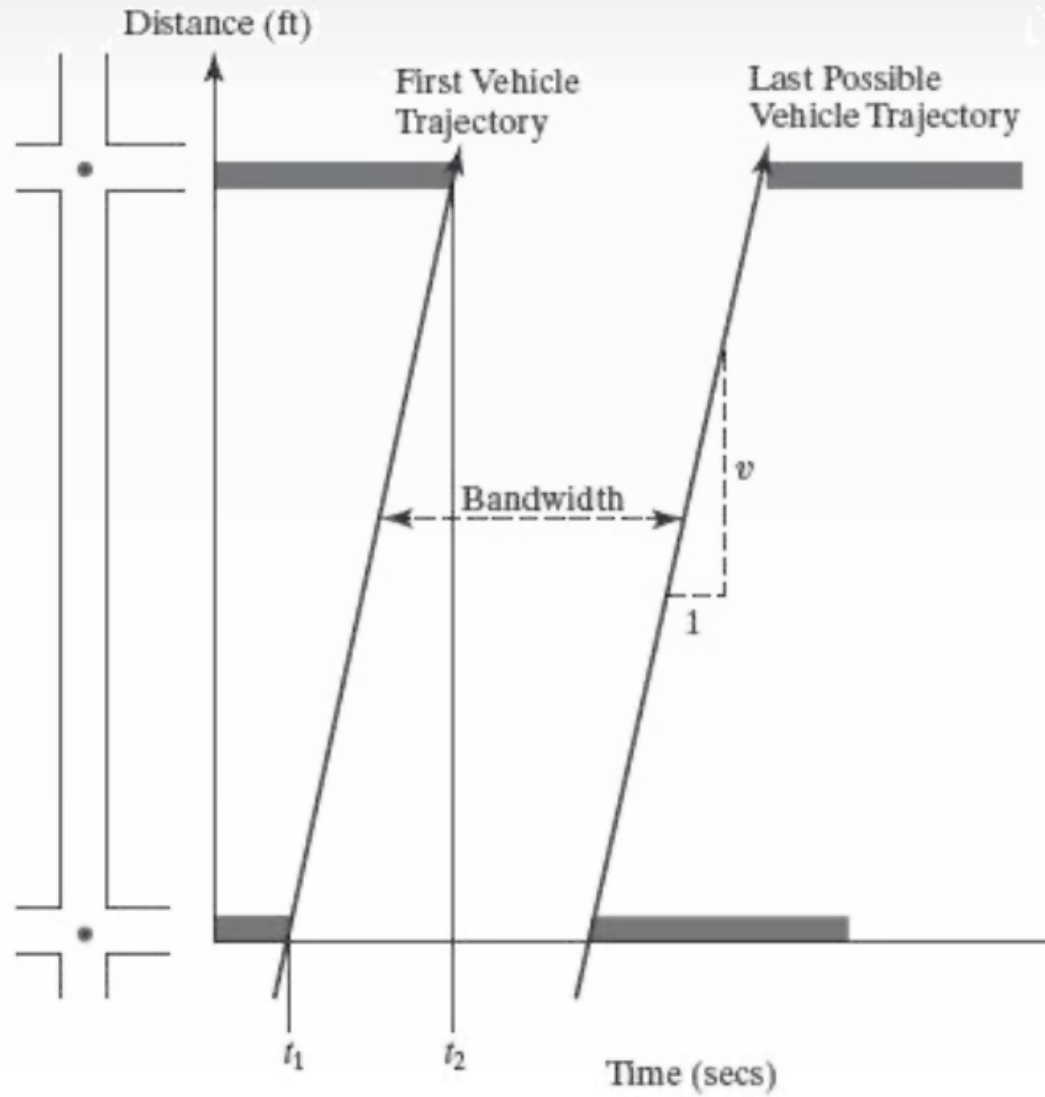
The objective of **traffic light coordination** is smoothing of traffic progressions and continuous platoon movement. Coordination provides the following advantages:

- Reduced number of stops
 - Fewer delays, faster travel times
 - Reduced gas consumption and air pollution (from idling and acceleration action)
- Better fluidity
 - Marginal increase in capacity and system efficiency, sometimes
 - Can alleviate some gridlock breakdowns
- Influences driving speed, or implements traffic calming

CHALLENGES

The efficiency of coordination depends on a certain degree of homogeneity of the network. In extreme cases, coordination can hinder fluidity!

- Lateral friction (parking, drive-ways, delivery trucks, turning queues, etc.)
- Shared cycle length means individual intersection optimisation cannot be achieved
 - Particularly the case for highly complex intersections and actuated traffic lights*
- Variable geometry (problem in Montreal):
 - speed limits
 - approach distance
- Direction of travel



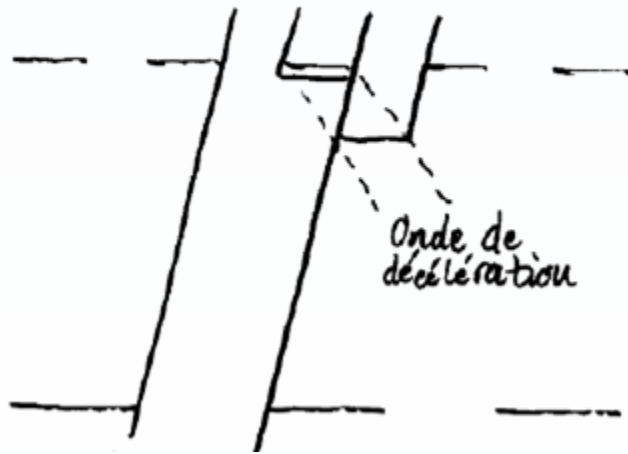
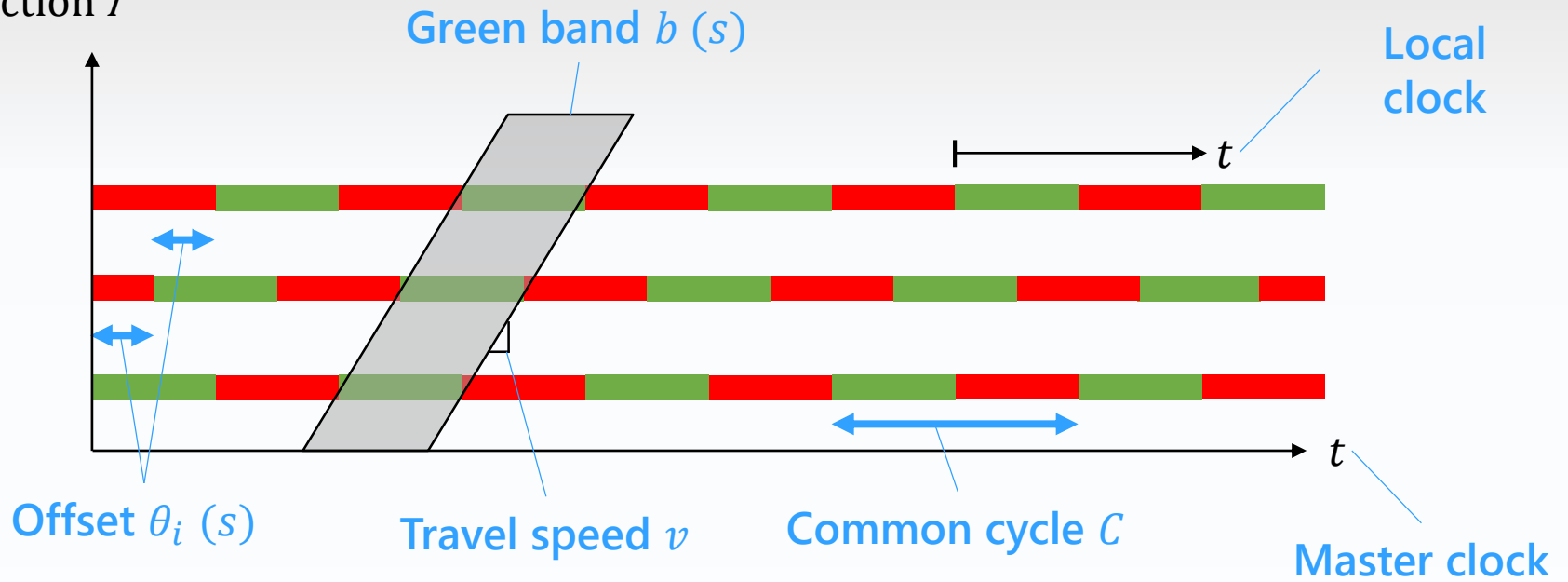
PARAMETERS

The **offset** θ_i between the intersection i and the upstream intersection $i - 1$ is the offset between the two starts of the green over the common cycle length.

- At the most basic level, it represents the travel time $t_2 - t_1$, such that intersection i will turn green just before users arriving from intersection $i - 1$ arrive.

The **cycle length** is shared among all intersections such that they stay in phase with one another. For optimal efficiency, the **effective green time** should be shared too, though this is not strictly necessary.

Intersection i



Good progression



Poor progression

MEASURES OF EFFECTIVENESS

Band efficiency E :

$$E = \frac{b}{C} \times 100\%$$

- Notice that the **band width** b (in seconds) is generally limited by the smallest effective green time, i.e. $\min(g_i)$, thus the utility of using similar effective green times everywhere if possible and reasonable.
- E between 40 and 50% or more is considered good.

Band capacity Q_b :

$$Q_b = \frac{3600 \times b \times N}{h \times C} \text{ veh/h}$$

where: h = saturation flow rate (s)
 N = number of lanes being served (ln)

Note that if the corridor is saturated (demand $> Q_b$), the efficiency of the coordination will quickly disintegrate as progressively larger overflow queues form (more on this shortly).

IDEAL OFFSET

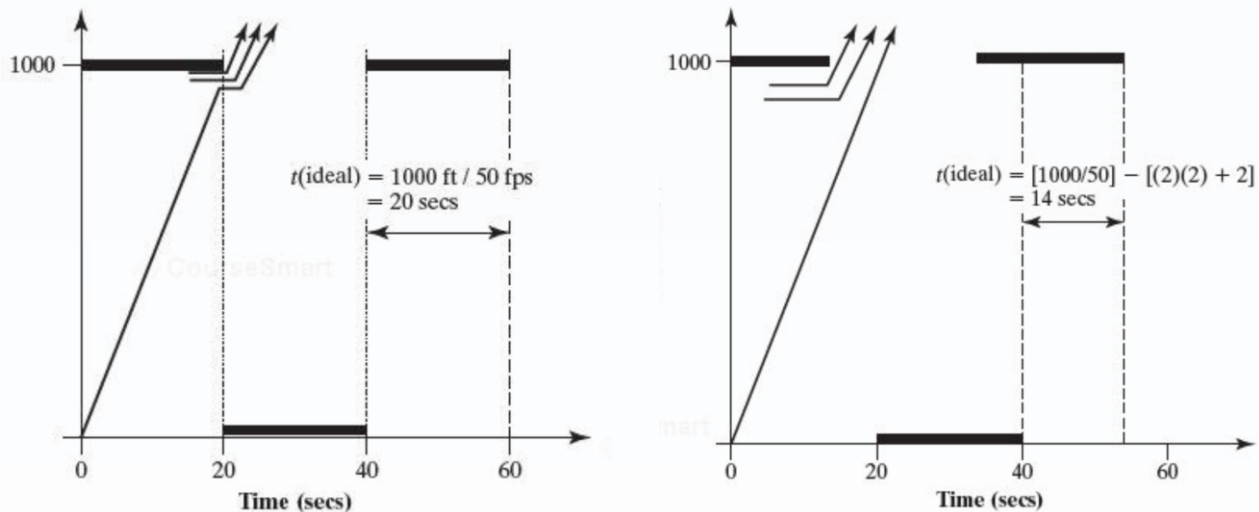
Allows a vehicle leaving intersection $i - 1$ at the start of the green to obtain a green light just before arriving at intersection i .

$$\theta_i = \frac{D_i \times 3.6}{v}$$

where: D_i = travel distance between the two intersections
(in metres); $300m < D_i < 800m$
 v = travel speed of the platoon (km/h)

How to manage downstream queues?

- Reduce the delay pre-emptively, such that the queue will have dissipated by the time the first vehicle arrives at the intersection i .



$$\theta_i = \frac{D_i \times 3.6}{v} - t_q$$

where: t_q = queue dissipation time

ESTIMATION OF QUEUE DISSIPATION TIME

Rudimentary estimation:

$$t_q = PIEV + \frac{L_q}{\omega}$$

where: $PIEV$ = reaction time (2 to 4 seconds)

L_q = queue length (metres)

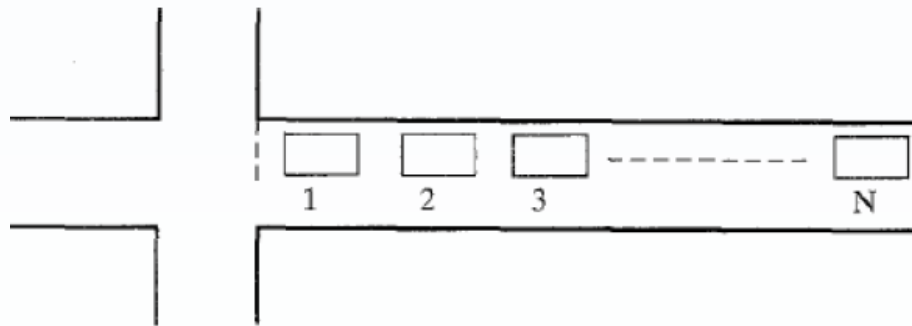
$\omega = \frac{Q_{capacity}}{k_{queue}}$ dissipation speed, approximately
 $\sim 10m/s$

Estimation with queue model:

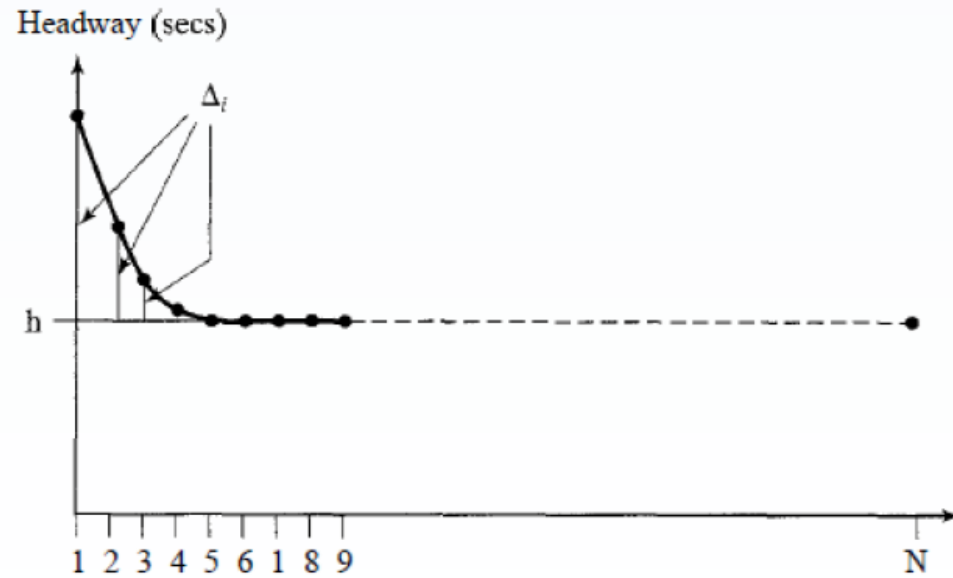
$$t_q = \sum_{i=1}^N h_s + \Delta t_i$$

where: h_s = saturation headway (s)

Δt_i = lost time per vehicle i at intersection



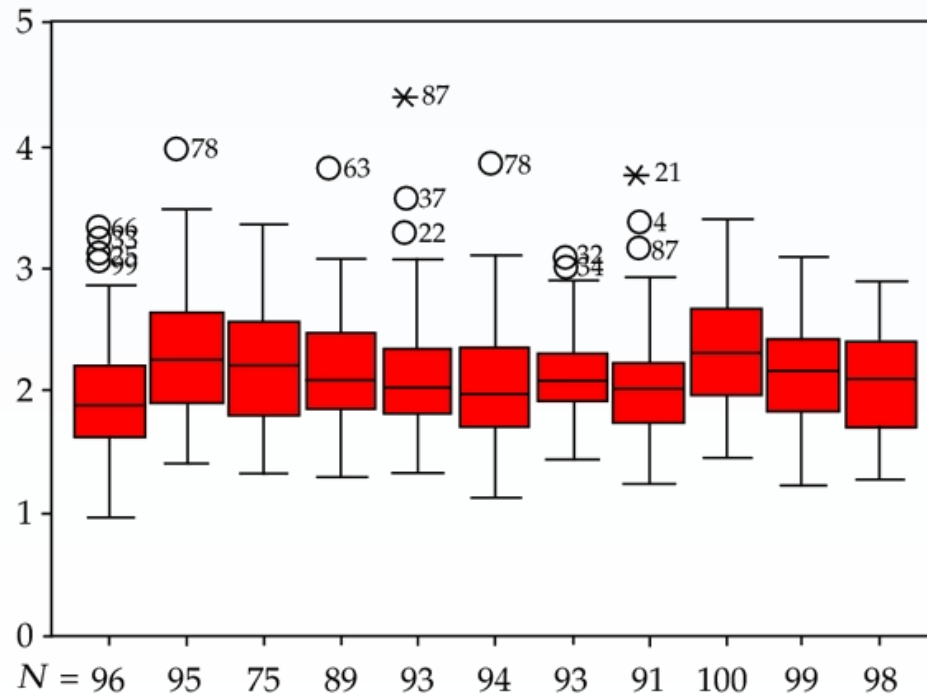
(a) Vehicles in an Intersection Queue



(b) Average Headways Departing Signal

Δt_i is typically a decay model as a $f(i)$, the sum of which is l_1 . See Chapter 4 for more details.

Typical saturation headway ~ 2 seconds.



<http://www.hindawi.com/journals/ddns/2012/720474/>

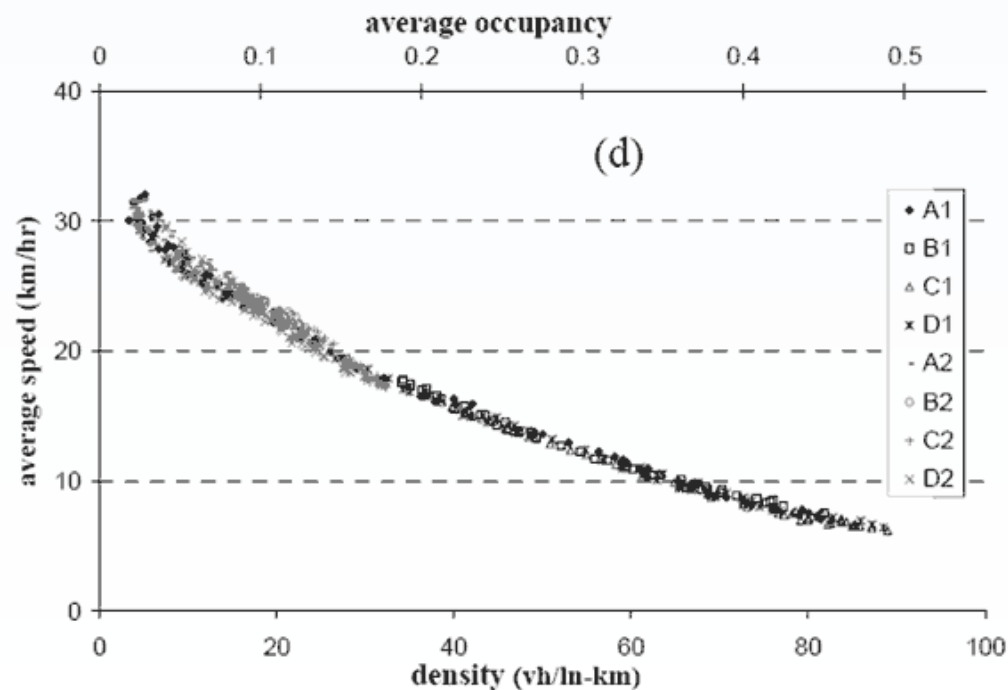
TRAVEL SPEED OF PLATOON

The design speed used can influence behaviour, according to design policy:

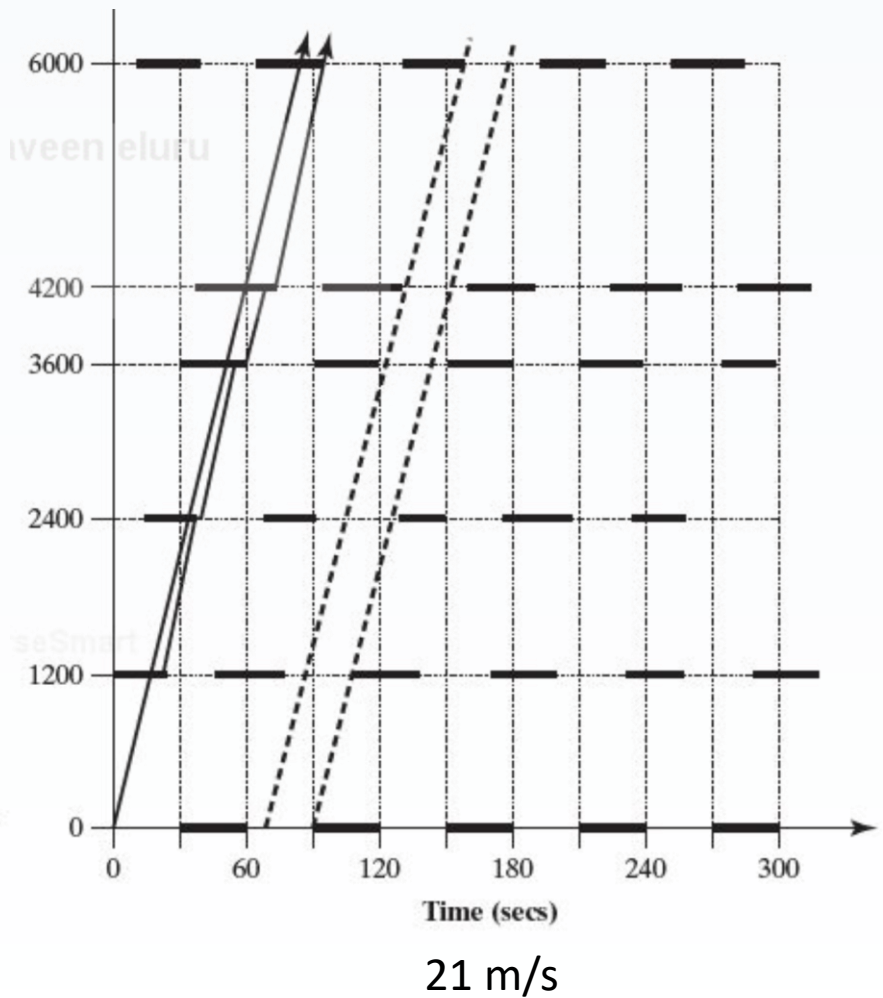
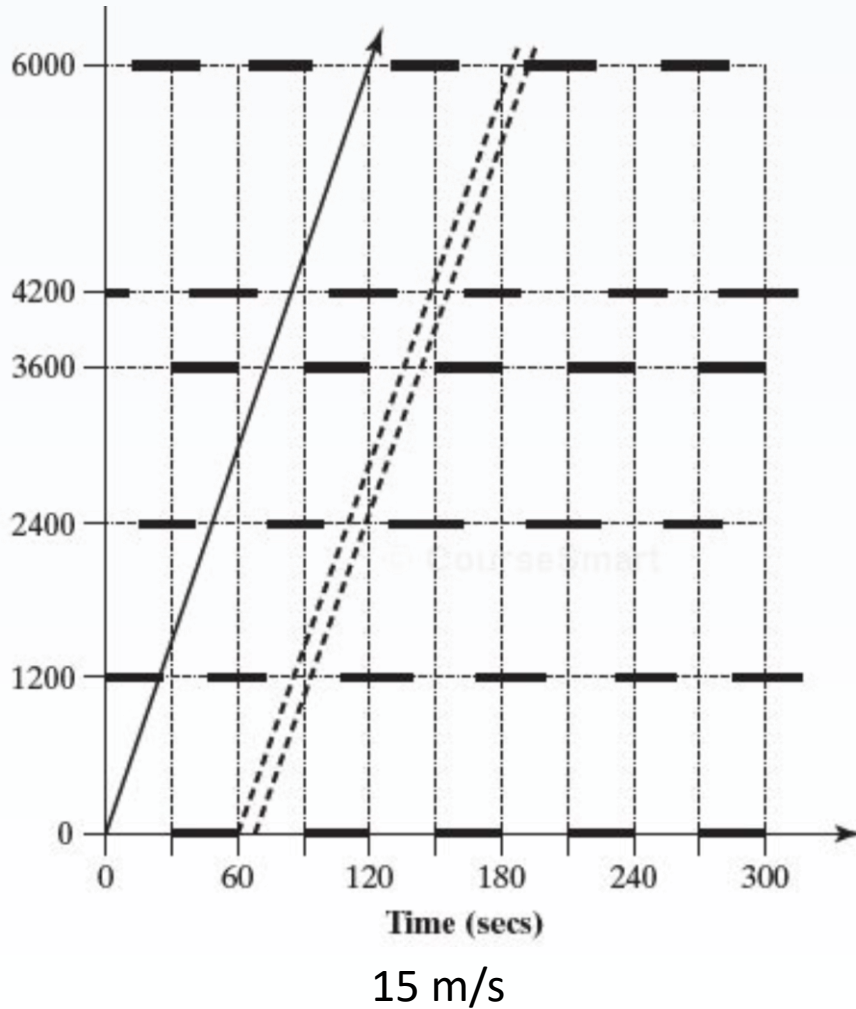
- Speed limit
 - Upper constraint on design speed focusing on safety
 - Default state for motorised traffic, except for situations of congestion
- Average speed
 - Focus on capacity
 - Better adapted for average speeds under the speed limit, due to congested conditions (and thus lower speeds) or other factors
- Free flow speed
 - Focus on comfort

Estimate speed using a traffic model if travel speed data is missing or there is high variability, e.g. Greenshields or Greenberg.

$$v = \frac{q}{k}$$

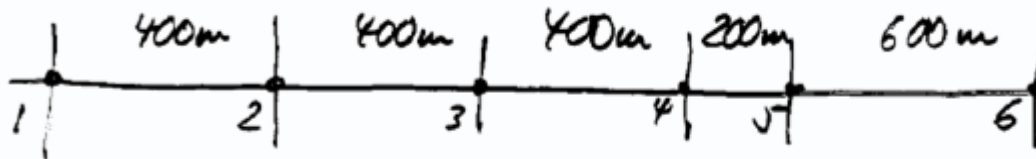


Compare progression for different (actual) driving speeds when using 18 m/s as the design speed:

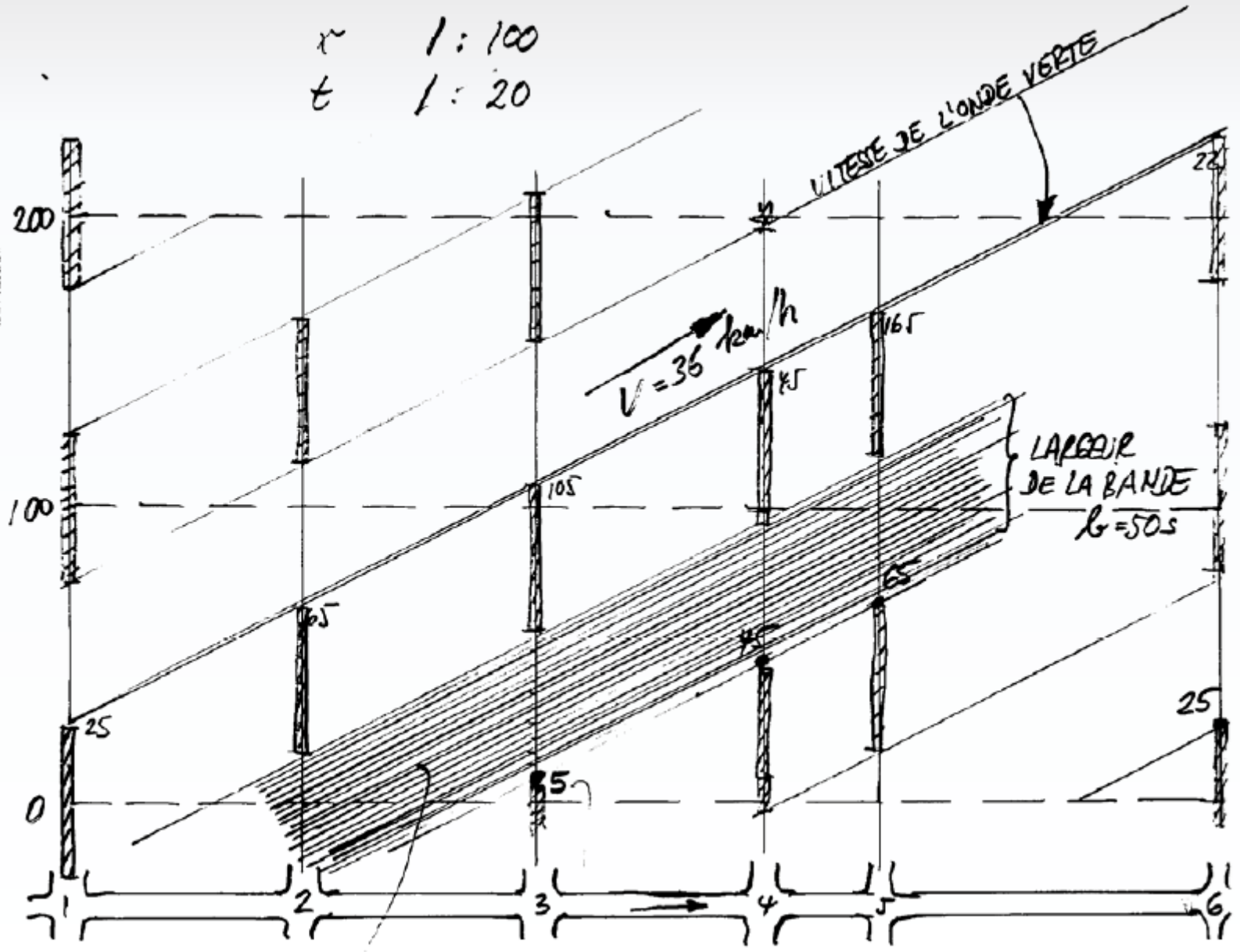


EXAMPLE

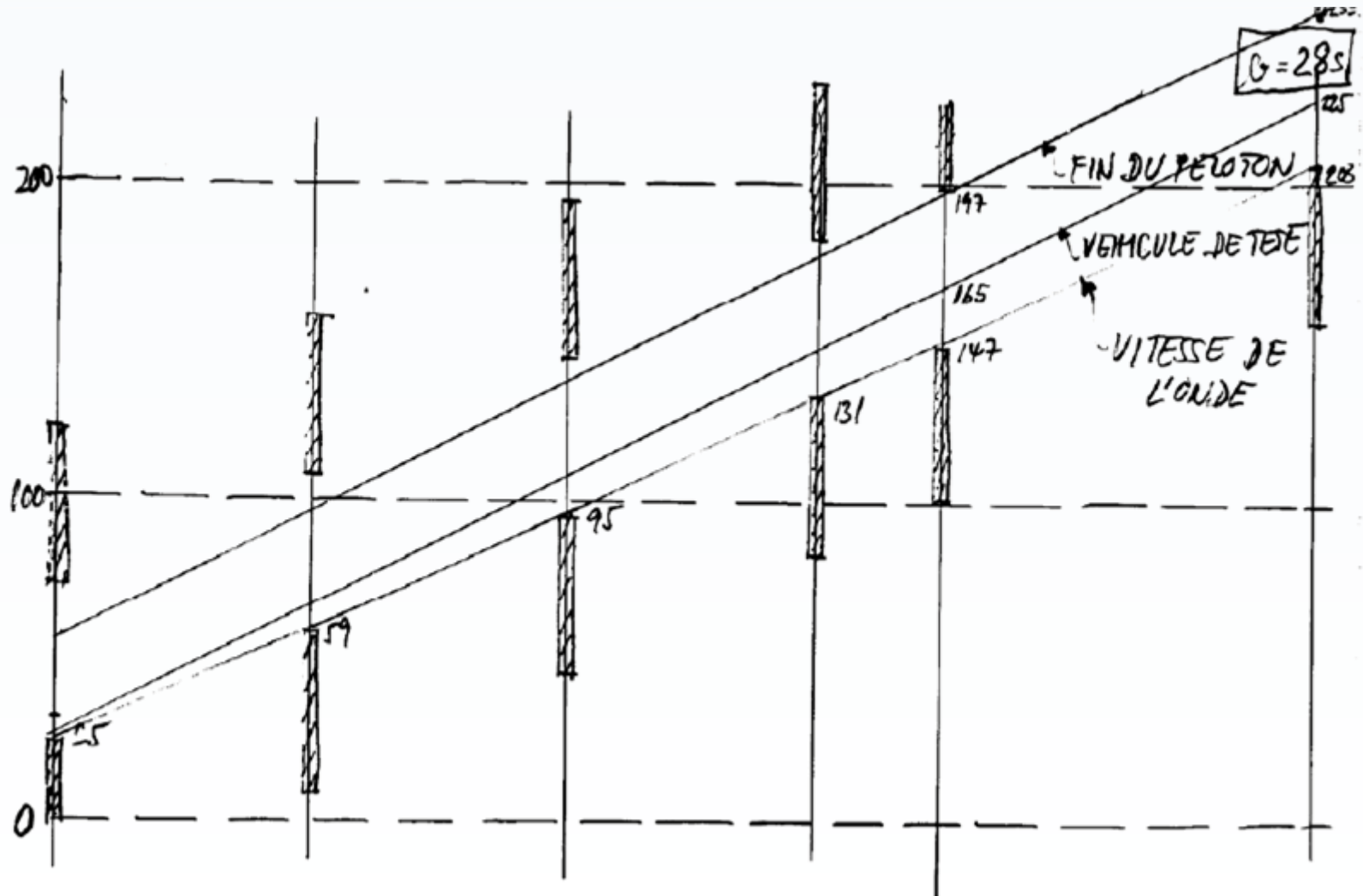
Determine one-way coordination, knowing that $C = 100\text{ s}$, $v = 36\text{ km/h}$, and there is a 50/50 green split.



r 1:100
 t 1:20



The same example assuming an average queue length of 2 vehicles per cycle at each intersection:

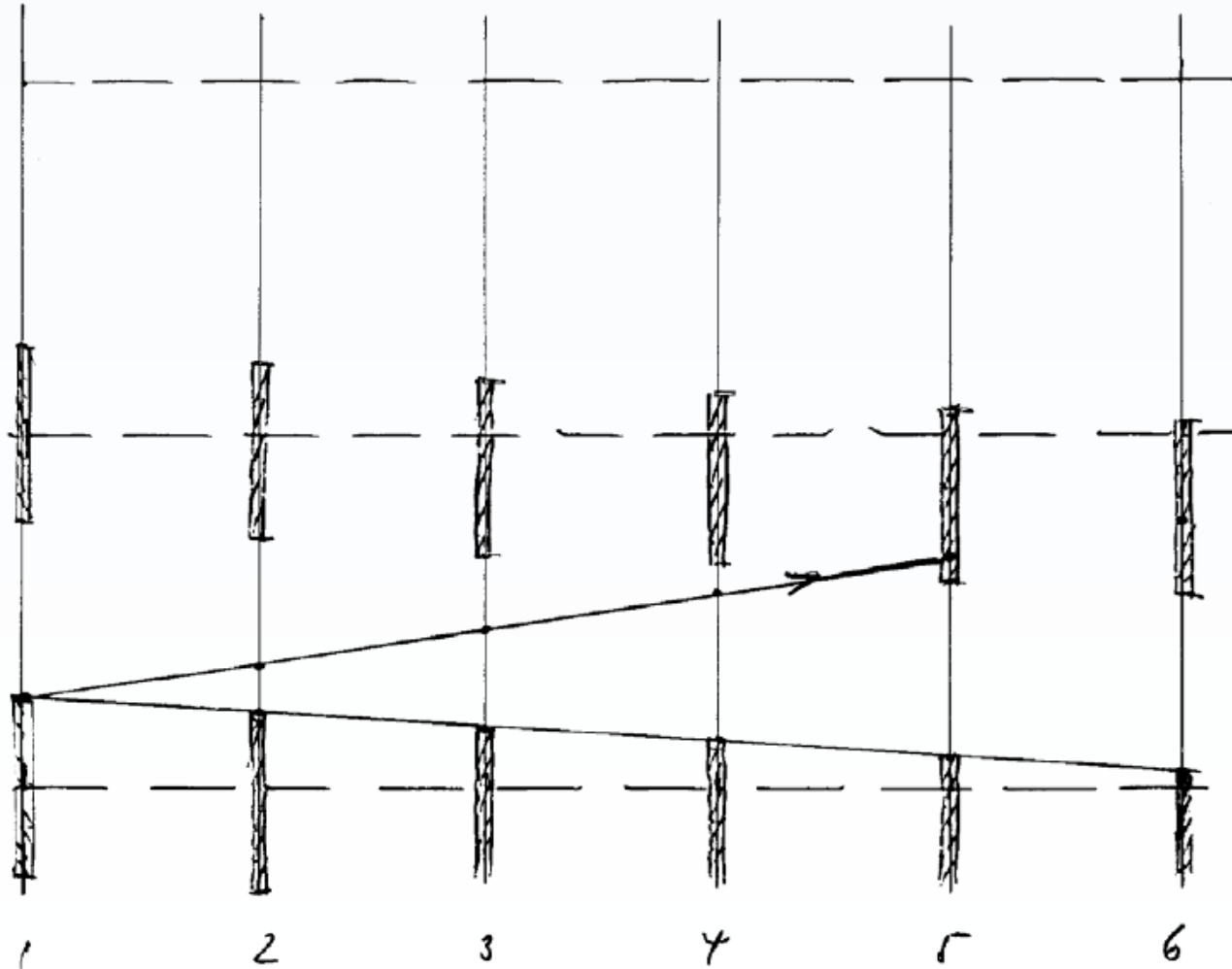


Notes:

- Coordination can follow the turning lane of an intersection with high turning ratios (typically when left or right turns are > 50%).
- It is possible to experience reverse coordination (downstream lights turn green “before” the upstream lights). This occurs in high congestion, when the queue dissipation time is larger than the travel time ($n \times C > t_q > \frac{D_i \times 3.6}{v}$).
- It's also possible to use coordination as a **traffic calming measure** or to discourage use of a particular road by intentionally placing arrivals out of phase (red light upon arrival). This can frustrate drivers and even local residents, so it is used infrequently and must be implemented with great care!

Reverse coordination example when:

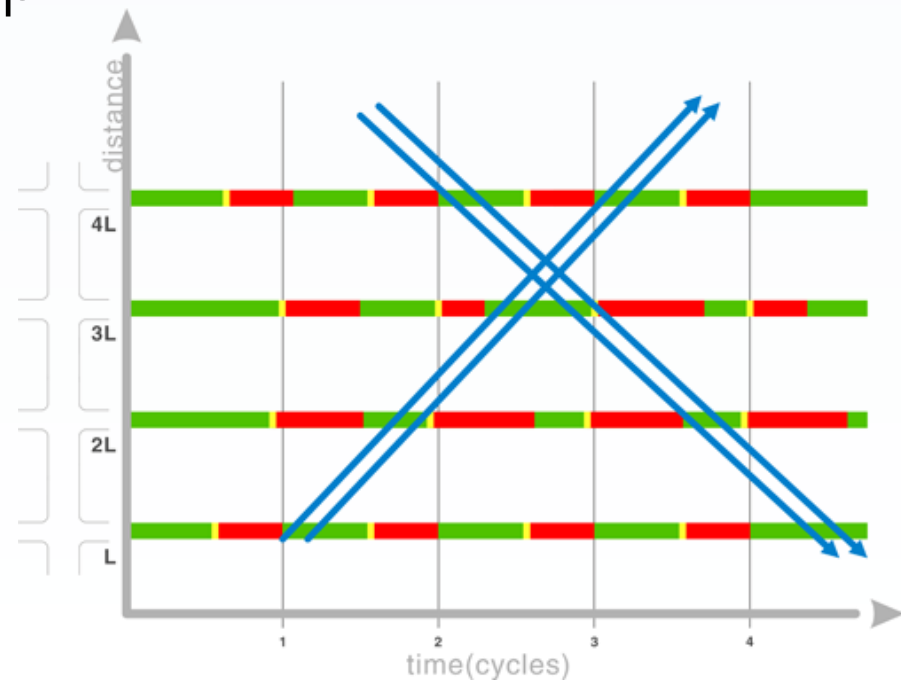
Average queue = 7 veh; $v = 60 \text{ km/h}$; $D_i = 167\text{m}$



DIRECTION OF COORDINATION

A **coordination group** or **coordination direction** is a platoon of vehicles moving together along the same velocity vector (same direction and magnitude of rate of displacement). Each group generates a distinct offset.

- Typically two directions of travel for most streets
- Other distinct movements:
 - pedestrians
 - cyclists
 - public transit
 - service roads*

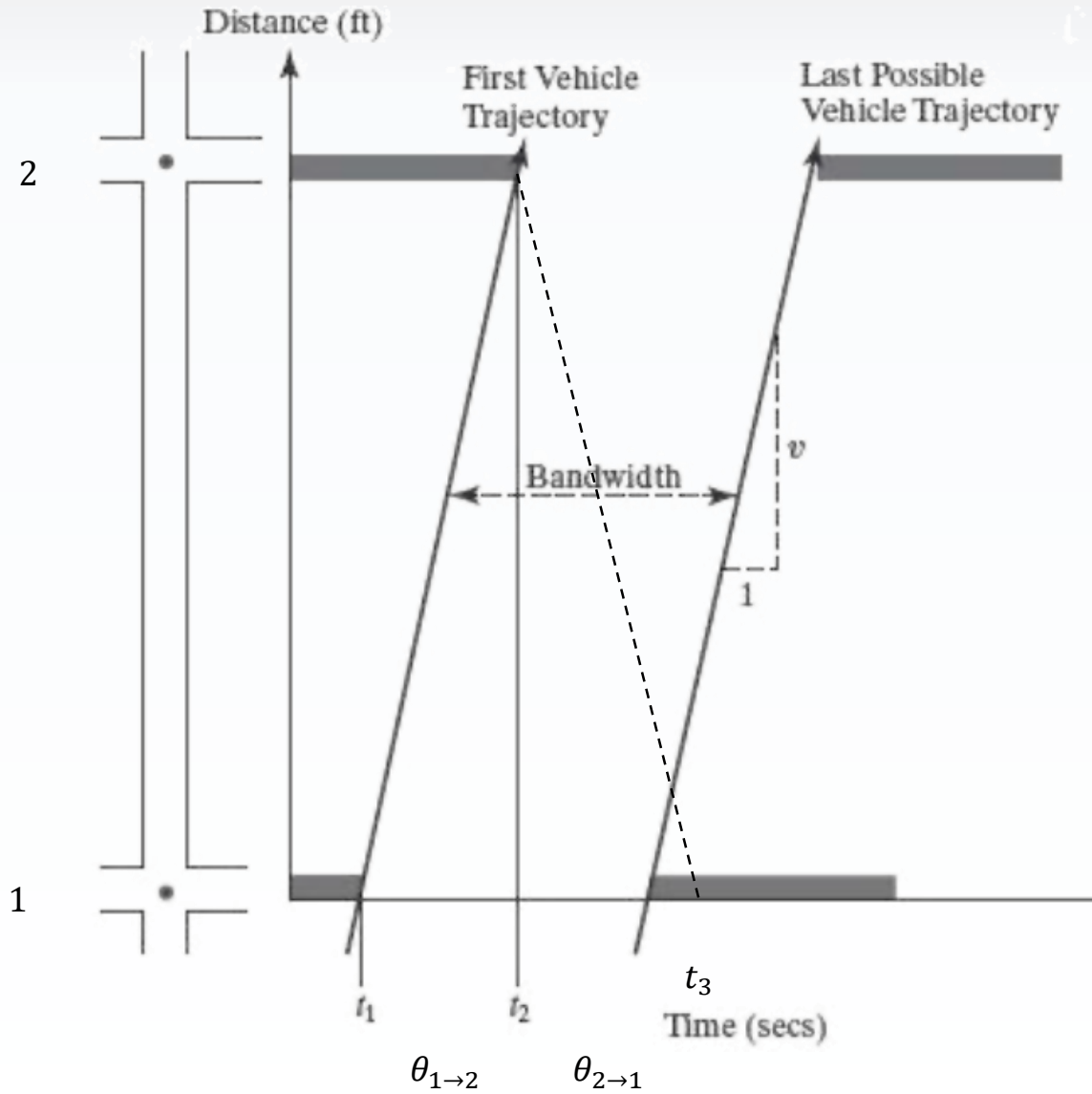


Single-direction coordination is easy, as each pair of intersections can be offset ideally and exactly once (relative to the upstream intersection).

Single direction coordination is typically used for **one-way arterials** (e.g. [University](#), [St-Laurent](#), [St-Catherine](#)). It can also be used on **two-way streets** where traffic is highly polarised.

- In this way, the congested direction is coordinated.

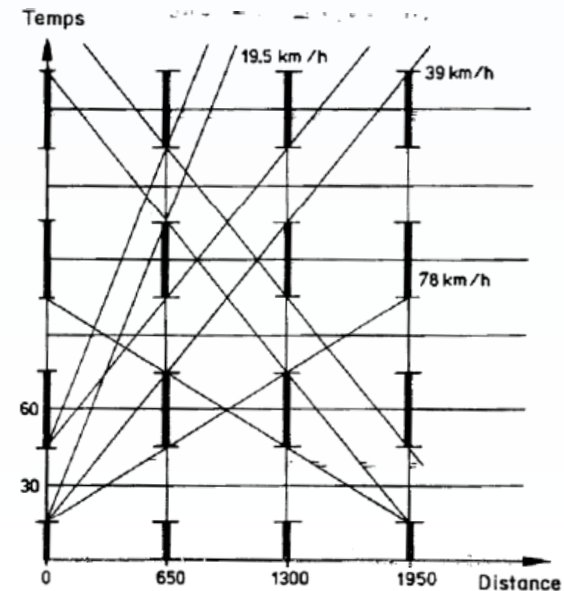
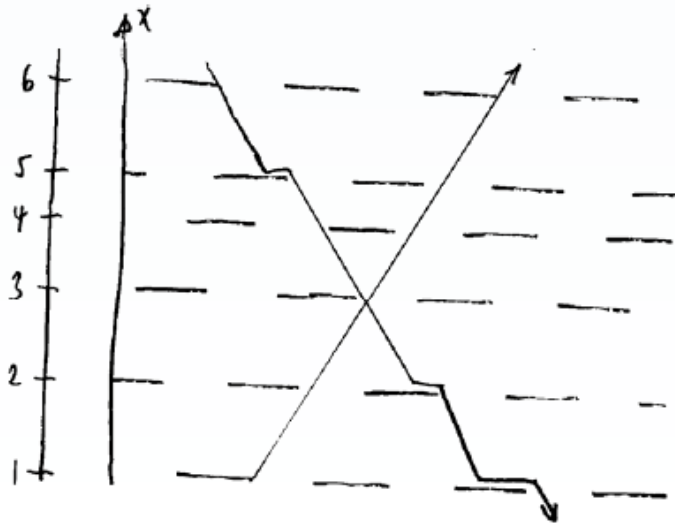
Coordination of multiple directions will generate multiple ideal offsets per pair of intersections, which will almost always conflict with one another.



TWO-WAY COORDINATION

Assuming intersection homogeneity, there exists a combination of C , D , and v that will still generate ideal offsets.

But when intersections are heterogeneous, there are no ideal solutions.



Montréal example:

$$g_{\text{Sherbrooke}} = 40s$$
$$C = 60s$$



124m

156m



Even for the same block (and same cycle length C and distance D), v can vary for coordination groups:

- Pedestrians



94m



$$g_{\text{St-Catherine}} = 35s$$

$$C = 70s$$

$$v_{\text{veh}} = 50\text{km/h}$$

$$v_{\text{ped}} = 5\text{km/h}$$

Even for the same block (and same cycle length C and distance D), v can vary for coordination groups:

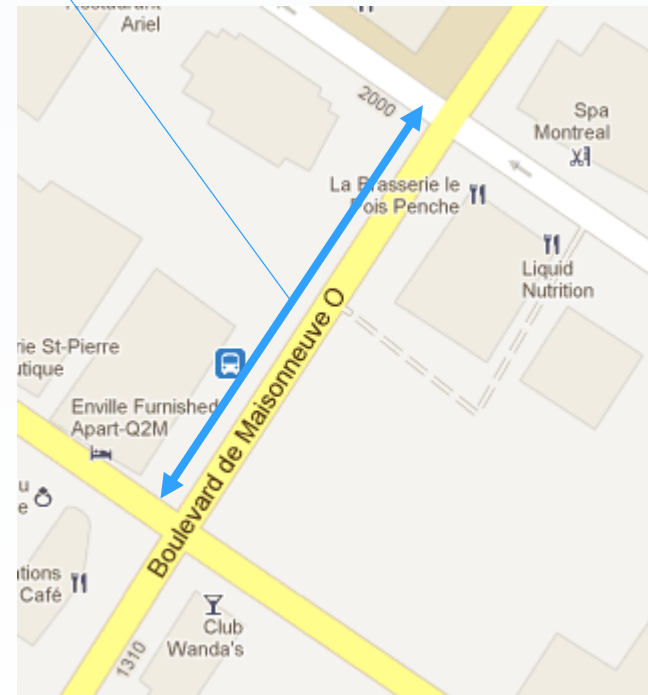
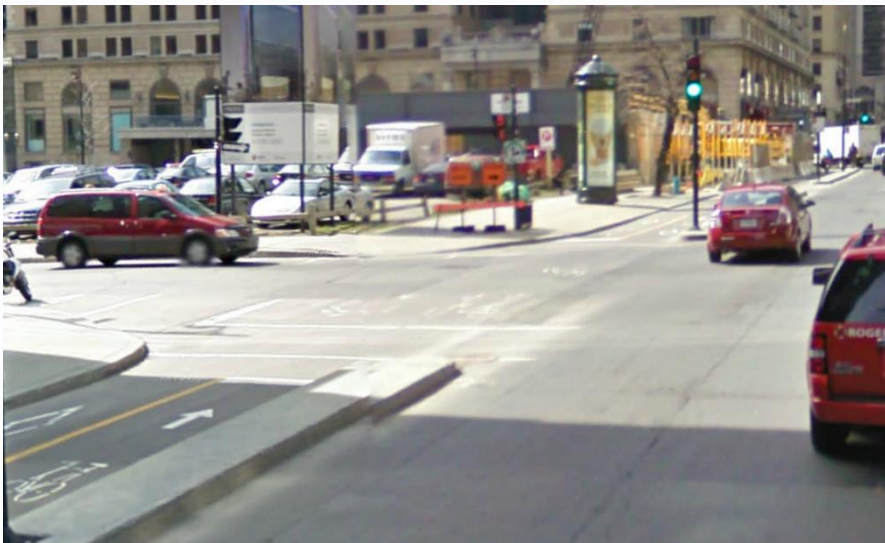
- Cyclists

$$g_{Maisonneuve} = 35s$$
$$C = 70s$$

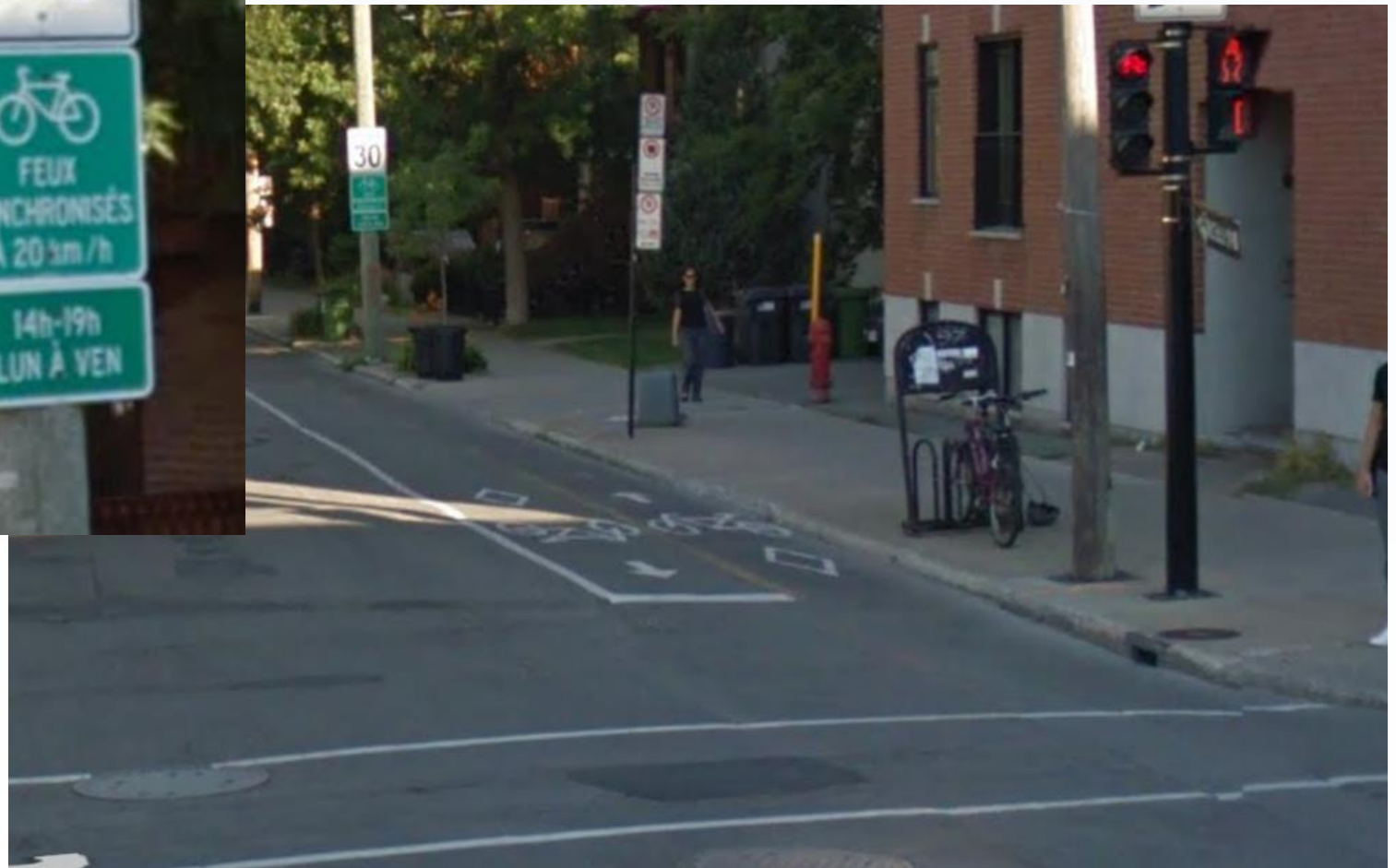
$$v_{veh} = 50km/h$$

$$v_{cyc} = 22km/h$$

103m



v_{cyc} varies between 10 and 30 km/h. Who to design for?

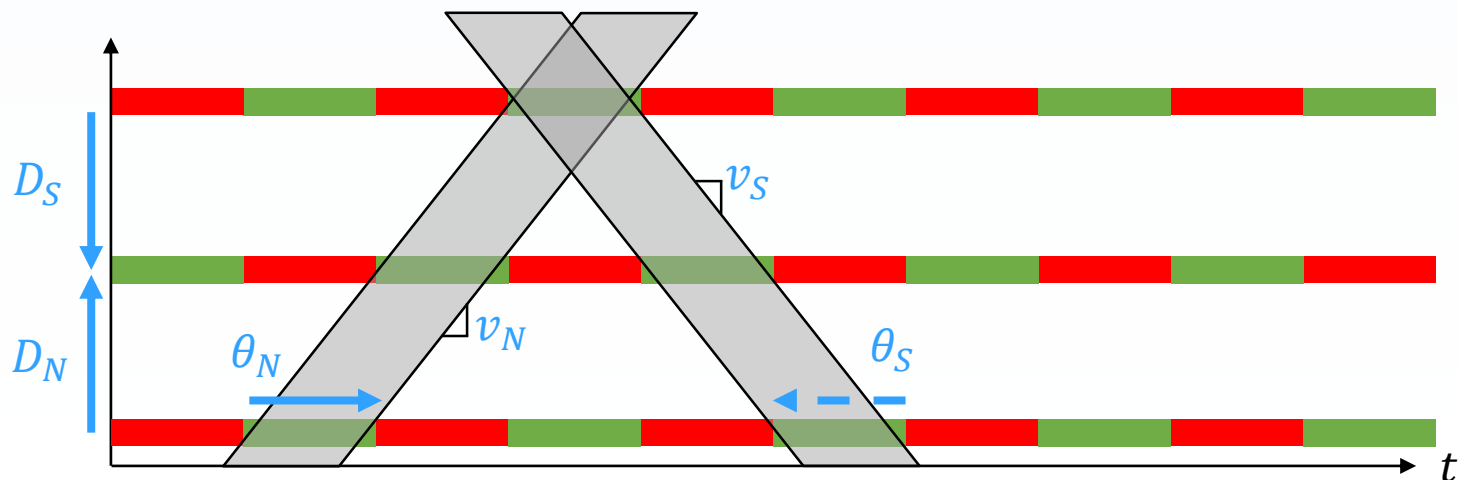


Ideal solution: $g_i = r_i$ (50/50 split), and choose D_i , C and/or v such that the travel time of both directions is in phase with the cycle length.

- Requires regular distances D_i and travel speeds v (or at least constant proportions between the two).

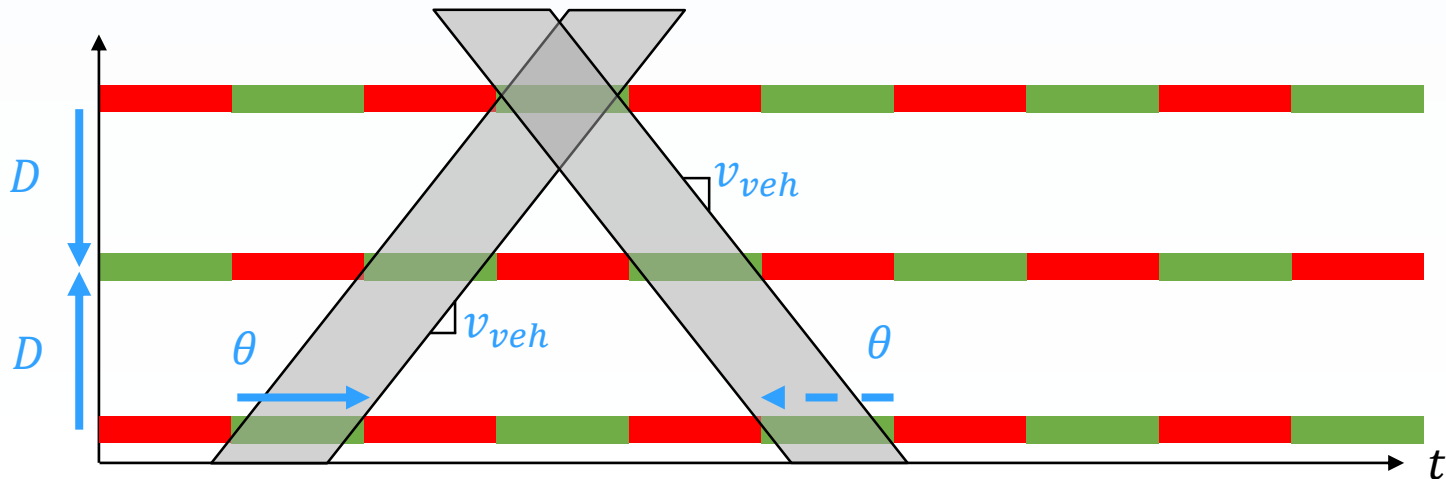
$$C = \theta_N + \theta_S$$

$$C = \frac{D_N \times 3.6}{v_N} - t_{qN} + \frac{D_S \times 3.6}{v_S} - t_{qS}$$



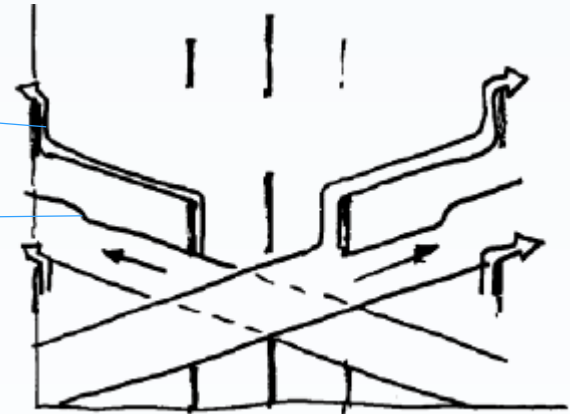
$$C = \frac{2D \times 3.6}{v} - t_{qN} - t_{qS}$$

- With $v_{veh} = 50km/h$ and no queues:
 - a cycle of 30 seconds requires $D_i = 208m$
 - a cycle of 90 seconds requires $D_i = 625m$
- Parameter constraints:
 - D_i typically inflexible, enormous reconstruction costs
 - Loss of efficiency of green split calculation for isolated intersections
 - Design speed may or may not be flexible (safety versus comfort)

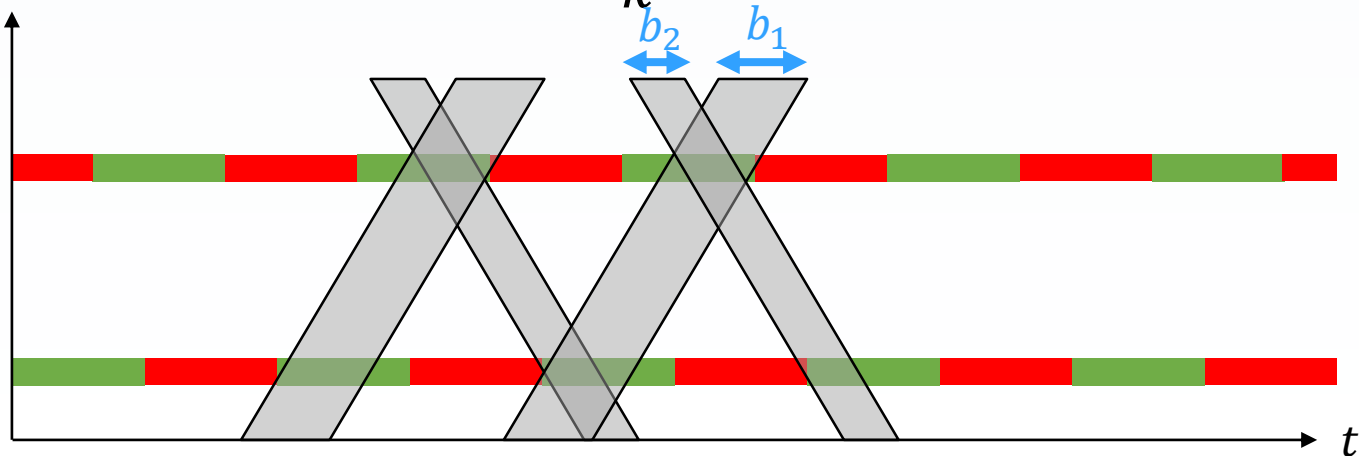


Otherwise, the bandwidth will be constrained and queues will form.

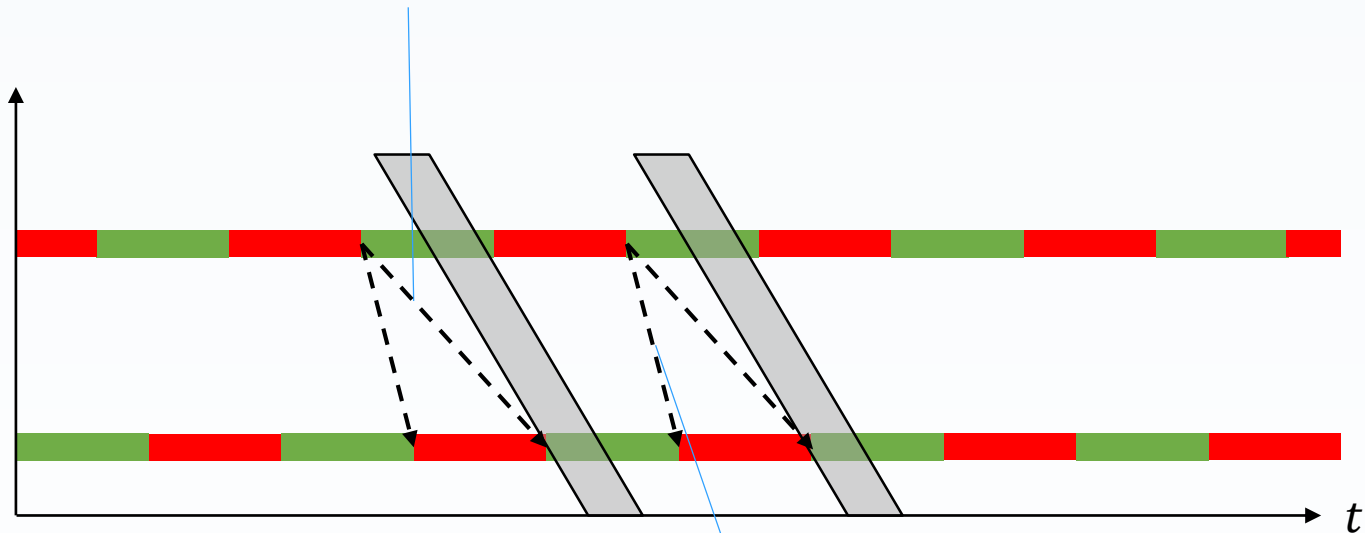
- Queue due to poor progression
- Queue due to saturation and progression overflow



Optimisation problem to choose a coordination offset scheme that maximises b_k for each movement k .



Traffic slow down?



Acceleration?

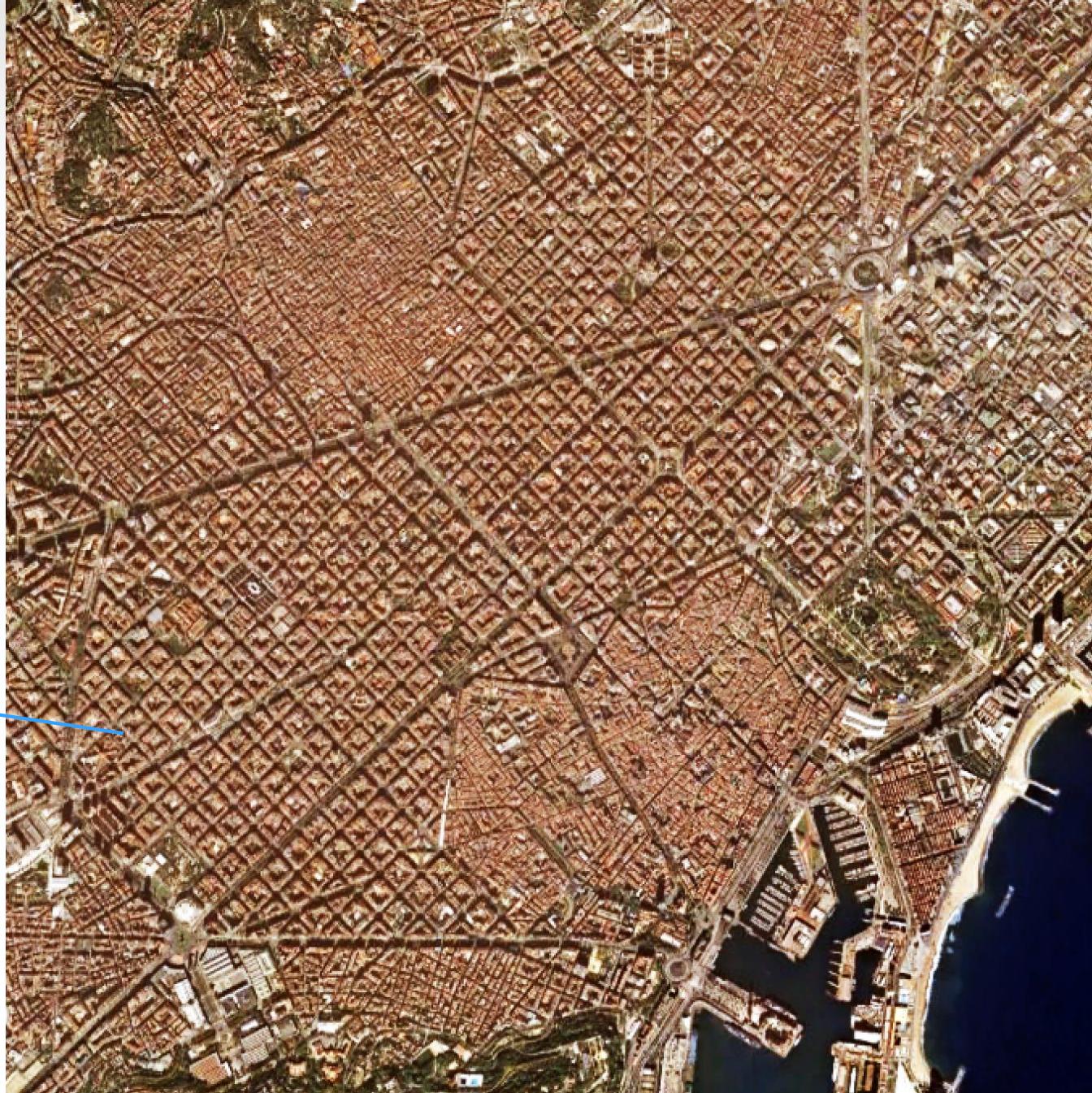
Non-offsetted ($\theta_i = 0$) coordination is sometimes used, the **simultaneous system**, of an entire network (e.g. New York).

<https://www.youtube.com/watch?v=0giNAJZgOdM>

This approach may benefit full network coordination when block sizes are ideal and homogenous. It also drastically reduces complexity of an otherwise only marginally beneficial coordination.

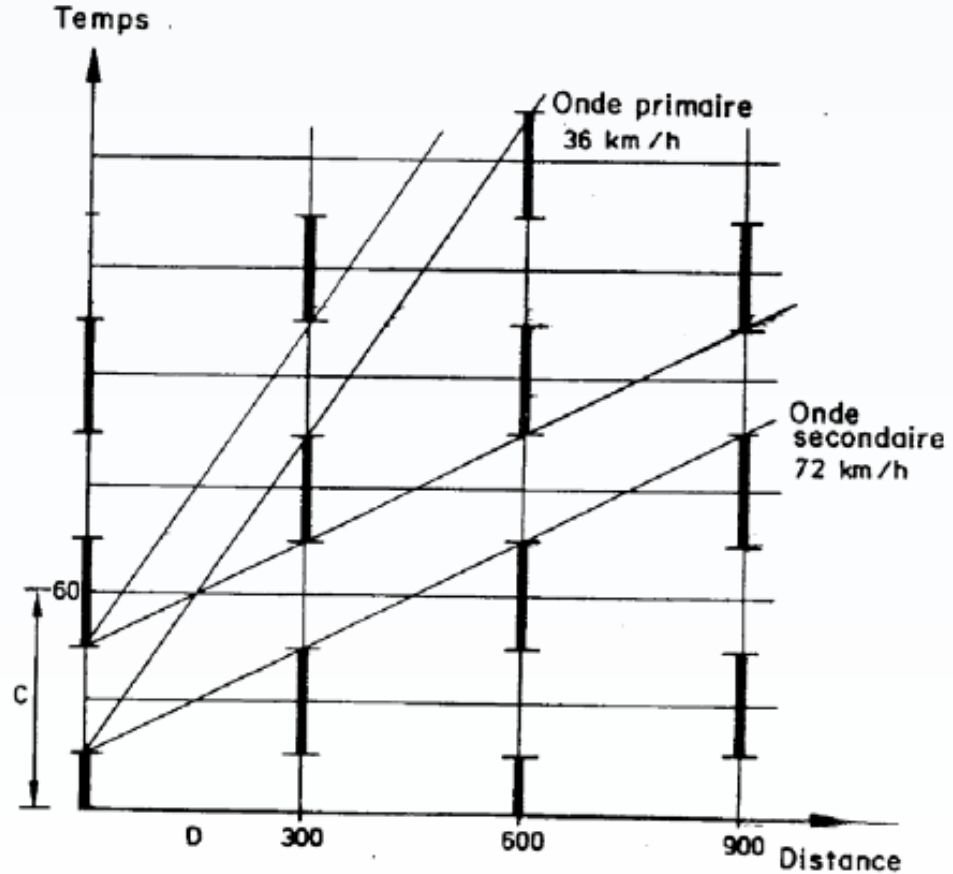
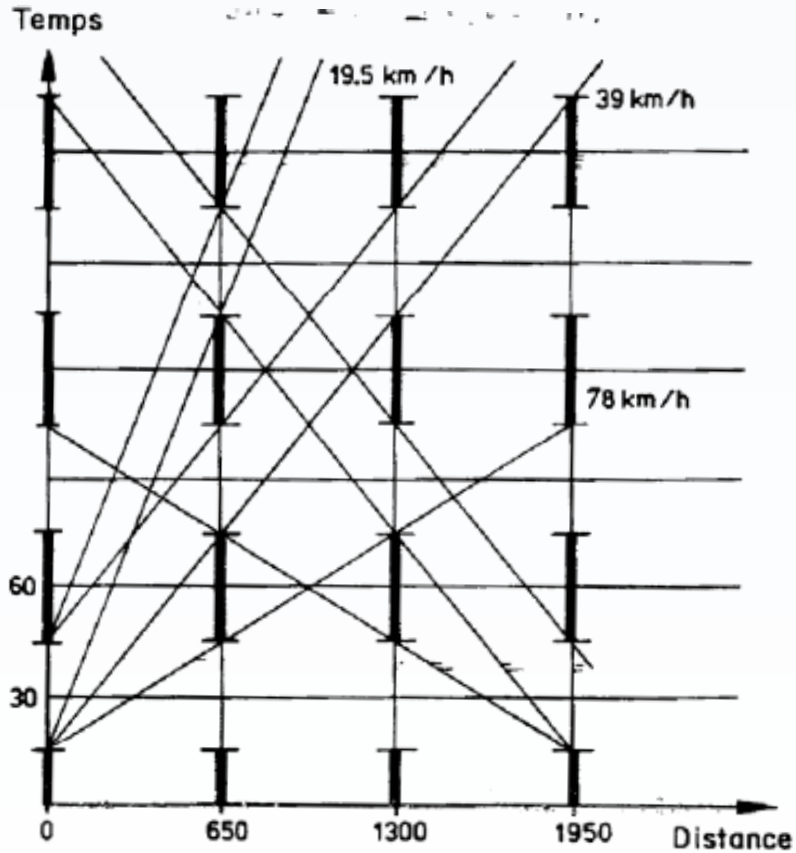
If traffic engineers were exclusively in charge of urban planning, all cities would be arranged in perfect square grids of 125 or 250 metres in length!

125m



Simultaneous progression

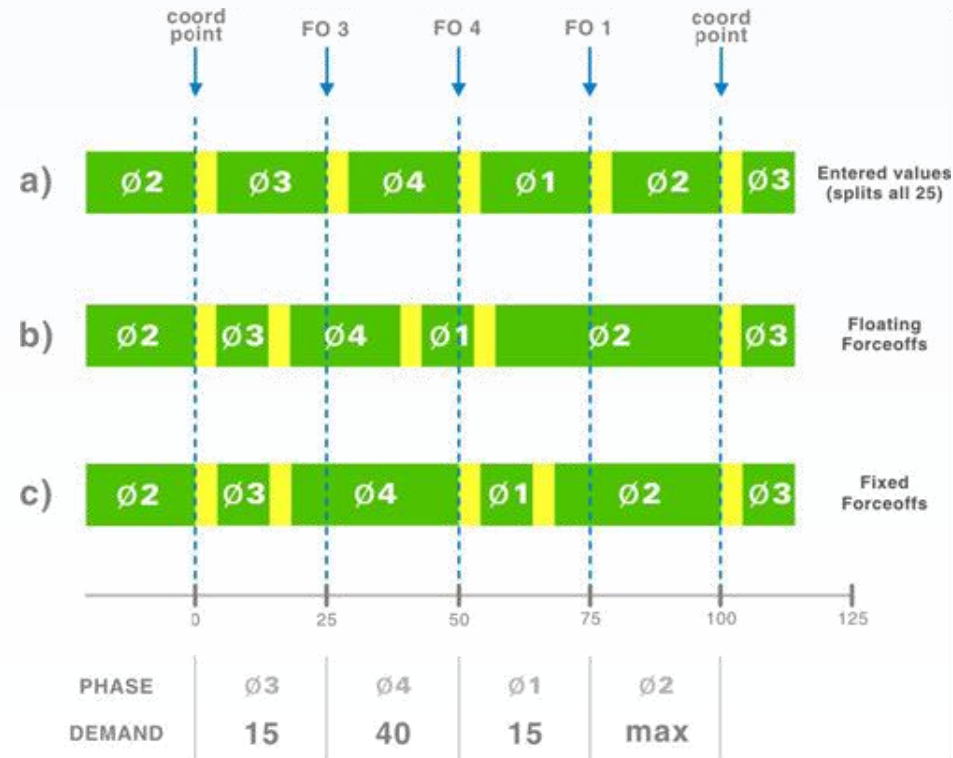
Alternate progression



INTERFACE WITH ACTUATED CONTROL

The “forceoff” functionality of certain actuated controllers permit a limited amount of coordination of actuated traffic lights.

- Essentially an additional constraint on extension time such that the cycle length remains the same, and the start of the coordinated phase (in this example $\emptyset 2$) is synchronised.
- The cycle length remains unchanged.



That's all for today!