CIVE 440

Traffic Engineering and Simulation - Introduction

McGill

Faculty of Engineering
Department of Civil Engineering and Applied Mechanics
Fall 2016

INTRODUCTION

This course will help you become familiarised with the fundamentals of traffic engineering, one of the major sub-topics of transportation engineering alongside transportation planning, public transit planning, and freight management.

Traffic engineering encompasses:

- All implementation aspects of road-based transportation
- Network and traffic management systems, including
    - traffic control systems
- Objective is to optimise capacity, road safety, and cost

INTRODUCTION

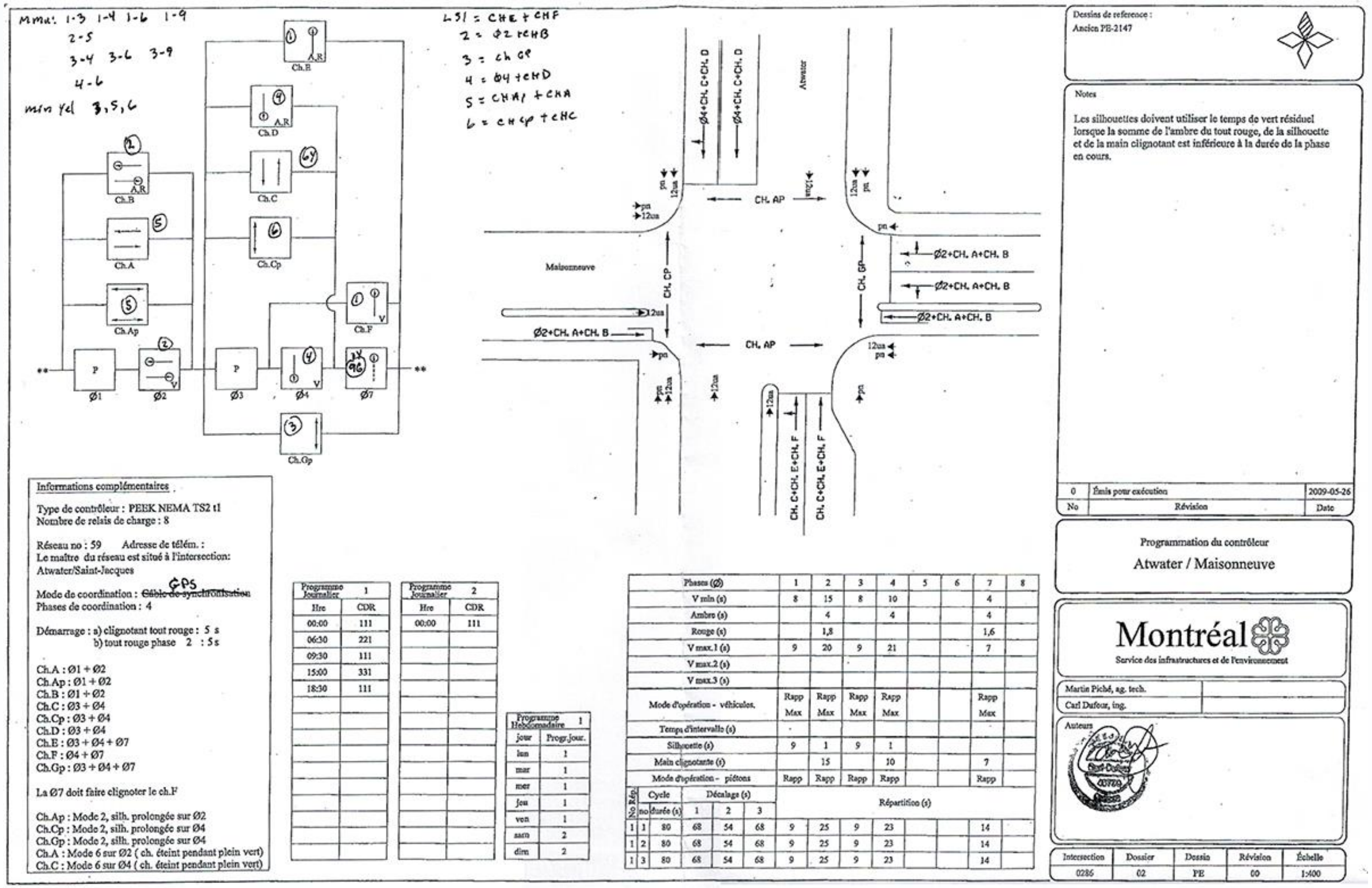
Traffic engineering is that phase of transportation engineering which deals with the

- planning,
- geometric design,
- and traffic operations

of roads, streets, and highways, their networks, terminals, abutting lands, as well as the relationships between these and all relevant modes of transportation, including:

- cars, trucks, busses, pedestrians, cyclists, and any special needs, such as emergency vehicles

During this course, you will have the opportunity to experience a typical project undertaken by municipal traffic engineers for a large city such as Montreal.



Informations complémentaires

Type de contrôleur : PEEK NEMA TS2 t1
Nombre de relais de charge : 8

Réseau no : 59 Adresse de télém. :
Le maître du réseau est situé à l'intersection:
Atwater/Saint-Jacques

Mode de coordination : ~~Câble de synchronisation~~ GPS
Phases de coordination : 4

Démarrage : a) clignotant tout rouge : 5 s
b) tout rouge phase 2 : 5 s

Ch.A : Ø1 + Ø2
Ch.Ap : Ø1 + Ø2
Ch.B : Ø1 + Ø2
Ch.C : Ø3 + Ø4
Ch.Cp : Ø3 + Ø4
Ch.D : Ø3 + Ø4
Ch.E : Ø3 + Ø4 + Ø7
Ch.F : Ø4 + Ø7
Ch.Gp : Ø3 + Ø4 + Ø7

La Ø7 doit faire clignoter le ch.F

Ch.Ap : Mode 2, silh. prolongée sur Ø2
Ch.Cp : Mode 2, silh. prolongée sur Ø4
Ch.Gp : Mode 2, silh. prolongée sur Ø4
Ch.A : Mode 6 sur Ø2 (ch. éteint pendant plein vert)
Ch.C : Mode 6 sur Ø4 (ch. éteint pendant plein vert)

Programme Journalier	1
Hre	CDR
00:00	111
06:30	221
09:30	111
15:00	331
18:30	111

Programme Journalier	2
Hre	CDR
00:00	111

Programme Hebdomadaire	1
jour	Progr.Jour.
lun	1
mar	1
mer	1
jeu	1
ven	1
sam	2
dim	2

Phases (Ø)	1	2	3	4	5	6	7	8
V min (s)	8	15	8	10			4	
Ambre (s)		4		4			4	
Rouge (s)		1,8					1,6	
V max.1 (s)	9	20	9	21			7	
V max.2 (s)								
V max.3 (s)								
Mode d'opération - véhicules.	Rapp Max	Rapp Max	Rapp Max	Rapp Max			Rapp Max	
Temps d'intervalle (s)								
Silhouette (s)	9	1	9	1				
Main clignotante (s)		15		10			7	
Mode d'opération - piétons	Rapp	Rapp	Rapp	Rapp			Rapp	

No Rép.	Cycle no	Cycle durée (s)	Décalage (s) 1	Décalage (s) 2	Décalage (s) 3	Répartition (s) 1	2	3	4	5	6	7	8
1	1	80	68	54	68	9	25	9	23			14	
1	2	80	68	54	68	9	25	9	23			14	
1	3	80	68	54	68	9	25	9	23			14	

Dessins de reference :
Ancien PE-2147

Notes

Les silhouettes doivent utiliser le temps de vert résiduel lorsque la somme de l'ambre du tout rouge, de la silhouette et de la main clignotant est inférieure à la durée de la phase en cours.

No	Révision	Date
0	Émis pour exécution	2009-05-26

Programmation du contrôleur
Atwater / Maisonneuve

Montréal
Service des infrastructures et de l'environnement

Martin Piché, ag. tech.
Carl Dufour, ing.

Auteurs

Intersection	Dossier	Dessin	Révision	Échelle
0286	02	PE	00	1:400

FUNDAMENTAL CONCEPTS

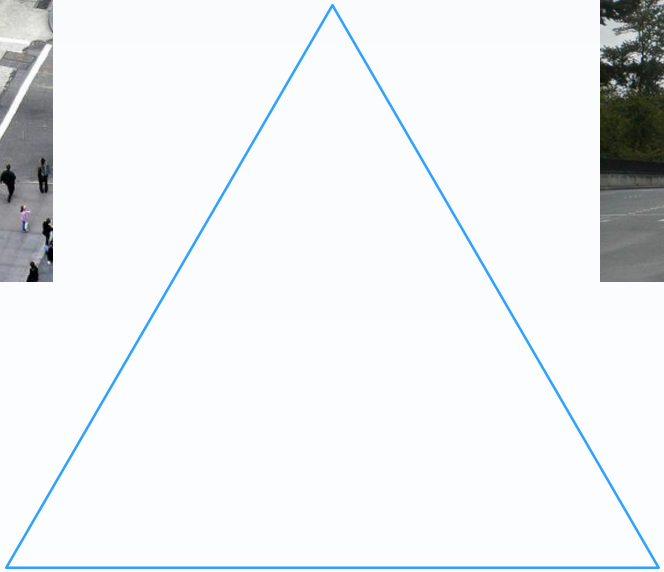
Most traffic engineering projects are optimisation problems:

- With the exception of some highways and some suburban development projects, roads are always pre-existing
- In addition to regular maintenance, roads constantly need to be adapted to meet the needs of changing traffic conditions as the urban makeup and transportation needs evolve and grow over the decades
- Good news: there is always work!

Most decisions will involve tradeoffs…

ACCIDENTS ▲

CAPACITY ▼



ECONOMY

CAPACITY

ROAD SAFETY

COST ▲

At the policy level, these choices are for the client to make:

- Public policy
- Available budget
- Many stakeholders:
    - Local residents
    - Business owners
    - Through traffic
    - Politicians
    - Special interest groups
    - Transportation mode advocates

Interests are rarely aligned, almost always in conflict!

FUNDAMENTAL CONCEPTS

Technical decisions are the responsibility of traffic engineers to ensure smooth traffic flow, that the system is running smoothly, and that the overarching design goals are maximised.

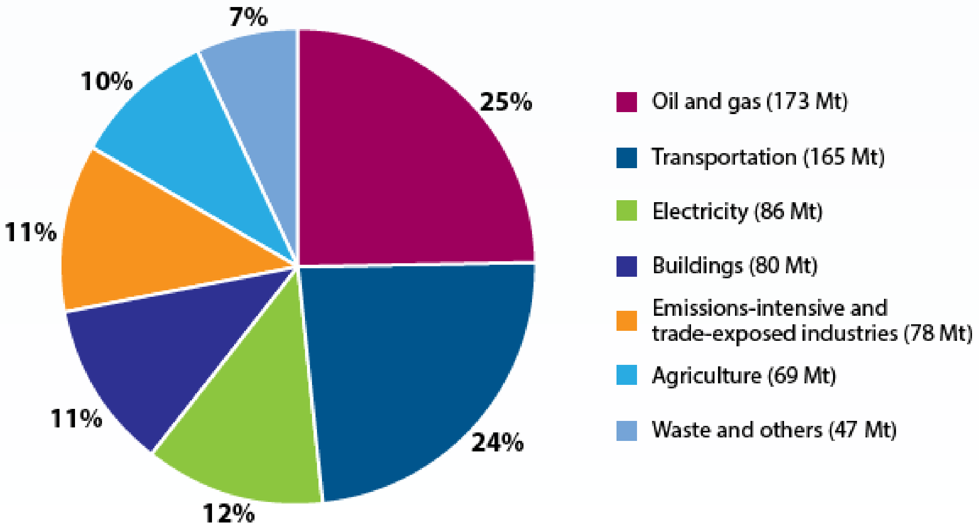
For this course, we will focus on network capacity, including:

- Maximised flow
- Lost time
- Travel time
- Avoiding gridlock

Derived design goals:

- Comfort of road users
- Convenience
- Transport economy and efficiency for road users
- Environmental impact

How can traffic engineering decisions impact greenhouse gas emissions?

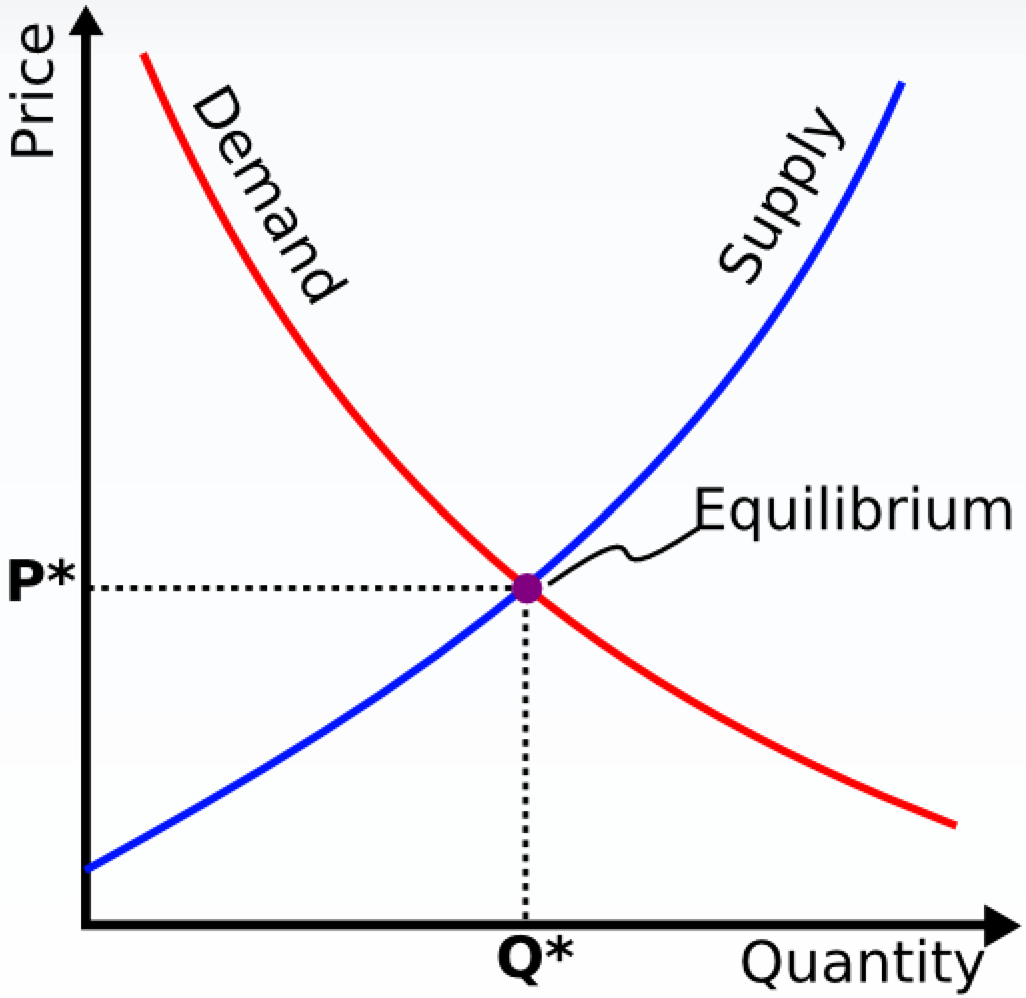


www.ec.gc.ca/indicateurs-indicators

SCENARIO

We have improved Décarie highway (A-15) so much that every vehicle on the highway travels near the speed limit at all times of day (the rest of the city is still clogged as usual).

- What are the consequences of this?
  - We improved travel times
  - We reduced idling and therefor lost time and pollution
  - However, individuals and businesses realize they can do more things and faster, for cheaper, so start moving everything through this route.. Thus increasing demand on the road.
- Arguably, the rest of the city is a bit better off now.
  - On the other hand, the same equilibrium effect occurs as more people move into the city.


Price
Demand
Supply
Equilibrium
P*
Q*
Quantity

What is the impact on capacity and safety of the following two scenarios?

Which one has higher capacity?

REVIEW OF TRAFFIC FLOW MODELS

Flow ($\boldsymbol{q}$) is the number of vehicles traveling across a section of road per unit of time (units typically veh/h or veh/h/ln).

- A variety of specific measures representing daily or annual traffic flow exist such as ADT, AADT, DDHV, etc. which will be covered later.

The conservation of flow applies:

$$\sum Q_{out} - Q_{in} = V$$

- where $V \approx 0$ over small sections of road and long measuring times (i.e. assuming no queue formations).

REVIEW OF TRAFFIC FLOW MODELS

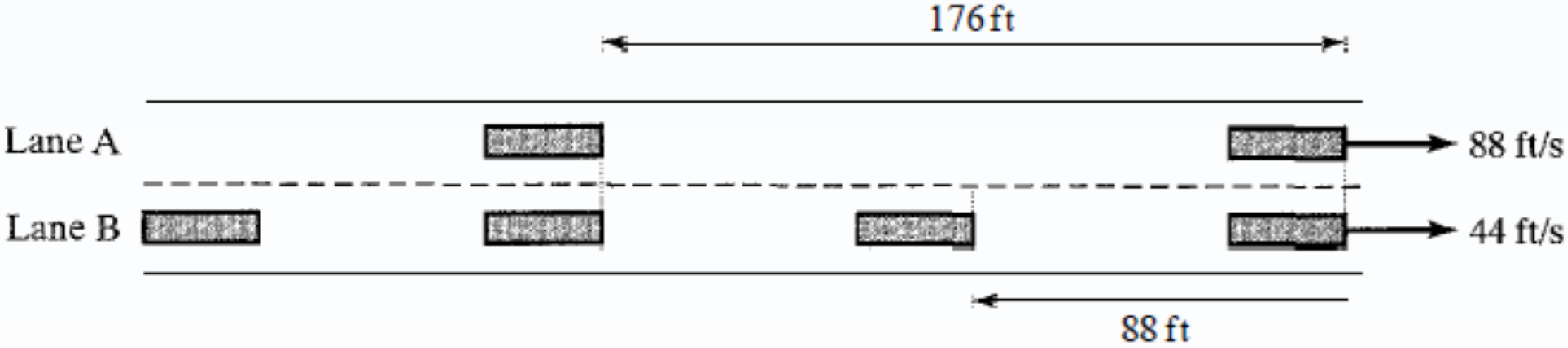
Speed (v) is the distance traveled over time (units typically km/h or sometimes m/s). Speed varies from individual to individual. A traffic stream is typically characterised by a simple average or by a speed distribution.

Two types of speed:

- Time mean speed: Average speed of vehicles passing a single point over time.
- Space mean speed: Average speed at an instant in time of all vehicles on a stretch of road

Time mean speed: $TMS = v_t = \frac{\sum_i \frac{d}{t_i}}{n} = \frac{\sum_i v_i}{n}$

Space mean speed: $SMS = v_s = \frac{d}{\sum_i \frac{t_i}{n}}$



For the math enthusiast here, this is the difference between an **arithmetic mean** and a **harmonic mean**. More reading:

- http://www.meronoiac.com/blog/2011/07/what-the-hell-is-a-harmonic-mean-or-a-few-thoughts-on-traffic-intersections/

REVIEW OF TRAFFIC FLOW MODELS

Density (k) is the number of vehicles occupying a stretch of road (units typically veh/km or veh/km/ln) at a given instant.

Density can be counted in Google Earth!

Map Length: 200.12 Meters

Ground Length: 200.13

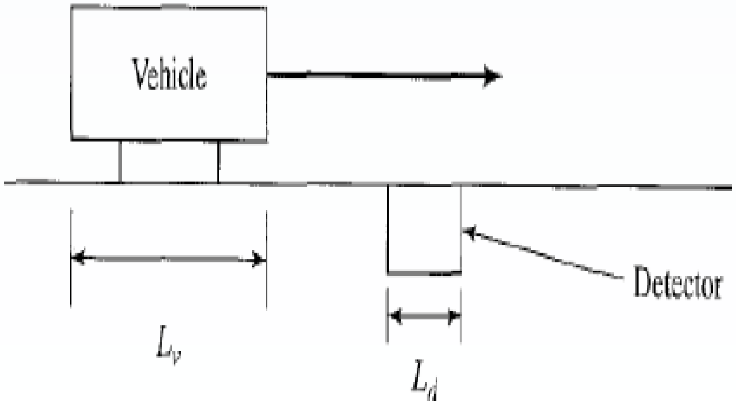
Heading: 272.01 degrees

Problem:

- Accuracy is poor (small sample size)
- Aerial photography is expensive, particularly for continuous measurement.

Alternative: occupancy

- A detector in the road measures the time a vehicle occupies the road surface o in seconds.
- $k = \frac{1000\ o}{L_v + L_d}$



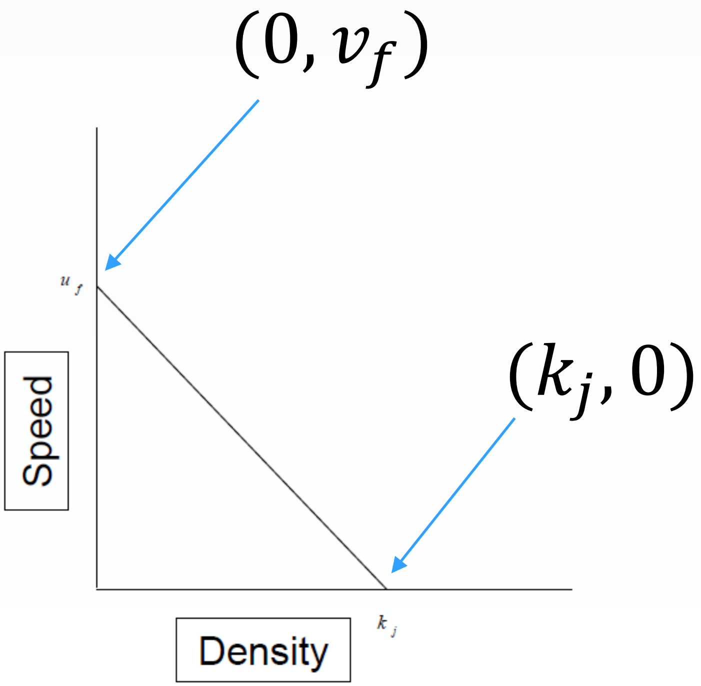
REVIEW OF TRAFFIC FLOW MODELS

Traffic flow relationship:

$$\boxed{q = vk}$$

Assuming linear speed-density relationship (Greenshields):

- **Free-flow speed:** v_f
- **Jam density:** k_j
- $v = v_f\left(1 - \frac{k}{k_j}\right)$

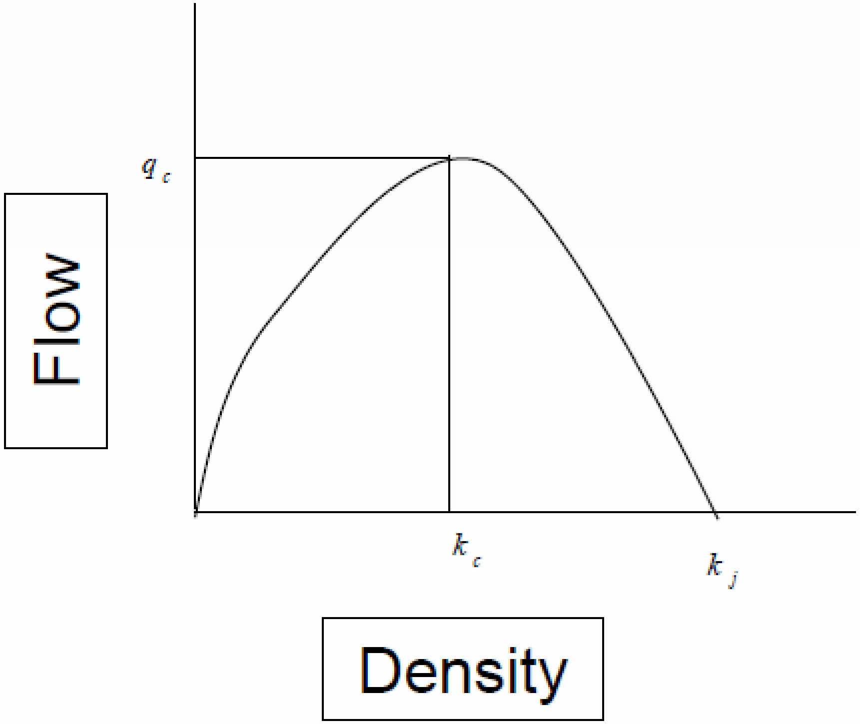


$(0, v_f)$

$(k_j, 0)$

$$q = vk = v_f\left(1 - \frac{k}{k_j}\right)\mathrm{k}$$

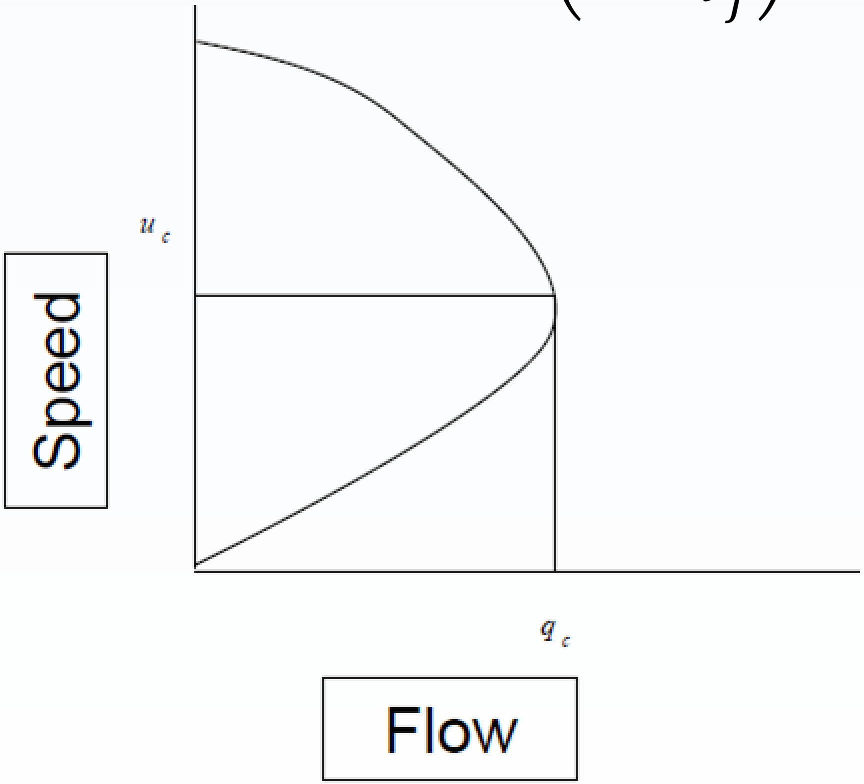
$$q = v_f\left(k - \frac{k^2}{k_j}\right)$$



Solve for q_{max} to determine optimal capacity!

$$k = k_j\left(1 - \frac{v}{v_f}\right)$$

$$q = vk = vk_j\left(1 - \frac{v}{v_f}\right)$$



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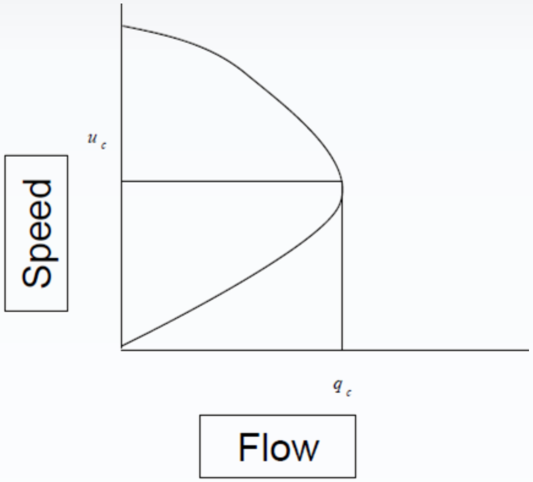
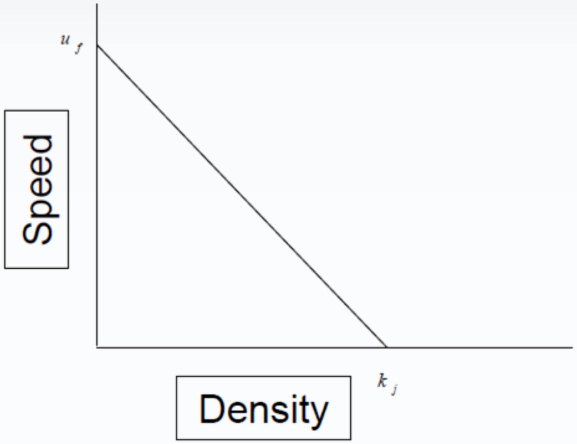
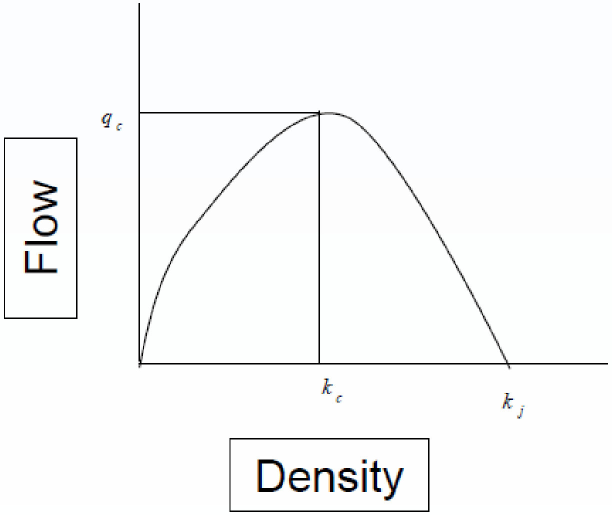

Speed
u c
q c
Flow


u f
Speed
k j
Density


q c
Flow
k c
k j
Density

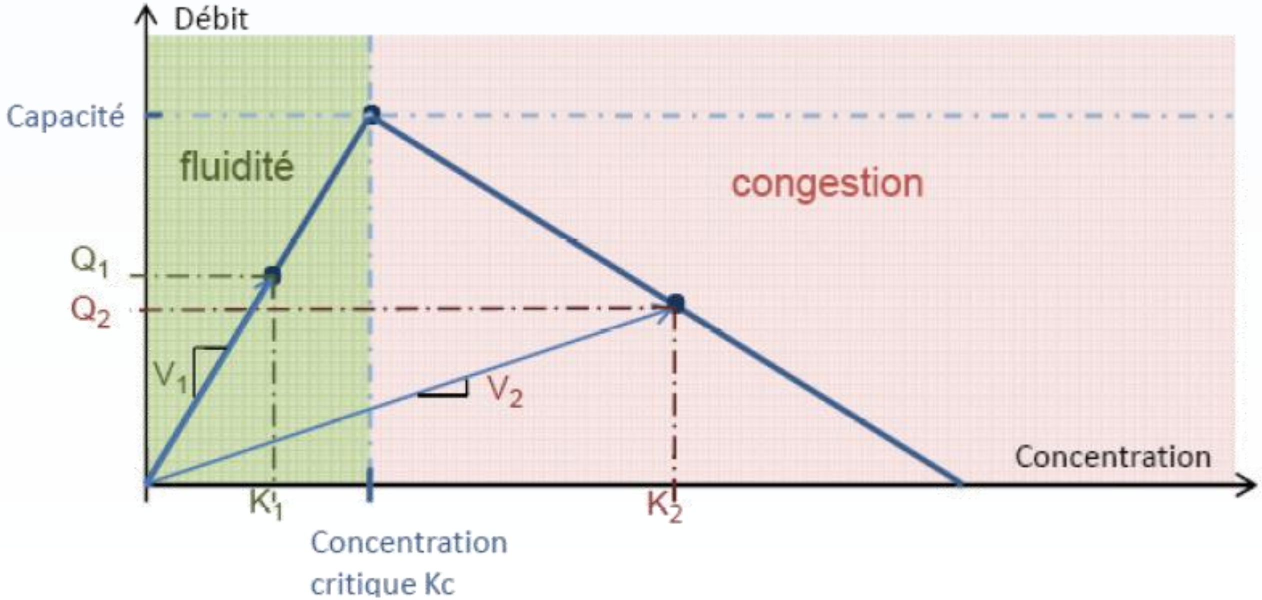
EXAMPLE

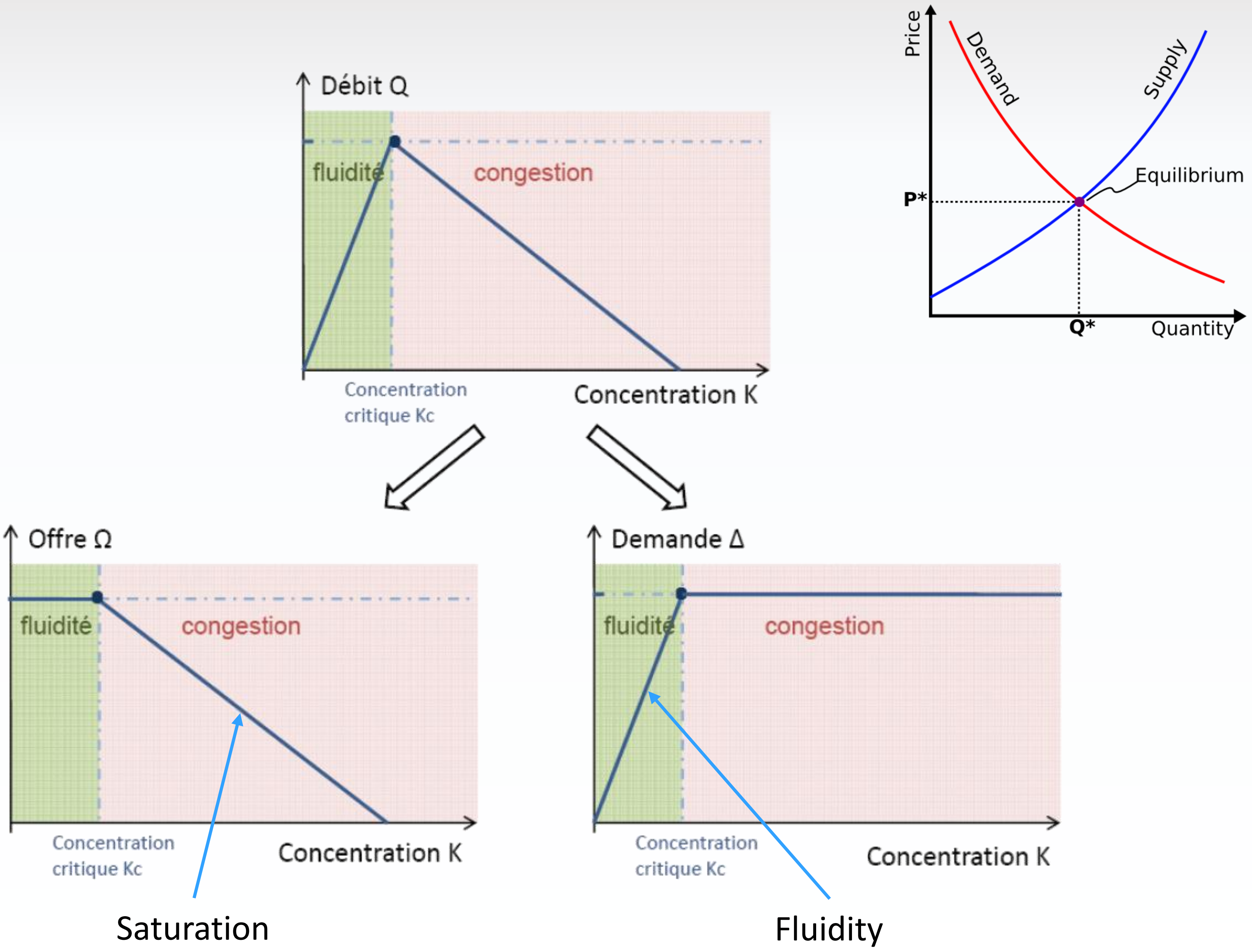
Given a road with known speed-density relationship $v = 75e^{-0.015k}$, determine the free-flow speed, jam density, speed-flow relationship, flow-density relationship and capacity.

SUPPLY-DEMAND

The flow-density curve is often simplified as a triangle to simplify discussion and theoretical calculations.

Here we demonstrate the basic mechanics operating supply-demand equilibrium.





Saturation

Fluidity

TRAFFIC ARRIVALS

Scenario: an intersection is rated to handle 1000 vehicles per hour.

How are the arrivals at the intersection actually realized?

- Is all traffic flow uniformly arriving? i.e. one vehicle every 3.6 seconds!
- Cars are entering/exiting driveways, grouped together by downstream intersections, driving at different speeds, etc.
- Traffic flow arrivals can be more realistically represented by random probability distributions.

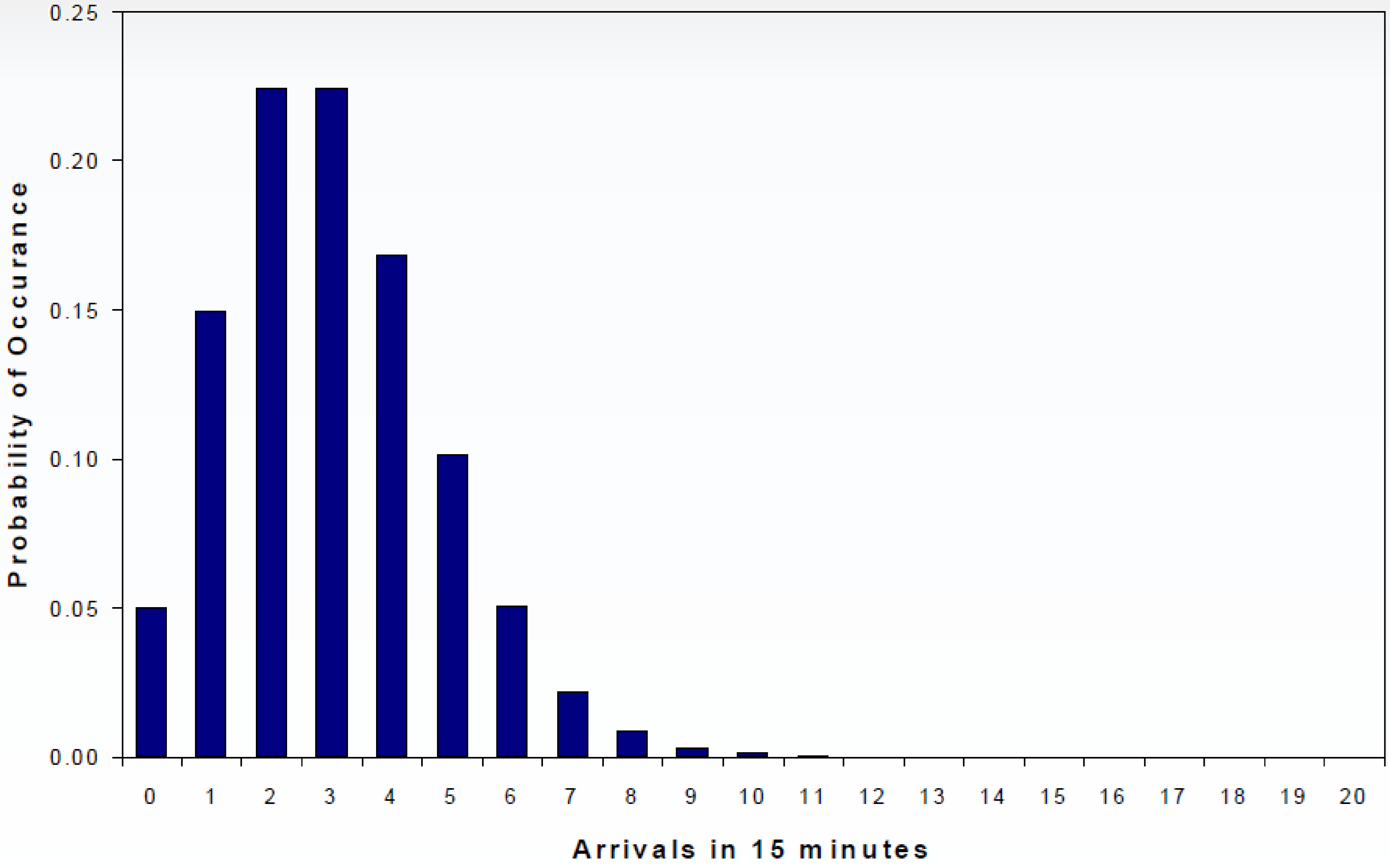
Arrivals are modeled using the Poisson model.

Probability for n arrivals over a time period t:

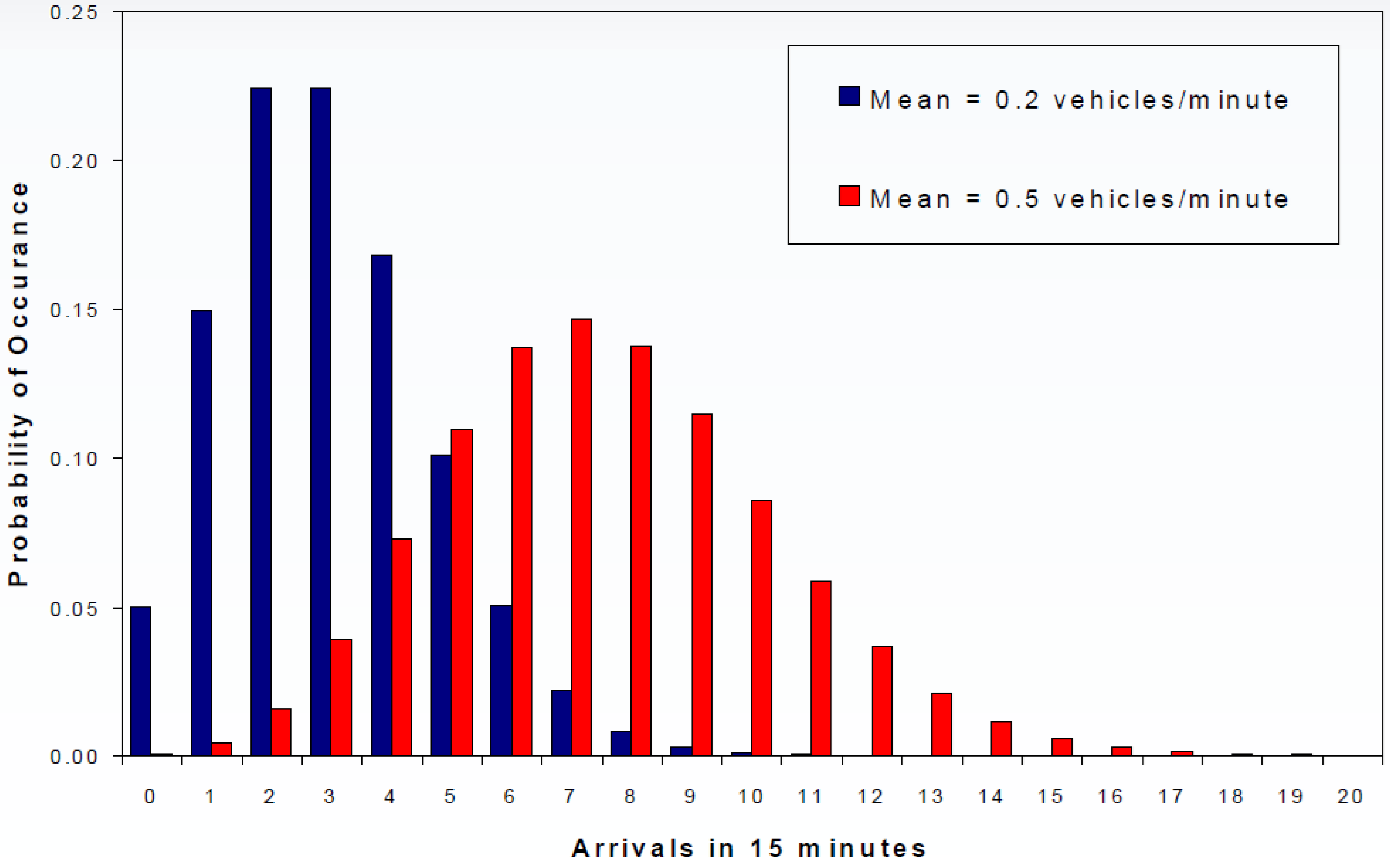
$$P(n) = \frac{(\lambda t)^n e^{-\lambda t}}{n!}$$

where:

λ is the average flow rate per unit time



Mean = 0.2 vehs/min


0.25
0.20
0.15
0.10
0.05
0.00
Probability of Occurance
Mean = 0.2 vehicles/minute
Mean = 0.5 vehicles/minute
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Arrivals in 15 minutes

EXAMPLE

An observer counts 720 veh/h at a location. Assuming the arrivals are Poisson distributed, estimate the probability for 0, 1, 2, 3, 4, and 5 or more vehicles over a 20 second time period.

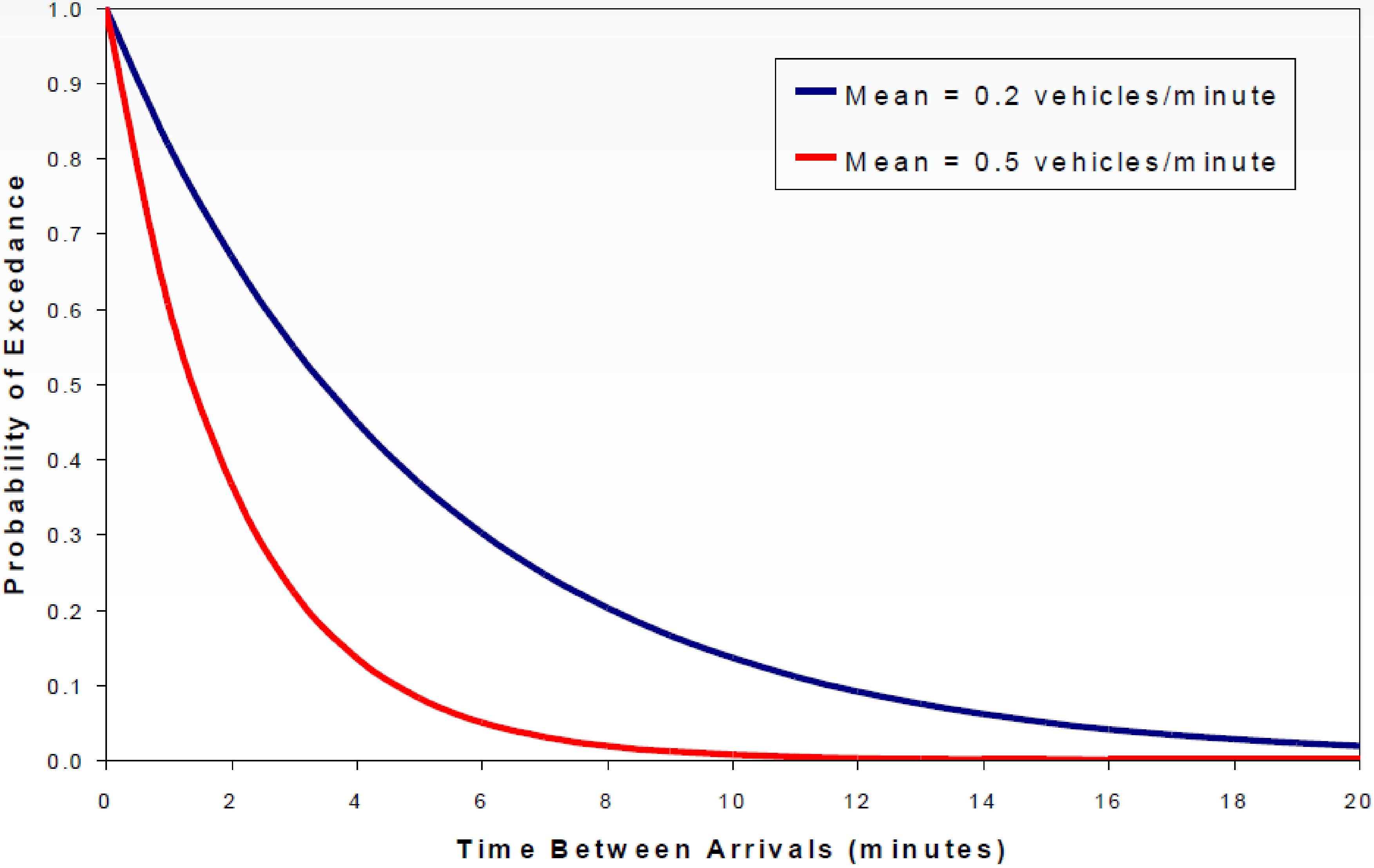
GAP

P(0) provides us information on probability that the number of vehicles arriving in the interval t are 0.

This can be interpreted in a subtly different fashion:

- the probability that the gap between two vehicles is greater than or equal to t.

Why are we interested in gap lengths?


Mean = 0.2 vehicles/minute
Mean = 0.5 vehicles/minute
Probability of Excedance
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
20
Time Between Arrivals (minutes)

GAP EXAMPLE

Consider an unsignalised highway left-turning lane with an oncoming flow rate of 360 veh/h in the opposite direction of flow. Suppose drivers in the turning lane need a gap of 4 seconds to clear the intersection. <u>How many vehicles</u>, on average, will be able to turn left in an hour, assuming continuous demand of 1800 veh/h?

How does that <u>compare</u> with a highway serving a flow rate of 720 veh/h?

ISSUES WITH POISSON ARRIVALS

Empirical tests have shown that Poisson works well for less congested settings, but:

- In congested settings the traffic at an intersection is heavily affected by traffic upstream and downstream of it (streams of traffic leaving a green light are not random)
- Poisson, being a memory-less process, does not work well in such situations!
- We tend to assume uniform flow in situations of congestion.
  - Aside from signalized traffic interruptions (e.g. traffic lights) can you think of an example under congested conditions where flow is still not uniform?

QUEUING THEORY

Queues are ubiquitous:

- At toll booths (we want to study how many servers we need to ensure smooth flow)
- Bank tellers
- Costco cashiers
- Airport security line
- *TCP/IP* and other networking software

Traffic flows are regularly impeded by queues and they account for a large portion of the delay in travel.

- Queues form any time instantaneous capacity is less than instantaneous demand.

QUEUING THEORY

Little’s Theorem:

$$N \propto \lambda\mu$$

where $N =$ average no. of customers

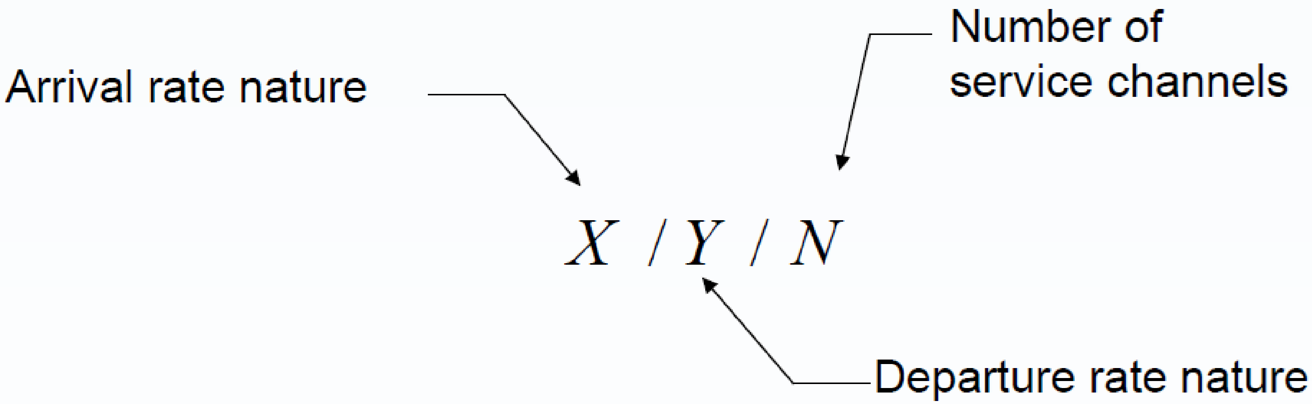
$\lambda =$ arrival rate

$\mu =$ departure rate (service rate, processing rate)

Intuitively

- If arrival rate increases -> N increases
- If departure rate decreases -> N decreases

QUEUE NOTATION



Typically:

- D/D/1, M/D/1, M/M/1, M/M/N
- D: deterministic distribution
- M: exponential distribution

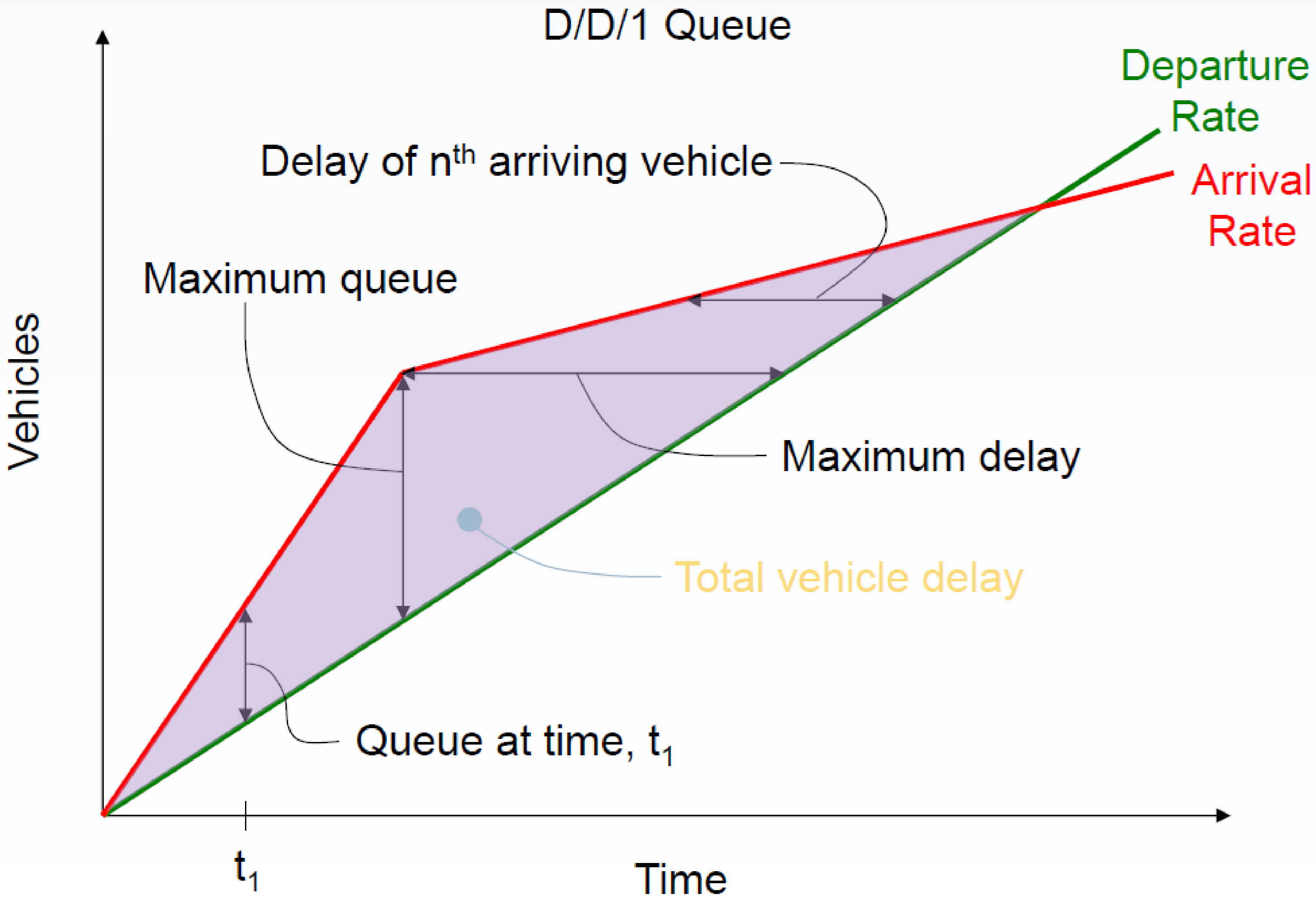
QUEUING THEORY

Recall:

$$\sum Q_{out} - Q_{in} = V$$

where V is the unprocessed volume of vehicles (queue) in the network.

- Ideally, $V = 0$
- Optimisation constraint.


D/D/1 Queue
Departure Rate
Arrival Rate
Delay of nth arriving vehicle
Maximum queue
Maximum delay
Total vehicle delay
Queue at time, t_1
Vehicles
t_1
Time

EXAMPLE

A D/D/1 bridge with a capacity (supply) of 240 veh/h/ln opens at 8:00 AM. Traffic demand is as follows:

- 0:00-8:00 AM: 0 veh/h
- 8:00-8:20 AM: 480 veh/h
- 8:20 AM and after: 120 veh/h

What is the maximum length of the queue? What is the maximum delay?

What is the total delay?

Is the demand before opening realistic?

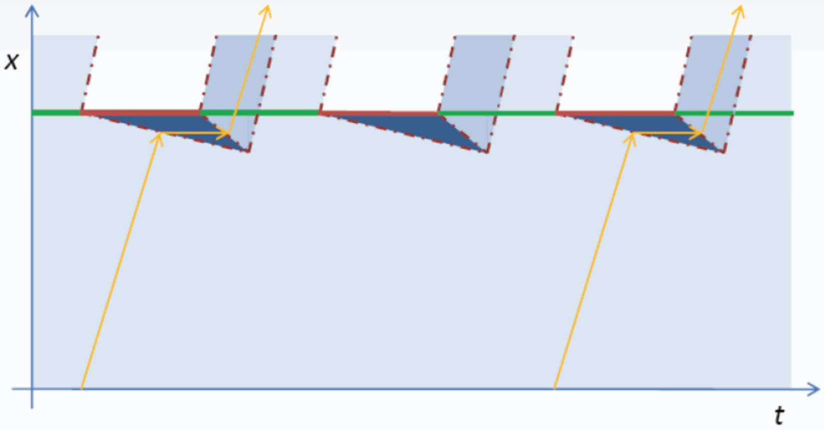
NON-DETERMINISTIC QUEUES

So far we examined queues that are based on deterministic arrivals. Now let's relax that assumption and assume arrivals are Poisson with mean λ and departures are uniform with mean μ.

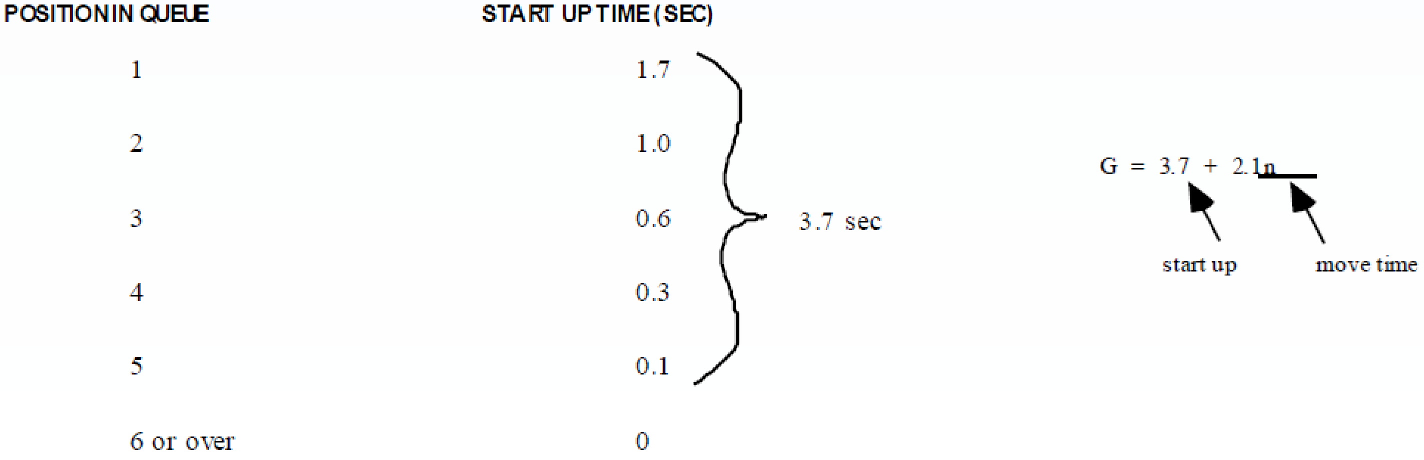
If $\lambda < \mu$ and $\rho = \lambda / \mu < 1$:

- Ave. Length of queue $= \frac{\rho^2}{2(1-\rho)}$
- Ave. waiting time (per vehicle) $= \frac{\rho}{2\mu(1-\rho)}$
- Ave. time spent in queue (per vehicle) $= \frac{(2-\rho)}{2\mu(1-\rho)}$

Consider queues at traffic lights:



Departures are in reality never this clean. Traffic light calculations include start-up time to account for acceleration delays:



POSITION IN QUEUE	START UP TIME (SEC)
1	1.7
2	1.0
3	0.6
4	0.3
5	0.1
6 or over	0

3.7 sec

$G = 3.7 + 2.1n$

TRAFFIC CONTROL DEVICES

Traffic control devices provide the medium for communication with transportation system users.

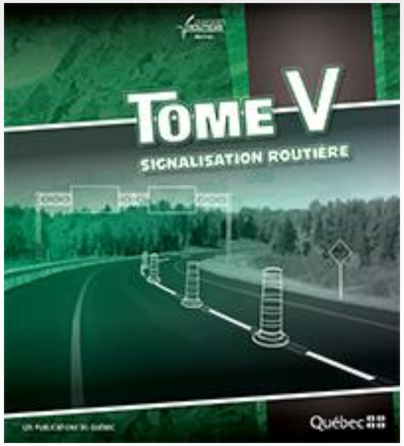
Language-independent communication:

- Colour
- Shape
- Symbology
- Pattern (in the case of markings)

Three flavours of TCDs:

- Traffic markings (*signalisation horizontale*)
- Traffic signs (*signalisation verticale*)
- Traffic signals

GOVERNING BODIES



In Québec, traffic signalisation guidelines are set by the MTQ in Tome 5 – Signalisation Routière in great detail.

- This is a design guide. Regulations regarding driver behaviour are set in the legal document Code de la sécurité routière and a **very** large list of misc. laws.

At the national level there is the Canadian Capacity Guide for Signalized Intersections and at the North American level there is the FHWA's MUTCD : *Manual on Uniform Traffic Control Devices*

- Note that a certain degree of standardisation is present to reduce visiting driver confusion.

TRAFFIC MARKINGS

Three types:

- Longitudinal markings
- Transverse markings
- Object markers and delineators

Colours used for traffic markings:

- Yellow – separate traffic in opposite direction
- White – separate traffic in same direction
- Red – do not enter (rarely seen in Canada)
- Blue – separate handicapped parking
- Green – Cyclists

Patterns used for traffic markings:

- A solid line prevents crossing.
- Double solid is a stricter version often implemented for (but not limited to) HOV and bus lanes.
- Broken line allows crossing.
- Hybrid line allows passing only in one direction or particular lane.
- Dotted line (with smaller line segments) is used for trajectory guidance (highway ramps and intersection turning guides).

Longitudinal markings:

- Centerlines
- Lane markings
- Edge markings

Transverse markings:

- Stop lines
- Crosswalk markings
- Parking space markings
- Etc.

Object Markers and Delineators:

- Used to instruct the drivers of obstacles on or close to the roadway

TRAFFIC SIGNS

Regulatory (red, black, and/or white)

- Informs and reminds motorists the rules and regulations of the road and are actively enforced.

Warning (yellow)

- Notifies motorists of possible dangers.

Indication (green, brown, blue)

- Itinerary-relevant information

Construction (orange)

- A special case of regulatory signs, these infamous signs are of a temporary nature and remind conditioned drivers of recently changed and temporary signage.

Shape and context also plays a part in sign recognition.

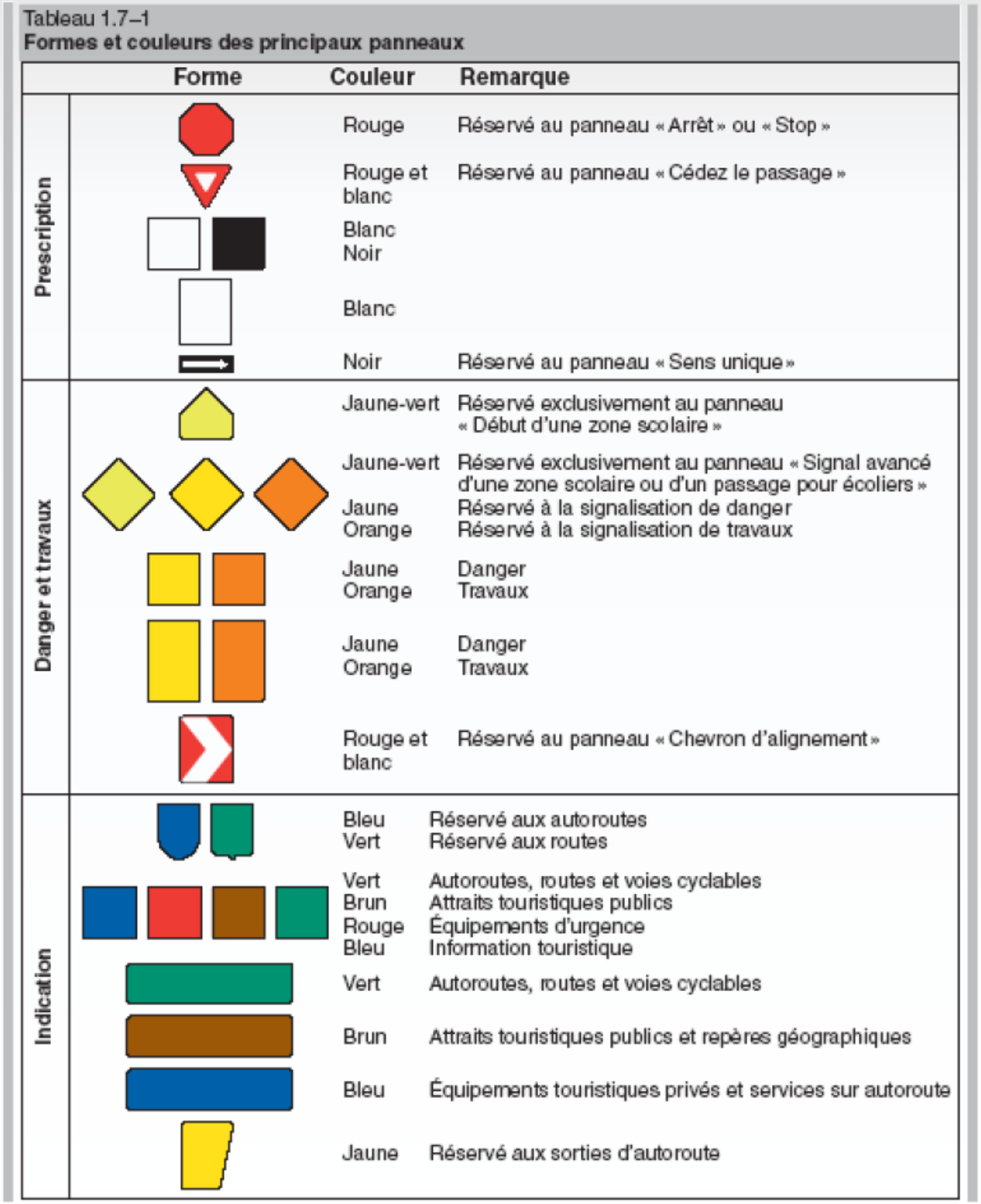


Tableau 1.7–1

Formes et couleurs des principaux panneaux

	Forme	Couleur	Remarque
Prescription	⯃	Rouge	Réservé au panneau « Arrêt » ou « Stop »
	▽	Rouge et blanc	Réservé au panneau « Cédez le passage »
	□ ■	Blanc Noir	
	▯	Blanc	
	▭	Noir	Réservé au panneau « Sens unique »
Danger et travaux	⬠	Jaune-vert	Réservé exclusivement au panneau « Début d'une zone scolaire »
	◆ ◆ ◆	Jaune-vert Jaune Orange	Réservé exclusivement au panneau « Signal avancé d'une zone scolaire ou d'un passage pour écoliers » Réservé à la signalisation de danger Réservé à la signalisation de travaux
	🟨 🟧	Jaune Orange	Danger Travaux
	▮ ▮	Jaune Orange	Danger Travaux
	❯	Rouge et blanc	Réservé au panneau « Chevron d'alignement »
Indication	⛉ ⛉	Bleu Vert	Réservé aux autoroutes Réservé aux routes
	🟦 🟥 🟫 🟩	Vert Brun Rouge Bleu	Autoroutes, routes et voies cyclables Attraits touristiques publics Équipements d'urgence Information touristique
	▬	Vert	Autoroutes, routes et voies cyclables
	▬	Brun	Attraits touristiques publics et repères géographiques
	▬	Bleu	Équipements touristiques privés et services sur autoroute
	▱	Jaune	Réservé aux sorties d'autoroute

2016-09-06 r2m1 Paul St-Aubin

TRAFFIC SIGNALS

Offer many benefits:

- Improved traffic flow (in most scenarios)
- Frequency and severity of accidents can be reduced
- Can even contribute to near non-stop movement when coordinated

Several types

- Stop signs
- Traffic lights
- Pedestrian lights
  - Typically walking stickman, upraised hand (steady) upraised hand (flashing)

Pre-timed or actuated controls

Special types of control:

- School zones
- Railroad crossings
- Construction and maintenance zones
- Pedestrian and bicycle controls

Much more on this topic later throughout the course.

How do driverless cars fit into all of this?

Will they make traffic engineering obsolete?

(hint: no, on the contrary http://www.cs.utexas.edu/~aim/,
https://www.youtube.com/watch?v=4pbAI40dK0A)

That’s all for today!