Intro

Wednesday, September 24, 2008
7:08 AM

Tornado 2007 summer
3 hrs
Rain, wind, all kinds of good stuff
Saw funnel cloud approaching
All traffic lights out
Detours flooded, cars stuck

(I even have more experience w/ traffic than these kids)

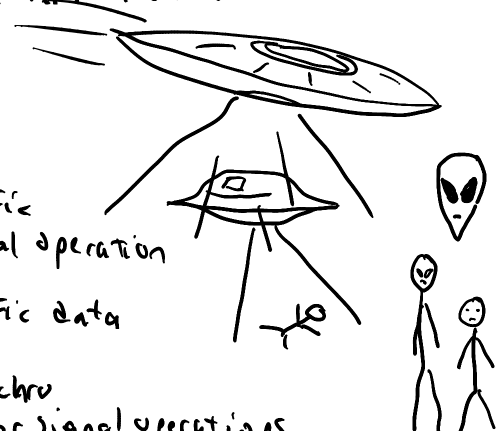
Leading factors of traffic jams:

Weather
Accidents
Construction

Sometimes you can't see the accident
Or it's not even an accident, it's an "invisible accident"

How vehicles interact w/ each other on the road.

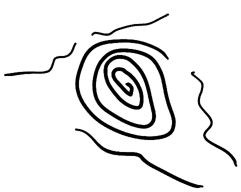
Office hrs Mon/Wed

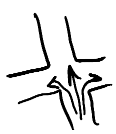


No final yay!

Class project: traffic signal operation

- Collect traffic data
  15 min
- Put into Synchro
  designed for signal operations
  70% of US use it for signal design
- Evaluate traffic patterns





HW 40%
Midterm 30%
Class project 25%
Participation 5%

A310

More intro

Monday, September 29, 2008
7:01 AM

Transportation & traffic engineering

Application of the scientific principles - calculus, calculus-based physics, & differential equations

Apply to the planning, design, operation, & management of any mode of transportation in order to provide safe, rapid, efficient movement of ppl & groups

Operation & management is focus of this class

Safety, mobility, & efficiency

We will focus on mobility

	Land	Water	Air
People	Rail Cars bikes bus walk	boats ships ferries	Commercial General aviation
Goods	Rail Truck other vehicles Pipelines	boats ships ferries	Commercial General aviation

Avg person travels 40 mi a day total

90% of that is on the road

Highway system is dominant in America

William Vickery – morning commute problem – traffic patterns during rush hour

ppl have to be late or early, but everyone can't be on time

The bottleneck ~~B~~ moves

GPS system allows ppl to upload traffic info & inform

Predict highway traffic at a later time

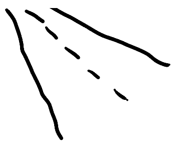
Scope:

1. Studies of traffic characteristics
   - Vehicle & driver factors ←
   - Traffic flow, volume, speed delay ←
   - Capacity & level of service ←
   - Parking & truck loading facilities
   - Accident Analysis
   - Transit
2. Transportation planning
   - National level
   - Regional level → CMAP

   Traffic Analysis Zone

   4 step model – trip generation
   trip distribution
   model split
   traffic assignment

3. Geometric design
   - Horizontal alignment
   - Vertical alignment & grade, minimum grade
   - Stopping distance, safe passing distance



- Stopping distance, safe passing distance
- Cross sections

(4) Traffic operations & control
- Control devices { Signals / Marks
-

Challenges
- Mobility ← defines safety & efficiency
- safety
- Efficiency

Congestion
- Makes ppl angry, poor judgment
- Hard for emerging vehicles
- Fuel consumption
- Time loss
- Pollutants

Can be translated to a $ value.
$63 billion

Understanding Causes of traffic congestion
Only congested when you want to use it
Demand > Supply

	Supply	Demand
More capacity	Bigger roads	Transit
	New roads	Time-shift
		Diff land use
		Car pools

Intelligent transportation systems ITS
This is how to reduce congestion but by reducing demand you have a more effective method.

43,443 ppl die each yr on highways

Seatbelt law made # of fatalities ↓, but # accidents ↑

An Inconvenient Book – bring this to class

Clean Air Act - every state should have a plan to implement the Federal Standard by 2003.

Transportation consumes more energy than industrial & residential. Consumes a lot of oil

Transportation oil consumption has gone up & everything else has stayed the same

Alternative fuel sources aren't doing so well

13.679 million ppl in transportation, 10% of total work force.
Traffic engineers are much fewer. 10,000

Consulting firms & gov't employ most of them.

ITE (Institute of Traffic Engineers)

AASHTO (American Association of State Highways Transportation)

Basic Characteristics of Highway Transportation

1. Drivers
2. Vehicles
3. Roads

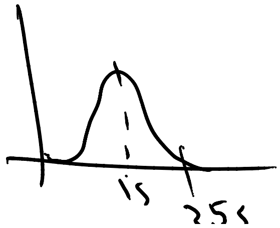
Drivers - professional & non-professional

following distance ↓, capacity ↑ but if you get too close there's a wave and then congestion.

Rxn time

1. Perception

2. Identification
3 Emotion
4. Rxn



90th percentile is what we design for

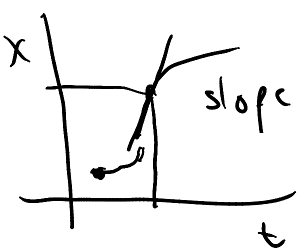
Cars
1. Size 19 ~ 105 long 6-8.5 wide
2. Weight 1800 lb ~ 108,000 lb
3. Turn radius 73.5 ~~x~~ 45
4. Acceleration/deceleration
5. Fuel type

location x
speed v

$\frac{dx}{dt} = v$ $\quad x(t) = \int_0^t v(t)\,dt$

$\frac{dv}{dt} = a$ $\quad v = \int_0^t a(t)\,dt$

$\frac{da}{dt} = j$

Trajectory


slope = speed

$$v = \int_0^t a(t)\,dt$$ a_0

$$= at + v_0 = v(t)$$

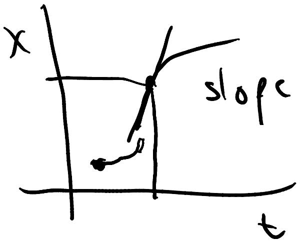
$$x = \int_0^t v(t)\,dt$$

$$= \underline{v_0 t + .5at^2} + x_0$$

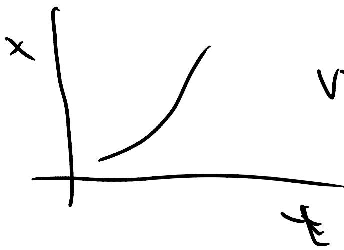
$$\frac{dv}{dt} = a = \alpha - \beta v$$

$$\frac{dv}{\quad} = 1$$

Trajectory



slope = speed



$$v = \int_0^t a(t)\,dt \quad (\to a_0)$$

$$= at + v_0 = v(t)$$

$$x = \int_0^t v(t)\,dt$$

$$= \underline{v_0 t + .5 a t^2} + x_0$$

$$\frac{dv}{dt} = a = \alpha - \beta v$$

$$\frac{dv}{\alpha - \beta v} = 1$$

$$d \ln x = \frac{1}{x} \qquad -\frac{1}{\beta} \frac{d \ln(\alpha - \beta v)}{dt} = 1$$

$$-\frac{1}{\beta} \ln(\alpha - \beta v) = t + C_0$$

$$C_0 = -\frac{\ln(\alpha - \beta v_0)}{\beta}$$

$$-\frac{1}{\beta} \ln(\alpha - \beta v_0) = t - \frac{1}{\beta} \ln(\alpha - \beta v_0)$$

$$\ln(\alpha - \beta v) = -\beta t + \ln(\alpha - \beta v_0)$$

$$\alpha - \beta v = e^{-\beta t + \ln(\alpha - \beta v_0)}$$

$$\int e^{-\beta t} = \frac{1}{\beta} e^{\beta t} \qquad = (\alpha - \beta v_0) e^{-\beta t}$$

$$v = \frac{\alpha}{\beta} - \left(\frac{\alpha}{\beta} - v_0\right) e^{-\beta t}$$

$$x(t) = \int \frac{\alpha}{\beta} - \left(\frac{\alpha}{\beta} - v_0\right) e^{-\beta t}$$

Too complicated to be used for engineering traffic

$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$

$x_0 = 0$

We need to know t.

$v = v_0 + at$

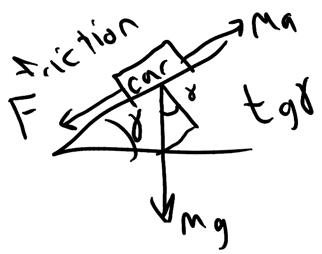
v_0 we know

$v = 0$

$t = \frac{-v_0}{a}$

$$v_0 \frac{v_0}{ta} - \frac{1}{2} a \frac{v_0^2}{a^2}$$

$$= \frac{v_0^2}{2a} \qquad (3.24)$$



$mg\cos\gamma F + mg\sin\gamma = ma$

$a = g\sin\gamma + g\cos\gamma F$

braking time

$$1.47vt + \frac{v^2}{30\left(\frac{a}{g} \pm G\right)} \qquad v \text{ is } v$$

$$\frac{2g}{1.47^2}\left(\frac{a}{g} \pm G\right)$$

$2g \rightarrow 29.8$

grade

$$vt + \frac{v^2}{2(a \pm g\tan v)}$$

Braking time is 1.47 s.

Safe following distance is not the same as
Related to reaction time

45 mph ~ 66 ft/s   435 ft

$5 ft/s^2$

$x = v_0 t + \frac{1}{2} a t^2 = \frac{v^2}{2a}$

$x = v_0 t + \frac{v^2}{2a}$ rxn time

95 mph   66 ft/s

66 ft

15

when visibility is good
You can see past the car
in front of you.

Deceleration/acceleration

$\frac{45 \text{ mph}}{66 \text{ ft/s}}$ 1320 ft from intersection
30 s red light
Full stop

How much time does the driver lose due
to the signal.

$V_0 = 44 \text{ mph} = 66 \text{ ft/s}$ given $a = 10 ft/s^2$
$X = 1320$ ft   dec. $= 6 ft/s^2$
$V = 0$ mph

$x = v_0 t + \frac{v^2}{2a}$

$1320 = 66t + 0$

$\frac{1320}{66} = t$

$$x = v_0 t + \frac{1}{2} a t^2 = 66t + \frac{1}{2} 6 t^2 = 1320$$

$$t = 12.685 \text{ s}$$

Acceleration/Deceleration ; Types of roads

Monday, October 06, 2008
7:04 AM

1. stopping sight distance

$$s = \frac{v^2}{2(a \pm g)} + vt$$

$a \rightarrow 11.2\ ft/s^2$

$\pm g$ ← in the book this is gradient G

2- Following distance

$s = vt$ 15 ft 45 mph = 66 ft/s

rt = 1s

3. Estimation of initial speed

4. Estimation of geometric delay

Deceleration/acceleration

$\frac{45\ mph}{66\ ft/s}$ 1320 ft from intersection
30 s. red light
Full stop

How much time does the driver lose due to the signal.

$V_0 = 44\ mph = 66\ ft/s$ $a = 10\ ft/s^2$ ← given
$x = 1320\ ft$ dec. $= 6\ ft/s^2$
$V = 0\ mph$

$$x = v_0 t + \frac{v^2}{2a}$$

$$1320 = 66t + 0$$

$$\frac{1320}{66} = t$$

$$x = v_0 t + \frac{1}{2}at^2 = 66t + \frac{1}{2}6t^2 = 1320$$

$t = 12.685\ s$

Acc 10   45mph / 66ft/s
Dec 6   1320ft   Total delay
No ct   30 sec   (stopping + accel) = 13.3

Stop Distance = 336 ft

Time needed for that = 3 s

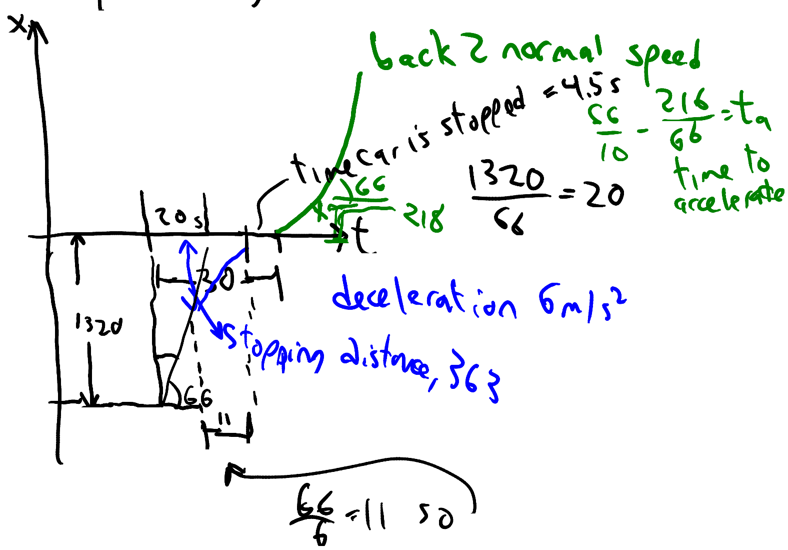
Light is red for 30 sec but 17.5s is the car slowing down

Car accelerates 6.6s & 218.8 ft.

336 + 218.8 ft → 36.6 s

23.3 s

Time-space diagram



$\frac{1320 - 363}{66} = 14.5$

30 + 6.6 = total time
w/ no signal total time is $\frac{1320 + 218}{66}$ so the diff between the 2 is what gave you this delay

We're comparing it to what it would look like if there was no signal was no signal

Min stopping delay is 12s if you start decelerating earlier.

Achieve minimal delay. There are diff ways to achieve this. 10s is a realistic min delay

5. Calculation of super elevation

Roads

Diff classes of roads

Freeway - used to provide uninterrupted flow
- limited access

Arterial streets - high mobility (through traffic)
- long
- 2 kinds: Principal

Minor

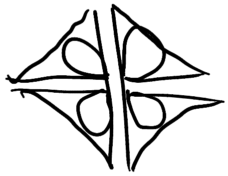
I don't think he knows the diff between these 2

Collector - Provide access to arterial streets

Local street - provide access to small groups

Junctions

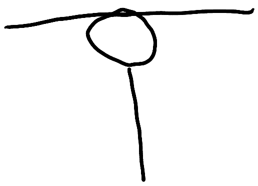
1. Interchanges (freeways & expressways)



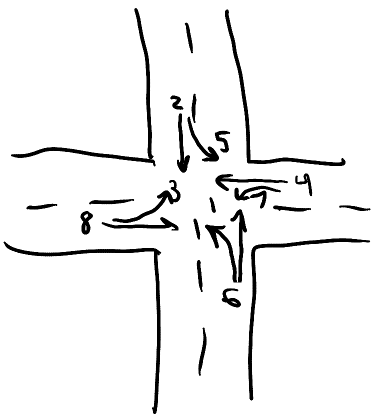
clover leaf

② Roundabout

Yield to circle traffic



③ Controlled intersection { signal light
- stop/yield signs



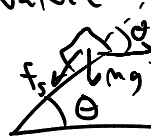
NEMA
National Electrical Manufacturers Association

GLENN BECK

Geometric factors

Lanes (width 12ft)

Curvature , Superelevation



radial force

$$\frac{mv^2}{R}\cos\theta = mg\sin\theta + mg\cos\theta f_s$$

$$R = \frac{v^2}{g\tan\theta + gf_s}$$

superelevation

Table 3.3

Grades $\longrightarrow$ { Freeways 0 ~ 6%
urban ~ 11%

Urban ~11%
Rural ~8%

Pavement - comfortable driving
- guide drivers

The most expensive and important components of the road. 1 million/mile minimum

Traffic Studies

Connecting information that describes congestion, delay, accident, & banking difficulty

Inventory study: Static; street width, lanes, transit routes

Administrative study: existing data

Most important → Dynamic Study: Collection of data under operational conditions
- Speed
- Volume
- Travel time
- Parking

Traffic studies: Why?
- users — How good was the trip?
- operator — How many vehicles did traffic system serve?
  Vehicle mi traveled

How well did the system move us?
- total time/speed
- volume/capacity ratio
- severity & duration of congestion

Deficiency

1. High Volume/Capacity
2. Bottlenecks
3. Accident hot spots

Types
(1) Volume → demand
- freeway
- traffic signal

(2) ~~[illegible]~~ travel time studies

(3) Speed studies

(4) Accident studies

Terminology

Wednesday, October 08, 2008
7:03 AM

Volume
# of vehicles that pass a point on a hgwy, or a given direction of a hgwy, during a specific time interval

(1) Average Annual Daily Traffic [AADT] sounds like a rehab society

(2) Average Daily Traffic [ADT] the security company

(3) Peak hour volume [PHV] sounds like a vaccination

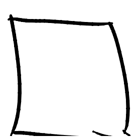
(4) Design hour volume [DHV] sounds like the disease prevents

30 th highest hourly volume in a year

(5) Vehicle Classification

(6) Vehicle Miles Traveled [VMT] Vaginal Massaging Troupe

For sensors, There is a sensor window:



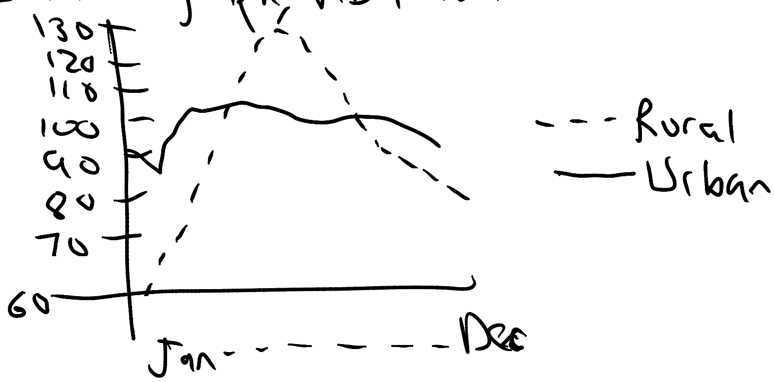
And you can calculate the density of traffic

volume

There's a weekday & weekend pattern.
Seasonal difference
Urban vs Rural

Rural used for recreational activities

In the graph ADT is 100%



Rural Roads end up w/ a LOT less traffic when recreational activities are down.

$$k\ factor = \frac{V_{peak}}{ADT}$$ 8 - 18% Recreational
9% - 4.5% Urban

$$\text{peak hour factor} = \frac{V}{4 \times V_{15}} \leq 1$$

Count expansion factors

hourly expansion factor = ADT / hourly volume

$$\text{daily expansion factor} = \frac{\text{volume of a week}}{\text{ADT for a day}}$$

Monthly expansion factor = ADT / ADT of a month

Table 4.5 - 4.7

Rural primary road

Sat.	0800-0900	615
July	0900-1000	720
	1600-1700	1050
	1700-1800	1015

24 hr volume

$$\frac{615 \times 22.05 + 720 \times 18.8 + 1050 \times 12.85 + 1015 \times 13.85}{4}$$

$= 13675$

adjust 4 week

$$\frac{13675 \times 6.510}{7} = 12714$$

b/c you want weekly traffic

adjust 4 July

$12714 \times .578 = 7349$

AADT

Field Trip, midterm prep

Wednesday, October 15, 2008
7:04 AM

Field trip – Oak Park

Continuous counts
24 hr/day 365 days trends - peaks & valleys

Control counts 24 hrs for 5 days (weekend)
once a month

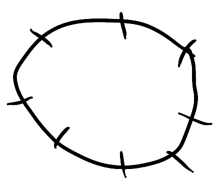
Coverage counts 24 hr weekday
every 4 yrs

AADT peak hour (30th highest)

VMT = AADT × Link length

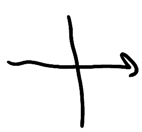
Special Study

cordon Line



Line goes across all Major roads

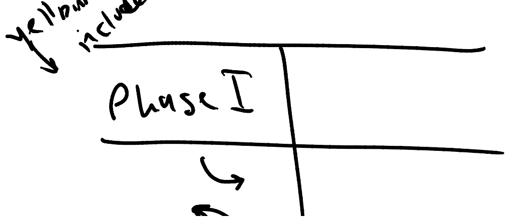
Screen Line

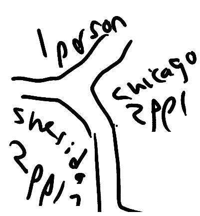


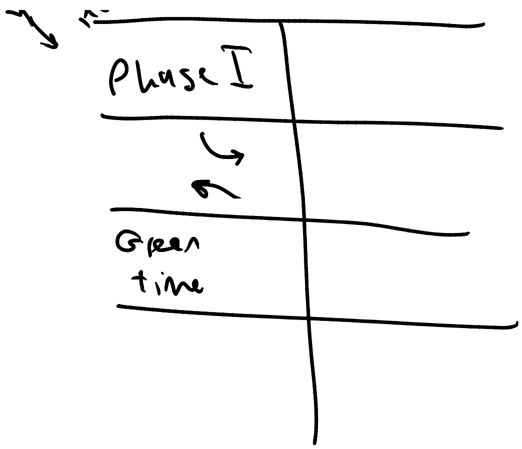
OD (Original Destination) Counts

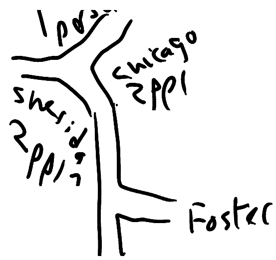
Need electronic device

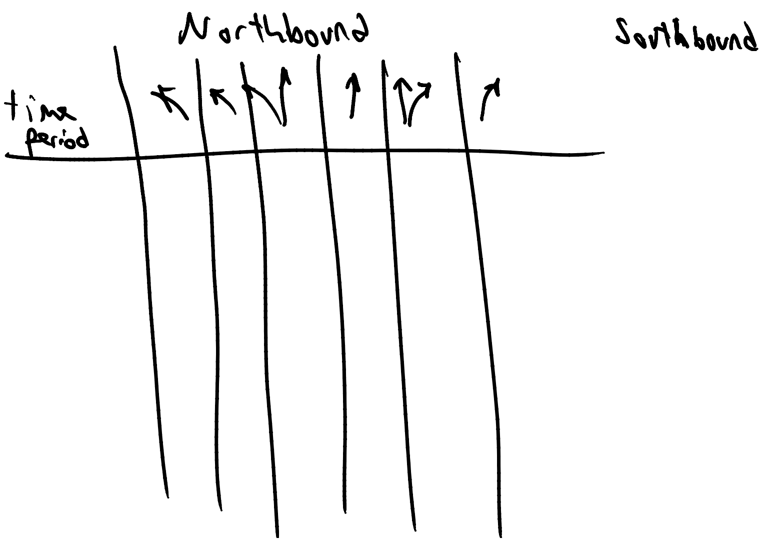
yellow time included











Record time in which ppl join the que

at the red light

Gary-Chicago-Milwaukee Corridor

http://gcmtravel.com

Use travel times

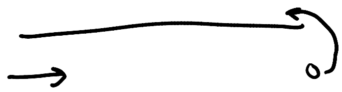
p.84-99 - How To do a study

Spot Speed Study

Travel Time Study

- Probe vehicle
- Floating car
- Avg speed
- moving vehicle

Moving Veh.



Count traffic on way east
(westbound traffic)
On way back (west) count #
vehicles overtaking you & passing
you. Westbound (overtaking)
Eastbound (passing)
Count travel time west & east
bound

$N_w, T_w, O_w, P_w, T_e,$

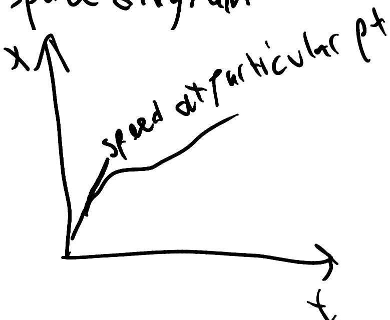
$$\frac{N_w + O_w - P_w = \text{total cars}}{T_e + T_w} \; V_w$$

$$T = T_w - \frac{O_w - P_w}{V_w}$$

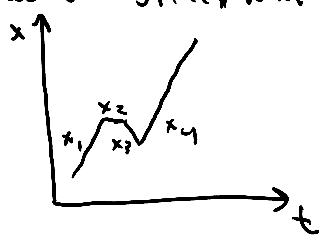
MIDTERM INFO

Traffic Flow

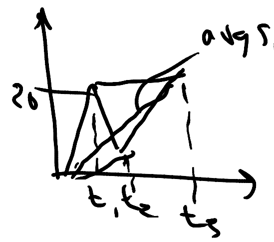
Time-space diagram



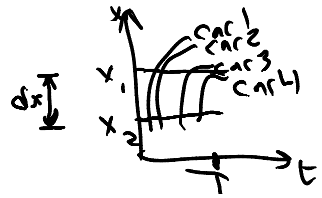
Avg speed of bikers/walkers



$$\text{Avg speed} = \frac{\frac{dx_1}{dt} + \frac{dx_2}{dt} + \frac{dx_3}{dt} + \frac{dx_4}{dt}}{4}$$



avg speed is slope of this line



Many car trajectories

flow rate

$q = \frac{N}{T} = \frac{1}{h} = \frac{1}{\left(\frac{T}{N}\right)}$

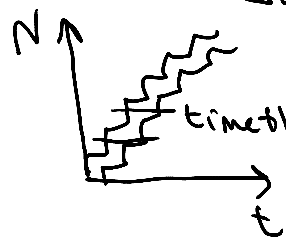
headway h N

If you have an avg headway

$T = \Sigma h_i$ Avg of headway = $\frac{\Sigma h_i}{N}$

Can calculate speed & avg speed w/ 2 x's (x_1 & x_2)

$v_i = \frac{dx}{\Delta t_i}$ $\frac{\Sigma v_i}{N}$ time-mean speed



time that it takes to get from x_1 to x_2

vertical distance is Volume of cars at a certain time

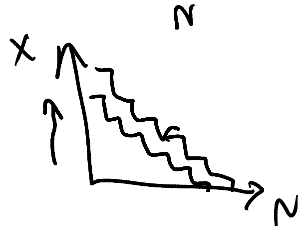
$\frac{N}{L}$ = density of road, k L is length

distance between vehicles = s

speed in picture

$v_i = \frac{\Delta x_i}{dt}$ - distance each car travels

$\frac{\Sigma v_i}{N}$ Average speed
space-mean speed



s_i $k = \frac{1}{\bar{s}}$ $\bar{s}$ = avg s

staircases for diff times

horizontal distance = # of cars between 2 spots

vertical distance = distance traveled by vertical distance = distance traveled by a car for that dt

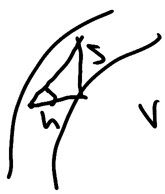
$N_i v_i$ $\quad \frac{\sum N_i v_i}{\sum N_i}$ = speed?

$$\frac{\sum \frac{N_i}{T} v_i}{\sum \frac{N_i}{T}} =$$

Every car has a diff speed. You have a flow rate for each class

$$\frac{\sum q_i v_i}{q} =$$

$$\frac{\left(\frac{\sum N_i v_i}{L}\right)}{\left(\frac{\sum N_i}{L}\right)} = \frac{\sum k_i v_i}{k}$$ density



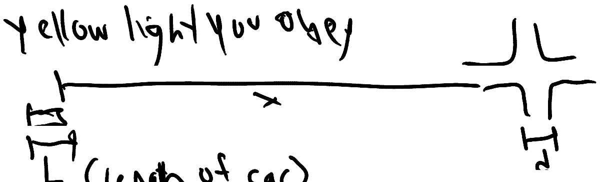
$$v = \frac{s}{h} = \frac{\frac{1}{k}}{\frac{1}{q}} \Rightarrow q = kv$$
$$= \sum k_i v_i$$
$$= k \boxed{\frac{\sum k_i v_i}{k}}$$

Harmonic Avg

Monday, October 20, 2008
7:04 AM

11.2 ft/s^2 is frictional factor used

Min. yellow light you obey



Yellow light duration y

speed limit v

$$\begin{cases} yv \geq x + (L+d) \\ x \geq \frac{v^2}{2a} \end{cases}$$

$yv < x + L + d$ dangerous

$x < \frac{v^2}{2a}$ dangerous

$$yv < (L+d) < x$$

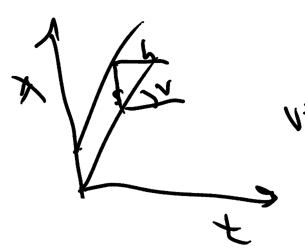
$$yv - (L+a) < x < \frac{v^2}{2a} \quad \text{safe}$$

$$y \leq \frac{v}{2a} + \frac{L+a}{v} \geq 2\sqrt{\left(\frac{x}{2a}\right)\left(\frac{L+a}{x}\right)}$$

$$= 2\sqrt{\frac{L+d}{2a}}$$

α^2

1. $q = kv$



$v = \frac{s}{h}$ $\quad s = \frac{1}{k}$

$h = \frac{1}{q}$

$$q = \frac{N}{T} = \frac{1}{h}$$

time mean speed $\bar{v} = \frac{\sum v_i}{N}$ $\quad v_i = \frac{dx}{dt_i}$

$$\bar{v} = \frac{\frac{\sum N_i v_i}{T}}{n} = \frac{\sum q_i v_i}{q}$$

$\frac{N}{T}$

2. $q = \sum_{i=1}^{n} k_i v_i$

$= k\left[\sum_{i=1}^{n} \frac{k_i}{k} v_i\right]$ space mean speed

$= k\bar{u}$

$\bar{u} = \frac{\sum k_i v_i}{k} \leftarrow \bar{u} = \frac{\sum \frac{N_i}{L} v_i}{\frac{N}{L}} = \frac{\sum k_i v_i}{k}$

$= \frac{\sum \frac{q_i}{v_i} v_i}{\sum \frac{q_i}{v_i}} = \frac{q}{\sum q_i / v_i}$ harmonic avg

speed measured in the space

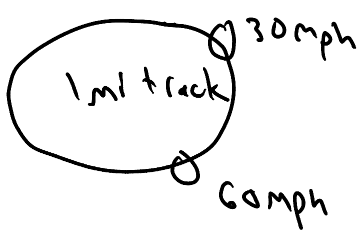
$\bar{v} = \frac{\sum q_i v_i}{q} = \frac{\sum k_i v_i v_i}{\sum k_i v_i}$

$= \frac{\sum k_i v_i^2}{\sum k_i v_i} = \frac{\sum v_i^2}{\sum v_i} \geq \frac{\sum v_i}{N}$

Cauchy Schwartz

$\sum x_i y_i \leq \sqrt{\sum x_i^2 \sum y_i^2}$

Harmonic avg < ____ avg



Space mean speed?
time mean speed?

Space mean speed

$\bar{u} = \left(\frac{1 \text{ car/mile}}{2} \text{ (density)}\right) 30 + \frac{1}{2}(60) = 45$ mph

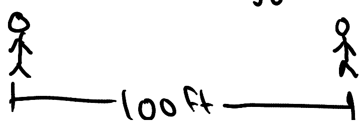
Time mean speed = flow rated avg

$\bar{v} = 30 \quad 60$

$$v = \frac{30}{30+60}30 + \frac{60}{30+60}60$$
$$= 10 + 40 = 50$$

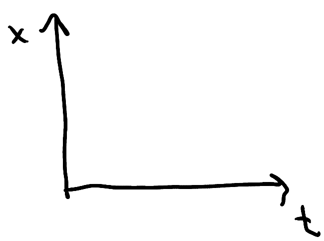
	1	2	3	4	5	6
x-1	15	18	23	24	27	29
x-2	17	19.5	25	26	28.5	30

You see the higher speed cars more than the lower speed cars. This is why the time mean speed is not accurate.



30 s

MIDTERM ?



flow rate: $\frac{5 \times 3600}{30} = 720$ vph

vehicles

s per h

s total

vehicles per hour

Space mean speed:

arismatic average gives time mean speed

U = density avg

$$\bar{U} = \frac{\sum k_i v_i}{k} = \frac{q}{\sum \frac{q_i}{v_i}}$$

3 cars/30 s = 360 cars/hr

$\frac{3600}{15} = 240$

$$\bar{U} = \frac{\sum \frac{q_i}{v_i} v_i}{\sum \frac{q_i}{v_i}} = \frac{\sum q_i}{\sum \frac{q_i}{v_i}} = \frac{720}{\frac{360}{(100/2)} + \frac{240}{66.7} + \frac{120}{100}}$$

50 ft/s 3 cars

ft/s 2 cars

1 car

$$= \frac{6}{\frac{1}{50}+\frac{1}{50}+\frac{1}{50}+\frac{1}{66.7}+\frac{1}{66.7}+\frac{1}{100}}$$

$\bar{U}$ = 60 ft/s = 40.9 mph

Time mean speed:

density

$$k = \frac{q}{\bar{U}} = \frac{720}{40.9} = 17.6 \text{ vpm}$$

vehicle per mile

$\bar{V}$ = 63.9 ft/s

$$= \frac{50+50+50+66.7+66.7+100}{6}$$

G

All trucks travel at $v_t = 50$ km/hr.
All cars travel at $V_c = 80$ km/hr
Fraction of vehicles passing observer that are cars $= \rho = .3$
What fraction are trucks in a photograph?

Car length is ℓ, length of a truck is 2ℓ. Avg vehicle length in photograph?

Time mean speed $\bar{v} = \frac{50+80}{2} = 65$ km/hr

Space mean speed $\bar{v}$ = flow proportion $\bar{v}$ = density proportion

harmonic avg $= \dfrac{1}{\frac{.3}{80} + \frac{.7}{50}} = 56.3$

arithmatic avg for taking a picture $= \dfrac{56.3-50}{80-50} = (\rho_c)(80)+(1-\rho_c)(50)$ $= 21\%$

% cars through photo

If you take a pic space mean speed = arithmatic avg

q

$q_c = \rho q$ $q_t = (1-\rho) q$ $\dfrac{k_c}{k_c+k_t} = 21\%$

$k_c = \dfrac{\rho q}{V_c}$ $k_t = \dfrac{(1-\rho) q}{V_t}$

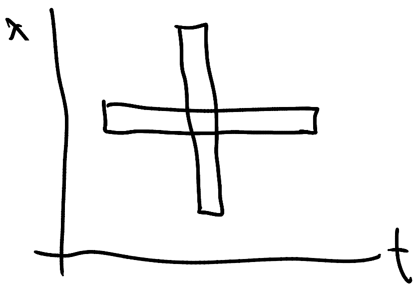
Once you know the flow rate you can get the density.

Once you know the density you can get the % on a pic

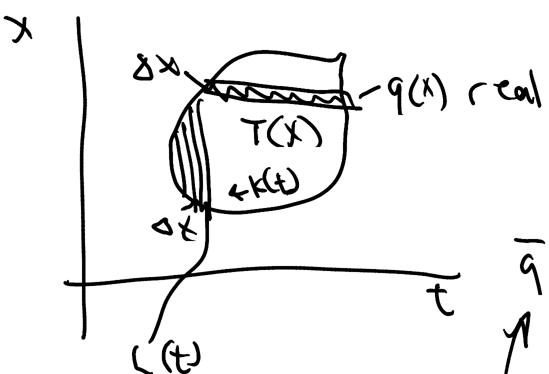
Fundamental Diagrams

Wednesday, October 22, 2008
7:04 AM

	time-mean system	space-mean system
space mean speed → $\bar{\upsilon}$	$\dfrac{N}{\sum \frac{1}{v_i}}$	$\dfrac{\sum v_i}{N}$
time mean speed → $\bar{V}$	$\dfrac{\sum v_i}{N}$	$\dfrac{\sum v_i^2}{\sum v_i}$



ideal



\# cars

N

distance

$$\bar{q} = \frac{\int_{x_L}^{x_U} q(x)T(x)\,dx}{\int_{x_L}^{x_U} T(x)\,dx}$$

Avg q (flow rate)

$$= \frac{\text{total distance}}{\text{area}}$$

\#cars

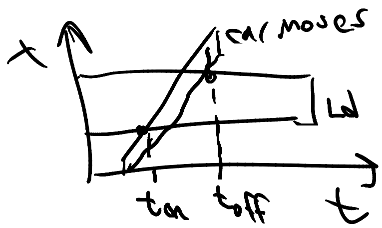
Avg density $$\bar{k} = \frac{\int_{t_L}^{t_U} k(t)L(t)\,dt}{\int_{t_L}^{t_U} L(t)\,dt}$$

$$= \frac{\text{total travel time}}{\text{area}}$$

$$\frac{N\Delta x}{\Sigma t_i} = \frac{N}{\Sigma \frac{t_i}{\Delta x}}$$

$$\frac{\Sigma \Delta x_i}{Nt}$$

We need this too: We have a loop detector, want to calculate space mean speed.



$L_d + \ell$ → length of vehicle

$L_d + L_i$

$\Delta t_i = t_{off} - t_{on}$

$$V_i = \frac{L_d + L_i}{\Delta t_i} \qquad q = \frac{N}{T}$$

$$\text{occupancy} = \left(\frac{\Sigma \Delta t_i}{T}\right) \times 100$$

= total time the detector is on

$$\text{Space mean speed } \bar{u} = \frac{\text{total dist}}{\text{total time}} = \frac{\Sigma(L_d + L_i)}{\Sigma \Delta t_i}$$

$$\text{occupancy} = \left(\frac{\Sigma \Delta t_i}{T}\right) 100 = 100 \frac{N}{T} \frac{\Sigma(L_d + L_i)}{N} \frac{\Sigma \Delta t_i}{\Sigma(L_d + L_i)}$$

$$= 100 (q)(\bar{\ell})\left(\frac{1}{\bar{u}}\right)$$

$\frac{q}{\bar{u}} = k$ $\bar{\ell}$ avg distance

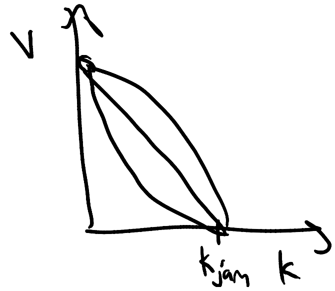
$$\text{occ} = 100 k \bar{\ell}$$

Vehicle Length 15 ft

$L_d = 6$ ft

occ= 15%

$$15 = 100(k)\frac{(15+6)}{5280} \leftarrow \text{ft/mi}$$



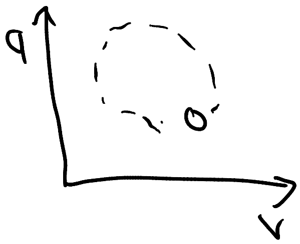
jam density

Avg 20ft Jam density

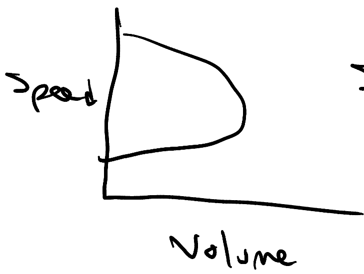
$\frac{5280}{20}$ vpm

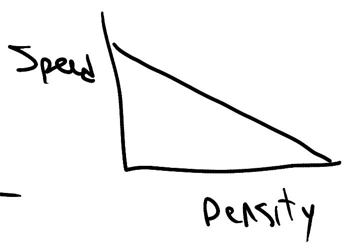
260 cars

max # freeway can handle per mile



Greenshield
1934
traffic engineering founder





Not very accurate - Greenshield's work was still studied despite being flawed

q-o

Greenshield's model

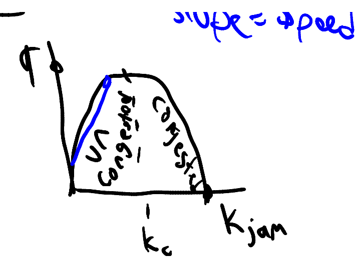
$$v = v_f\left(1 - \frac{k}{k_j}\right)$$

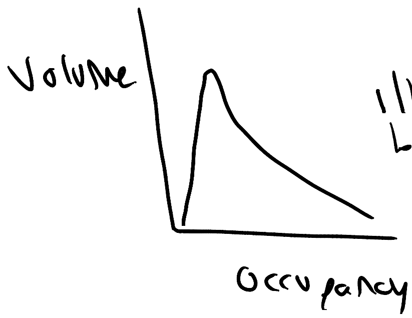
Fundamental Diagram

slope = speed

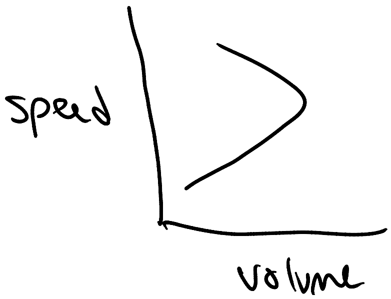
Fundamental Diagram

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





Illustrates break down - lose capacity



flow speed = 55 mph   density = 200 vpm
capacity = 3600 vph

$$v = v_f e^{-\alpha k}$$

v?

$$q = v_f k e^{-\alpha k}$$

$$\frac{dq}{dk} = 0 \quad (\text{max})$$

$$\frac{dq}{dk} = v_f e^{-\alpha k} + v_f k(-\alpha) e^{-\alpha k} = 0$$

$$v_f e^{-\alpha k} = v_f k \alpha e^{-\alpha k}$$

$$1 = \alpha k \qquad k = \frac{1}{\alpha}$$

$$q_{max} = v_f \frac{1}{\alpha} e^{-1}$$

$v_f = 55$ mph

$k = 200$

$q = 3600$ vph

Hello my friend
we meet again

Been a while
Where should we
begin?

Seems like
forever

Within my
heart are
memories

the perfect
love that you
gave to me.

Oh I
remember..

When you
are with
me

I'm free

I'm careless

I believe

Above all
the others
we'll fly

This brings
tears to my
eyes

My

$$q_{max} = 3600 \text{ vph}$$

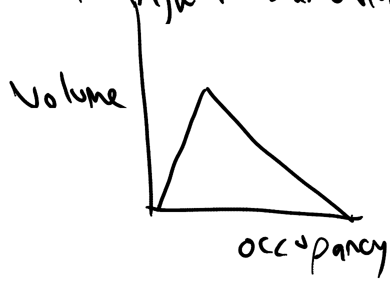
$$3600 = 55\left(\tfrac{1}{\alpha}\right) e^{-1}$$

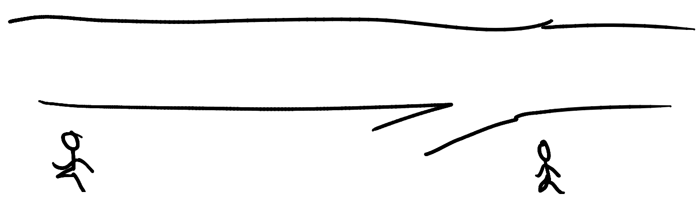
$$\# = \alpha \quad (.00565)$$

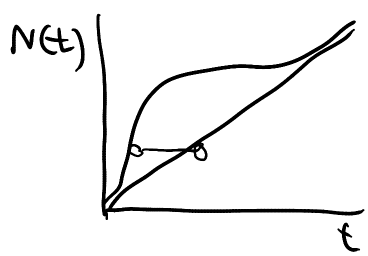
volume or "flow rate" $q = (55)(200)\, e^{-(\#)(200)}$

$$q \text{ (volume)} = \#_2$$

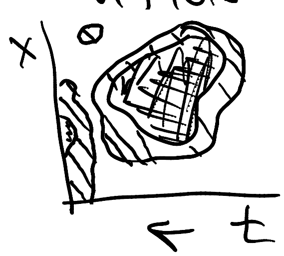
Triangle Fundamental Diagram







Contour Plots

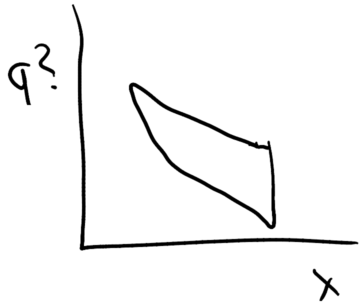


My sacrifice

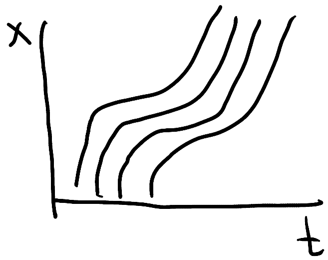
We've seen our share of ups & downs

Oh how quickly Life can turn around In an instant

It feels so good to be alive



typically we use density, not volume, for graphs



time-space diagram

Greenshield

Monday, October 27, 2008
7:04 AM

help pemsdata

give a file to program & it returns, x, t, & a

```
[x,t,speed] = pemsdata('data\d1_spd_agg.dat');
```

Only select by detector ID
or
by postmile range

'who' gives variables

```
[x,t,flow] = pemsdata('data\d1_spd_agg.dat')
```

```
plot(flow, speed, 'o')
   "          'marker size', 3)
```

print out

first get flow, then density, then plot

Contour Map – postmile range

```
contourf (t, x, speed)
colorbar
```

low speed during rush hour

1. $q = ku$
2. $u = f(k)$
   $q = ku = kf(k)$

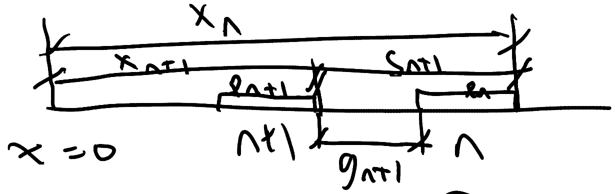
$u = v_f\left(1 - \frac{k}{k_j}\right)$

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

etc

$q = kv = k\,f(k)$ etc.

Car-following



$S_{n+1} = g_{n+1} + l_n$

$S_{n+1} = x_n - x_{n+1}$

$g_{n+1} = l_{n+1} \dfrac{V_{n+1}}{10}$

for every 10 mph of speed, one car length distanc

related to rxn time

$g_{n+1} = \tau V_{n+1}$

$S_{n+1} - l_n = x_n - x_{n+1} - l_n = \tau v_{n+1}$

$V_n - V_{n+1} = \tau a_{n+1}$

IMPORTANT → $\boxed{a_{n+1} = \dfrac{V_n - V_{n+1}}{\tau}}$ (1)

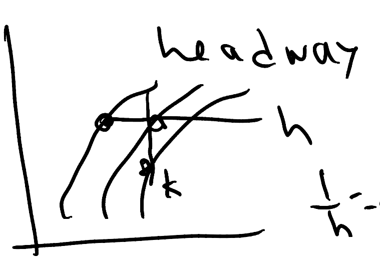
$S_{n+1} - l_n = \tau V_{n+1}$

(2) $\dfrac{d s_{n+1}}{dt} = \tau \dfrac{d v_{n+1}}{dt}$

$$\int \frac{dv_{n+1}}{dt} = \int \frac{\frac{dS_{n+1}}{dt}}{\tau}$$

$v = \frac{1}{\tau}(S - l)$

$V_{n+1} = \dfrac{S_{n+1}}{\tau} + b$



$\frac{1}{h} = q$

$V = \dfrac{S}{\tau} + b$

if $S = l$, $b = 0$

so $v = \frac{S}{\tau} = \frac{l}{\tau}$

$\frac{1}{h} = q$

$V = \frac{s}{\tau} + b$ if $s = \ell$, $b = 0$

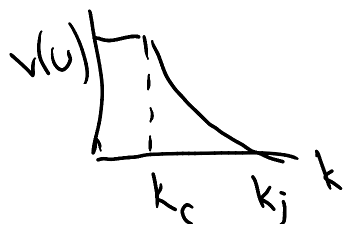
so $V = \frac{s}{\tau} = \frac{\ell}{\tau}$

$s = \frac{1}{k}$

$$\boxed{V = \frac{1}{\tau}\left(\frac{1}{k} - \ell\right)}$$

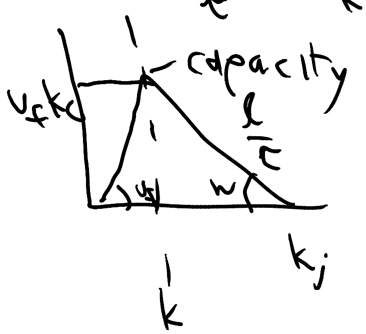
$$V = \frac{1}{\tau}\left(\frac{1}{k} - \frac{1}{k_j}\right)$$

$k_j = \frac{1}{\ell}$ if $k = 0$,



$$V = \begin{cases} U_f & k \le k_c \\ \frac{1}{\tau}\left(\frac{1}{k} - \frac{1}{k_j}\right) & k > k_c \end{cases}$$

$$q = \begin{cases} U_f k & k \le k_c \\ \frac{1}{\tau}\left(1 - \frac{k}{k_j}\right) & k > k_c \end{cases}$$



$\tau = 1s$ $\quad \ell = 20$ ft

$V_f = 60$ mph $\quad$ find capacity

$$V = \frac{1}{\tau}\left(\frac{1}{k} - \ell\right)$$

$$60 = \frac{1}{1s\left(\frac{1h}{3600s}\right)}\left(\frac{1}{k} - 20ft\left(\frac{1mi}{2850ft}\right)\right)$$

$$60 + \frac{3600(20)}{2850} = \frac{3600}{k}$$

$\frac{3600}{\quad}$ $\quad$ k = critical density

$$k = \frac{3600}{60 + \frac{3600(20)}{2850}}$$

k_c = critical density

$$k = 42.777$$

$q = U_f k_c$ = Capacity
= 2533.32 ?

$$U_f k_c = w(k_j - k_c)$$

$$k_j = \frac{1}{\ell}$$

$w = -\frac{\ell}{\tau}$ slope of the line

solve for k_c

plug into $q = U_f k_c$

$$(60\text{mph})k_c = \left(\frac{-20\text{ft}}{1\text{s}}\right)\left(\frac{1}{20\text{ft}} - k_c\right)$$

$$a_{n+1} = \frac{V_n - V_{n+1}}{\tau}$$

$$a_{n+1} = \frac{V_n + U_{n+1}}{\tau(X_n - X_{n+1})^{\gamma}}$$

$$a_{n+1} = V_n^{\beta}\,\frac{V_n - V_{n+1}}{\tau(X_n - X_{n+1})^{\gamma}}$$

GM Family Car Model

Robert Herman

β & γ are test parameters

$$a_{n+1} = \frac{V_n - V_{n+1}}{\tau(X_n - X_{n+1})^2}$$

$$a \quad = \frac{dS_{n+1}}{\quad}$$

$$\frac{dt}{\tau(s_{n+1})^2}$$

$$v_{n+1} = \frac{-1}{\tau s} + b \quad \text{and if } s = l, v = 0$$

$$b = \frac{1}{\tau l}$$

$$v_{n+1} = \frac{1}{\tau}\left(\frac{1}{l} - \frac{1}{s}\right)$$

$$v_{n+1} = \alpha\left(\frac{1}{l} - \frac{1}{s}\right) = \alpha(k_j - k)$$

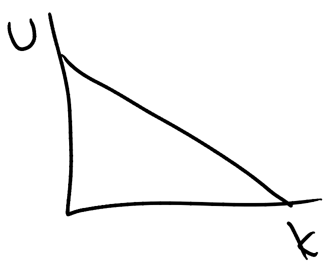
$k = 0, v = v_f$

density $= 0$,

speed $= v_f$

$$\alpha = \frac{v_f}{k_j}$$

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



Greenshield $\beta = 0$ $\gamma = 2$

$$\gamma > 1$$

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

$$b = -\alpha \ln l$$

$v_{n+1} = \alpha - \ln s + b$ b/c $a_{n+1} = \ln s$

$\beta = 0$, $\gamma = 1$ $\leftarrow$ $$\boxed{v = \alpha \ln\left(\frac{k_j}{k}\right) = \alpha \ln\left(\frac{s}{l}\right)}$$

Underwood Model

Underwood, ...

When $\gamma = 2$ follows linear relationship

Using Underwood Model, find relationship between Speed & density

$\beta = 1, \gamma = 2$

α	β	γ	
$\frac{1}{\tau}$	0	0	Triangle
	0	1	Greenberg
	0	2	Greenshield
	0	≥ 2	Polynomial
	1	2	Underwood

$$v = \alpha \ln\left(\frac{s}{\ell}\right)$$

$$a = \alpha v_n \frac{v_n - v_{n+1}}{(x_n - x_{n+1})^2}$$

$$\frac{dv}{v\,dt} = \alpha \frac{\frac{ds}{dt}}{s^2} = \cdot \alpha \frac{d\frac{1}{s}}{dt}$$

Hierarchy of Intersection Ctrl

Wednesday, October 29, 2008
7:05 AM

$$a_{n+1} = \alpha v_n^{\beta} \frac{v_n - v_{n+1}}{(x_n - x_{n+1})^{\alpha}}$$

$(x_n - x_{n+1}) \rightarrow S_{n+1}$

$s = \frac{1}{k}$

$v = f(k)$

$q = kv = kf(k)$

$\frac{dq}{dk} = 0 \rightarrow k_c$ critical density/max

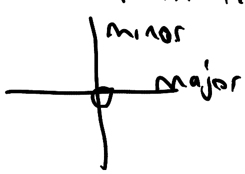
Heirarchy of intersection control

Level I: no control ← residential area

Level II: stop signs/yield signs → T-intersection

Level III: traffic lights/signals → safety
→ efficiency
→ help pedestrians

warrant 1. traffic volume requirement



	Major	Minor
1 lane	>500 vph	>150 vph
2 lanes	>600 vph	>150 vph

2. Interruption of continuous traffic

3. Pedestrian volume $\begin{cases} 100 \\ 190 \end{cases}$

$250,000 to install a light system

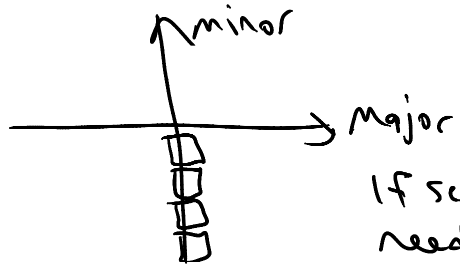
4. School

5. Progressive movement

6. Accident experience - 5 or more accidents per year

7. System needs

7 seconds to make decision at intersection

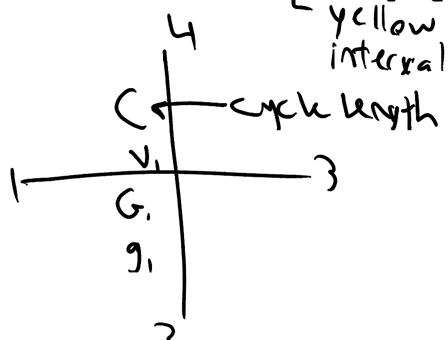


If second car follows, only need 2 more sec

How many cars can cross? Headway dist. on major rd.

H. - M Headway after 1st driver

lost time { Geometric delay
- Alien abductions
- Rantime
- Unused yellow interval



S, ← saturation flowrate

Not subject to time-free flow of traffic

Capacity means, w/ signal in place, how many cars can move?

Usually saturation is much larger than capacity.

Kerry finally faces down the Wizard & discovers who he used to be - a great federal agent of the 1940s, who began nanite injections in the ~~20~~ 2000's to live forever for the mission of eradicating evil. Kerry has resorted to extreme measures in the past. Neil is against them. Wizard tries to entice Neil to take his conscience through 289, + it almost works. Wouldn't work on Kerry b/c she knows she is imperfect - knows she is broken. And it's only with that knowledge that she can beat the "good" that turns to evil.

Religious message. Neil thinks he's on the good side. Thinks he's morally perfect

Kerry knows her own imperfection

Can beat the Wizard, in the end cannot be controlled.

They make a jamming device to block the kids but Wizard gets

1) $v_i C \leq s_i g_i$

2) $\Sigma g_i + L = C$

All green time + time lost = Cycle Length

$$\Sigma \frac{v_i}{s_i} + \frac{L}{C} \leq \frac{\Sigma g_i}{C} + \frac{L}{C} = 1$$

$$1 - \frac{L}{C} \geq \Sigma \frac{v_i}{s_i}$$

$$C \geq \frac{L}{1 - \Sigma \frac{v_i}{s_i}}$$

Big Fish

The Boy in the Striped Pajamas

Kids, but Wizard gets through.

Use of children b/c of their profound innocence

this is how Kerry gets over her revenge thing - convincing Neil he's broken convinces her of what she knew all along - revenge doesn't bring justice - that's God's job.

Decides to keep the scars b/c they are a constant reminder of her own imperfection

Guilt - Seamus
Shame - Kerry
Rage
Weariness - Connor, Kathleen
Innocence - Amy
Delusion/Sin - Neil

Webster, Change Intervals, Cycles

Monday, November 03, 2008
8:08 AM

$$\begin{cases} v_i C \le s_i g_i \; v_i \\ \sum g_i + L = C \end{cases} \Rightarrow C \ge \frac{L}{1 - \sum \frac{v_i}{s_i}}$$

capacity

"=" when $v_i = \frac{g_i s_i}{C} = c_i$

cycle = a complete sequence of signal indication
(consists of # of phases)

phase = part of a cycle allocated to a movement or combination of several movements

interval =

change interval = all red / all yellow intervals

offset of signals in 2 intersections

v_i — demand for movement i (cars/hour)

find $\frac{v_i}{s_i}$ for each movement & then pick the higher value for v_i

Left turn is movement

2 lanes for left turn

C — cycle length (s)

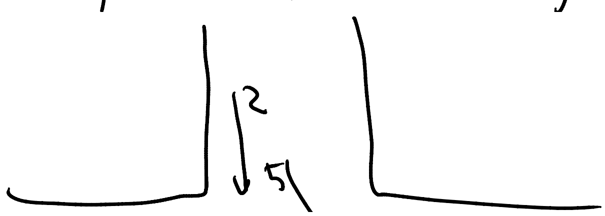
(G_i) g_i — effective green time (s) allocated to each movement

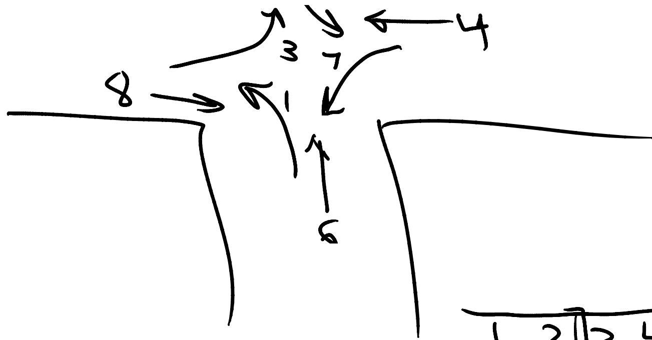
g_i < normal green interval

s_i — saturation flow rate (cars/hour)

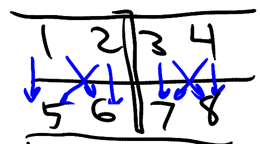
L — lost time (s) [start-up loss & clearance time]

nominal green time, the time the light is actually green





Should not cross the barrier



dual-ring barrier

ϕ_1	ϕ_2	ϕ_3	ϕ_4
1	2	3	4
5	6	7	8

1	2	3	4
6	5	8	7

i denotes movement

$\frac{v_i}{c_i}$ = volume to capacity ratio

27 sec green time
3 sec yellow + all red
cycle length = 60 s
saturation headway = 2.4 s/veh
total lost time = 3 s
flow rate of movement = 500 veh/hour
v/s & v/c ratio

$$v_i C \le s_i g_i$$

$$\sum g_i + L = C$$

$$n(27s) + 3s = 60s$$

$$n = \frac{57s}{27s}$$

$$60s \ge \frac{3s}{1 - \frac{57}{27}\left(\frac{v_i}{2.4\, veh/s^{-1}}\right)}$$

$g_i = 27 + 3 - 3 = 27$

$s_i = \frac{1}{2.4} \times 3600 = 1500$ vph

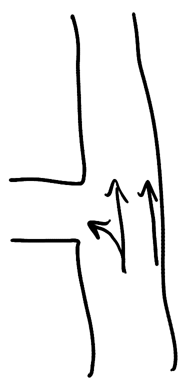
$c_i = \frac{s_i g_i}{C} = \frac{(1500)(27s)}{60s} = 675$ vph

$\frac{v_i}{s_i} = \frac{500}{1500} = \frac{1}{3}$

$\frac{v_i}{c_i} = .74$ Volume-to-capacity is much higher

pretimed signal timing

1. obtain v_i
2. decide lane groups
3. compute v_i/s_i & decide critical v_i/s_i for each lane group
4. decide on the number of phases
5. Compute C, g_i



[PRISONBREAK]

SB EB WB

Get ~~ln~~ critical volume to capacity ratios

$C \geq \frac{L}{1 - \sum \left(\frac{v_i}{s_i}\right)_c}$ lower bound

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

c

Webster formula

$$C = \frac{1.5L + 5}{1 - \Sigma\left(\frac{V_i}{S_i}\right)_c}$$

increase the Cycle length

Once you have cycle length...

$$g_i = \frac{\left(\frac{V_i}{S_i}\right)_c}{\Sigma\left(\frac{V_i}{S_i}\right)_c}(C - L)$$

HCM Highway Capacity Manual

$$C = \frac{L}{1 - X_c \Sigma\left(\frac{V_i}{S_i}\right)_c}$$

Designed following to capacity ratio

$$V_i \le X_c C_i$$

$$g_i = \frac{\left(\frac{V_i}{S_i}\right)_c}{X_c} C$$

$$\frac{C}{X_c} = \frac{C - L}{\Sigma\left(\frac{V_i}{S_i}\right)_c}$$

$$g_i = \frac{V_i C}{X_c S_i} = \frac{\left(\frac{V_i}{S_i}\right)_c}{X_c} C$$

Min cycle & phase splits

lost time = Σ yellow intervals, 3s each

Lost time = Σ yellow intervals, 3 s each
Min green = 15 s per phase
Traditional signal timing plan
Cycle = 5 s, phases in multiples
of .01 cycles

p. 300 Min green time

Lane group	NBLT	SBLT	NB			
Flow ratio	.18	.20	.28	.31	.27	.29

North-bound
Left turn

It is more beneficial to combine SBLT & NBLT, SB & NB for phases

$$\frac{.18 + .20}{2} = .19$$

$$\frac{.28 + .31}{2} = .295$$

Webster's Formula

$$C = \frac{1.5L + 5}{1 - \Sigma\left(\frac{V_i}{S_i}\right)_c}$$

$L = \Sigma l_i$ lost time per phase $= l_i$
Total lost time $= L$

$$g_i = \frac{\left(\frac{V_i}{S_i}\right)_c}{\Sigma \frac{V_i}{S_i}}(C - L) \quad \text{effective green time}$$

$$G_i = g_i + l_i - Y_i$$

$l_i = Y_i + R_i + t_{su i}$ yellow + red + startup loss
$- e_i$ — extension time

phase 1	phase 2	phase 3
NBLT + SBLT	NB + SB	EB + WB

$\left(\frac{V_1}{S_1}\right)_c = .2$ $\left(\frac{V_2}{S_2}\right)_c = .31$ $\left(\frac{V_3}{S_3}\right)_c = .29$

Serve max, satisfy max conditions, pick largest flow serve max, satisfy max conditions, pick largest flow ratio

$$L = \sum y_i = 3(3s) = 9s$$

$$C = \frac{1.5 \cdot 9 + 5}{1-(.2+.31+.29)}$$

$$= 92.5$$

$$\approx 95$$

$$g = C - L = 95 - 9 = 86$$

$$g_1 = \frac{.2}{.8} \cdot 86 = 21.5$$

$.8$ sum of flow ratios

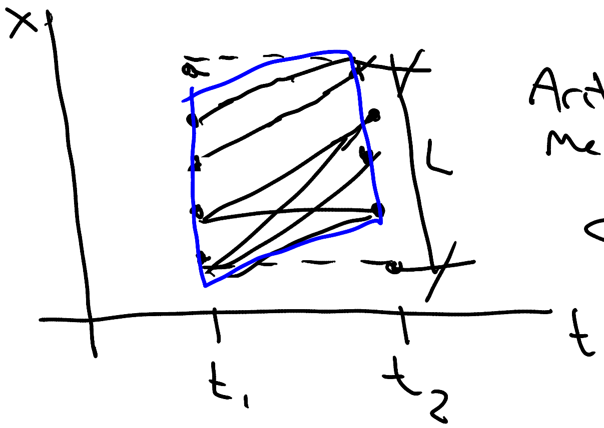
$$g_2 = \frac{.31}{.8} \cdot 86 = 33.3$$

$$g_3 = \frac{.29}{.8} \cdot 86 = 31.2$$

$$G_1 = 21.5 + 3 - 3 = 21.5$$

Flow Rates, Density

Wednesday, November 05, 2008
8:05 AM



Arithmatic avg = Space Mean speed

Calculate density

$$k = \frac{\text{total time (T)}}{\text{Area of blue}}$$

$$k = \frac{10 \cdot 15}{\left(\frac{(L_1 + L_2)15}{2}\right)}$$

Flow rates given, Determine min cycle & phase lengths. Min greens are 15s for each phase. Lost time = sum yellow intervals, 3s each. Critical saturation ratio should be no more than .85. Saturation ratio ≈ same for all critical lane groups & must be less than .85 in all cases.

Lane Group	NBLT	SBLT	NB	SB	EB	WB
Flow ratio	.18	.16	.22	.25	.20	.22

Highway Capacity Manual Method

$$V_i \le \frac{s_i g_i}{c} = c_i$$

$$\frac{V_i}{c_i} \le X_c$$

Phase I	Phase II	Phase 3	
.18	.25	.22	$\Sigma = .65$

$$C = \frac{9}{1 - \frac{.65}{.85}} \qquad L = 9 \qquad C = \frac{L}{1 - \sum\left(\frac{v_i}{s_i}\right)_c}$$

$$= 38.25$$

$$g_1 = (38.25 - 9)\left(\frac{.18}{.65}\right) = 8.1$$

$$= \frac{.18 \cdot C}{X_c} = \frac{.18 \cdot 38.25}{.85} = 8.1 < 15$$

$$\frac{C - L}{\sum\left(\frac{v_i}{s_i}\right)_c} = \frac{C}{X_c}$$

$$g_{i\,min} = \frac{\left(\frac{v_i}{s_i}\right)_{min}}{X_c} C$$

$$X_c = \sum\left(\frac{v_i}{s_i}\right)_c + \frac{L\left(\frac{v_i}{s_i}\right)_{min}}{g_{i\,min}} \qquad C = \frac{L}{1 - \frac{\sum\left(\frac{v_i}{s_i}\right)_c}{X_c}}$$

$$X_c = .6 + \frac{9 \cdot .18}{15} = .758$$

recalculate C

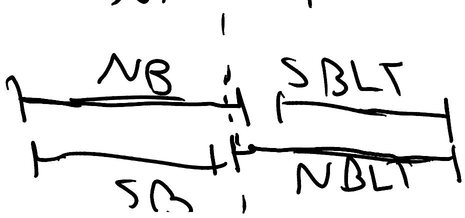
$$c_i = \frac{s_i g_i}{C} \qquad C = 63.2$$

$$g_i = \frac{.18}{.758} \cdot 63.2 = 15$$

$$.758 = \frac{.25}{\left(\frac{20.8}{63.2}\right)}$$

overlapping phase

Overlap is when one direction dominates another. SB (.31) dominates NB (.28) but not by much



NB larger than SB
NBLT larger than SBLT

If you don't overlap, total is higher

$$\sum \frac{v_i}{s_i} = \underset{NBLT}{.49} + \underset{SB\ (conflicting)}{.29} + WB? = .78 \quad (.8\ w/o)$$

$$C = \frac{1.5 \cdot 9 + 5}{1 - .78} = 84.1 \approx 85\,s$$

10 s diff - Significant

$$NBLT = \frac{.18}{.78} \cdot 85 = 17.5$$

$$SBLT = \frac{.2}{.78}(85-9) = 19.5$$

$$SB = \frac{.31}{.78}(85-9) = 30.2$$

$$NB = \frac{.28}{.78}(85-9) = 27.4$$

Try to overlap the #s

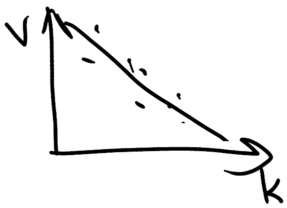
NBLT + SBLT = 17.5 overlap

SBLT + SB = 2 (diff between NBLT & SBLT)

SB + NB = 28

Greenshield's Model, Critical Density

Monday, November 10, 2008
8:04 AM



$$V = ak + b$$

$$q = ak^2 + bk$$ Greenshield's Model for density

$$\frac{dq}{dk} = 0 = 2ak + b$$

$$\frac{-b}{2a} = k_c$$ Critical density

$$q_{n+1} = \alpha V_{n+1}^{\beta} \frac{V_n - V_{n+1}}{(X_n - X_{n+1})^{\gamma}}$$

$$\beta = 0 \quad \gamma = 3 \quad \alpha = .001$$

$$a_{n+1} = .001 \frac{V_n - V_{n+1}}{(X_n - X_{n+1})^3} = .001 \frac{\frac{dS_{n+1}}{dt}}{(S_{n+1})^3}$$

$$\int \frac{dV_{n+1}}{dt} = \int .001 \frac{\frac{dS_{n+1}}{dt}}{(S_{n+1})^3}$$

$$V_{n+1} = -\frac{.001}{2} \frac{1}{S_{n+1}^2} + D$$

$$\text{if } k = k_j, \; V_{n+1} = 0$$
$$k = 0, \; V_{n+1} = V_f \text{ or } U_f$$

$$\frac{1}{S} = k$$

$$\left(\frac{1}{S}\right)^2 = k^2$$

$$0 = \frac{-.001}{2} k_j^2 + D$$

$$\frac{.001}{2} k_j^2 = D$$

$$V_f = \frac{-.001}{2}(0) + D$$

$$V_f = D$$

8.5) North

Left turn	133
Through	420
Right turn	140
PHF	.95

$PHF = \frac{V_{hour}}{V_{15} \cdot 4} < 1$ $\qquad \frac{133}{.95} = \text{Volume}$

highest consecutive 15 min volume

$1600 + 1400 = 3000$ NBLT + NB

3000 = Saturation

$$\frac{\left(420 + 140 = \frac{560}{.95}\right)}{3000} = \frac{V_i}{S_i}$$

Overlap

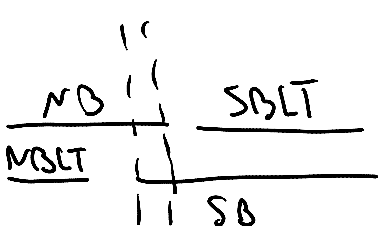
$\frac{V_i}{S_i}$	NBLT	SBLT	NB	SB	EB	WB
	.18	.2	.28	.31	.27	.29

Phase 1 $\qquad$ Phase 2

$.51 + .29 = .$

NBLT + SB = .49
SBLT + NB = .48

$.49 + .29 = .78$ total demand pressure



Webster's Formula

Total Lost time = 3s(3) = 9s

$c = \frac{1.5L+5}{\quad} = \frac{1.5(9)+5}{\quad}$

$$C = \frac{1.5L+5}{1-\Sigma\left(\frac{v_i}{s_i}\right)_c} = \frac{1.5(9)+5}{1-.78}$$

$$\frac{L}{C} = \frac{9}{85} = .12 \qquad = 84.1$$

Lost time proportion of cycle length

NBLT $.88\left(\frac{.18}{.78}\right) = .2$

Portion of .85

$$\frac{C-L}{C} = .88$$

$$\frac{C-L}{C} \frac{\left(\frac{v_i}{s_i}\right)_c}{\Sigma\left(\frac{v_i}{s_i}\right)_c}$$

SBLT $.88\left(\frac{.2}{.78}\right) = .23$

SB $.88(\quad) = .35$

NB $= .32$

WB $= .33$

Determine overlapping phasing

EB-WB is one phase

Phase1	NBLT + SBLT	.2 (20%) cycle length	
Phase2	NBLT shuts off, SBLT keeps going SBLT + SB	.03 (3%) cycle length	
Phase 3	SB + NB	.32 (32%) cycle length	
Phase4	WB + EB		

Synchro

A310 Lab

cee376
translab

Example 8.5 in book

create a street, create another

Click on node (intersection) to move it

Click on one approach

click on lane settings

click on ↖ (Lanes & Sharing)
click on ↑↑↗

Name the street
Specify Link distance (Length between 2 intersections) 850 ft
Linkspeed 30mph
Ideal Saturation Flow rate
Saturation Flow rate
Left

Volume Settings
Peak Hour Factor

Adjusted Flow $\frac{323}{.95}$ = ___

Do same thing for SB approach

Enter in traffic volumes

Phase template editor

Options → Ring + Barrier Designer

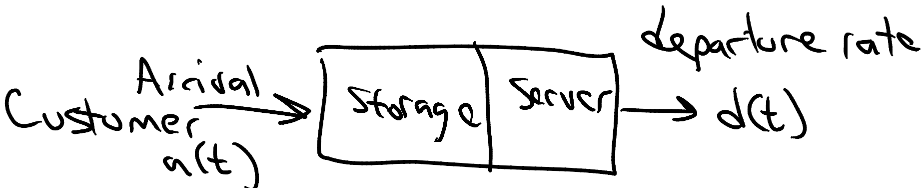
Node Settings → Cycle Length

Generate a report — File — create report

Lane Outputs
Volume "
Level of service info
timing inputs

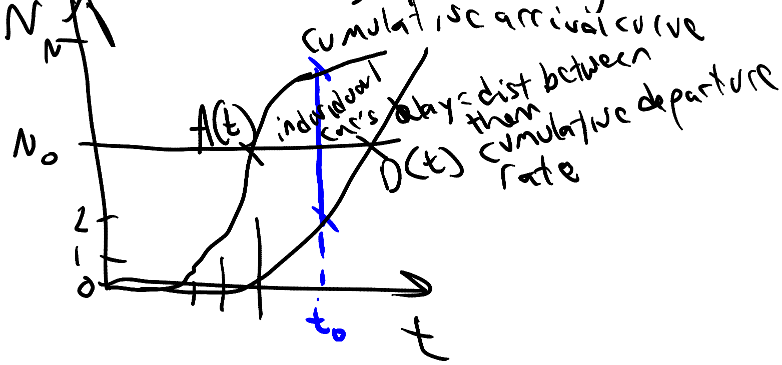
Service time

$$500\left(\frac{1}{500}\times 3600\right)$$



Avg delay $\bar{w}$

Avg queue length $\bar{Q}$



$t_{N_o} = D^{-1}(N_o) - A^{-1}(N_o)$ individual car's delay

$Q_{t_o} = A(t_o) - D(t_o)$

$A(t) \geq D(t)$ For all t $(\forall t)$

Total delay = area between 2 curves

$$\text{Total delay} = \int_0^T Q(t)\,dt$$

$$\bar{w} = \frac{\int_0^T Q(t)\,dt}{\int_0^T a(t)\,dt} = \frac{\frac{\int_0^T Q(t)\,dt}{T}}{\frac{1}{T}\int_0^T a(t)\,dt} = \frac{\bar{Q}}{\bar{a}}$$

$$\frac{\text{Avg queue length}}{\text{Avg arrival rate}}$$

$$\bar{Q} = \bar{w} \cdot \bar{a}$$

Equations

Monday, November 10, 2008
8:04 AM

1) $v = V_0 + .5at^2 + X_0$

2) $\frac{dv}{dt} = a = \alpha - \beta v$

2.5) $d\ln x = \frac{1}{x}$

$\frac{dv}{\alpha - \beta v} = 1$

3) $x(t) = \int \frac{\alpha}{\beta} - \left(\frac{\alpha}{\beta} - V_0\right) e^{-\beta t}$

5.5) $X_c = V_0 t_{min} - (W + L)$

$X_0 = V_0 \delta + \frac{V_0^2}{2a}$

eliminate dilemma, $X_0 = V_c$

X_c = dist from intersection

V_0 = speed lim

t_{min} = yellow interval

W = width of intersection

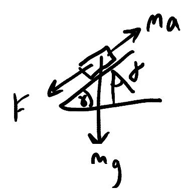
L = length of car $\approx$ 14 ft

X_0 = cannot stop dist

δ = rxn time a = acceleration

4) $v = V_0 + at$

5) $x = X_0 + V_0 t + \frac{1}{2}at^2$

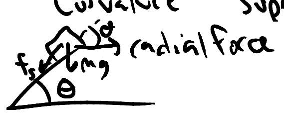


$mg\cos\gamma F + mg\sin\gamma = ma$

6) Stopping Distance $\quad s = \frac{v^2}{2(a \pm G)} + wt$

7) $SSD = 1.47vt + \frac{v^2}{30(\frac{a}{g} \pm G)} \leftarrow v = V_0 + at$

Curvature Superelevation



$\frac{mv^2}{R}\cos\theta = mg\sin\theta + mg\cos\theta f_s$

$\boxed{R = \frac{v^2}{g\tan\theta + gf_s}}$

superelevation

$R = \frac{v^2}{g(e + f_s)}$ coefficient of friction

$\tan\theta$, superelevation

8) k factor = $\frac{V_{peak}}{ADT}$ 8-18% recreational
4.5-9% urban

9) Peak hour factor = $\frac{V}{4 \cdot V_{15}} \leq 1$

10) hourly expansion factor = $\frac{\cancel{ADT}}{\text{hourly volume}}$

11) daily expansion factor = $\frac{\text{volume of week}}{\text{daily expansion factor}}$

12) Monthly expansion factor = $\frac{ADT}{ADT_{\text{of a month}}}$

13) Overtaking

$$V_N = \frac{(N_N + O_N - P_N)60}{T_N + T_S}$$

$$\bar{T}_N = T_N - \frac{60(O_N - P_N)}{V_N}$$

$$T = T_w - \frac{O_w - P_w}{V_w}$$

$$\bar{T}_S = T_S - \frac{60(\cancel{O_N} - P_N)}{V_S}$$

16) $q = \frac{N}{T} = \frac{1}{h} = \frac{1}{\left(\frac{T}{N}\right)}$ h - headway

$$T = \Sigma h_i$$

$$\frac{T}{N} = \frac{\Sigma h_i}{N}$$

17) $k = \frac{N}{L}$ L is length

18) $v = \frac{k \Sigma k_i v_i}{k}$

19) $q = kv$

20) $yv < x + L + d$ dangerous Light dist, intersection safety

$x < \frac{v^2}{2a}$ dangerous

$yv - (L+a) < x < \frac{v^2}{2a}$ safe

$yv < (L+d) < x$ safe

$2\sqrt{\frac{L+\alpha}{2a}}$?

21) $q = kv$ $s = \frac{1}{k}$ $v = \frac{s}{h}$ $h = \frac{1}{q}$

Time mean speed $\bar{v} = \frac{\Sigma v_i}{N}$

$$\bar{v} = \frac{\left(\frac{\Sigma N v_i}{T}\right)}{\left(\frac{N}{T}\right)} = \frac{\Sigma q_i v_i}{q}$$

22) $q = k\bar{u}$ space mean speed $\bar{u}$

$$\bar{u} = \frac{\Sigma k_i v_i}{k}$$

$$\bar{u} = \frac{\left(\frac{\Sigma N_i v}{L}\right)}{\left(\frac{N}{L}\right)} = \frac{\Sigma k_i v_i}{k} = \frac{\left(\frac{\Sigma q_i u_i}{v_i}\right)}{\Sigma \frac{q_i}{u_i}} = \frac{\Sigma q_i}{\left(\frac{q}{v_i}\right)}$$ harmonic avg

23) $\sum x_i y_i \le \sqrt{\sum x_i^2 + \sum y_i^2}$

24) $q_c = pq \qquad q_t = (1-p)q$

$k_c = \frac{pq}{v_c} \qquad k_t = \frac{(1-p)q}{v_t}$

25)

	time-mean system	space-mean system
space mean speed → $\bar{v}$	$\frac{N}{\sum \frac{1}{v_i}}$	$\frac{\sum v_i}{N}$
time mean speed → $\bar{v}$	$\frac{\sum v_i}{N}$	$\frac{\sum v_i^2}{\sum v_i}$

26) $\bar{q} = \dfrac{\int_{x_L}^{x_U} \underbrace{q(x)T(x)}_{\#\text{cars}}\underbrace{dx}_{\text{distance}}}{\int_{x_L}^{x_U} T(x)\,dx}$ = Avg Flow rate = $\frac{\text{total distance}}{\text{area}}$

27) $\bar{k} = \dfrac{\int_{t_L}^{t_U} \underbrace{k(t)L(t)}_{\#\text{cars}}\,dt}{\int_{t_L}^{t_U} L(t)\,dt}$ = Avg density = $\frac{\text{total travel time}}{\text{area}}$

28) Occupancy

$\Delta t_i = t_{off} - t_{on}$

$v_i = \frac{L_d - L_i}{\Delta t_i} \qquad q = \frac{N}{T}$

avg dist

$\text{occupancy} = \left(\frac{\Delta t_i}{T}\right)100 = 100\frac{N}{T}\frac{\sum(L_d - L_i)}{N}\frac{\sum \Delta t_i}{\sum(L_d - L_i)} = 100\, q\, \bar{l}\, \frac{1}{\bar{v}}$

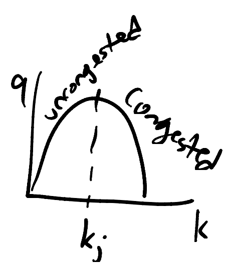
$= 100 k \bar{l}$

29) Greenshield's Model

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

Fundamental diagram

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



30) $v = v_f e^{-\alpha k}$

$q = v_f k e^{-\alpha k}$

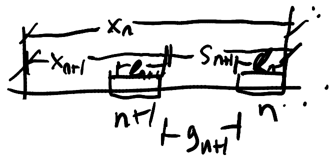
$$\frac{dq}{dk} = 0 \quad \text{max}$$

$\Rightarrow 1 = \alpha k$ after solving

31) $u = f(k)$

$q = k f(k)$

32) Car-following



$s_{n+1} = g_{n+1} + l_n$

$s_{n+1} > x_n - x_{n+1}$

$$g_{n+1} = l_{n+1} \frac{v_{n+1}}{10}$$

for every 10 mph, 1 car length distance

related to rxn time

$$g_{n+1} = \tau v_{n+1}$$

$$s_{n+1} - l_n = \frac{x_n - x_{n+1} - l_n}{v_n - v_{n+1}} = \frac{\tau v_{n+1}}{\tau a_{n+1}}$$

$$\boxed{a_{n+1} = \frac{v_n - v_{n+1}}{\tau}}$$

IMPORTANT

$$\int \frac{ds_{n+1}}{dt} = \int \tau \frac{dv_{n+1}}{dt}$$

$$v = \frac{1}{\tau}(s - l)$$

$$v_{n+1} = \frac{s_{n+1}}{\tau} + b \qquad \text{if } s = l,\ b = 0$$

$$\therefore v = \frac{s}{\tau} = \frac{l}{\tau}$$

$$s = \frac{1}{k} \Rightarrow v = \frac{1}{\tau}\left(\frac{1}{k} - l\right) \qquad \frac{1}{l} = k_j$$

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

$$v = \begin{cases} u_f & \text{if } k \le k_c \\ \frac{1}{\tau}\left(\frac{1}{k} - \frac{1}{k_j}\right) & \text{if } k > k_c \end{cases}$$

$$q = \begin{cases} u_f k & \text{if } k \le k_c \\ \frac{1}{\tau}\left(1 - \frac{k}{k_j}\right) & \text{if } k > k_c \end{cases}$$

33) GM Family Car Model

$$a_{n+1} = \alpha V_n^{\beta} \frac{(V_n - V_{n+1})}{\tau (X_n - X_{n+1})^{\gamma}}$$

34) $v = \alpha \ln\left(\frac{k_j}{k}\right) = \alpha \ln\left(\frac{s}{l}\right)$ Underwood Model

35) $v_i C \le g_i s_i$

36) $\Sigma g_i + L = C$

37) $\Sigma \frac{v_i}{s_i} + \frac{L}{C} \le \frac{\Sigma g_i}{C} + \frac{L}{C} = 1$

$$C \ge \frac{L}{1 - \Sigma \frac{v_i}{s_i}}$$

$$C = \frac{L}{1 - \Sigma \frac{v_i}{s_i}} \quad \text{when} \quad v_i = \frac{g_i s_i}{c} = c_i$$ capacity

38) Webster's Formula

$$C = \frac{1.5L + 5}{1 - \Sigma\left(\frac{v_i}{s_i}\right)_c}$$

$$g_i = C - L \quad \frac{\left(\frac{v_i}{s_i}\right)_c}{\Sigma\left(\frac{v_i}{s_i}\right)_c}$$

39) HCM

$$C = \frac{L}{1 - X_c \Sigma\left(\frac{v_i}{s_i}\right)_c}$$

Designed to follow capacity ratio

$$v_i \le X_c C_i$$

$$g_i = \frac{v_i C}{X_c s_i} = \frac{\left(\frac{v_i}{s_i}\right)_c}{X_c} C$$

40) $G_i = g_i + l_i + y_i \qquad l_i = y_i + R_i + t_{su_i}$ ext. time

41) $\frac{C - L}{\Sigma\left(\frac{v_i}{s_i}\right)_c} = \frac{C}{X_c}$

$$X_c = \Sigma\left(\frac{v_i}{s_i}\right)_c + \frac{L\left(\frac{v_i}{s_i}\right)_{min}}{g_{i\,min}}$$

$$C = \frac{L X_c}{1 - \Sigma\left(\frac{v_i}{s_i}\right)_c}$$

42) Portion of cycle length

$$\frac{C - L}{C} \; \frac{\left(\frac{v_i}{s_i}\right)_c}{\Sigma\left(\frac{v_i}{s_i}\right)_c}$$

43) Avg delay $\bar{w}$
Avg line length $\bar{Q}$

$t_{N_0} = D^{-1}(N_0) + A^{-1}(N_0)$ individual car's delay

$Q_{t_0} = D(t_0) + A(t_0)$

$A(t) > D(t)$ for all t

Total delay $\int_0^T Q(t)\,dt$

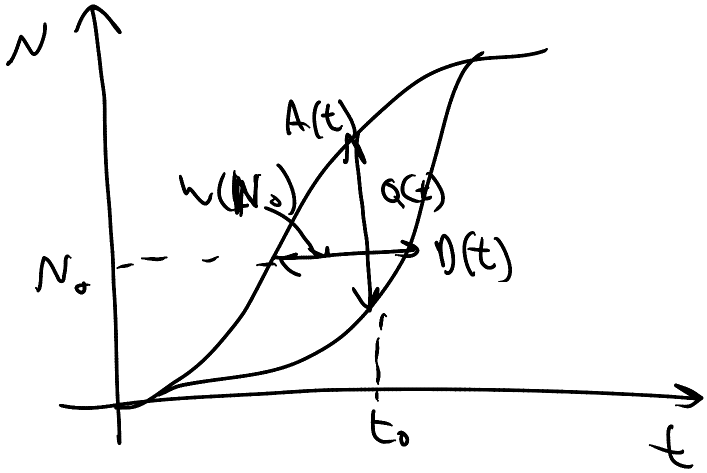
$$\bar{w} = \frac{\int_0^T Q(t)\,dt}{\int_0^T a(t)\,dt} = \frac{\left(\frac{\int_0^T Q(t)\,dt}{T}\right)}{\frac{1}{T}\int_0^T a(t)\,dt} = \frac{\bar{Q}}{\bar{a}}$$

$$\frac{\text{Avg line length}}{\text{Avg arrival rate.}}$$

$$\bar{Q} = \bar{w}\,\bar{a}$$

Examples

Wednesday, November 12, 2008
8:10 AM



$$\frac{dQ_n}{dt} = a(t) - d(t)$$

$$Q(t) = A(t) - D(t)$$

$$W(N_0) = D^{-1}(N_0) - A^{-1}(N_0)$$

$$\frac{dA(t)}{dt} = a(t) \qquad \frac{dD(t)}{dt} = d(t)$$

$$\bar{Q} = \bar{a}\,\bar{W}$$

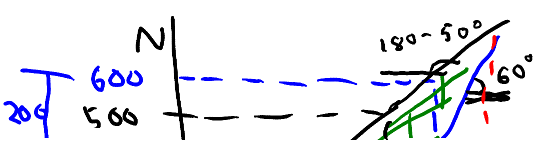
Example 1

An accident blocks 1 lane of a 2 lane hwy from t = 2 to t = 12 min

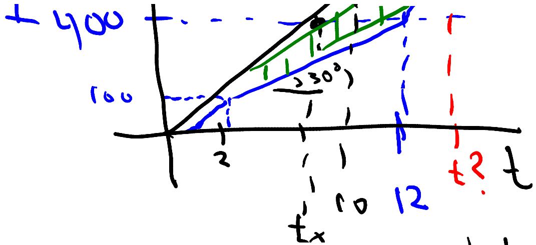
Capacity reduced from 60 veh/min to 30 veh/min

The arrival rate is 50 veh/min

1. Total delay
2. Maximum delay



Area = delay



$50t = 400 + 60(t-12)$

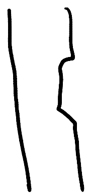
Largest delay at t_x b/c a car arriving at t_x will leave at $t=12$

$t_x = 8$

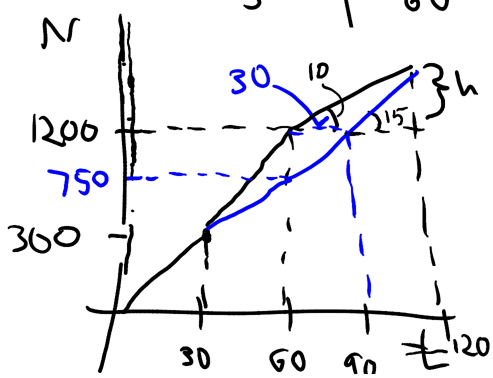
$A(t) > D(t)$ always

Area between 2 curves = total delay

Example 2



Period	(min) duration	a(t)	d(t)
1	30	10	15
2	30	30	15
3	60	10	15



$15(30) = 450$

$+ 300$

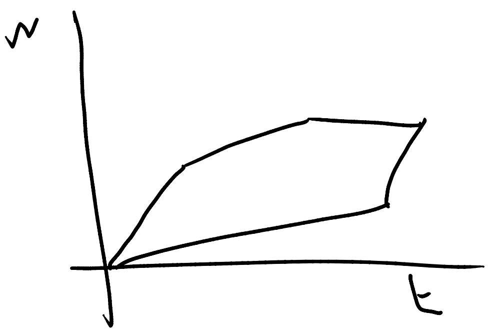
750

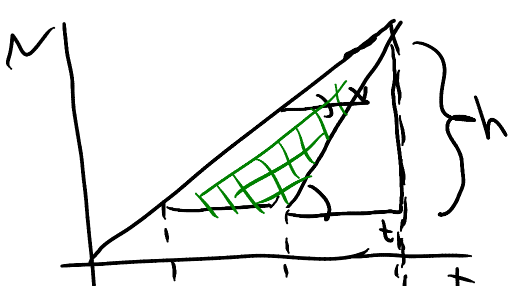
$\frac{450}{15} = 30$ min

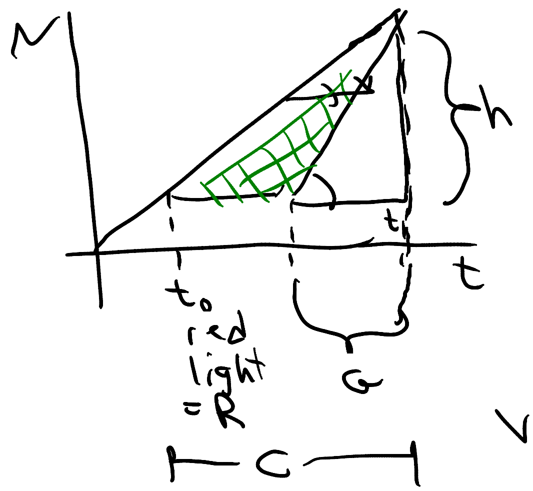
When $t = 90$, serve 1200 cars

Longest Q is 30 min

$1200 + (t-60)10 = 1200 + (t-90)15$







$V(C)$

$$V(R+t_1) = t_1 S$$

S = Saturation flow rate $\qquad t_1 = \frac{VR}{S-V}$

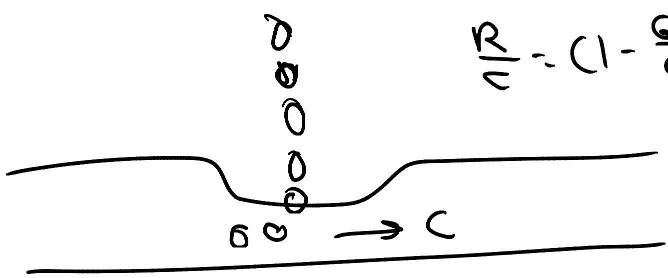
$$TD = .5R \frac{VRS}{S-V}$$

$$TD = \frac{.5R^2 VS}{S-V}$$

$$AD = \frac{.5R^2 VS}{(S-V)CV} = \frac{.5R^2 S}{C(S-V)} = \frac{.5CS}{S-V}\frac{R^2}{C^2}$$

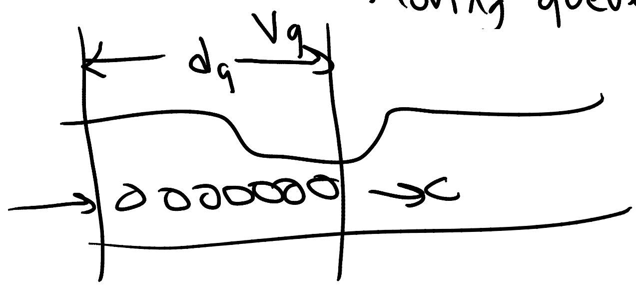
$$= \frac{.5CS}{S-V}\left(1-\frac{G}{C}\right)^2$$

$$\frac{R}{C} = \left(1-\frac{G}{C}\right)$$



$\frac{C}{V_q}$

Moving queue



Calculate delay?

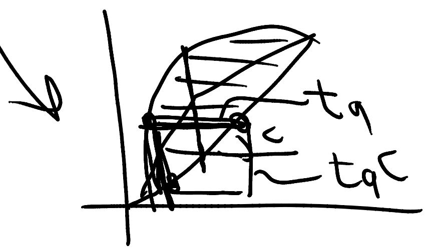
$W = \frac{d_q}{V} - \frac{d_q}{}$ Same W as before

$= t_q\left(1 - \frac{v_q}{v_f}\right)$

$t_q = \frac{w}{1 - \frac{v_q}{v_f}}$

$= \frac{w}{1 - \frac{v_q}{v_f}}$

Can do this for every w

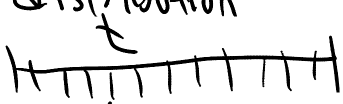


$\frac{C}{v_q}$ = density of q

$d_q = t_q v_q = \frac{w}{1 - \frac{v_q}{v_f}} v_q = t_q \frac{C_q}{k_q}$

$= (t_q C_q) S_q$

Poisson distribution



at Avg flow rate a

N pieces

$\frac{at}{N}$ = prob you will see a car in each piece

$\underbrace{C_N^x}_{\downarrow} \underbrace{\left(\frac{at}{N}\right)^x}_{\text{see the car x times}} \left(1 - \frac{at}{N}\right)^{N-x}$

$P_x(t) = \frac{N!}{(N-x)!\,x!} \cdot \left(\frac{at}{N}\right)^x \left(1 - \frac{at}{N}\right)^{N-x}$

$$= \frac{N!}{(N-x)!\, N^x} \frac{(at)^x}{x!} \left(1 - \frac{at}{N}\right)^{N-x}$$

$$= \frac{(at)^x}{x!} e^{-at} \quad \text{when } N \to \infty$$

if $x=0$,

$$P_0(t) = e^{-at}$$

Implication for headway

$$P_0(h \geq t) = e^{-at}$$

$$P(h < t) = 1 - e^{-at}$$

$$f_h = ae^{-at}$$

$$\bar{h} = \frac{1}{a} \quad Var = \frac{1}{a^2}$$

Avg performance index

$$\bar{Q} = \bar{a}\,\bar{W} \quad s = \frac{1}{d}$$

$$\bar{w} = \bar{Q}s + \bar{R}$$

avg residual service time

Terms

Wednesday, November 12, 2008
8:10 AM

1) ITE - Institute of Traffic Engineers

2) Stopping sight distance "S" - min sight distance required for a driver to stop a vehicle after seeing an object w/o hitting object

3) Gradient "G" relates to incline

4) Freeway - uninterrupted flow, limited access

Arterial Streets - high mobility, long

Collector - provide access to Arterial streets

Local Street - provide access to collector

5) Interchanges - Clover leaf, US hwys

Roundabout

Controlled intersections - lights / signs

6) Dynamic Study - study conducted under operating conditions

7) Volume - # vehicles that pass by a point during a specific time

8) Avg Annual Daily Traffic AADT

Avg Daily Traffic ADT

Peak Hour Volume PHV

Design Hour Volume DHV 30^{th} highest hourly volume in a year

Vehicle Classification

Vehicle Miles Traveled VMT

9) Continuous count - 24 hrs/day 365 days/yr

Control counts - 24 hrs/day 5 days/week, weekend

Coverage counts - 24 hrs/day 5 days/week, every 4 yrs

10) VMT = AADT · Link Length

11) Horizontal Distance - # cars between 2 spots

Vertical distance - distance traveled by a car for that dt

12) Capacity, flow, volume q
Density, k

13) Level I : No Control

Level II : Stop signs/yield signs

Level III: Traffic lights/signals

14) Lost time
- alien abductions
- Geometric delay
- Rxn time
- Unused yellow interval

15) Cycle - a complete sequence of signal indication (consists of # of phases)

16) Phase - part of a cycle allocated to movement/combo of movements

17) Change interval - all yellow/red

18) v_i demand for movement i, veh/hr

19) g_i effective green time s

20) S_i saturation flow rate veh/hr

21) L lost time s

22) G_i Nominal green time (light actually green)

23) $\frac{v_i}{c_i}$ volume to capacity ratio

24) arrival rate $a(t)$
departure rate $d(t)$
Avg delay $\bar{w}$
Avg queue length $\bar{Q}$

Sample prob

Monday, November 17, 2008

8:05 AM

$$f(y=x) = \frac{(at)^x}{x!} e^{-at}$$

prob arrivals = x (# arrivals)   y = # arrivals in t

poisson dist.

$\frac{1}{a} = t$ a = arrival rate

mean arrival rate = at

$f(h=t) = ae^{-at}$ $\bar{h} = \frac{1}{a}$ mean of headway $= \frac{1}{\text{arrival rate}}$

negative exp $\bar{y} = at$

$var(y) = at$

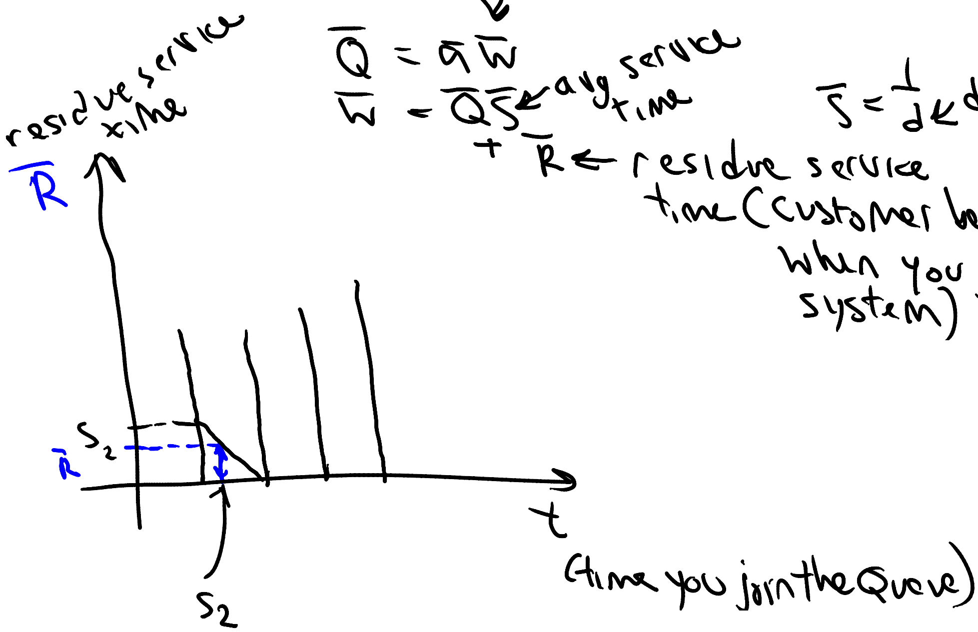
$var(h) = \frac{1}{a^2}$

Avg waiting time

$\bar{Q} = a\bar{W}$

$\bar{W} = \bar{Q}\bar{S}$ ← avg service time $\bar{S} = \frac{1}{d}$ ← departure rate

$+ \bar{R}$ ← residue service time (customer being served when you join the system)



area of Δ gives you sum over time

$$\bar{R} = \frac{.5 \sum s_i^2}{T \leftarrow \text{total time}}$$

$\cancel{n}$ $\sum s_i^2$

$$= .5 \left(\frac{N}{T}\right) \frac{\sum s_i^2}{N}$$

$\frac{N}{T} \to \bar{a}$

$$= .5\, \bar{a} \frac{\sum s_i^2}{N}$$

$\frac{\sum s_i^2}{N} = E(s^2)$

Expectation of s^2

$E(s^2) = Var(s) + [E(s)]^2$

$= Var(s) + \bar{s}^2$

$$\bar{R} = .5\, \bar{a}\,(Var(s) - \bar{s}^2)$$

$$\bar{W} = \frac{.5\, \bar{a}(Var(s) - \bar{s}^2)}{1 - \bar{a}\bar{s}}$$

<u>M/M/1</u> partial dist in a + d, # servers = 1

$$\bar{w} = \frac{.5\, \bar{a}\left(\bar{s}^2 + \frac{1}{d^2}\right)}{1 - \bar{a}\bar{s}}$$

variance

$f(h \geq t) = a e^{-at}$ a is flow rate

$$= \frac{\bar{a}\left(\frac{1}{d^2}\right)}{1 - \bar{a}\bar{s}}$$

let $\rho = \frac{\bar{a}}{d}$ $\left(\frac{1}{a}\right)^2$ $\left(\frac{1}{d}\right)^2$

$\bar{s} = \frac{1}{d}$

$$= \frac{\rho}{d(1-\rho)}$$

d is departure rate or capacity

$$\bar{Q} = \bar{w}\,\bar{a}$$

$$= \frac{\rho}{d(1-\rho)} (\rho d)$$

$$= \frac{\rho^2}{1-\rho}$$

$T_s = \bar{w} + \frac{1}{d}$ Total time in the system

$$= \frac{\rho}{d(1-\rho)} + \frac{1}{d} = \frac{1}{d(1-\rho)}$$

$N_s = T_s a = \frac{\rho}{1-\rho}$ # customers in the system

$N_s = T_s a = \frac{\rho}{1-\rho}$ #customers in the system

$d = \frac{1}{s}$

Prob of having n customers in the system

$$\boxed{P_n = \rho^n(1-\rho)} \qquad \rho = \frac{a}{d}$$

$1 - \sum^{N} P$ = Prob of having $> n$ customers

$= 1-(1-\rho)(1+\rho+\dots\rho^n)$

$$1-(1-\rho)\underbrace{(1+\rho+\dots+\rho^n)}_{\frac{1-\rho^{n+1}}{1-\rho}}$$

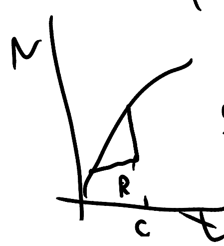
$= 1-\rho^{n+1}$

M/D/1 deterministic departure

$$\bar{w} = \frac{.5a(var(s)+s^2)}{1-as} \qquad s = \frac{1}{d}$$

var(s) = 0 w/ deterministic departure

$$= \frac{.5\rho}{d(1-\rho)}$$ 2nd part



$$\frac{.5C(1-\frac{g}{C})^2}{1-v/s}$$

$v_i C \le g_i S_i$

$c = \frac{g_i}{C} s_i$ ← saturation flow rate

cap

capacity

$$\bar{w} = \frac{.5\frac{v}{c}}{c(1-v/c)}$$

for random arrival rate

capacity

Example: $\bar{q} = 180$ veh/h. Avg time required 15 s

% time gate operator free?
Avg time 1 veh exp
Avg # veh in queue

15 s → 4 cars/min = d

$$P_n = \frac{1-\rho^{n+1}}{\rho}$$

$$\frac{1-\left(\frac{180}{4\frac{veh}{min}\left(\frac{60 min}{h}\right)}\right)}{\left(\frac{180}{4\frac{veh}{min}\left(\frac{60 min}{h}\right)}\right)}$$

$$\bar{w} = \frac{\rho}{d(1-\rho)} + \frac{1}{d}$$

$$= \frac{1}{d(1-\rho)} = \frac{1}{4 \cdot .25} = 1$$

Avg veh in queue

$$\bar{Q} = \bar{w}\bar{q} = \frac{\rho}{d(1-\rho)} q = \frac{\rho^2}{1-\rho}$$

$$= \frac{.75^2}{1-.75} \text{ veh}$$

Mid-term
- 6 T/F
- 6 Mult choice
- 4 small probs
- 3 big probs

Modes of transportation — car, bus, train, aircraft
Market shares of diff modes

Traffic engineering (characteristics, planning)

Characteristics of hwy system
- Components (road, vehicle, driver)
- Road facility type (freeway, arterial, etc)
- Driver characteristics
- Geometric design (turning radii, stopping dist)

Traffic Studies
- Volume, AADT, ADT, PHV, VMT
- Measure methods
- Hour, daily, seasonal & directional variations
- Travel time studies (measure methods)
- Spot speed studies (won't do much of this)

Basic concepts
- Travel time
- Flow (Flow = Volume)
- Headway
- Speed
- Spacing
- Density
-

Headway - flow
Spacing - density
Occupancy - density
Travel time - speed
Queue - delay
Capacity - Flow
Flow - density
Flow - speed
Density - speed

Operation - signals
- Warrants (no #s, general idea)

- Basic concepts (cycle, phase, offset...)
- Design timing plan
  - Webster method
  - HCM method (min green time)
  - Overlapping phase

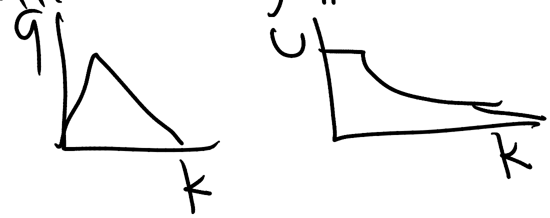
Models: I

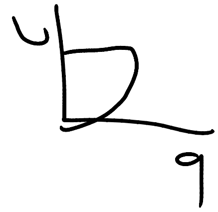
Space-time diagram

- How to build & read time-space diagram
- Stopping distance, safe following distance
- Understand gen. definitions of time-mean speed, space-mean speed, flow rate, density derived from time-space diagram

Models: II

Traffic flow diagrams





$q = vk$

Contour maps

Diff car-following assumptions lead to diff traffic flow diagrams

$$a_{n+1} = \frac{1}{T}(v_n - v_{n+1}) \Rightarrow \text{get } \Delta \text{ model}$$

rxn time

Models: III

Queue System

- Basics of FIFO System
- Understand queuing diagram

- Understand queuing diagram
- Analyze queuing systems
- Control delay
-

A 1. c
2. Motorcycles
3. d   trip generation, dist, mode choice, —

B 1. Expand network, build more roads
Optimize signal control (efficient management)
New tech.
Reduce demand, encourage ppl to work @ home
Change job locations
Shift demand (charge a toll)
Flexible work time
Carpooling

Contour map — traffic direction
(left-right)
Cause of jam
(accident)

HCM - cycle length 55s
SBLT $g_{min} = 25s$, not meeting req.
reduce s_i from .9 to .86 → 78

4. Length of intersection = 30
$x - (30 + 15) \le vy$
v - speed lim
y - yellow time

$x = \frac{v^2}{2a}$

vy 45 − x −

$vy \geq \frac{v^2}{2a} + 45$

$y \geq \frac{v}{2a} + \frac{45}{v} \geq \sqrt{\frac{v}{2a}\left(\frac{45}{v}\right)}$

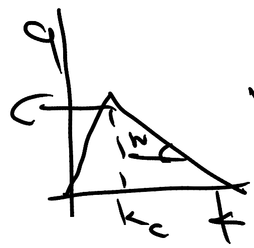
find min speed

$\frac{dy}{dv} = \frac{1}{2a} - \frac{45}{v^2} = 0$

$v = \sqrt{2a(45)}$

$= 30$ ft/s

5.



$w = \frac{-l}{\tau}$ slope

$-l$ ← length of car

τ ← rxn time

$w = -13.3$ ft/s

$k_j = \frac{1}{\text{car length}}$

$w(k_c - k_j) = c$ capacity

$c = k_c v_f$ ← free flow speed

$(k\bar{l})\,100$

$.15 = k\bar{l}$

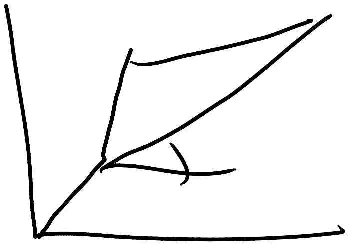
$\frac{(.15)(5280)}{15+6} = k$

$37.7 = k$

Space mean speed =

$\frac{6}{15} = \frac{x}{200}$

6



$$\frac{10}{70}(0) + \frac{20}{70}(10) + \frac{40}{70}(20)$$

density

$20(10)$ = flow rate 1

speed

$40(10)$ = flow rate 2

Total Flow rates 1000

$$\frac{200}{1000}(10) + \frac{800}{1000}(20) = 14$$

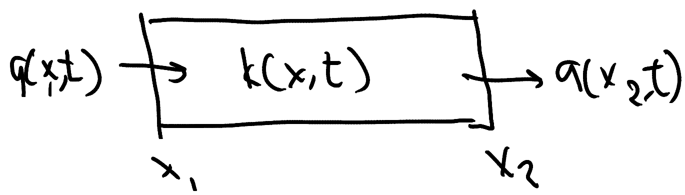
Conservation Law

Monday, November 24, 2008
9:04 AM

Shock wave theory
An interface of rapid transition in traffic quantities

The queue moves backward gradually & creates a shock wave

Conservation Law
Cornerstone of shockwave theory
Cannot create or destroy cars



$$N(t) = \int_{x_1}^{x_2} k(x,t)\,dt$$

$$\frac{\partial N}{\partial t} = q(x_1,t) - q(x_2,t)$$

$$\int_{x_1}^{x_2} \frac{\partial k}{\partial t}\,dx = q(x_1,t) - q(x_2,t)$$

$$\int_{x_1}^{x_2} \frac{\partial k}{\partial t}\,dx = \frac{q(x_1,t) - q(x_2,t)}{(x_1 - x_2)}(x_1 - x_2)$$

$$(x_1 - x_2)\frac{\partial q}{\partial x} = \frac{\partial k}{\partial t}(x_2 - x_1)$$

When x is very small $\frac{\partial k}{\partial t} = \text{const}$

$$-\frac{\partial k}{\partial t} = \frac{\partial q}{\partial x}$$

$$\boxed{\frac{\partial k}{\partial t} + \frac{\partial q}{\partial x} = 0}$$ Conservation Law

$$q = kv = f(k)$$

$$\frac{\partial q}{\partial x} = \frac{\partial q}{\partial k}\frac{\partial k}{\partial x}$$

$$\frac{\partial k}{\partial t} + \underbrace{\frac{\partial q}{\partial k}}_{f'(k)}\frac{\partial k}{\partial x} = 0$$

non-linear hyperbolic PDE

$$\frac{\partial k}{\partial t} + c_0\frac{\partial k}{\partial x} = 0$$

$$\begin{cases} y = x - c_0 t \\ \tau = t \end{cases}$$

$$\frac{\partial}{\partial t} = \frac{\partial}{\partial y}\frac{\partial y}{\partial t} + \frac{\partial}{\partial \tau}\frac{\partial \tau}{\partial t}$$

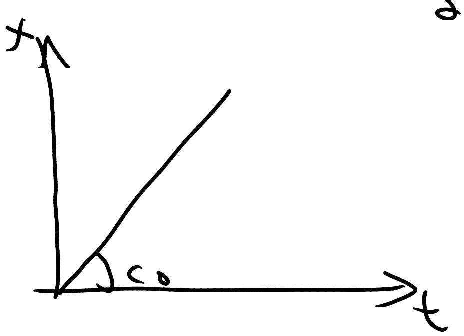
$$\frac{\partial}{\partial y}\underbrace{\frac{\partial y}{\partial x}}_{1} + \frac{\partial}{\partial \tau}\underbrace{\frac{\partial \tau}{\partial x}}_{0} = \frac{\partial}{\partial x}$$

$$\frac{\partial}{\partial y} = \frac{\partial}{\partial x}$$

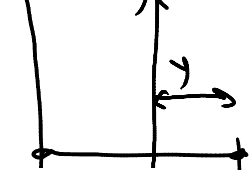
$$\frac{\partial}{\partial t} = -c_0\frac{\partial}{\partial y} + \frac{\partial}{\partial \tau}$$

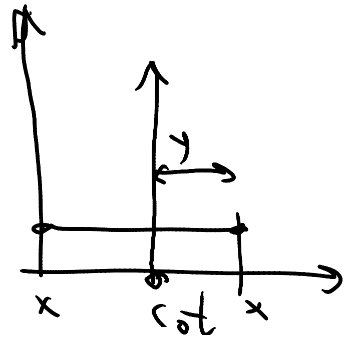
$$-c_0\frac{\partial k}{\partial y} + \frac{\partial k}{\partial \tau} + c_0\frac{\partial k}{\partial y} = 0$$

$\frac{\partial k}{\partial \tau} = 0$ density is const over new coordinate system

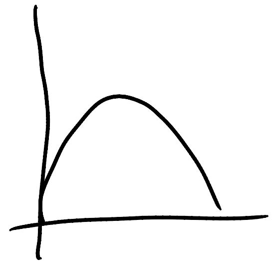


density is always the same as the density at $x=0$, $t=0$





$$y = x - c_0 t$$



A driver sitting in ideal homogenous traffic stream observes small disturbance downstream. Under what conditions will driver & disturbance meet?

$v - c_0 =$ rel speed

$c_0 = f(k)$

$v - kv =$

$v - \frac{d(kv)}{dk} =$

$v - \left(v + k\frac{dv}{dk}\right) = -k\frac{dv}{dk}$

If the traffic is congested

Shock Wave Theory

Wednesday, November 26, 2008
8:09 AM

Shock wave $\frac{\partial k}{\partial t} + f'(k)\frac{\partial k}{\partial x} = 0$

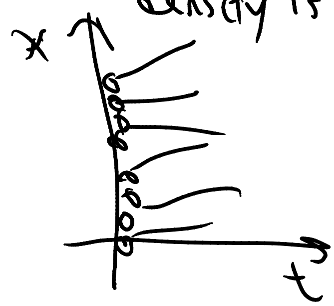
wave

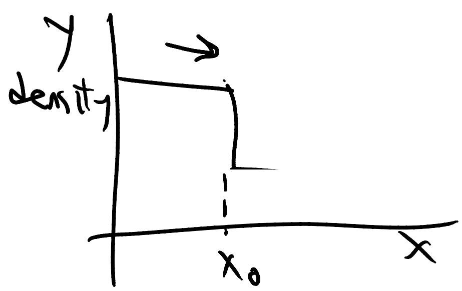
$$\frac{\partial k}{\partial t} + c_0\frac{\partial k}{\partial t} = 0 \qquad \begin{array}{l} y = x - c_0 t \\ \tau = t \end{array}$$

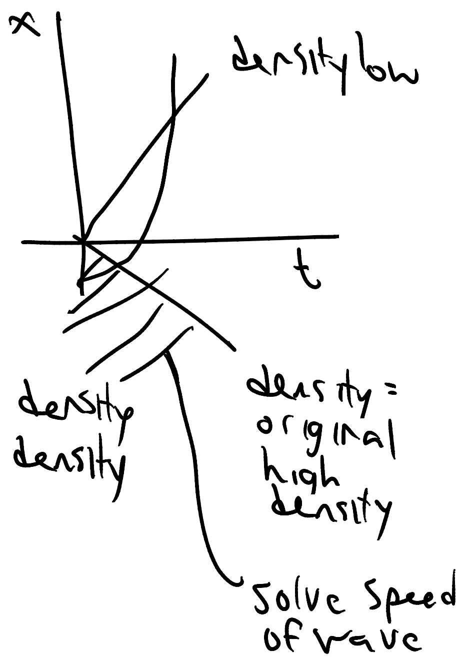
Moving coordinate system

$$\frac{\partial k}{\partial \tau} = 0$$

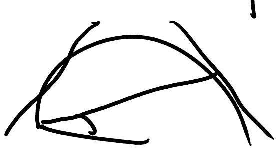
density is the same as τ moves







downstream low density
upstream high density



$w = \frac{\ell}{r}$

Calculate wave speed ~ density & flow rate

q_1 flow rate $\quad k_1$

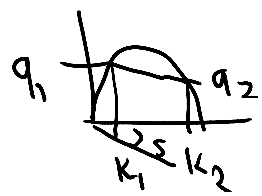
$q_2 \quad k_2$

upstream has lower density

Speed of shockwave is slope of line

$$S = \frac{q_2 - q_1}{k_2 - k_1}$$

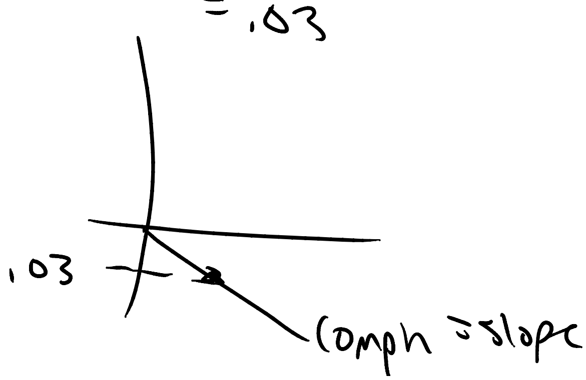
→ $uk_1 - Sk_1$ relative flow



Calculate how many cars pass by the observer

$$(10-1)\left(\frac{1}{300}\right) = \text{dist 10th car is from intersection}$$

$= .03$



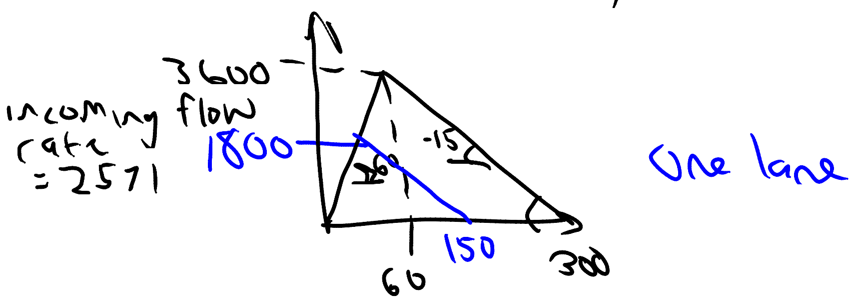
calculate speed

$$\frac{.03}{10}(3600) = 10.8 \text{ seconds}$$

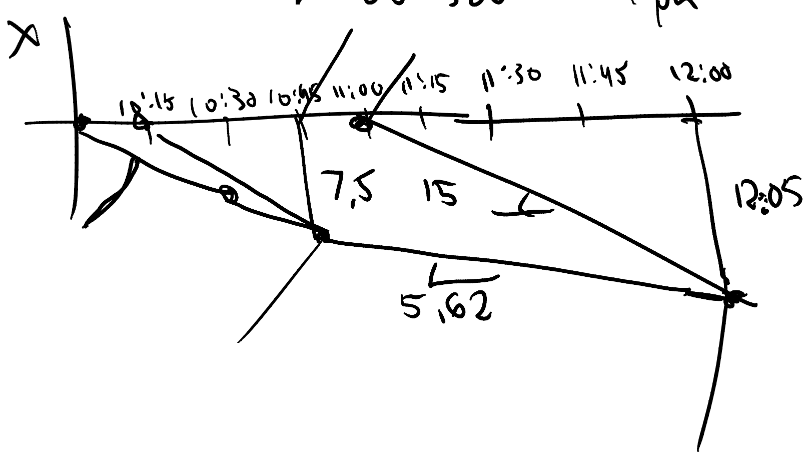
10.8 s delay

Accident occurs at 10am at point A, blocking the entire road in that direction. 15 min after the accident one lane is cleared + traffic flows by point A. Cleared at 11:05am

- Queue at 10:15 am
- Time when vehicles last forced to stop in queue
- Max dist that end of queue has travelled away from accident site



$$V_{s} = \frac{-2571}{42.85 - 300} = -10 \text{ mph}$$

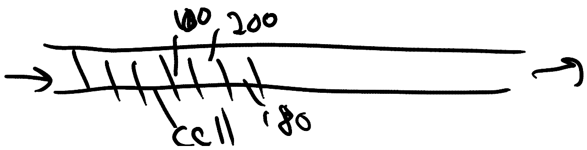


Finite Difference Method

Monday, December 01, 2008
8:52 AM

Finite difference method, nanoscopic

Divide road into cells



for each cell, you know density

need to know how many cars are moving in & out.

We know in & out are same

Predict density evolution over time for the road

$$v + \frac{\Delta t}{\Delta x} \geq 1$$

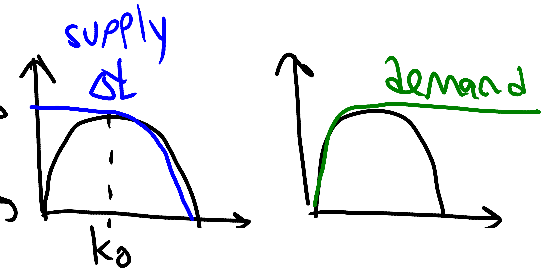
① Divide road section into cells of identical length

② Divide time [0, T] into small intervals Δt

$$v_f \geq \frac{\Delta x}{\Delta t} \qquad \text{CFL condition}$$

Cell supply →

cell demand →



Supply ≤ k_c

demand $D_i = \begin{cases} f(k_i) & k \leq k_c \\ q_{max} & \text{other} \end{cases}$

supply $S_i = \begin{cases} q_{max} & k \leq k_c \\ f(v) & \text{other} \end{cases}$

$$V_{i,i+1} = \min(D_i, S_{i+1})$$

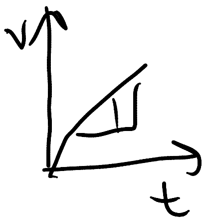
Step 1: Calculate D_i, S_i, for $i=1 \ldots N$

2: Compute flux $V_{i,i+1}$ for $i=0 \ldots N$

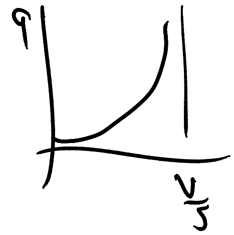
3: Compute densities

$$k_i^t = k_i^{t+1} + \frac{\Delta t}{\Delta x}\underbrace{\left(V_{i-1,i}^t - V_{i,i+1}^t\right)}_{\text{influx + outflux = net change of flow}}$$

4: Back to step 1



$$d = \frac{.5C\left(1-\frac{g}{C}\right)^2}{1 - \frac{v}{s}}$$



Input data

↓

Volume adjustment

↓

Saturation flow adjustment

↓

capacity analysis

↓

estimate LOS → No → Changes → Input data

↓

okay

↓

Volume adjustment

$$V_p = \frac{V}{PHF}$$

HCS HCM

$$s = s_o N f_w f_{HV} f_g f_{bb} f_a f_p f_{LU} f_{RT} f_{LT} f_{Lpb} f_{Rpb}$$

$$f_w = 1 + \frac{w-12}{30}$$

$$f_{HV} = \frac{1}{1 + P_{HV}(E_T - 1)}$$

$f_{Rt} = .85$

$f_{Rt} = 1 - .15 P_{Rt}$

Flow Chart

Wednesday, December 03, 2008
8:05 AM

input
↓
Volume adjustment
↓
Saturation flow adjustment
↓
Capacity analysis
↓
Estimate loss

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

C ← cycle length

c_i ↑ capacity

Volume-to-capacity ratio

$$X_i = \frac{V_i}{c_i}$$

$X_i < 1$

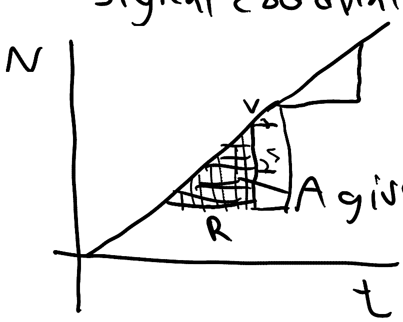
b/c if $X_i \geq 1$, delay increases infinitely

Level of service & delay

A	$\leq$ 10 sec
B	10-20
C	20-35
D	35-55
E	55-80
F	>80

If it is unsatisfactory & you want to redesign,

- timing plan might not be efficient
- large enough turning lane
- increase green time for turning
- increase cycle length, allocate more green time
- add lanes (last resort)
- Signal coordination



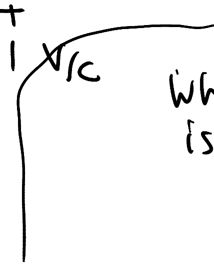
A gives you total delay

$$d = \frac{.5C(1-\frac{G}{C})^2}{1 - V/s}$$

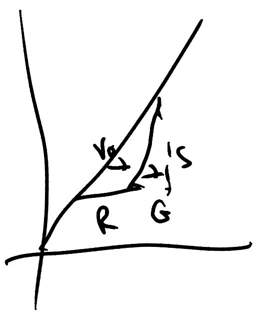
Optimized by using area of that triangle.

only works if v/c < 1

When v/c → 1, graph goes to ∞



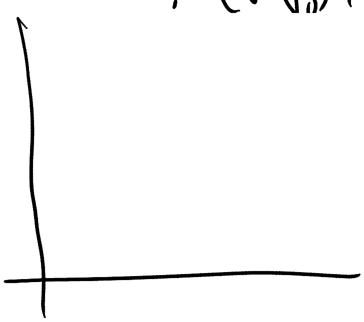
When v/c > 1, delay is neg (not possible)



$SG = CV_0$ $\quad R + G = C$

$$\frac{V_0}{S} = \frac{G}{C}$$

$.5(V - V_0)T \times T$



When $\frac{V}{S} = 1$ w/ oversaturation

$\left(d = .5C(1 - \frac{G}{C}) \text{ b/c } \frac{V}{S} = \frac{G}{C}\right)$

$$d = d_1 PF + d_2 + d_3$$

$$d_1 = \frac{.5C(1 - g/c)^2}{1 - \min(1, X)\, g/c}$$

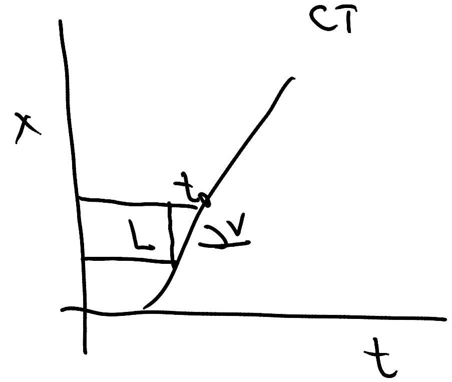
$d_2 = 900T\,[(X-1) + \sqrt{(X-1)^2 + ...}]$

$$d_2 = 900T\left[(x-1) + \sqrt{(x-1)^2 + \frac{8kIx}{cT}}\right]$$

Table 10.8

PF = propogation factor

$$d_3 = \frac{1800Q(1+u)t}{cT}$$



$$t_0 = \frac{L}{V}$$

Efficiency $= \frac{L}{(V/c)} = \frac{1}{2N}$

Bandwidth $\frac{L}{V} = \frac{c}{2N}$

$$c = \frac{2NL}{V}$$