REFLECTIONS ON TRANSPORTATION NETWORK MODELING

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OUTLINE

- CLASSES OF TRANSPORTATION NETWORK MODELS
- COMMENTS ON THE MODELS
- PERSONAL EXPERIENCES
- CHALLENGES

TRANSPORTATION NETWORK MODELS

- TRANSPORTATION SYSTEM HAS A VARIETY OF MODES
  - (AIR, WATER), AUTO, BUS AND RAIL TRANSIT, NON-MOTORIZED
- TRAVELERS FACE COMPLEX CHOICES
  - WHETHER TO TRAVEL, WHERE TO TRAVEL, WHEN TO TRAVEL, HOW TO TRAVEL (MODE/ROUTE COMBINATIONS)
- (IN THIS TALK) : HOW TO TRAVEL

PRINCIPLES OF CHOICE

- NON-COOPERATIVE (USER-OPTIMAL)
  - TRAVELERS CHOOSE A COMBINATION OF MODES/ROUTES/DEPARTURE TIMES TO MINIMIZE THEIR OWN TRAVEL COST
  - NASH EQUILIBRIUM
- CO-OPERATIVE (SYSTEM-OPTIMAL)
  - TRAVELERS COOPERATE TO REDUCE OVERALL SYSTEM COSTS, NOT NECESSARILY THEIR OWN
  - INCENTIVES OR CENTRAL CONTROL
- MIXED (ONE-SHOT DYNAMICS, MULTIPLE USER CLASSES)

(LINK) TRAVEL COST MODELS

- STATIC MODEL
  - TRAVEL COST IS A FUNCTION OF FLOW
  - BPR TYPE OF LINK COST FUNCTIONS (PLANNING)
- DYNAMIC MODELS
  - MICRO: CF OR CA MODELS (MICRO SIMULATION)
  - MACRO: QUEUING (PQ, SQ), FLUID MODELS (CTM, LWR), WHOLE LINK (CONVEYOR BELT) MODELS (DTA)

PROS AND CONS

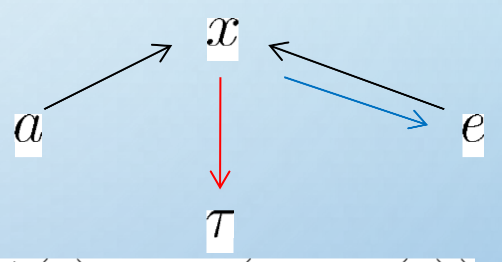
- NETWORK MODELS WITH STATIC COST FUNCTIONS
  - PROS: LESS DATA, COMPUTATIONALLY EFFICIENT, WELL STUDIED
  - CONS: COARSE GRAINED, PEAK SPREADING/CONGESTION NOT ADEQUATE
- NETWORK MODELS WITH CF/CA MODELS
  - PROS: FINE GRAINED, DETAILED MODELING OF CONGESTION
  - CONS: DATA INTENSIVE, HARD TO SCALE UP, CALIBRATION IS DIFFICULT
- NETWORK MODELS WITH MACRO DYNAMIC MODELS
  - PROS: CONGESTION MODELING IS ADEQUATE (QUEUING, PEAK SPREADING)
  - CONS: DATA AND COMPUTATION INTENSIVE, CALIBRATION IS DEMANDING

Network models with macro dynamic flow models are good compromises

DYNAMIC LINK MODELS

- DTA NEEDS TRIP TIMES
- PERFORM NETWORK LOADING
  - FLOW CONSERVATION
  - FLOW PROPAGATION
    - CAUSALITY
    - QUEUING
    - FIFO

$$\dot{x}(t) = q(t) - e(t)$$
$$x(t) = A(t) - E(t)$$



NC for FIFO $\longleftarrow$ $A(t) = E(t + \tau(t))$

TRAFFIC FLOW MODELS COMMONLY USED IN DTA

- LINK TRAVEL TIME IS KNOWN **BEFORE** TRIP ENDS
  - THE DELAY FUNCTION MODEL: $\tau(t) = f(x(t))$ $\tau(t) = f(x, q, e)(t)$
- LINK TRAVEL TIME IS KNOWN **AFTER** TRIP ENDS
  - EXIT-FLOW MODELS
    - M-N
    - **PQ/SQ/KW**
    - OTHER FLUID-LIKE MODELS

$$e(t) = E^{'}(t) = f_*(\bar{x})(t)$$

  - CONVEYOR-BELT MODELS
    - GREENSHIELDS ETC

$$u(t) = v_*(x(t)/l) \qquad \int_t^{t+\tau(t)} u(y)dy = l$$

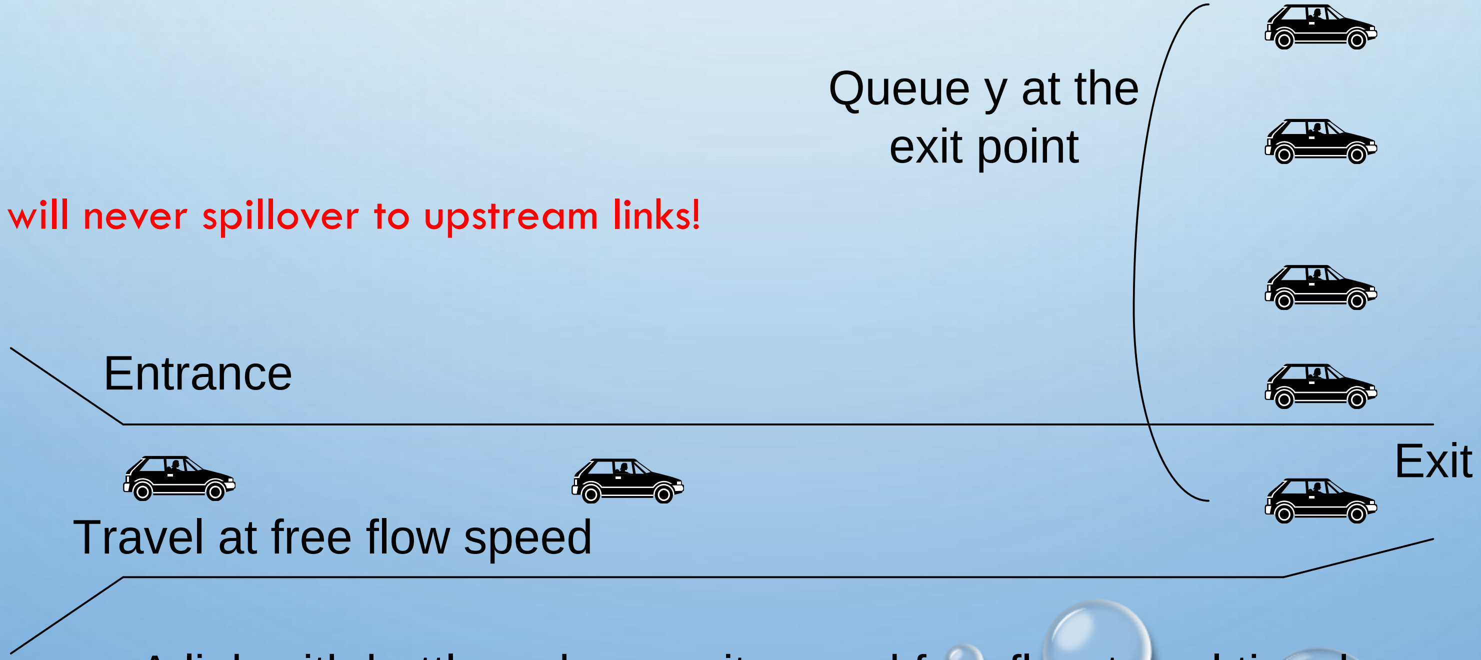
MODELING NETWORK FLOW WITH THREE QUEUING MODELS

- TRAFFIC EVOLUTION WITHIN LINKS
  - POINT-QUEUE MODEL
  - SPATIAL-QUEUE MODEL
  - THE KINEMATIC WAVE/CELL TRANSMISSION MODEL
- LINKS INTERACT THROUGH NODES
  - MERGE
  - DIVERGE

LINK MODEL I: POINT-QUEUE

$$
\begin{aligned}
\dot{y}(t) &= q(t-h) - e(t) \\
e(t) &= \begin{cases} q(t-h) & \text{if } y(t) = 0 \text{ and } q(t-h) < c \\ c & \text{otherwise} \end{cases}
\end{aligned}
$$

Queue will never spillover to upstream links!



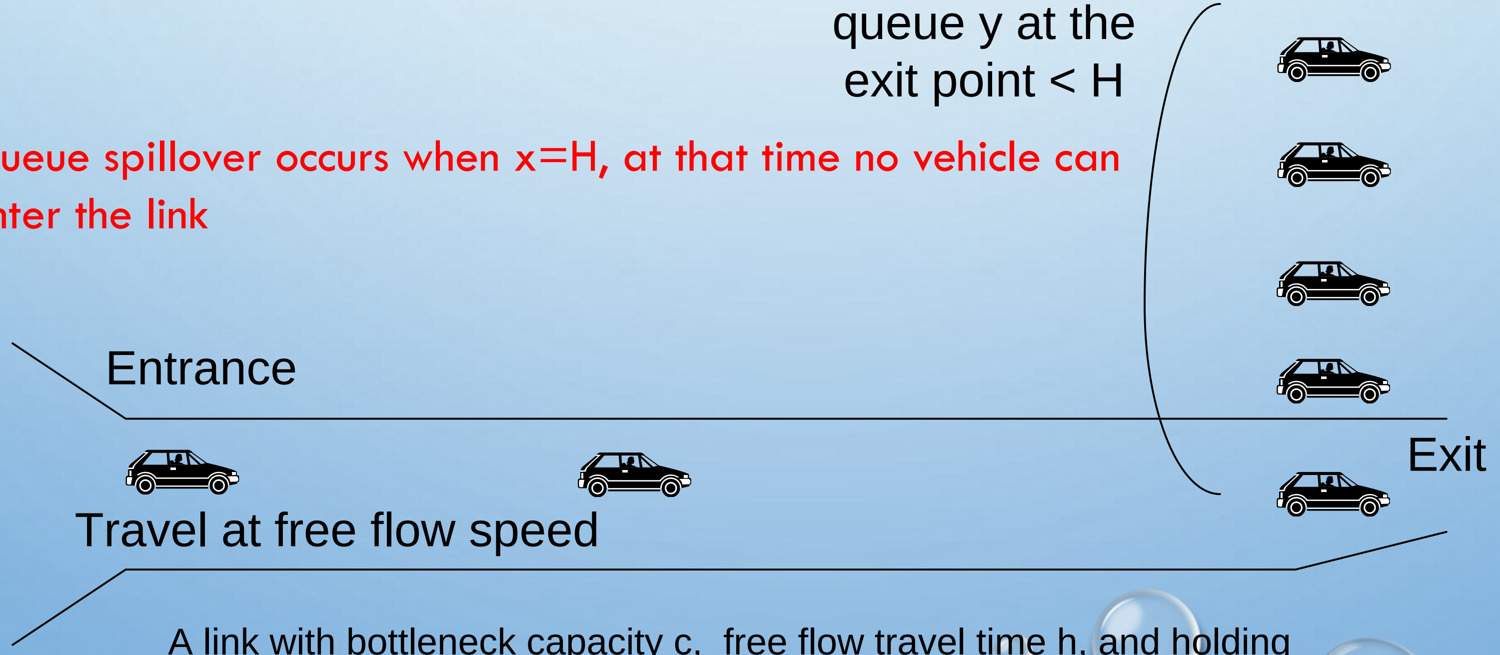
A link with bottleneck capacity c and free flow travel time h

LINK MODEL II: SPATIAL QUEUE

$$
\begin{aligned}
\dot{y}(t) &= q(t-h) - e(t) \\
e(t) &= \begin{cases} q(t-h) & \text{if } y(t) = 0 \text{ and } q(t-h) < c \text{ and } z(t) < G \\ c & y(t) > 0 \text{ or } q(t-h) > c \text{ and } z(t) < G \\ 0 & \text{if } z(t) \geq G \end{cases}
\end{aligned}
$$

z(t) is the volume on the downstream link

Queue spillover occurs when x=H, at that time no vehicle can enter the link



A link with bottleneck capacity c, free flow travel time h, and holding capacity H, its downstream link has holding capacity G.

LINK MODEL III: KW/CTM

$$\rho_t + F(\rho, x)_x = 0$$

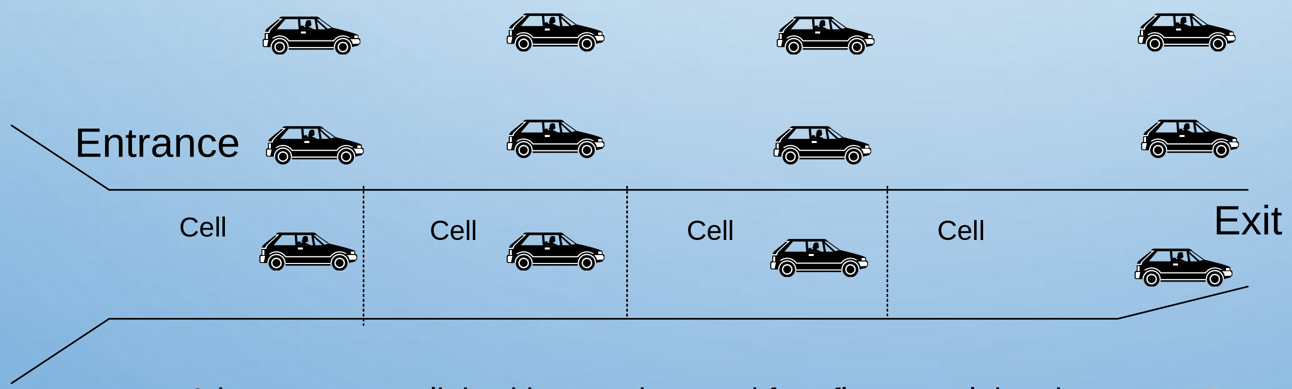
Cell Demand D = min(number of vehicles at the cell exit, cell flow capacity c)

Cell Supply S = min(*w* (cell holding capacity *H*(*i*)– number of vehicles in the cell x*i*), cell flow capacity c)

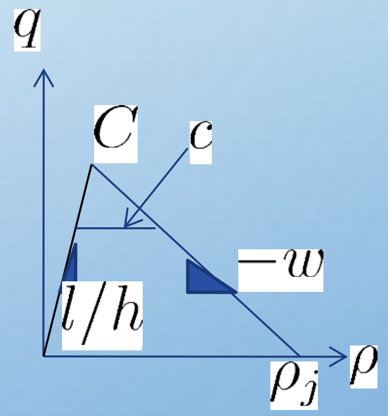
Flow across cell boundary f=min{D of upstream cell, S of downstream cell}

Queue spillover occurs when w(*H*(*Last*) – x_{Last})<c.

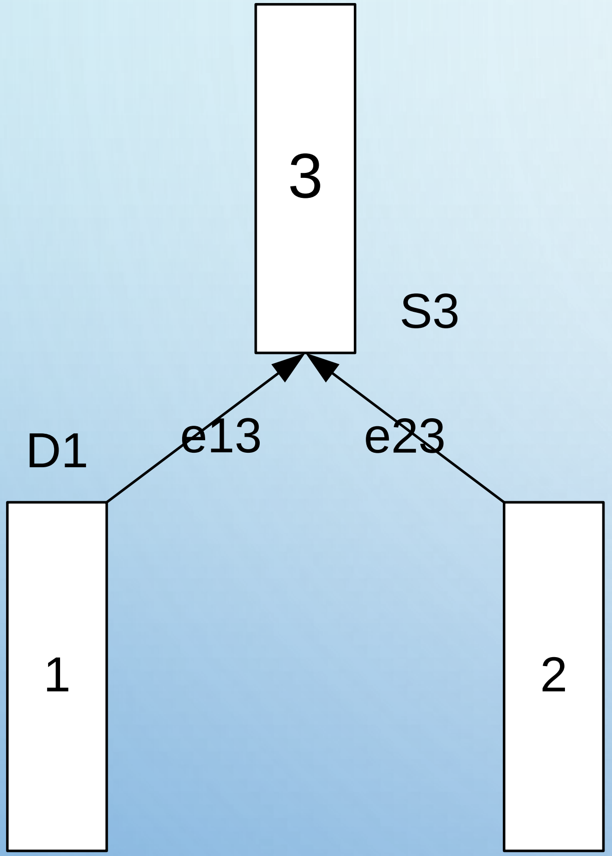
No vehicle can enter the link when *H*(*Last*) = x_{Last}



A homogeneous link with capacity c and free flow travel time h



NODE MODEL I: MERGE



Merge

$$e_{13} = \boxed{a_{13}} e$$

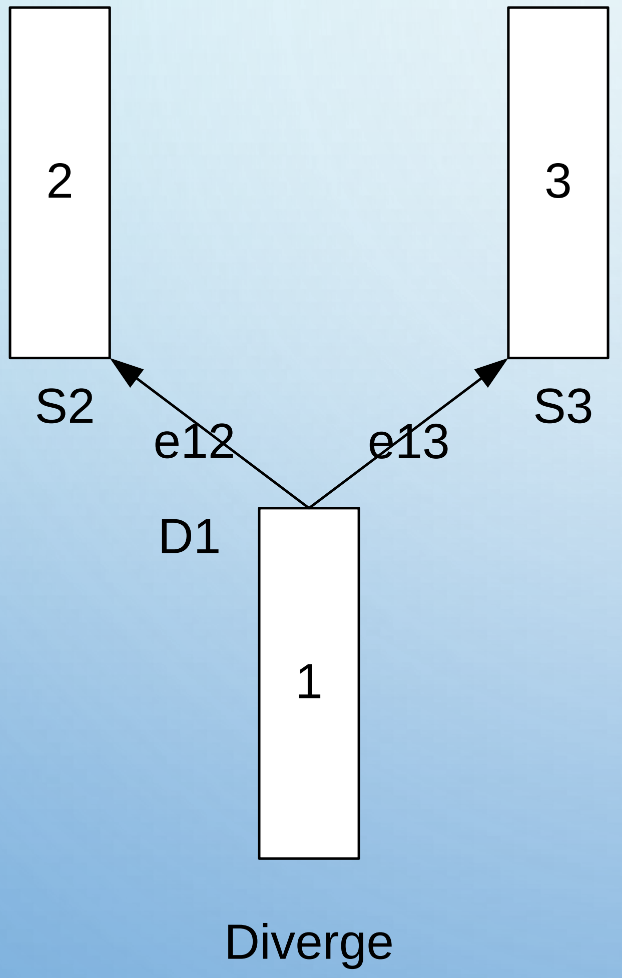
Distribution factor

$$e_{23} = \boxed{a_{23}} e$$

$$v = \min\{D_1 + D_2, S_3\}$$

$$a_{i3} = \frac{D_i}{\sum_i D_i}, \text{if } S_3 < \sum_i D_i$$

NODE MODEL II: DIVERGE



$$e_{12} = \boxed{a_{12}} e$$

$$e_{13} = \boxed{a_{13}} e$$

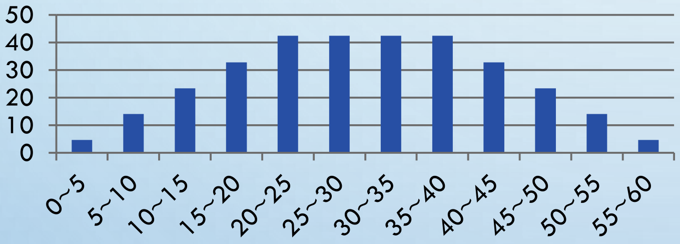
Turning percentage

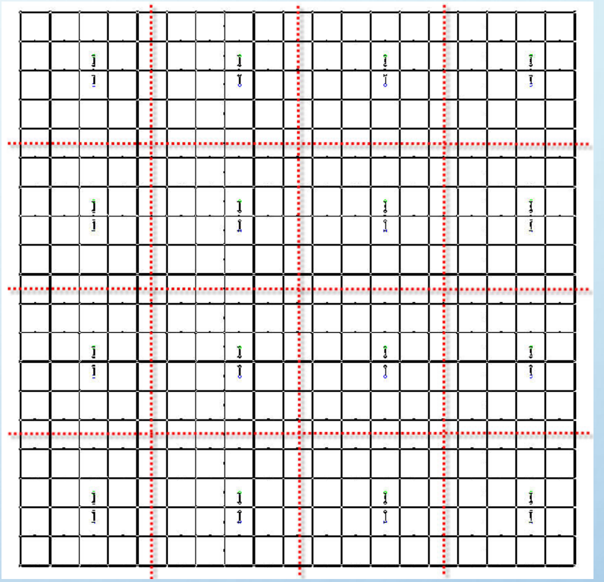
$$v(t) = \min\{D_1(t), \frac{S_2(t)}{a_{12}}, \frac{S_3(t)}{a_{13}}\}$$

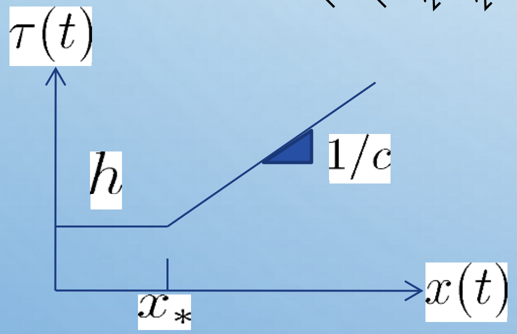
Turning percentage dependents on traffic composition, and hence vary with time and demand pattern

LOADING RESULTS FOR A SYNTHETIC GRID NETWORK

19x19 grid network, 256 OD pairs, 1 hour loading. Base demand: 300 vehicles per OD (h=30~100 sec, jam density: 180 veh/mi/lane, free-flow speed 50 mph, w=12.5 mph, flow cap 1800 veh/hr/lane, 2 lanes)

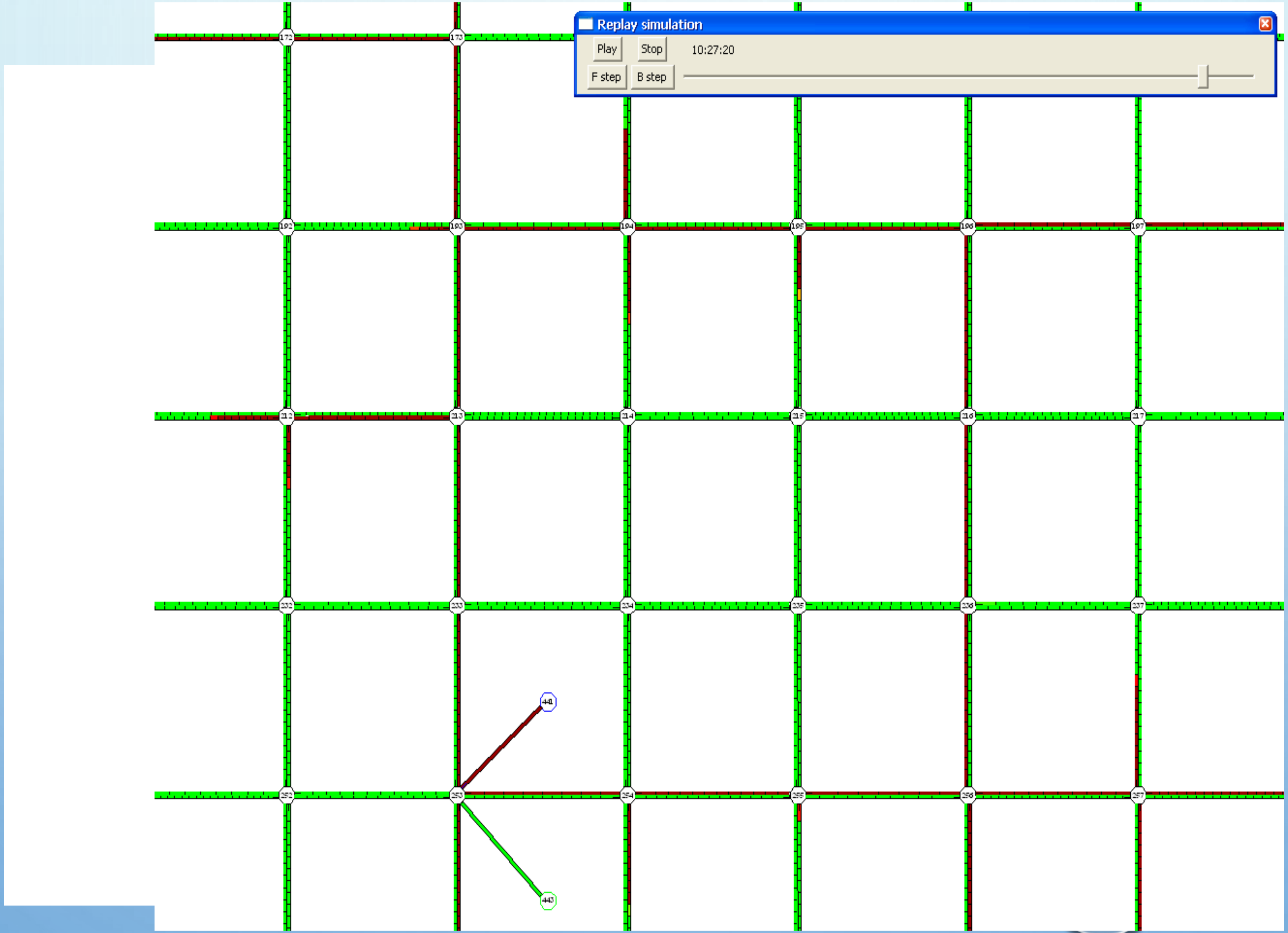






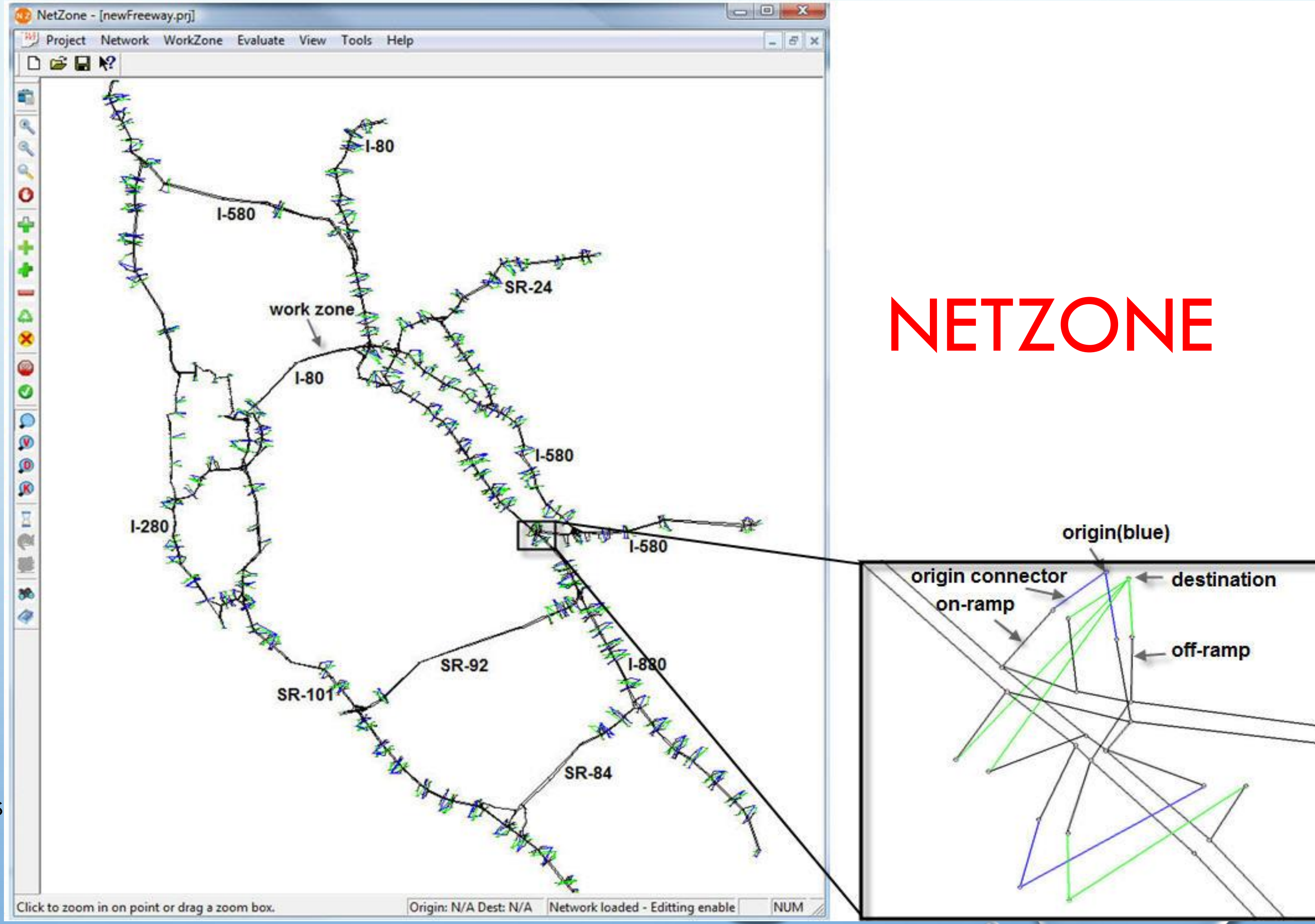
$$\tau(t) = \max\left\{h, h + \frac{x(t) - x_*}{c}\right\}$$

Delay (hours)	PQ	SQ	CTM	Delay func.
Light load (0.6*base)	196	190	210	308
Medium load (base)	17,022	23,011	30,819	18,926
Heavy load (2*base)	114,795	Gridlock	Gridlock	121,318


Replay simulation
Play
Stop
10:27:20
F step
B step

EXPERIENCES WITH REALISTIC NETWORKS

- 6 hours of Sunday (10AM-4PM)
- 582,606 total trips
- 2058 regular nodes
- 2711 regular links
- 21462 O-D pairs



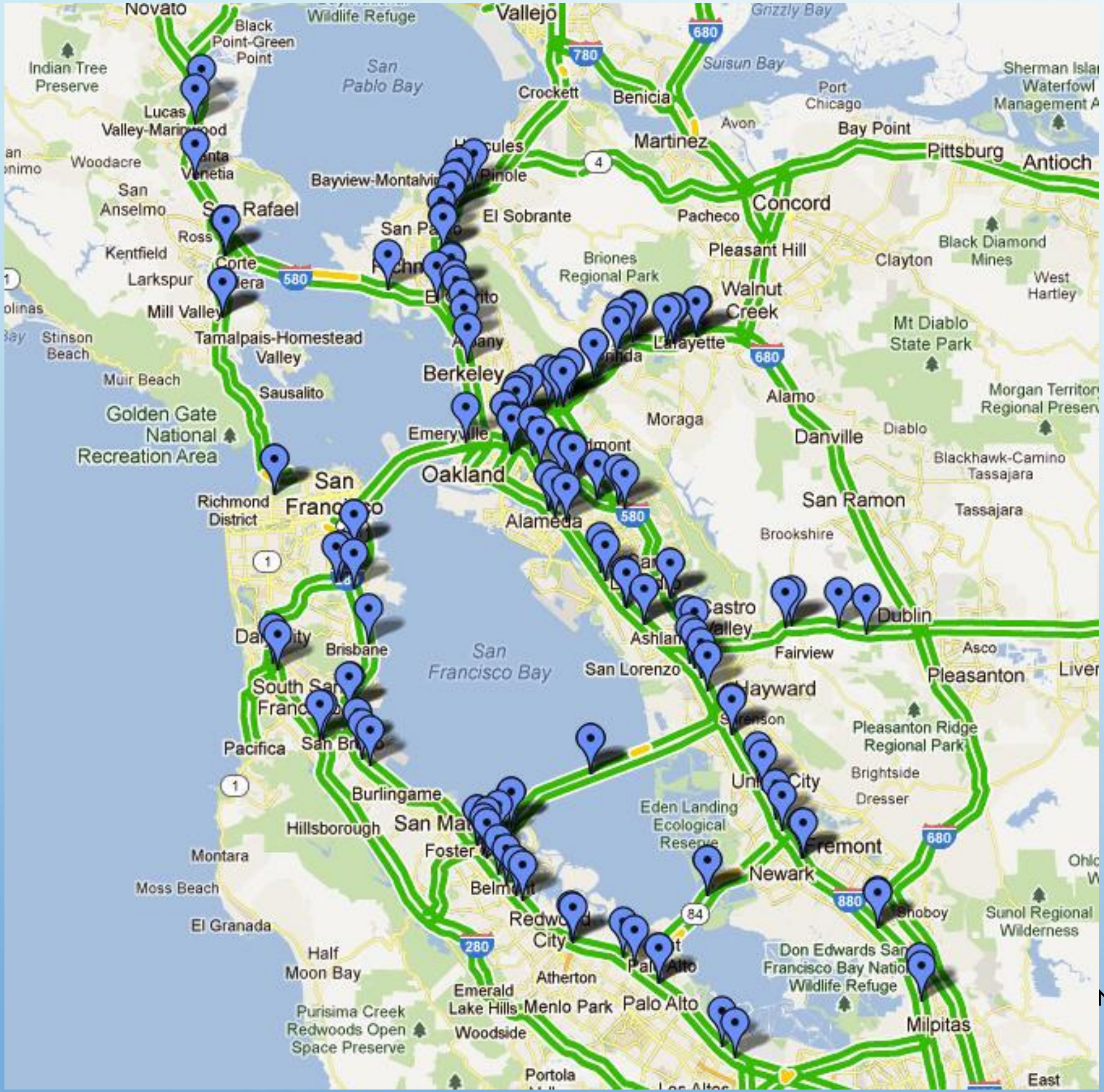
NETZONE

WORK FLOW

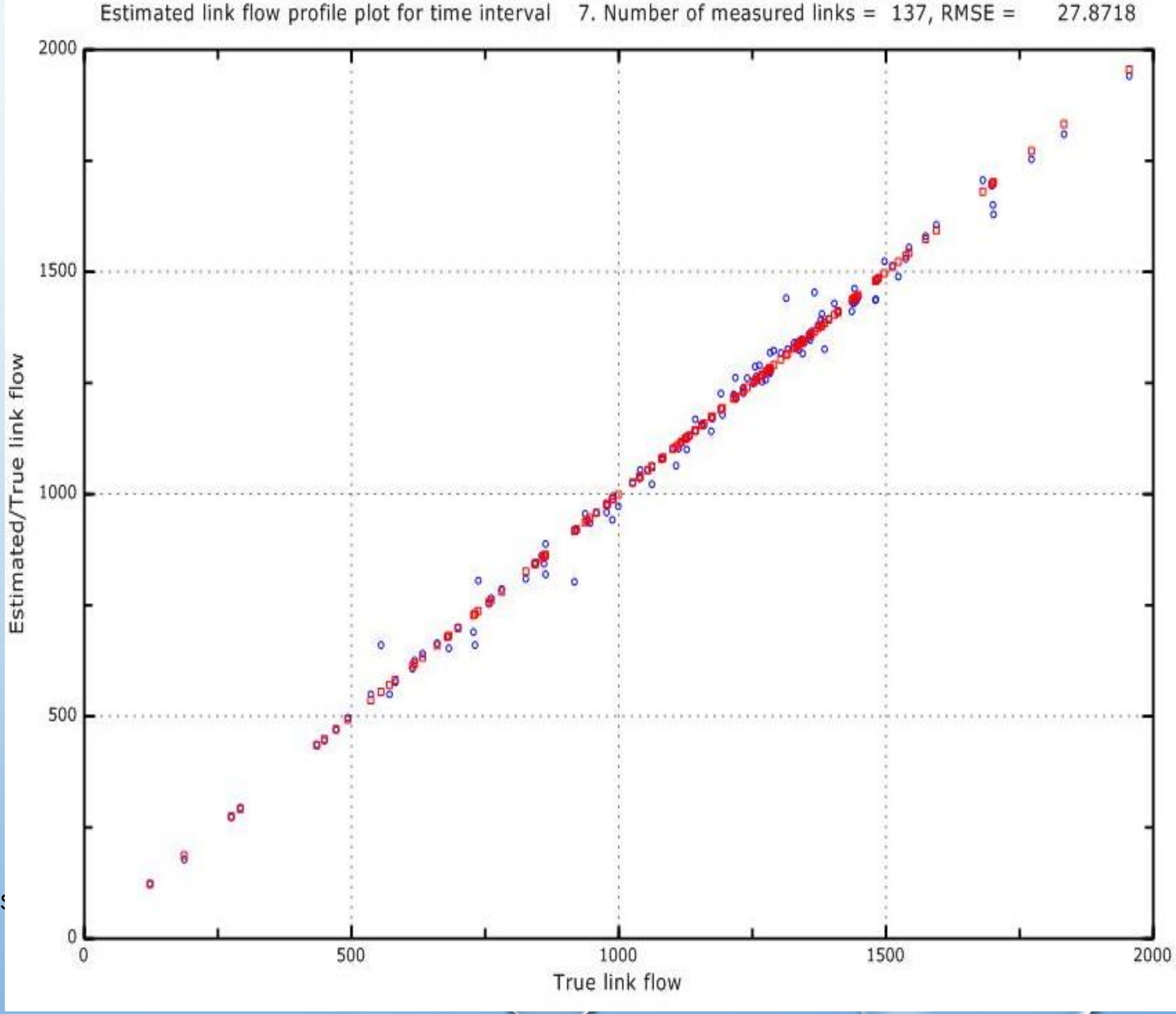
- NETWORK CODING
  - INMPORT GIS NETWORK FILE USING SHAPEFILE
  - CLEAN UP (CORRECT ERRORS AND REVISE O/D AND O/D CONNETORS)
- PREPARE INPUT DATA
  - TRAFFIC COUNTS, HISTORICAL O/D TABLE, FLOW PARAMETERS (SPEED LIMIT, CAPACITY, WAVE SPEED)
  - ESTIMATE O/D
- NETWORK DIAGNOSTIC
  - ERROR IN NETWORK CODING, INPUT DATA CAN ALL CAUSE ERREIOUS FLOW PATTERNS
- NETWORK LOADING
  - ONE-SHOT DYNAMICS WITH MIXED USER CLASSES, NO EQUILIBRIUM
- ANALYSIS AND REPORT OF RESULTS

TOOK 4 (GRDUATE STUDENTS)+1 (MYSELF) 10 EQUIVALENT DAYS TO COMPLETE THE PROJECT

DATA AND TIME DEPENDENT O/D ESTIMATION



NCIS



WHAT ABOUT SYSTEM-OPTIMAL DTA?

- IN SO-DTA, ONE HAS FULL CONTROL OF ALLOCATING TRIPS OVER SPACE AND TIME
- AT LEAST IN MANY-TO-ONE NETWORKS
  - ONE CAN SHOW THAT PQ, SQ, AND CTM PRODUCE THE SAME TOTAL SYSTEM COST IF BOTTLENECKS HAVE CONSTANT CAPACITIES
  - ONE SOLUTION IS TO ELIMINATE ALL INSIDE QUEUES IN THE NETWORK, AND LET THE VEHICLES QUEUE AT THE ENTRANCES
- PROOF FOR GENERAL NETWORKS IS HARD, IF THIS PROPERTY STILL HOLDS.

REFLECTIONS

- CODING EFFORT
  - LEVEL OF DETAIL
  - IN DYNAMIC MODELS, MINOR CODING ERROR CAN HAVE BIG CONSEUQENCES
- DATA NEEDS
  - DYNAMIC MODELS NEED MORE DATA!
    - TIME DEPENDENT O/D TABLES, MODEL PARAMETERS
  - MACRO MODELS ARE MORE PARSEMONIOUS
- CALIBRATION
  - ONE OF THE BIGGEST CHALLENGES
  - SMALL ERRORS IN CODING CAN LEAD TO LARGE ERROS IN FLOW PATTERNS
  - THE SPREAD OF CONGESTION MASKS THE TRUE CAUSE OF THE PROBLEM
- COMPUTATIONAL CHALLENGES
  - TYPICALLY LOADING TAKES THE BULK OF THE CPU TIME IN EACH ITERATION