Intersection auctions and reservation-based control in dynamic traffic assignment

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Motivation

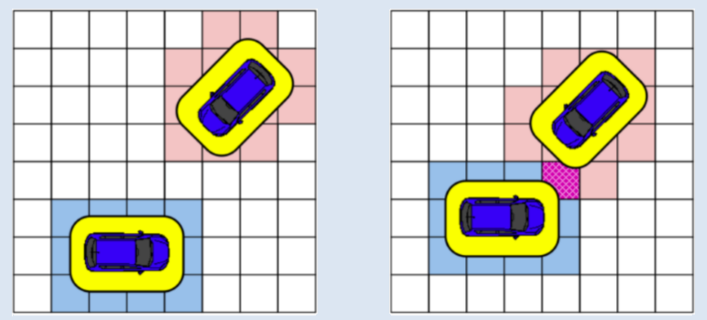
- Reservation-based intersection control increases capacity and reduces delay for single intersections (Fajardo et al., 2011)
- Auction priority may further reduce delay
- How are intersection auctions affected by user equilibrium (UE) behavior on city networks?

Contributions

- Intersection model of reservation-based intersection control compatible with general simulation-based dynamic traffic assignment (SBDTA)
- Computationally tractable for city networks
- Comparison of auctions with first-come-first-serve (FCFS) suggests its benefits are from the randomness of auctions

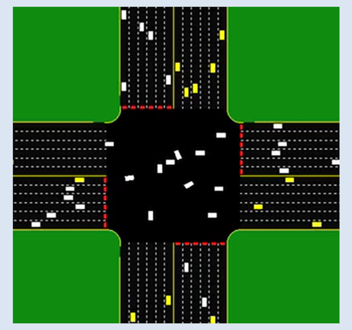
Background

1)Vehicles communicate with the intersection manager and request a space-time reservation through the intersection
2)Intersection manager accepts or rejects reservation based on tile occupancy of other reservations



Accepted Rejected

AIM4 microsimulator

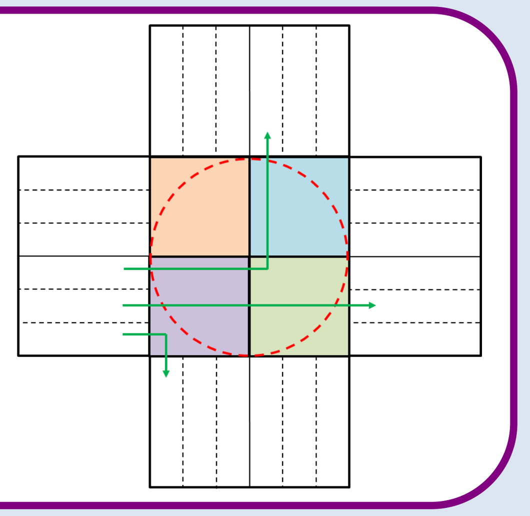


Properties

- Greater use of intersection—including simultaneous use by conflicting turning movements
- Flexible priority strategies—FCFS, auctions, etc.
- Requires microsimulation of intersections. Previous work on networks of intersections was limited in size or used a single tile, and did not consider UE behavior

Tiles → conflict regions

- For computational tractability, tiles collision checks are simplified to conflict regions—larger intersection areas with limited capacity
- Turning movements pass through 1 or more conflict regions
- Determined by radial division of intersection—automated method



Objectives

- Admit arbitrary priority strategies
- Retain simultaneous use by vehicles with conflicting paths
- Independent of specific intersection characteristics
- Satisfy invariance principle (Tampère et al., 2011)

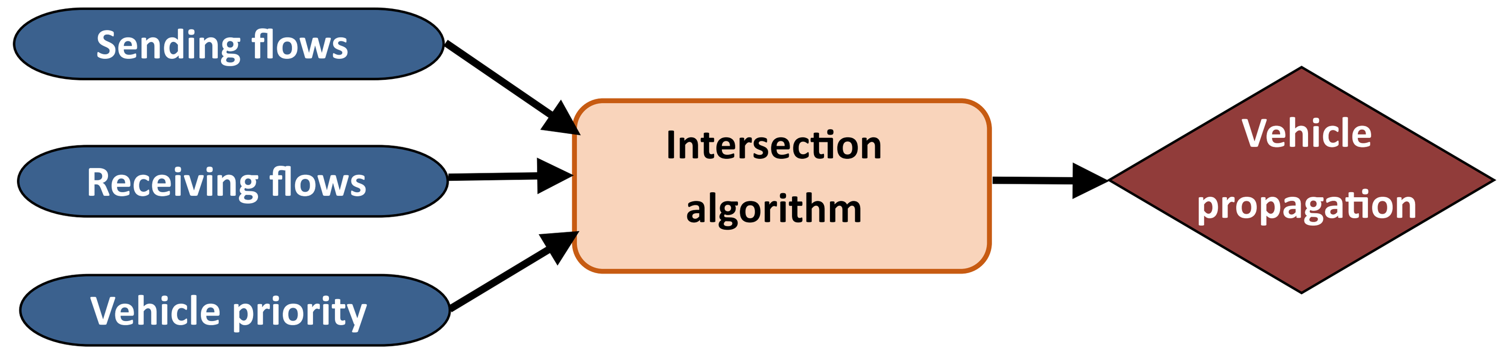
Assumptions

- Flow is discretized to assign vehicle priority
- All vehicles have the same physical characteristics
- In the absence of other demand, flow is restricted only by sending and receiving flows (to be independent of geometry)

Intersection algorithm

Initialization

1. Set $V = \emptyset$
2. For all incoming links i
3. Sort $S_i(t)$ by arrival time at I
4. Remove first ℓ_i vehicles from $S_i(t)$ and add them to V



Vehicle propagation

5. Sort V by $f(v)$
6. For all $v \in V$
7. Let (i, j) be the origin/destination links of v
8. If $R_j(t) - \sum_{i'} y_{i'j}(t) \geq 1$ and $Q_c - y_c(t) \geq Q_{ij} / Q_c$ for all $c \in C_{ij}$
9. $y_{ij}(t) := y_{ij}(t) + 1$
10. For $c \in C_{ij}$: $y_c(t) := y_c(t) + Q_{ij} / Q_c$
11. Remove first vehicle in $S_i(t)$ and add it to V
12. Go to 5

C_{ij}	conflict regions in the path from i to j
$f(v)$	priority of vehicle v
ℓ_i	number of lanes in i
$Q_c(Q_i)$	capacity of conflict region c (link i)
$S_i(t)$	sending flow of i at time t
R_j	receiving flow of link j at time t
V	vehicles that can enter the intersection
$y_{ij}(t)$ $(y_c(t))$	flow between i and j (through c) at t

Conclusions

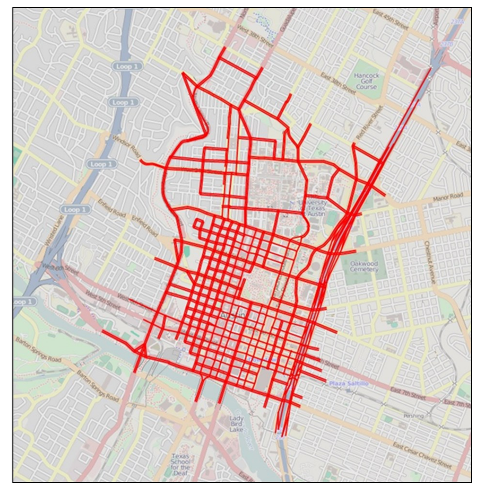
- Conflict region model for SBDTA of reservation-based intersection control for autonomous vehicles
- Compatible with general SBDTA and computationally tractable for large city networks
- Builds on characteristics of general DTA intersection models (Tampère et al., 2011):
  - First-in-first-out behavior within links
  - Satisfies invariance principle
  - Dependent on intersection geometry due to conflict regions, but conflict region division is automated
- Link transmission model (LTM) with conflict regions converges to dynamic user equilibrium
- Auctions reduce congestion over FCFS, but the effects are due to the randomness of bids: lottery has similar results

Future work

- Comparison of traffic signals and reservation-based control under user equilibrium behavior
- DTA model of shared roads (human drivers and autonomous vehicles)
- Optimal priority strategies for reservation-based control
- Possibility of Braess paradox-like phenomena due to higher capacity and/or reservation priority

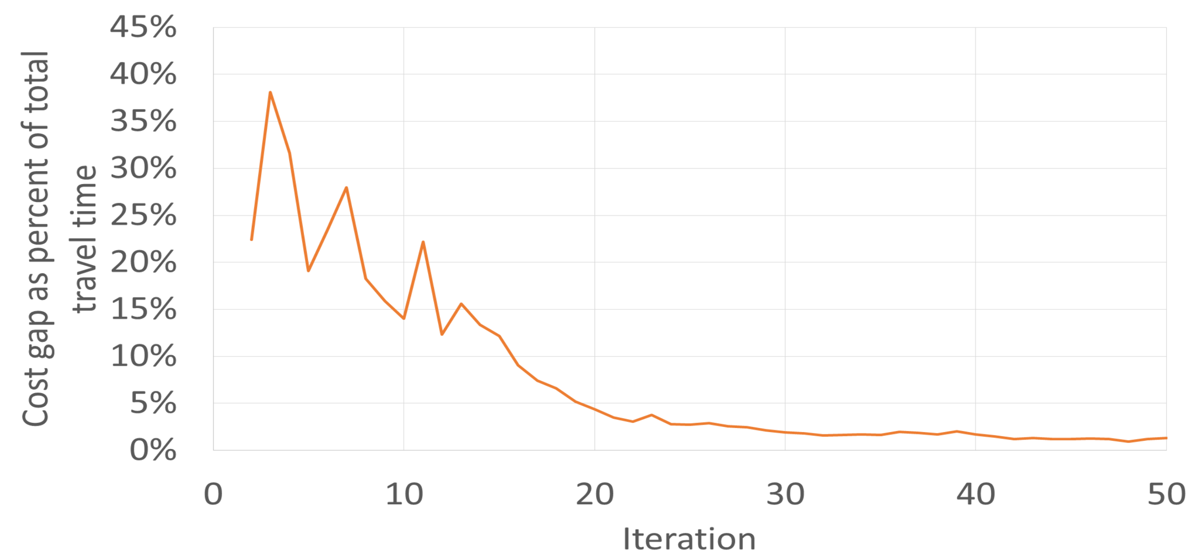
Computational results—first come first serve priority

Downtown Austin, Texas



- 171 zones
- 546 intersections
- 1247 links
- 62836 trips

Convergence of DTA with reservation-based intersections



- Link transmission model used for SBDTA
- Method of successive averages used to solve DTA
- 922.5 seconds for 50 iterations
- Estimated 150 hours for AORTA (Carlino et al., 2012)

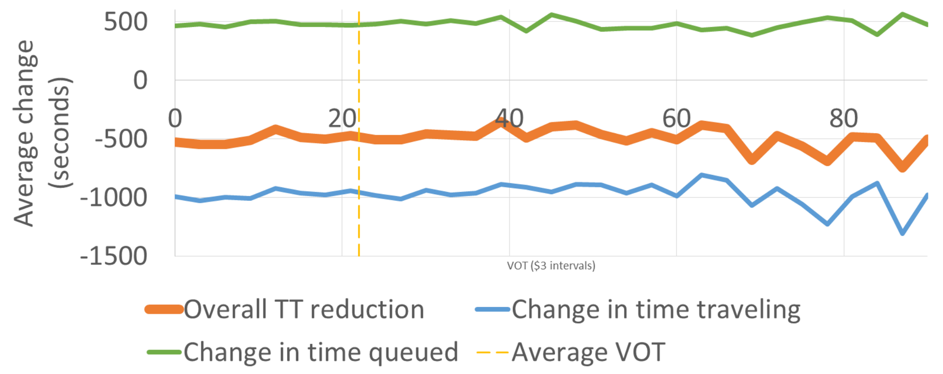
Analysis of auctions

on Sioux Falls network

Histogram of travel times in auctions/lottery compared with FCFS

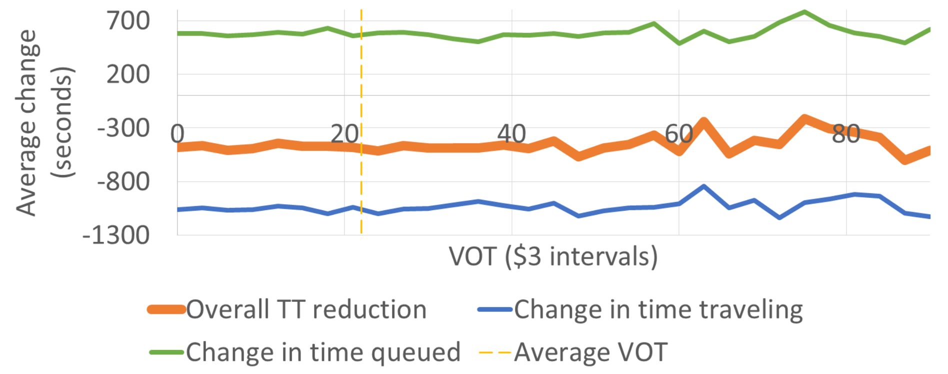
Auction experiment

- Vehicles bid value of time (VOT) at each intersection—highest bidder gets priority
- VOTs based on income distribution



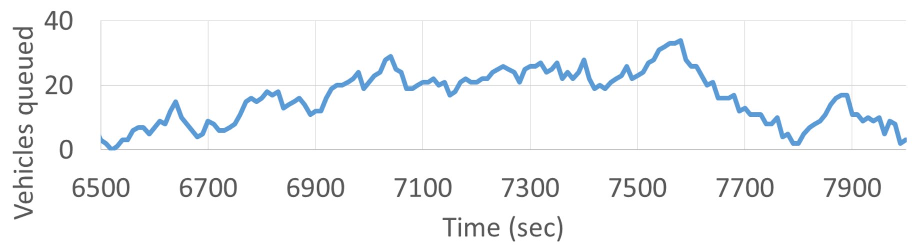
Lottery experiment

- Each vehicle is assigned a random number that is their priority

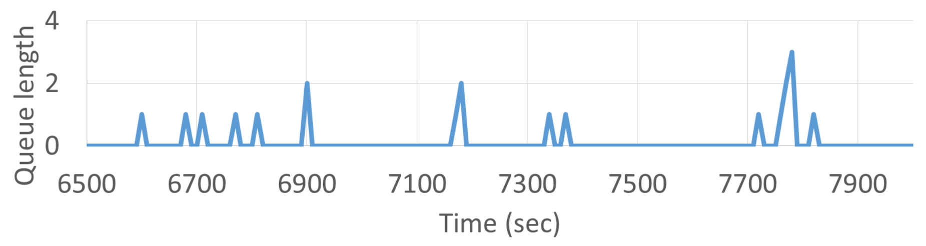


- Little to no benefit for high VOT vehicles from auctions
- Intersection delay increased but congestion decreased, leading to a net benefit
- Comparison of queue lengths indicates that FCFS creates large queues on high demand links

Queue length (FCFS)



Queue length (auctions)



- FCFS allows queues to build on high-demand links because priority is independent of queue size
- The randomness of auctions (and lottery) results in a more even distribution