Integration of Microsimulation and Optimized Autonomous Intersection Control

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Presentation Outline

• Introduction
• Methodology
• Integration with Microsimulation
• Analysis Scenarios
• Results
• Conclusions and Future Work
Introduction

• Autonomous Intersection Management (AIM)
  – What is it?
  – Benefits
    • Improved Efficiency
    • Improved Safety

• Integration with Microsimulation
  – Purpose
  – What makes the use of microsimulation unique in this work?

https://www.sandiegocounty.gov/content/sdc/dpw/transportation/lightsout.html

Introduction

• Research Contribution
  – Develop more realistic AIM optimization model
  – Integrate AIM with off-the-shelf microsimulation software (Aimsun)
  – Utilize microsimulation to analyze new AIM model against other forms of intersection control

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Methodology

• Conflict-point reservation-based AIM optimization (AIM+)
  – Based off the formulation from Levin and Rey (2017)
  – Improves formulation to give intersection manager more flexibility in optimizing vehicle paths

Methodology

• Model assumptions:
  – Vehicles utilize constant acceleration rate from first conflict point to last conflict point (intersection exit point)
    • Can use kinematics
  – Vehicle starts at rest at initial conflict point
    • Maintains convexity of formulation
    • Location of initial conflict point = 200 ft upstream
Methodology

- Mixed-integer linear program (MILP)
- Uses Gurobi for optimization solver

- Decision variables:
  - Time of arrival at every conflict point
  - Vehicle acceleration

\[
\begin{align*}
\min & \sum_{i \in V} \beta_i \left( t_i(v_i^0) + t_i(v_i^0) \right) \\
\text{subject to} & \quad t_i(v_i^0) \geq e_i, \quad \forall i \in V \\
& \quad t_i(v_i^0) = \frac{x_i}{w} + \frac{6x_i}{4d_0(v_i^0)} \quad \forall i \in V \\
& \quad t_i(v_i^n) + t_i(v_i^n) \leq \frac{6d_0(v_i^0) + 6z(v_i^n) - 6d_0(v_i^0)}{6d_0(v_i^0)} + \frac{2}{6d_0(v_i^0)} \quad \forall i \in V, \forall t_i^0 \in e_i, \forall i \in E, \forall n \in [1, N] \\
& \quad t_i(v_i^n) - t_i(v_i^n) = \frac{2d_0(x_i^0) - x_i^0}{2d_0(v_i^0)} \quad \forall i \in V, \forall t_i^0 \in e_i, \forall i \in E, \forall n \in [1, N] \\
& \quad \frac{1}{2} \leq \frac{t_i^0}{w} \leq \frac{3}{2} \quad \forall i \in V \\
& \quad \frac{2d_0(x_i^0)}{6d_0(v_i^0)} \leq t_i(v_i^n) - t_i(v_i^n) \leq \frac{2d_0(x_i^0)}{6d_0(v_i^0)} \quad \forall i \in V \\
& \quad t_i(v_i^n) + t_i(v_i^n) \leq t_i(v_i^n) \quad \forall i \in V, v_i^0 = v_i^n, x_i \leq x_i, \forall t_i^n \in e_i, \forall i \in E, \forall n \in [1, N] \\
& \quad t_i(v_i^n) + t_i(v_i^n) \leq t_i(v_i^n) \quad \forall i \in V, v_i^0 = v_i^n, x_i \leq x_i, \forall t_i^n \in e_i, \forall i \in E, \forall n \in [1, N] \\
& \quad \delta_i(v_i^n) + \delta_i(v_i^n) = 1 \quad \forall i, j \in V, v_i^0 = v_i^n, i < j, \forall t_i^n \in e_i, \forall i \in E, \forall n \in [1, N] \\
& \quad \delta_i(v_i^n) \in [0, 1] \quad \forall i, j \in V, v_i^0 = v_i^n, \forall t_i^n \in e_i, \forall i \in E, \forall n \in [1, N]
\end{align*}
\]

Integration with Microsimulation

- Aimsun Application Programming Interface (API)
  - Allows for creation of script that can interface with Gurobi
- Coordination between Aimsun and Gurobi during simulation
  - Output of vehicle information from Aimsun upon entering network →
- Aimsun output becomes Gurobi input
Integration with Microsimulation

• **Aimsun Modeling Choices**
  – Constant initial velocity
  – Lane-changing behavior

Integration with Microsimulation

• “Velocity smoothing”*
  – Provides alternative so vehicles in Aimsun do not physically have to come to a stop at initial conflict point
  – Piecewise acceleration function
  – Ensures that vehicle arrives at intersection at the assigned time and velocity to ensure collision-free traversal through intersection

*Velocity smoothing
Integration with Microsimulation

AIM+ in action: (intersection demand = 8,800 vph)

Analysis Scenarios

- Measures of effectiveness (MOEs): delay, speed
- Parameter: Intersection demand
- AIM+ Sensitivity Analysis
- AIM+ vs Conventional Traffic Signal
  - Signal timing obtained using Synchro
- AIM+ vs AIM “First-Come First-Served” (FCFS)
- Multiple 1-hour simulations run for each scenario
Results: AIM+ Sensitivity Analysis
Intersection Demand
(40 mph, 0 buffer, 22%/56%/22% LTR, 1:1:1:1)

Results: Traffic Signal vs AIM+
(40 mph, 0 buffer, 22%/56%/22% LTR, 1:1:1:1)
Results: AIM FCFS vs AIM+

Intersection Demand
(40 mph, 0 buffer, 22%/56%/22% LTR, 1:1:1:1)

Conclusions

- AIM+ robust to changing parameters
  - Delay increases of only several seconds (sometimes only tenths of a second) across scenarios
  - Speed decreases of only tenths of a mile per hour across scenarios

- 71%-91% reduction in delay with AIM+ over signals
- 5%-31% reduction in delay with AIM+ over AIM FCFS

- Correspondingly higher speeds with AIM+
Conclusions

• Future work:
  – Improve computational efficiency of Aimsun API and Gurobi Solver
    • Can test higher demands and larger safety buffers
  – Improve formulation to allow for fluctuating vehicle accelerations
  – Extend applicability of AIM+ to multi-intersection networks