The Braess's Paradox in Dynamic Traffic

Dingyi Zhuang, Yuzhu Huang, Vindula Jayawardana, Jinhua Zhao, Dajiang Suo, Cathy Wu

Agenda

- Introduction and Motivation
- Formulation and Methodology
- Experiment Setup
- Results
- Future work

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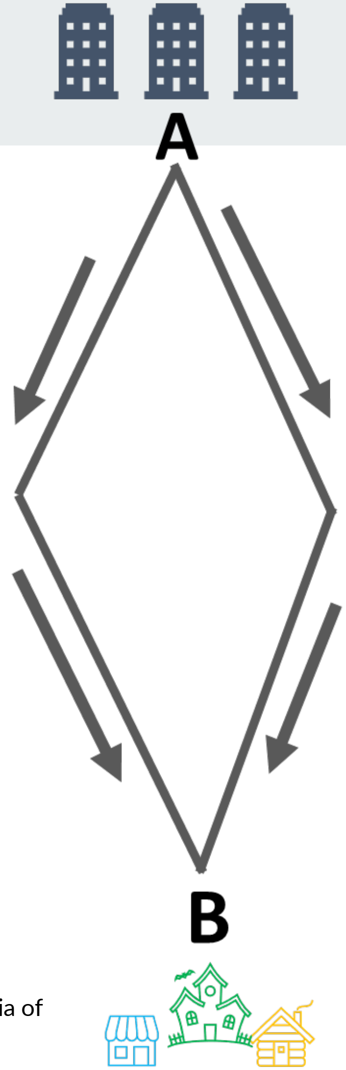
What is the Braess's Paradox?

Adding a new road to an existing road network could make traffic worse.



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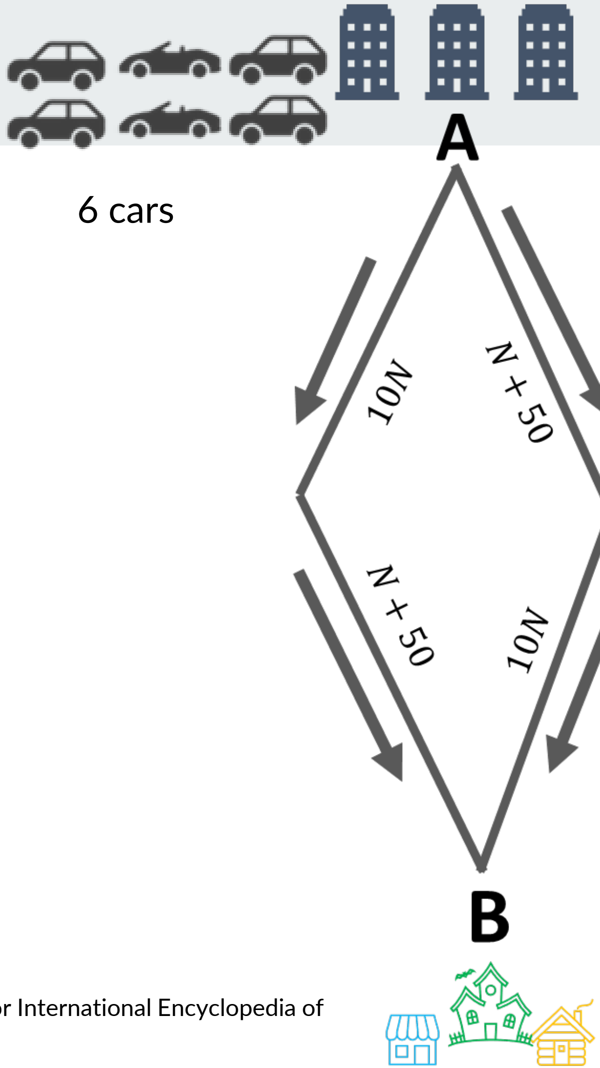

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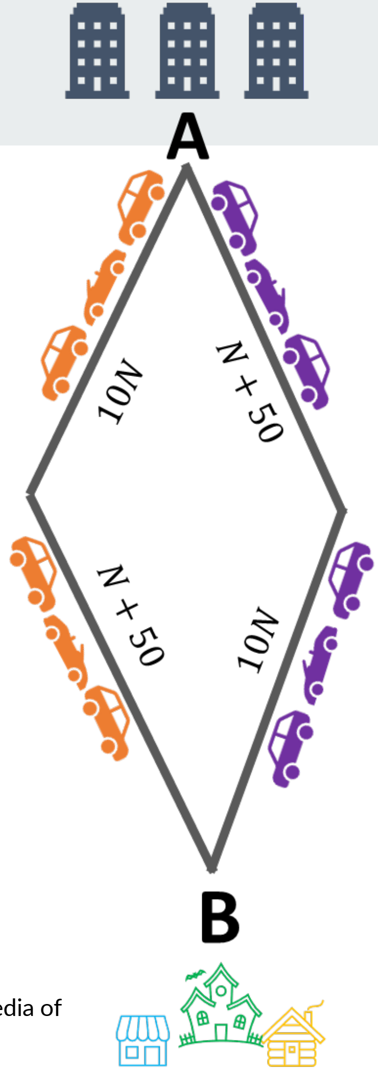
$$T = 3 * 10 + (3 + 50) = 83$$



$$T = (3 + 50) + 3 * 10 = 83$$

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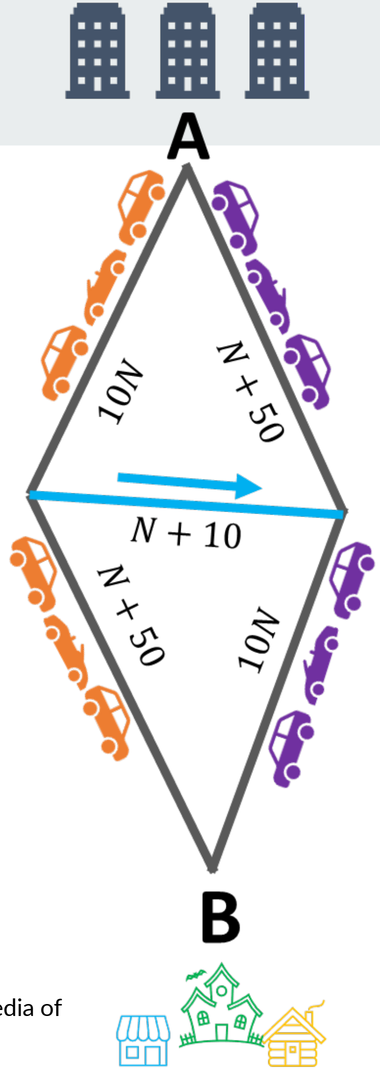
$$T = 3 * 10 + (3 + 50) = 83$$

$$T = 3 * 10 + (0 + 10) + 3 * 10 = 70$$



$$T = (3 + 50) + 3 * 10 = 83$$

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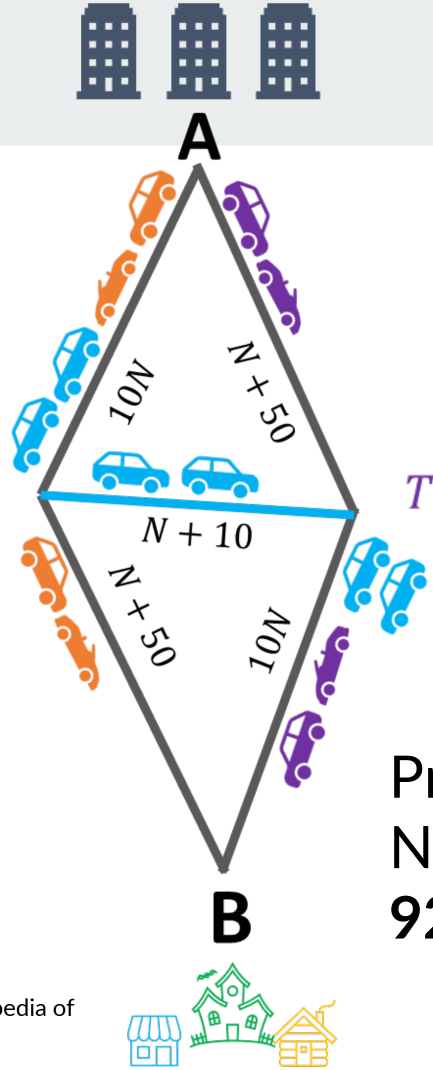
$$T = 4 * 10 + (2 + 50) = 92$$

$$T = (2 + 2) * 10 + (2 + 10) + (2 + 2) * 10 = 92$$



$$T = (2 + 50) + (2 + 2) * 10 = 92$$

Previous Equilibrium: 83
New Equilibrium: 92
92>83

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Motivation

Static Assignment

Given trip demand, assign trip **instantaneously** based on flow conservation and user equilibrium.

Dynamic Assignment

The junction effects and the **interactions** of human drivers are not fully studied

Microsimulation

Microscopic insight. There are few studies. The **routing** strategies are less discussed.

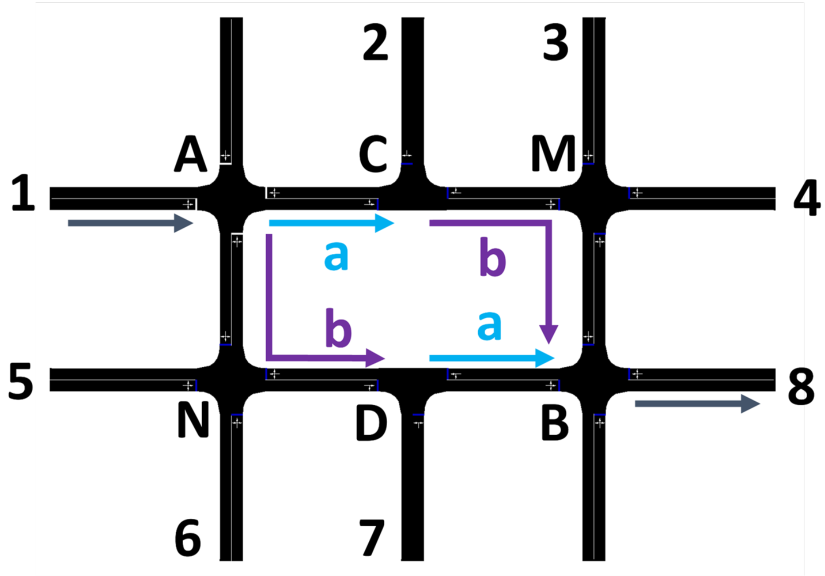
Formulation and Methodology

Questions

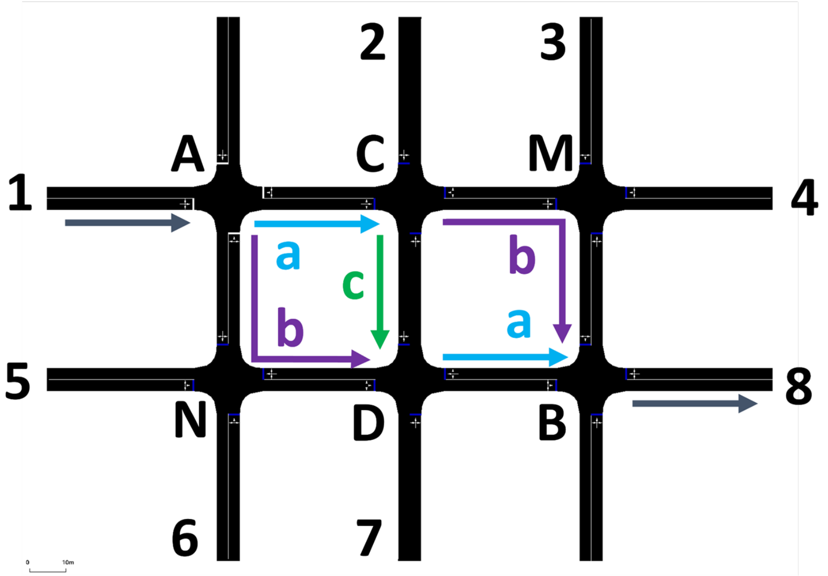
- Is there Braess's Paradox in an open system (e.g. grid network)?
- When does the Paradox appear?

Grid Network

Baseline Network



Added-Path Network



Available Routes

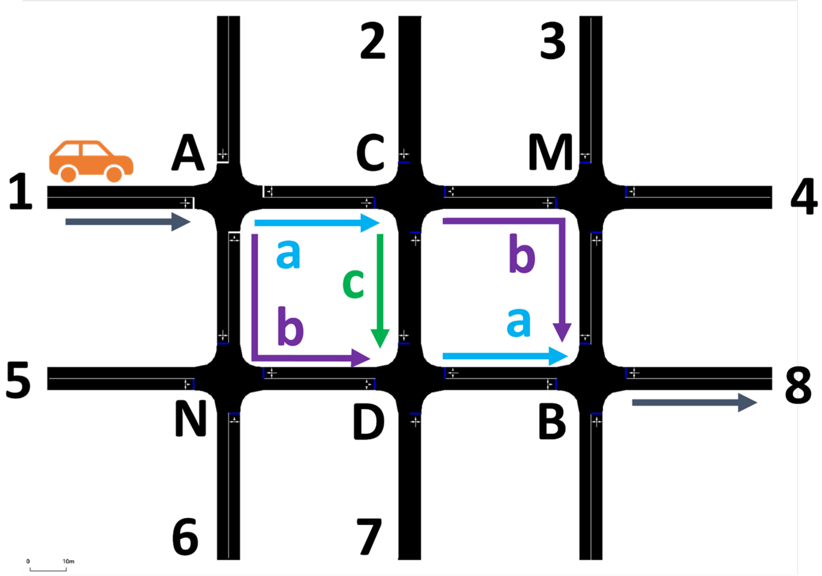
Baseline Network:

A→C→M→B
A→N→D→B

Added-Path Network:

A→C→M→B
A→C→D→B
A→N→D→B

Vehicle Routing



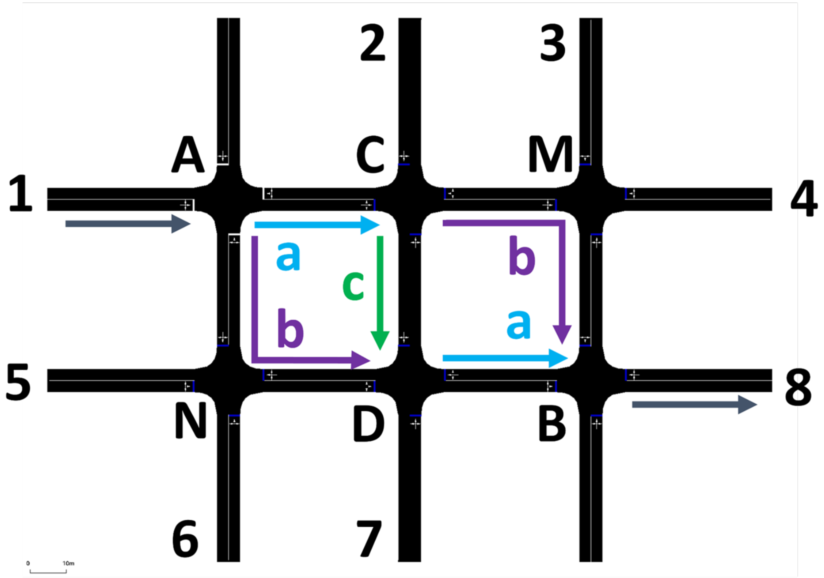
For any vehicle entering from Node 1, there are 2 decision-making points:

- At **Node A**, choose between:
  - A→C→M→B
  - A→N→D→B
- If chosen A→C→M→B, then at **Node C**, choose between:
  - C→M→B
  - C→D→B

Criteria for route selection:

Select route with the lowest **travel cost**, $C_p(t)$

Formulation of Travel Cost



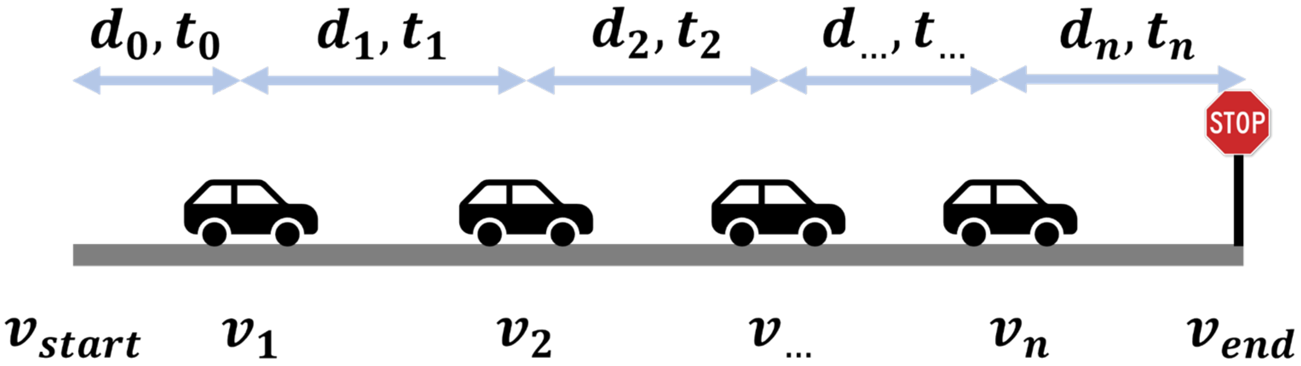
Cost Function

Edge cost: $C_e(t)$

Route cost: $C_p(t) = \sum C_e(t) 1_{e \in p}$

User cost: $C_u(t) = min\{C_p(t)\}$

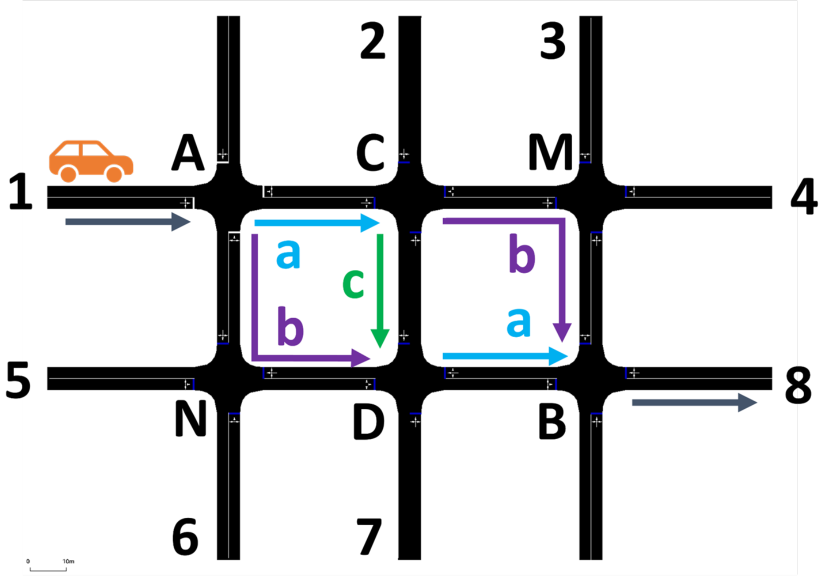
Travel Time Estimation



Edge Cost $C_e(t) = t_0 + t_1 + \ldots + t_n$

Decomposed Travel Time $t_1 = estimate\_time(v1, v2, a_1, a_2, d_1)$

Simulation Process



Throughout the simulation period, vehicles

- Enter from Node 1
- Travel through the network
- Exits from Node 8

At every simulation time step, each vehicle

- Travels following the IDM model
- At Node A or Node C, evaluates the travel cost of potential routes and chooses the route with the lowest estimated cost

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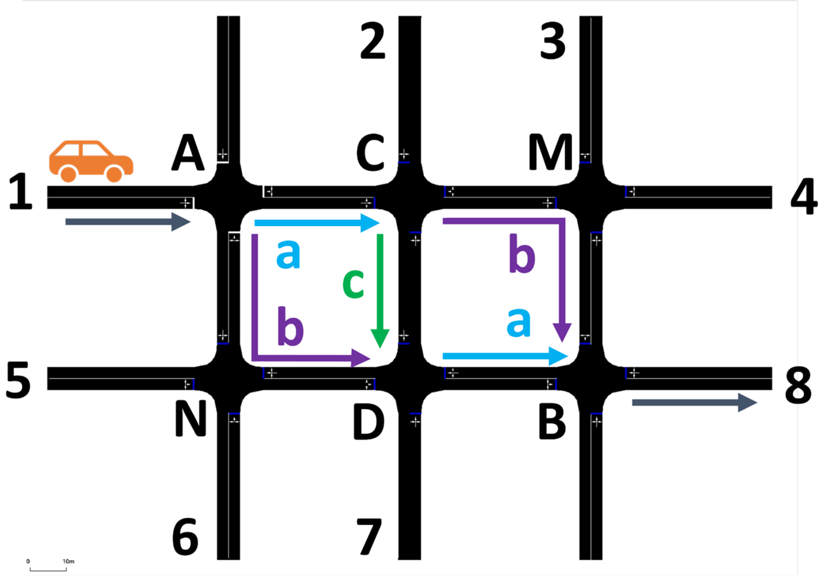
Experiments - Setup



Parameters of the network

- Edge length (default: 50 m ≈ 164 ft)
- Speed limit (default: 35 m/s ≈ 78 mph)

By changing combination of

length + speed length,

we can change the advantage of the shortcut.

<u>Example</u>:

Baseline: 400 m, 35 m/s on edges

Added-path: 400 m, 35 m/s on shortcut, 10 m/s on other edges

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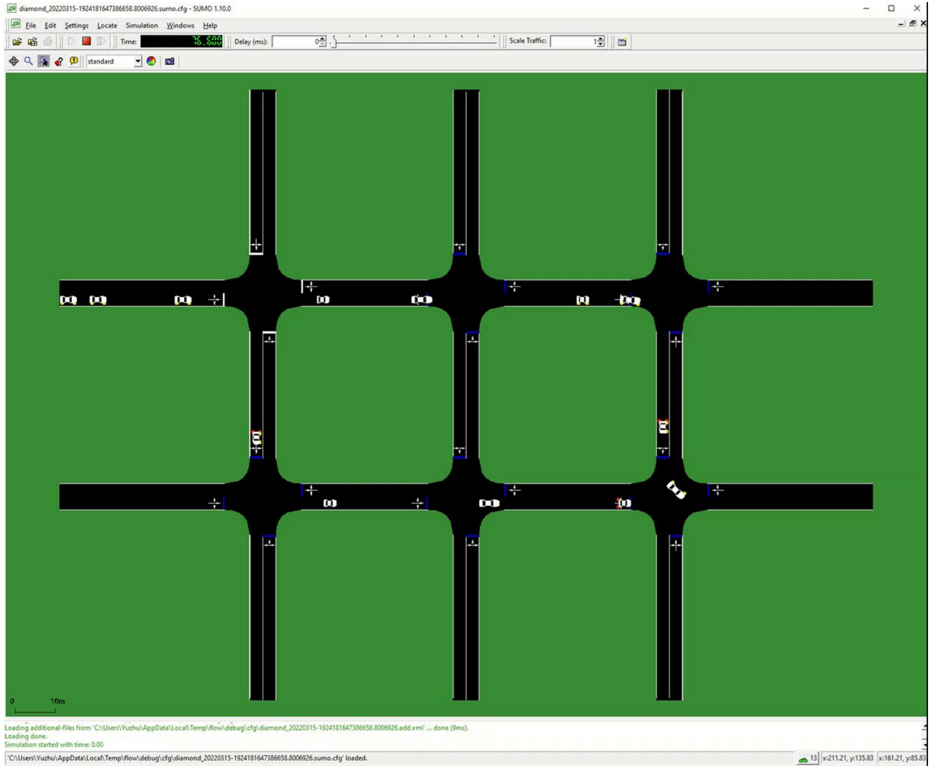
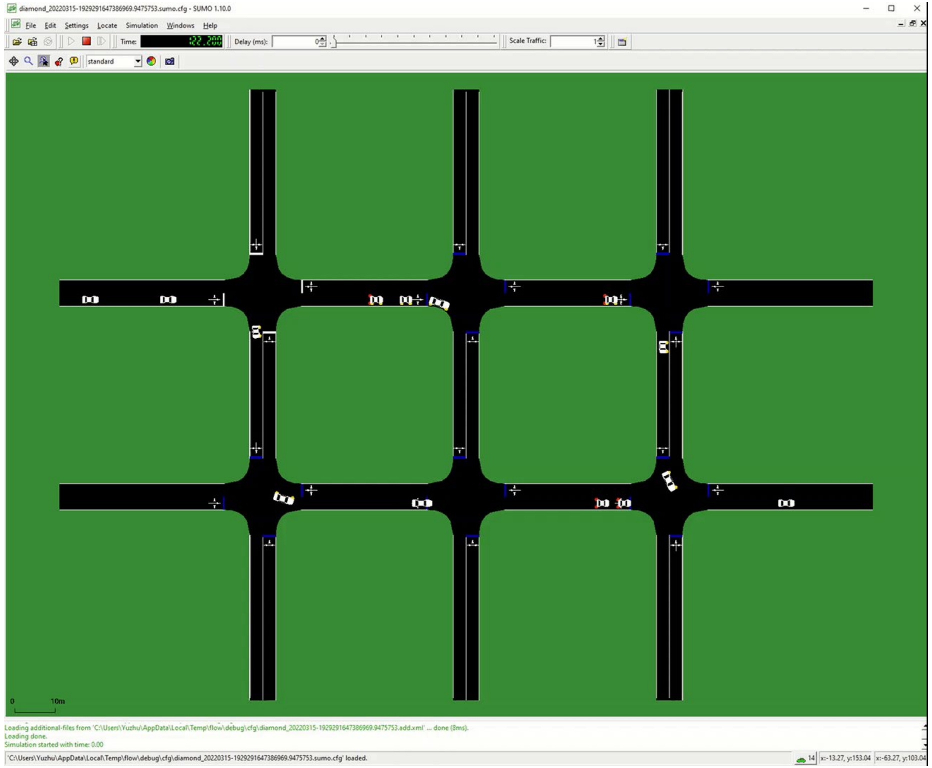
Network Output Flow

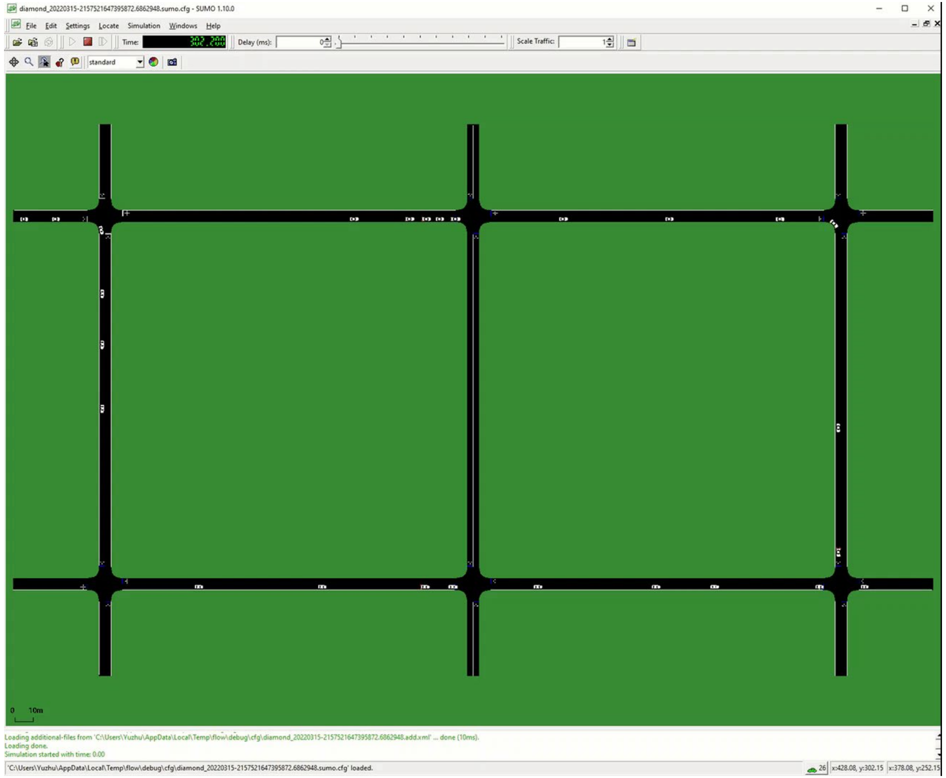
Baseline Network
50 m, 35 m/s



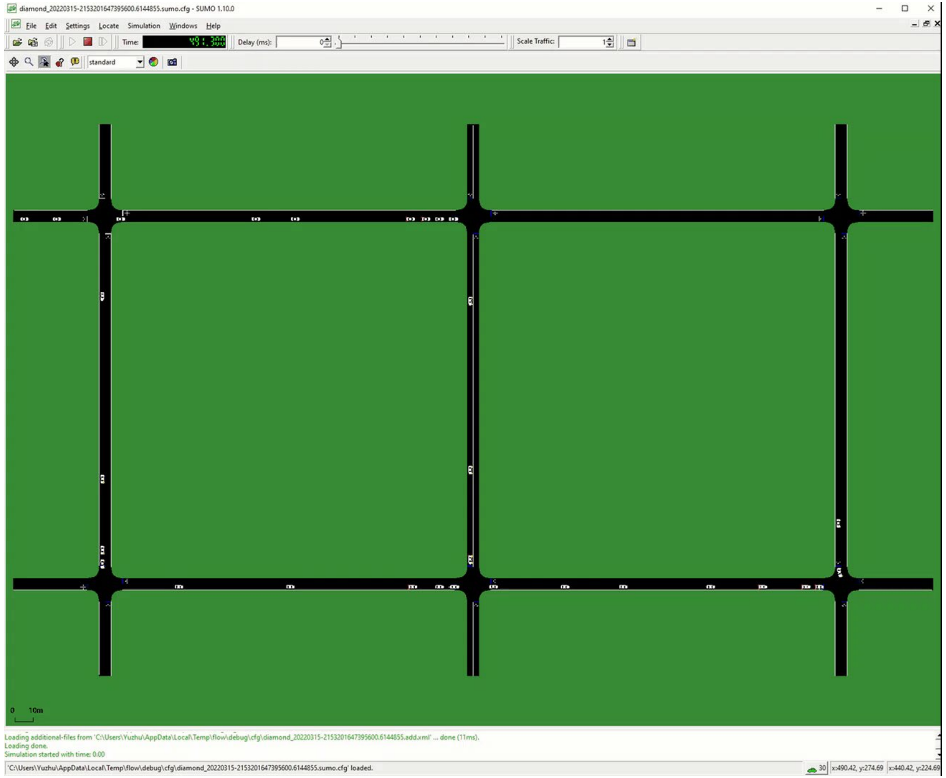
Added-Path Network
50 m, 35 m/s



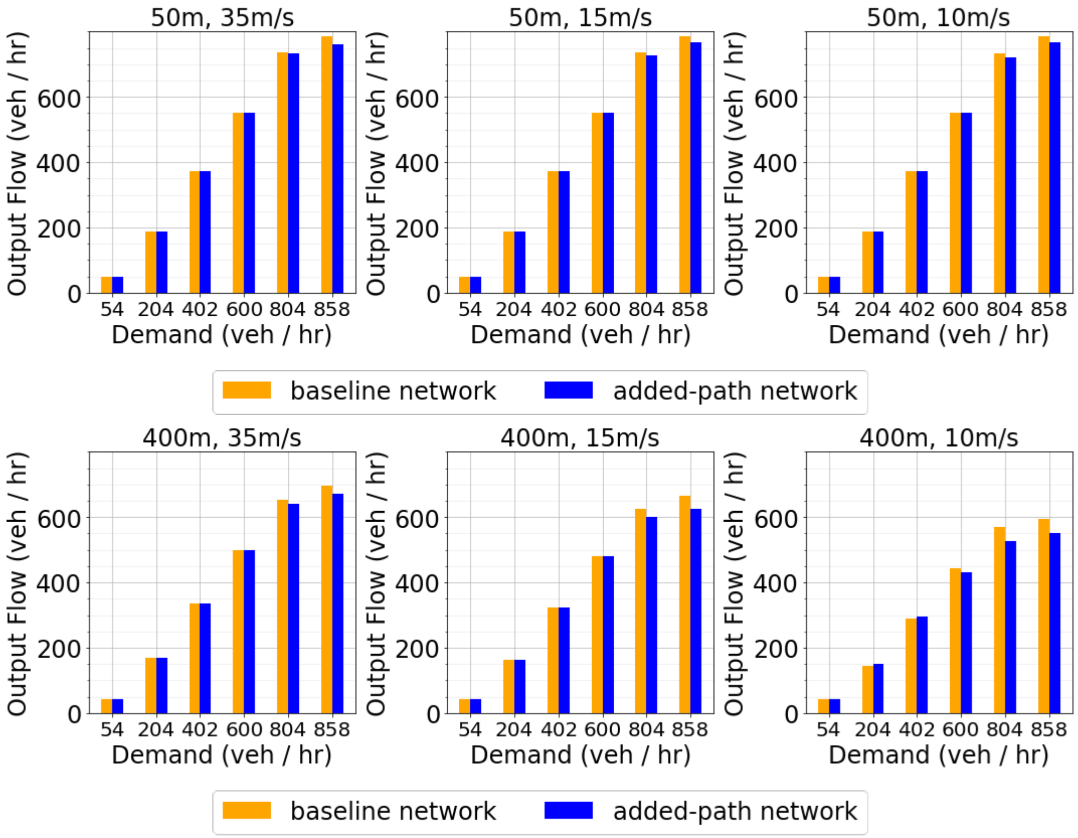
Baseline Network, 200 m, 10 m/s 1000 veh/hr



Added-Path Network, 200 m, 10 m/s 1000 veh/hr



Network Output Flow



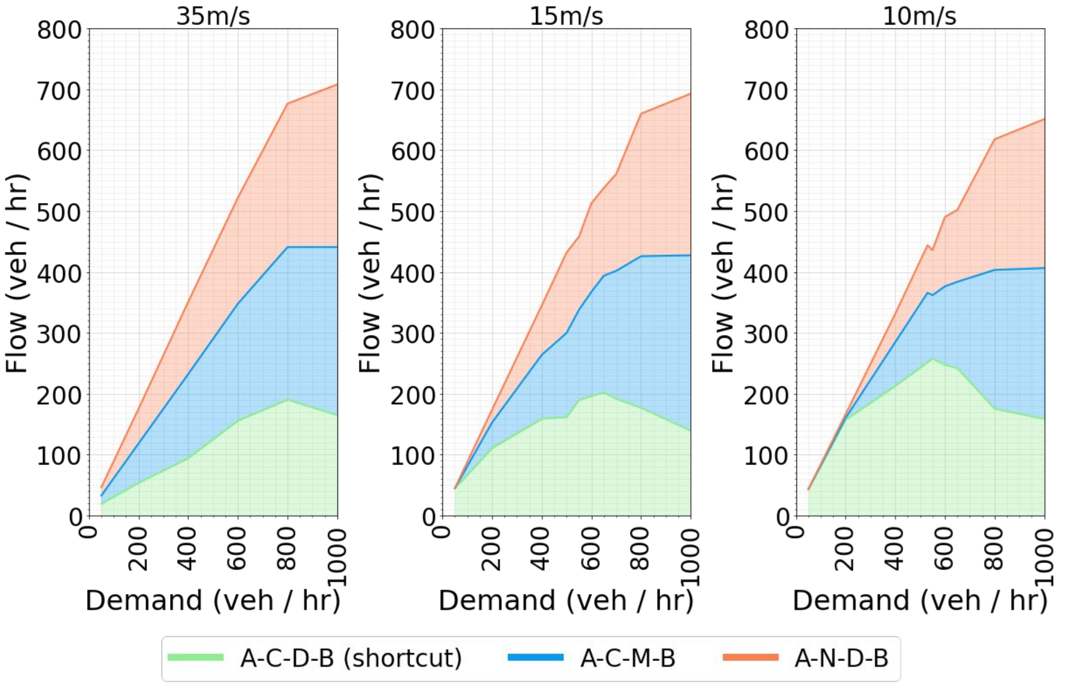
With an added path:

- Output flow from the network does not increase;
- When the shortcut is more advantageous, decrease in output flow is more obvious.

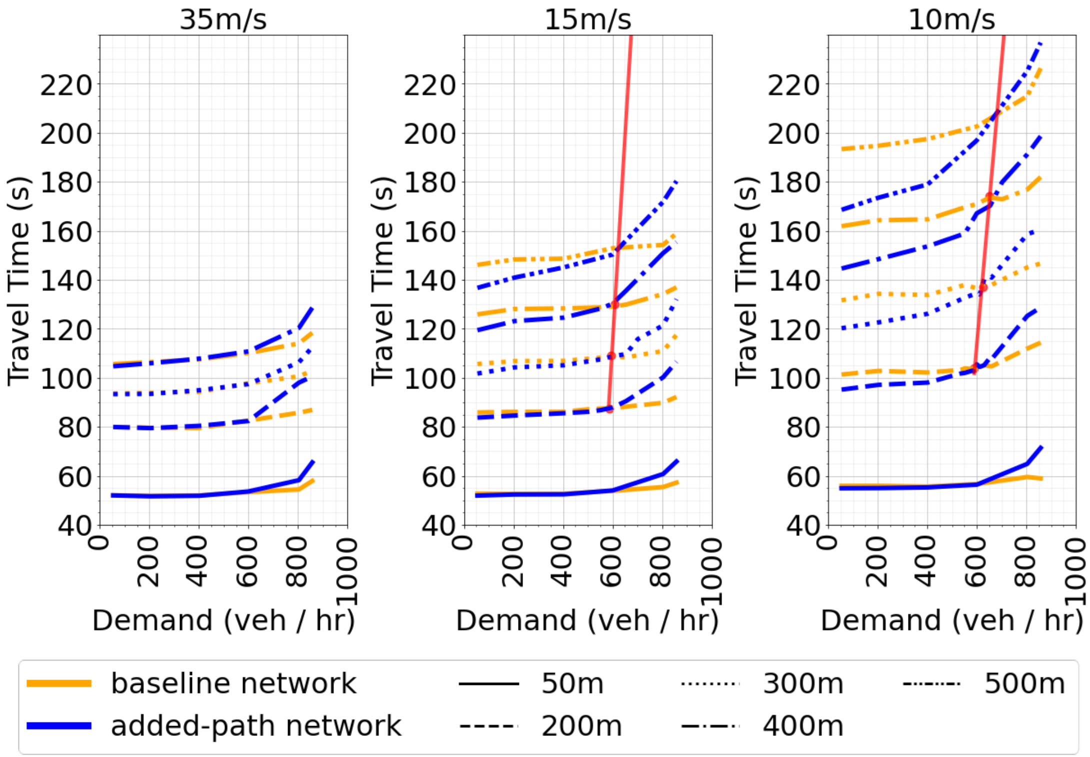
Flow on Each Route

As demand level increases,

- Flow on either of the original routes increases and converges;
- Flow on shortcut increases but then decreases after an inflection point.

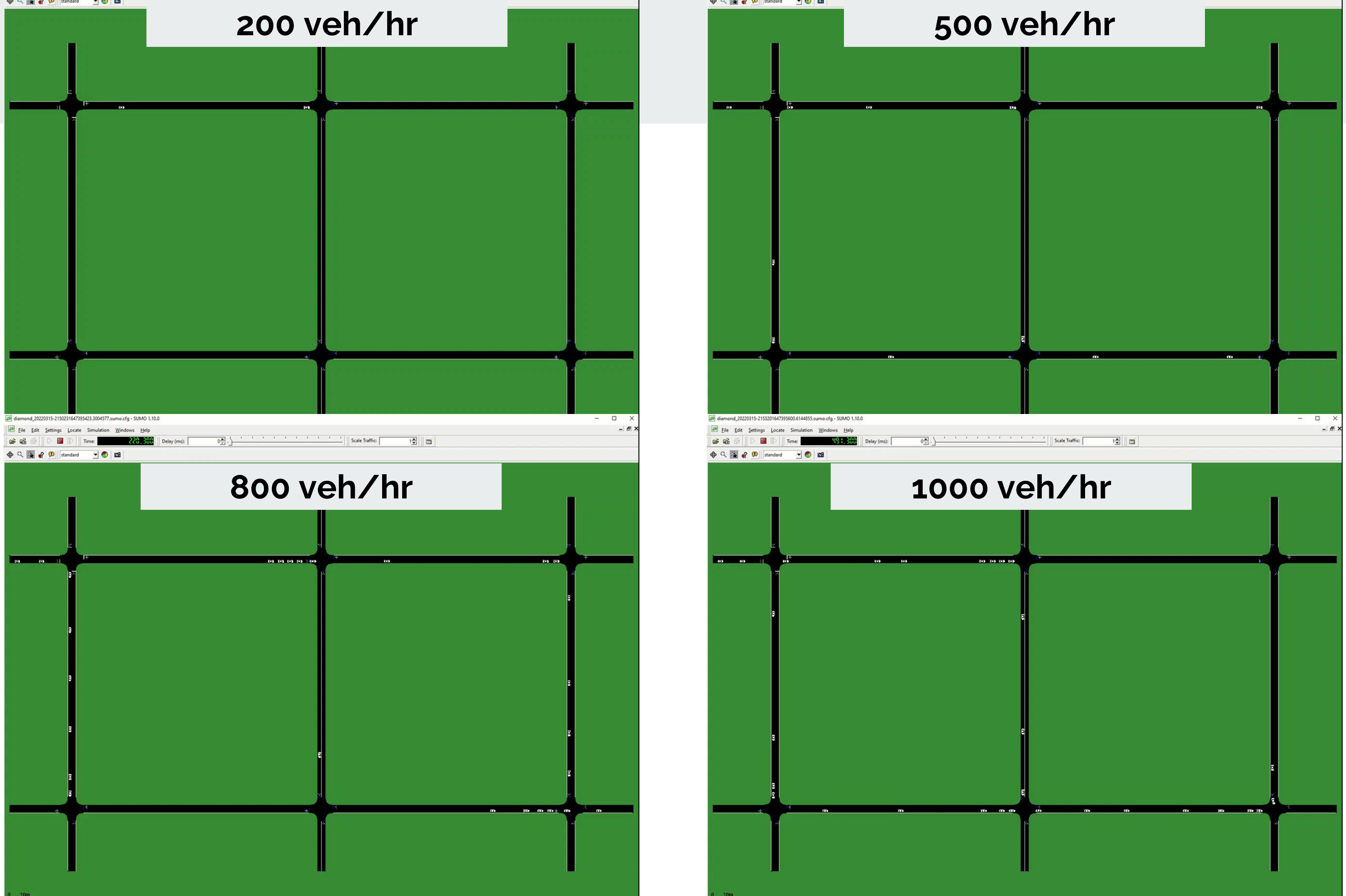


Travel Times Comparison



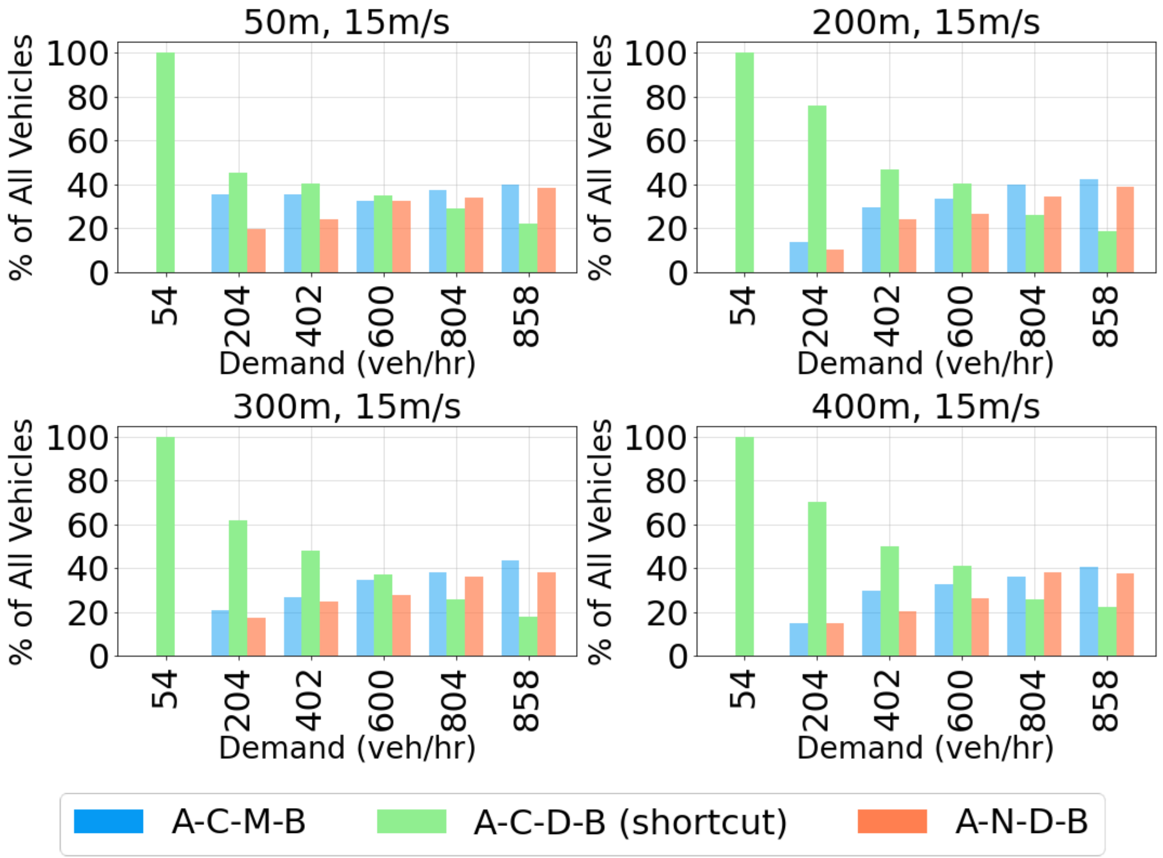
The added path

- Improves average travel time at lower demand level
- Worsens average travel time at higher demand level
- The appearance of the “critical point” seems to show linearity with edge length and demand level


200 veh/hr
500 veh/hr
800 veh/hr
1000 veh/hr

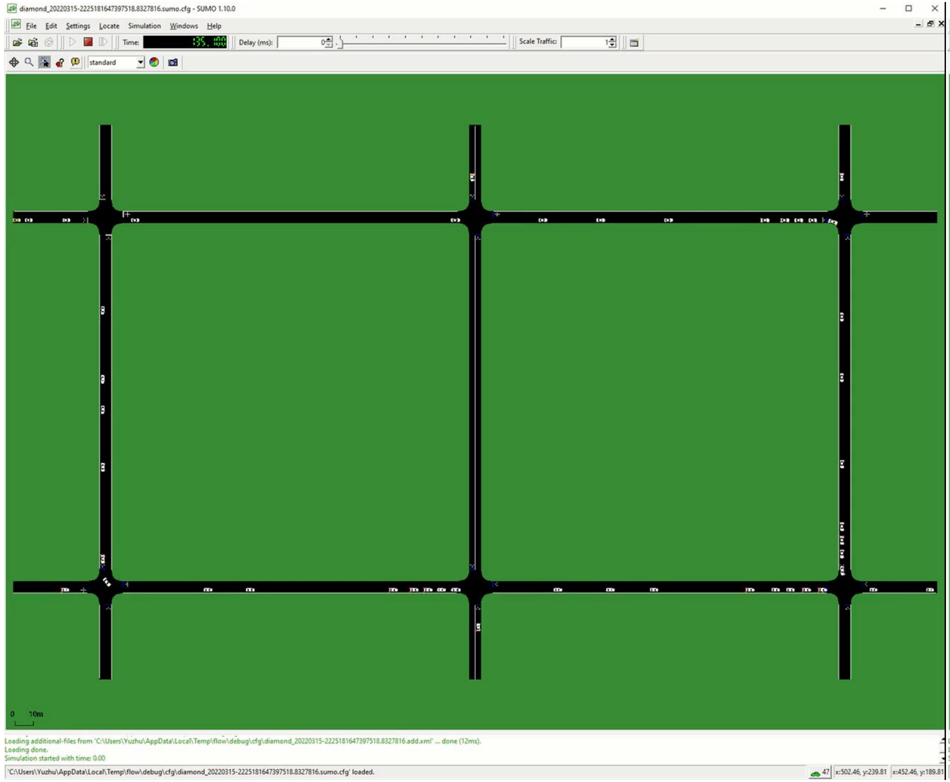
Percentage of Vehicles Using Each Route

Percentage of vehicles using the shortcut route decreases as demand level increases

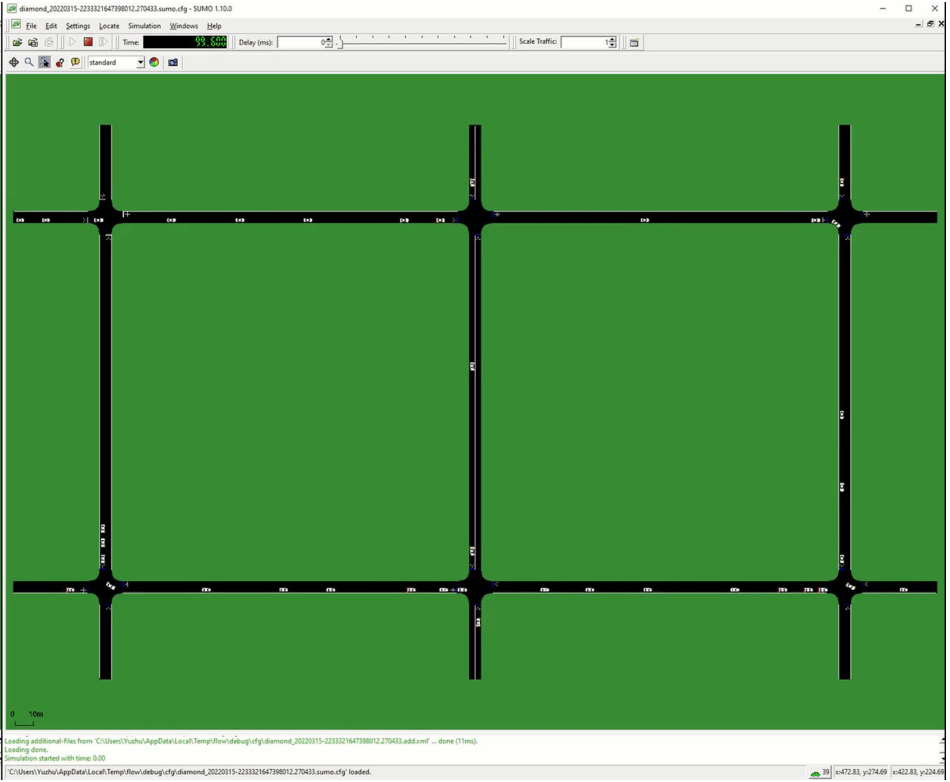


Network Capacity

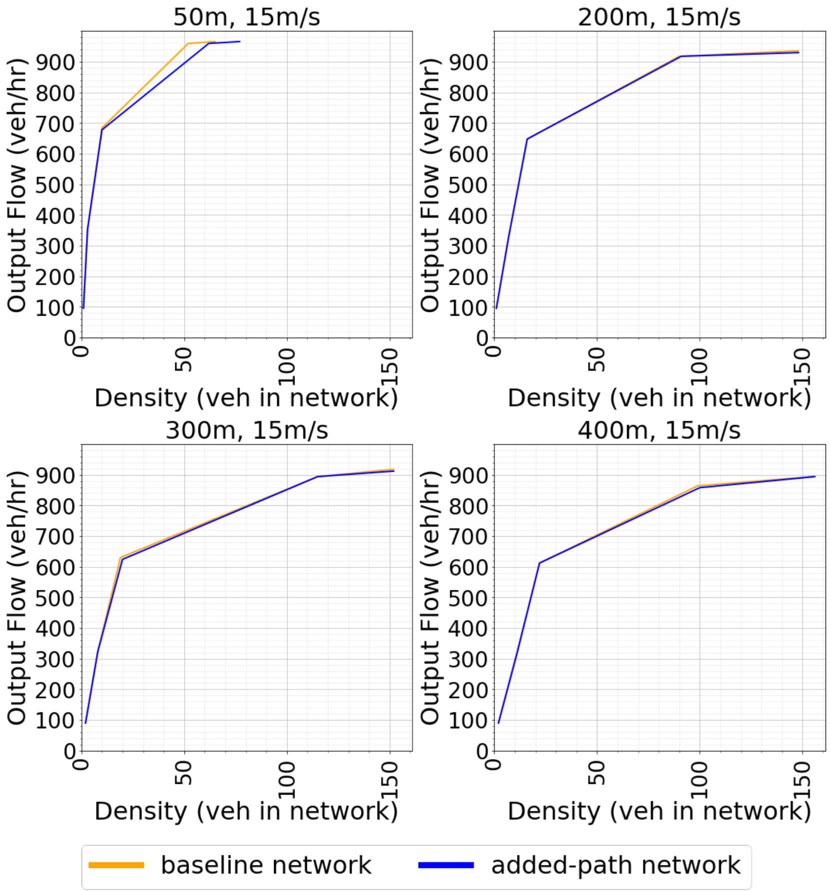
Baseline Network w/ additional inflow 1000 veh/hr



Added-Path Network w/ additional inflow 1000 veh/hr



Network Capacity



Conclusion

Adding a path to the grid network

- Does not increase network output flow
- Improves travel time when demand level is low
- Worsens travel time when demand level is high
- Does not improve operational capacity of the network

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Future Work

- Conduct sensitivity analysis on the design of users' travel cost function
- Generalize how real-world traffic networks might suffer from the BP;
- Explore how different traffic control strategies could potentially mitigate the Braess's Paradox

Thank you!

Dingyi Zhuang: dingyi@mit.edu

Yuzhu Huang: yuzhuh@mit.edu