A Deeper Look at the Impact of Driving Automation on Freeway Performance

The Case of the QEW in the Greater Toronto Area

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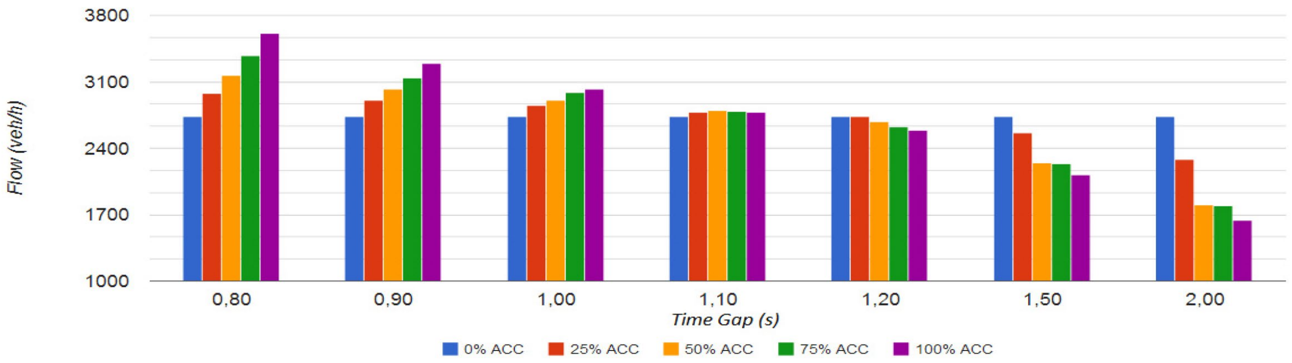
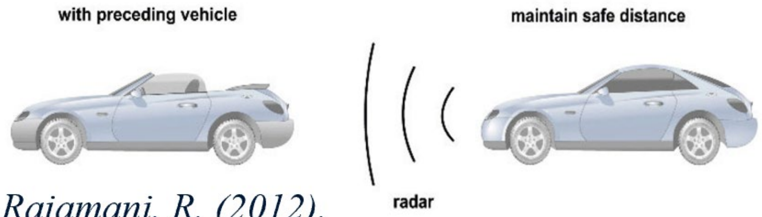
Our Main Question:

-- Vehicle Automation and Connectivity impact on Traffic

Can Smart Vehicles Lead to Dumb Traffic?



Ntousakis et al., 2015



Rajamani, R. (2012).

Freeway Control and Management with VACs

-- *Vehicle Automation and Connectivity Related*

What and Why VACs Traffic Management - Value

- ✓ Freeways largest road assets in large cities
- ✓ Performance and capacity limited by human driving (~2000 vphpl)
- ✓ Always congested in rush hours worldwide, capacity further drops by 10-20%during peaks, doubling time spent in congestion
- ✓ Freeway physical expansion is often highly constrained by tight space and budget
- ✓ Driving automation and VACs emerging rapidly and can potentially cut down delays be half or more without road expansion if properly exploited.
- ✓ Need innovative methods to control traffic while exploiting pervasive connectivity and automation, without expanding the road itself

Technical Challenges and Opportunities

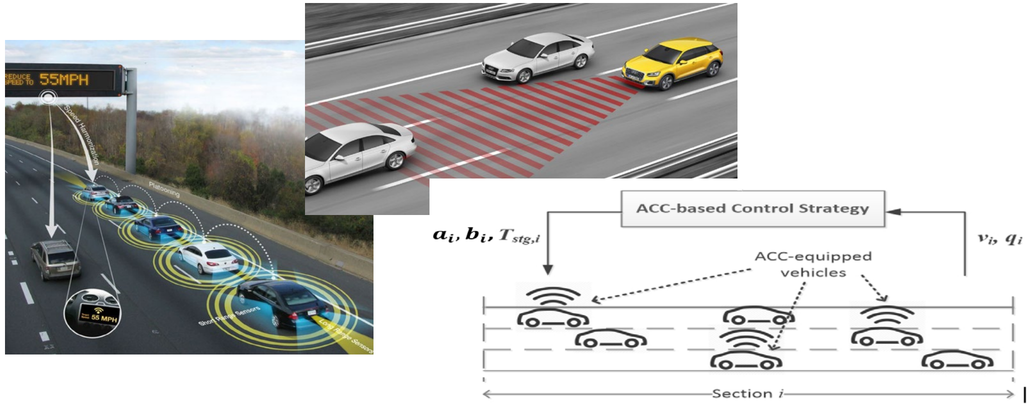
- ➢ Smart cars can lead to dump traffic and exacerbate congestion
- ➢ New intelligent control methods that exploit VACs: Open area of research
- ➢ Recent AI and Deep Learning advances are very promising
- ➢ Advances in v2i communication (DSRC, 5G), Smart Edge and Cloud Computing, together with AI, offer opportunity for 21st Century traffic management

Freeway Control and Management with VACs

-- *Vehicle Automation and Connectivity Related*

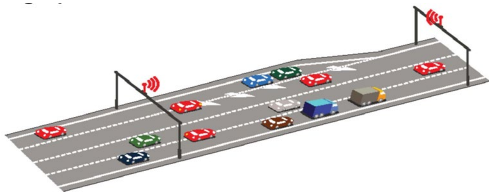
How – Possible Approaches

- ✓ Adaptive Cruise Control (ACC): headway and acceleration optimisation
- ✓ Dynamic Speed Adaptation (DSA), combined with Ramp Control
- ✓ Multi-agent control of headway and speed, via infrastructure-2-vehicle commands



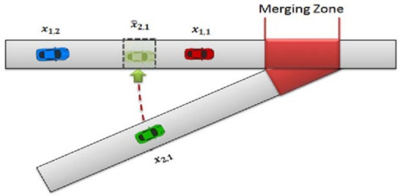
Potential Achievements

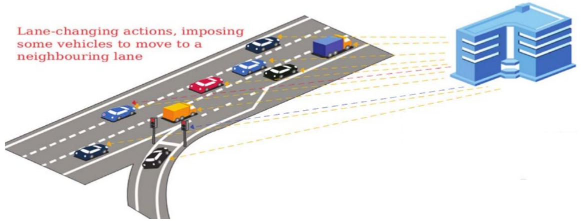
- ✓ Potential for more than 50% reduction in delays time spent in congestion
- ✓ Significant enhancement in safety and reduction in accidents



Steps

- ✓ 1. Quantify impact of automation on freeway performance
- ✓ 2. Develop control systems (headway, speed, and ramp Control)





The Impact of Adaptive Cruise Control on Traffic Operation

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June 3, 2020

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Outline: What are the research questions?

- **Step (1): Quantification**
  - **Q1**: What is the impact of desired headways of ACC-equipped vehicles on freeway performance (speeds, delay and throughput)?
  - **Q2**: What is the impact of reaction time of ACC-equipped vehicles on freeway performance?
  - A deeper look into results:
    - **Q3**: How does the headway distribution look like and how it relates to throughput?
    - **Q4**: Do target headways materialize?
      - On uninterrupted freeway (no bottlenecks, on-ramps, etc.)
      - On a realistic urban freeway with bottlenecks and ramps.
    - **Q5**: If target headways don't materialize, is there still an impact on performance?
    - **Q6**: What is the impact of traffic demand and prevailing congestion levels on the materialized headways?
  - Conclusions and insights
- **Next step: Exploitation** (Dynamic headway control)

Step (1): Dynamic Network Modeling with Automation (Quantification)

Literature review

- State-of-art of the VACS implications on the network performance.

Building the road network

- Aimsun Microscopic Simulator.
- Calibration using TTS 2016 data.

Modelling of ACC systems

- ACC models coded and embedded in Aimsun under various penetration rates.

ACC Quantification

- Analysis and quantification of the effects of the modelled ACC systems on the network performance.

Conclusions/Recommendations

- Conclusions and recommendations of the use of VACS.

Q1: What is the impact of desired headways of ACC-equipped vehicles on freeway performance?

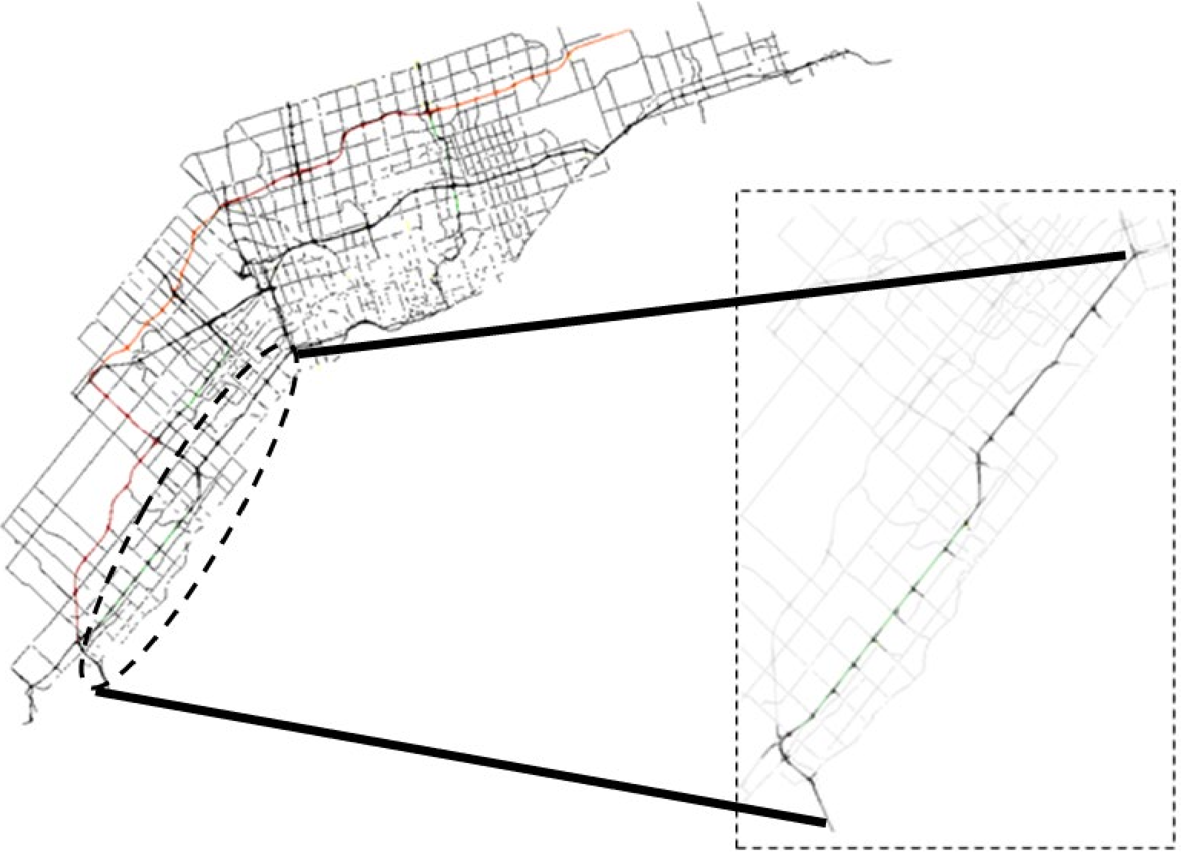
Step (1): Quantification

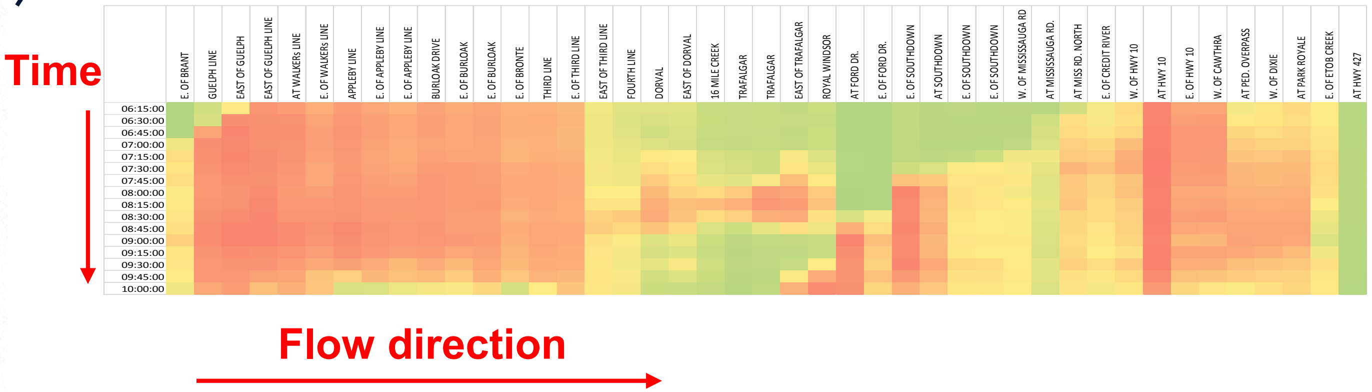
Assumptions:

- Gipps model for manually-driven vehicles (Aimsun default).
- IDM model for ACC equipped vehicles.
- Smaller reaction times for ACC equipped vehicles than that for manually-driven vehicles. (0.6 sec reaction time)
- Three headway scenarios considered: 0.8s, 2.0s and a range between 0.8-2.0s.
- Performance metrics: average delay, average speed, average throughput.

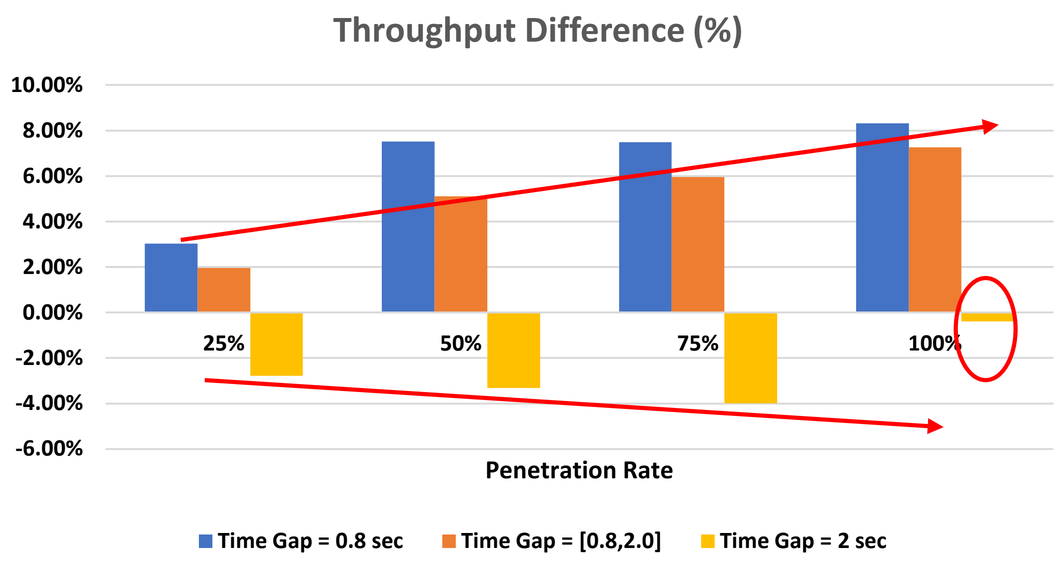
QEW subnetwork

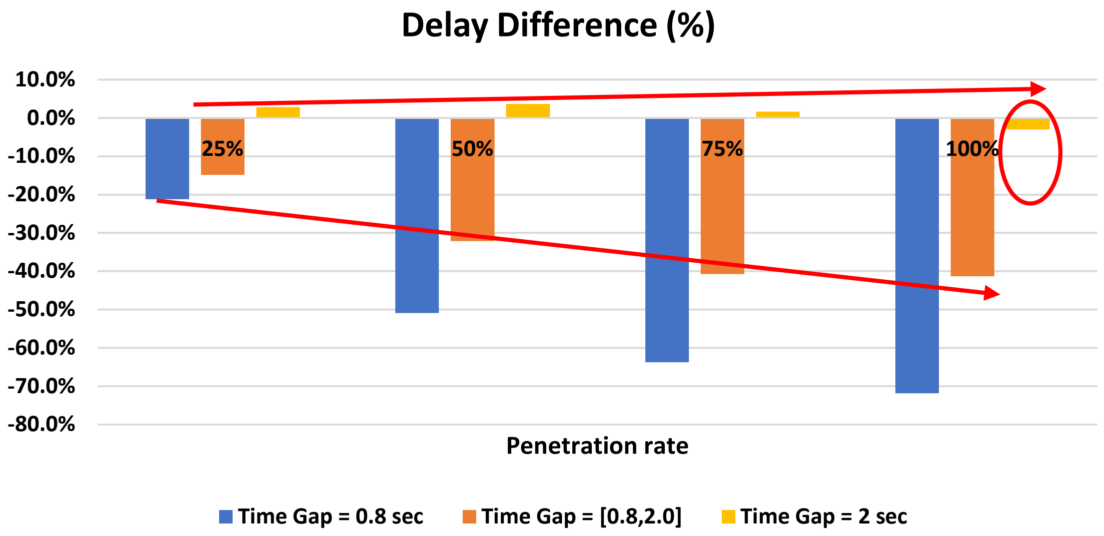
- Subnetwork of the GTA model: Extracted from a bigger Aimsun simulation model covering most of the GTA.
- Extending for about 45 km.

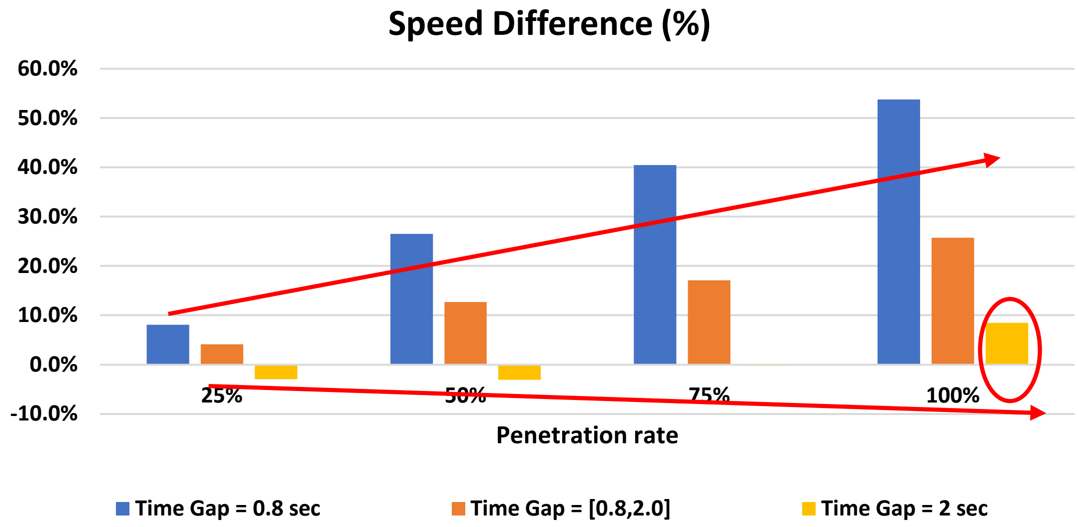




Performance Results: Impact of desired headways







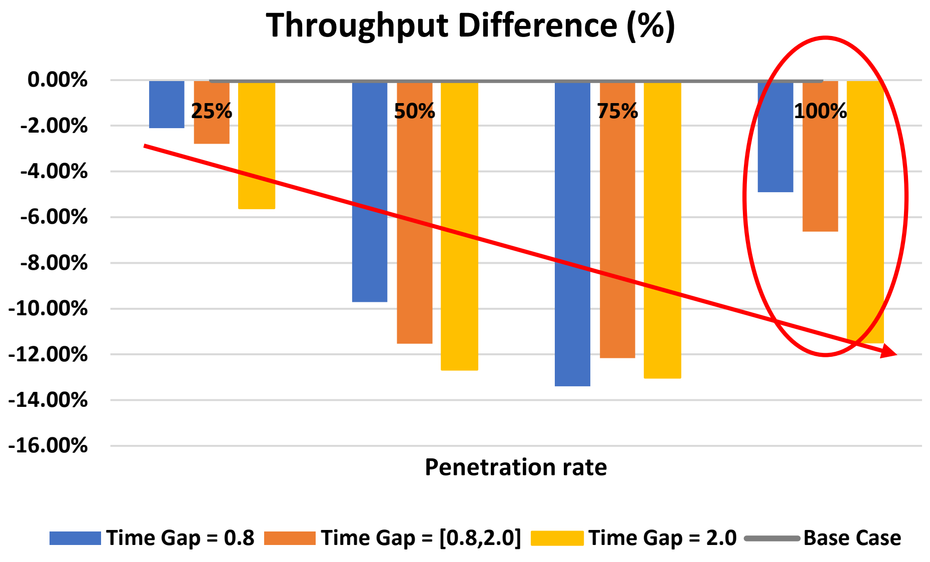
Q2: What is the impact of reaction time of ACC-equipped vehicles on freeway performance?

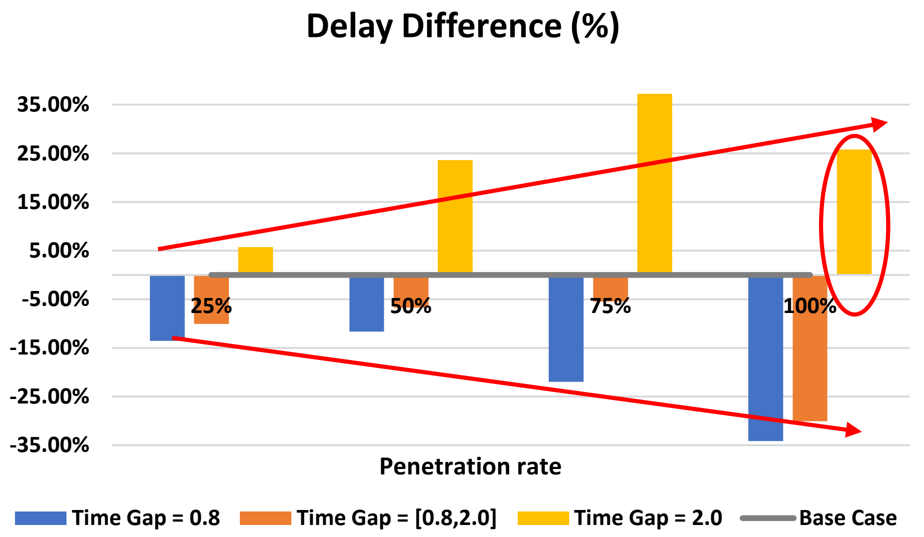
Step (1): Quantification

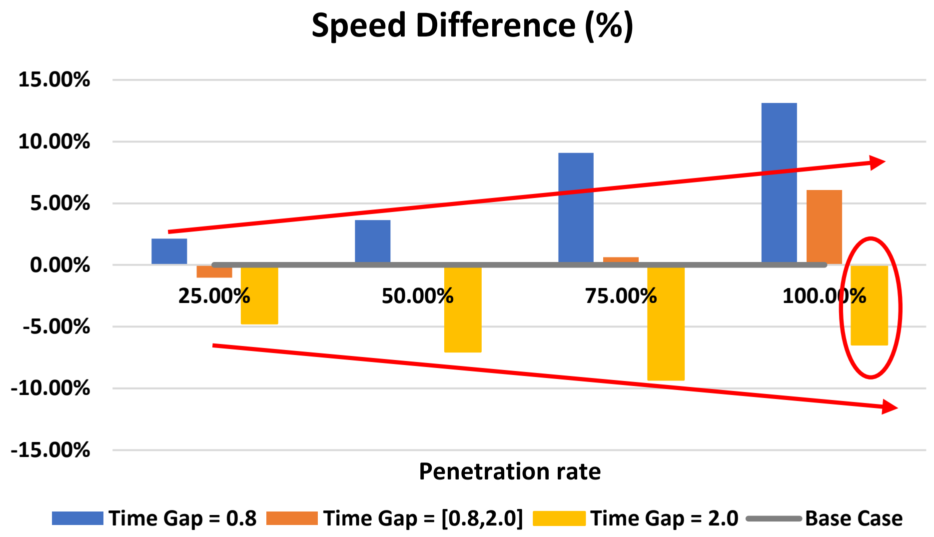
Assumptions

- Gipps model for manually-driven vehicles (Aimsun default).
- IDM model for ACC equipped vehicles.
- Reaction times of ACC equipped vehicles **equal to** reaction times of manually-driven vehicles. (1.2 sec reaction time)
  - Effect of reaction time increase/decrease.
  - Isolate impact of headway without impact of reaction time.
- Three headway scenarios considered: 0.8s, 2.0s and a range between 0.8-2.0s.
- Performance metrics: average delay, average speed, average throughput.

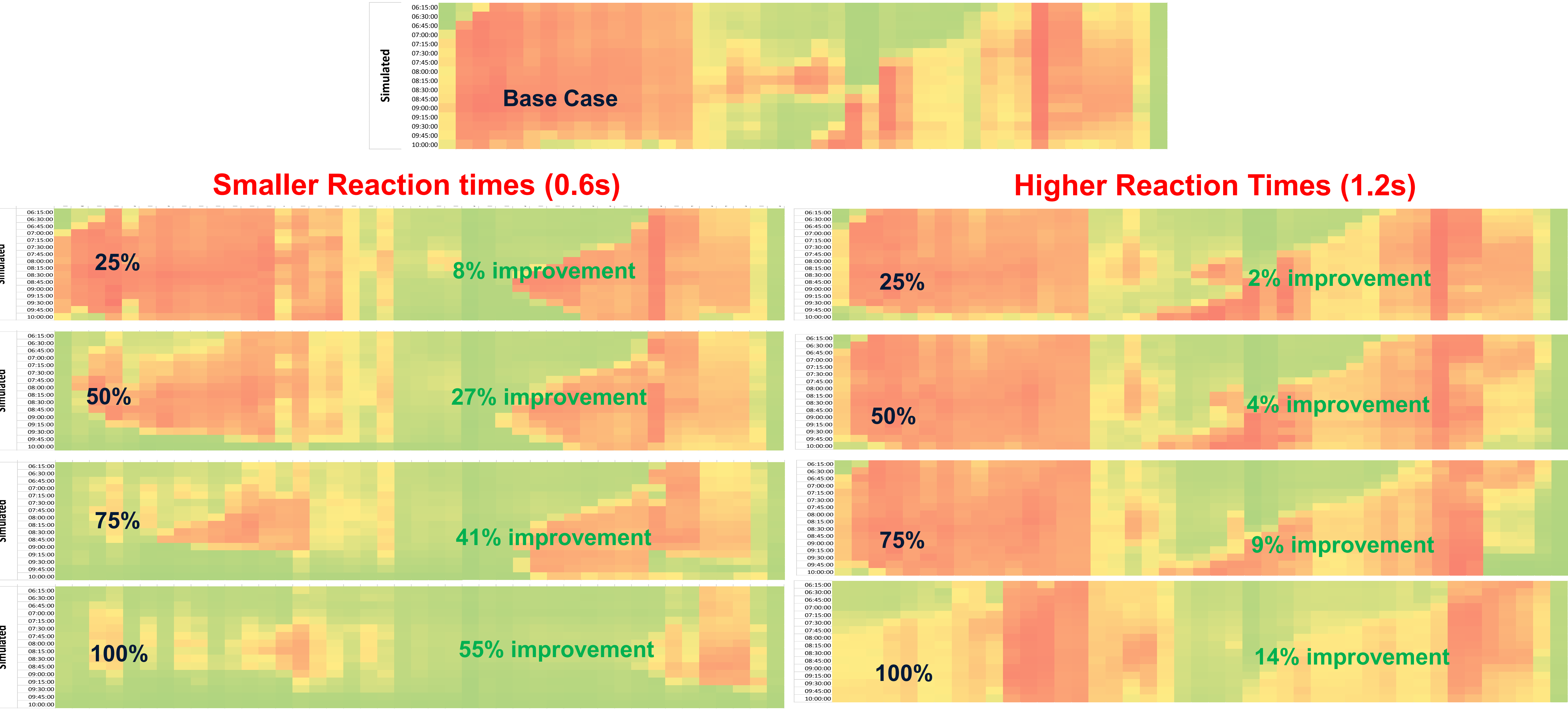
Performance Results: Impact of reaction time



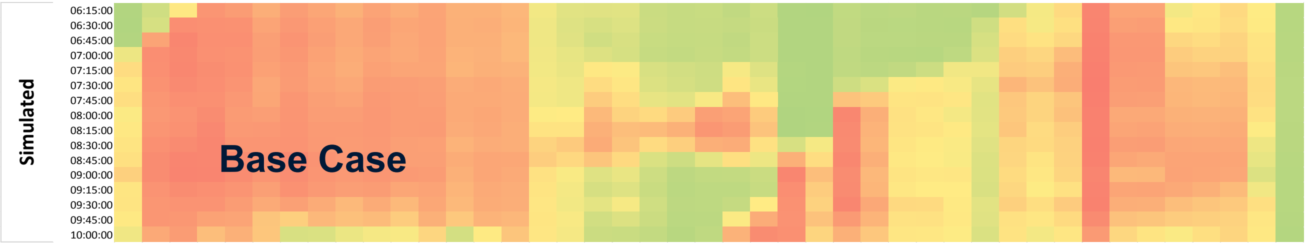




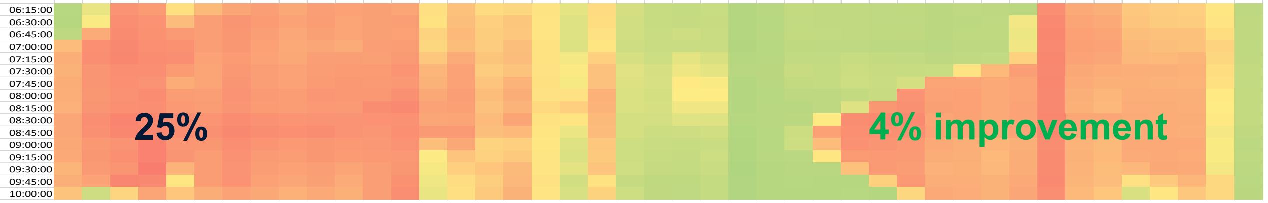
Speed Profiles – 0.8s Headway

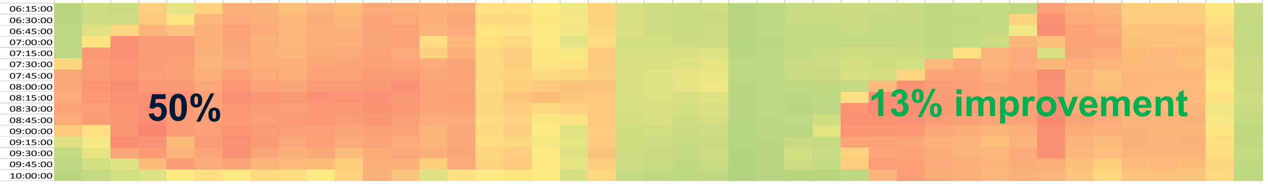


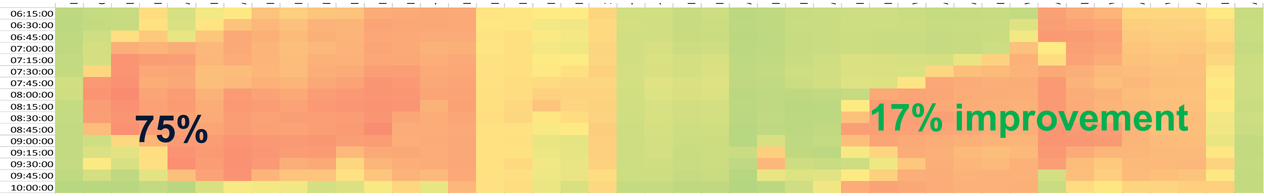
Speed Profiles – 0.8-2.0s Headway



Smaller Reaction times (0.6s)



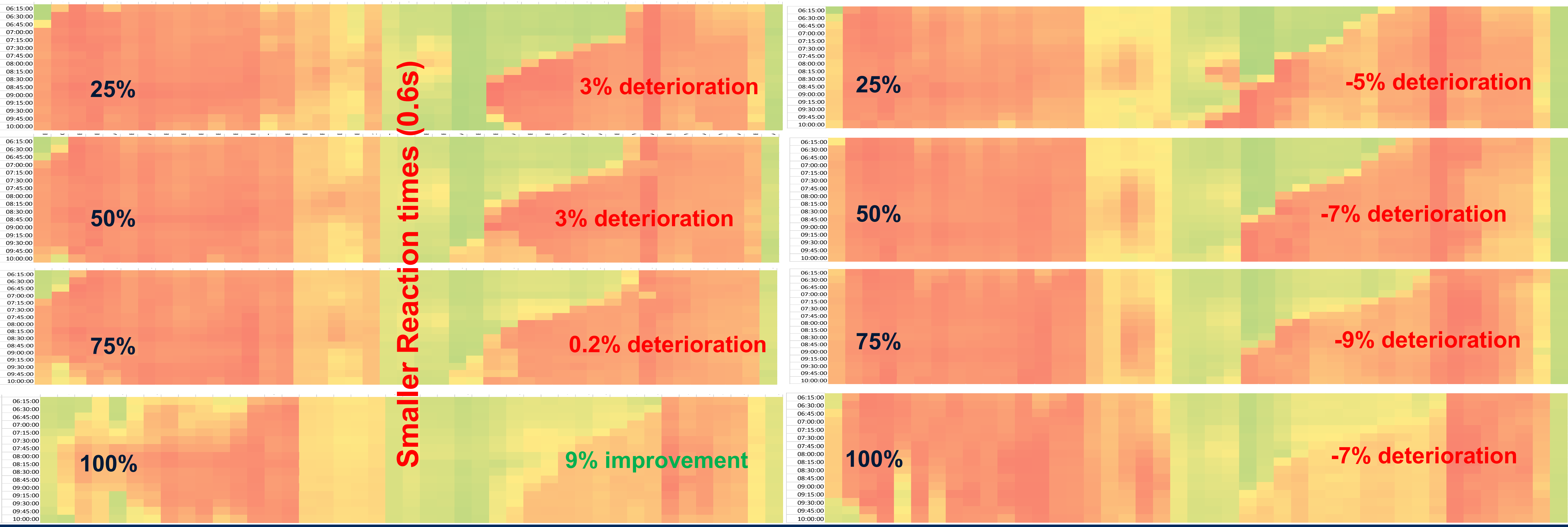




Higher Reaction Times (1.2s)

Speed Profiles – 2.0s Headway

Smaller Reaction times (0.6s) | **Higher Reaction Times (1.2s)**



Observations and Insights (1)

- Shorter headways lead to better performance.
  – For both reaction times scenarios considered.
  – Extent of improvement quantified as previously shown.

- Smaller reaction times lead to better performance.
  – Better prevailing traffic conditions → better speed profiles observed.
  – Performance improvement as penetration rate increases.

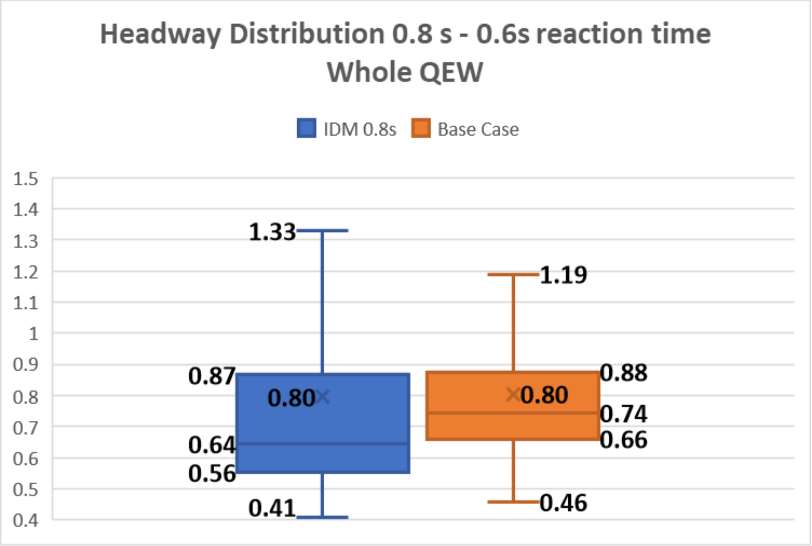
- Higher reaction times:
  – 0.8s and range headway:
    - Delay and Speed → improvement with penetration rate increase.
    - Throughput → decrease as penetration rate increase (gets better at 100%) → investigated next.
  – 2s headway:
    - Performance deterioration as penetration rate increase (gets better at 100%).

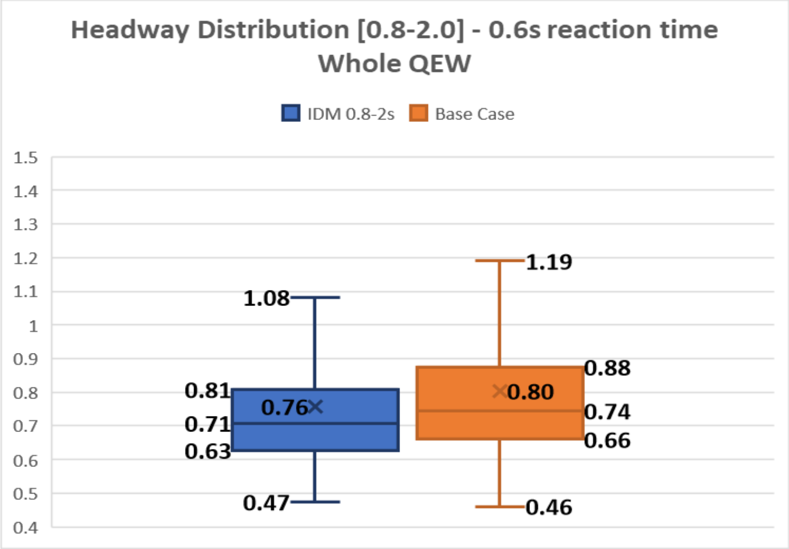
A deeper look into results

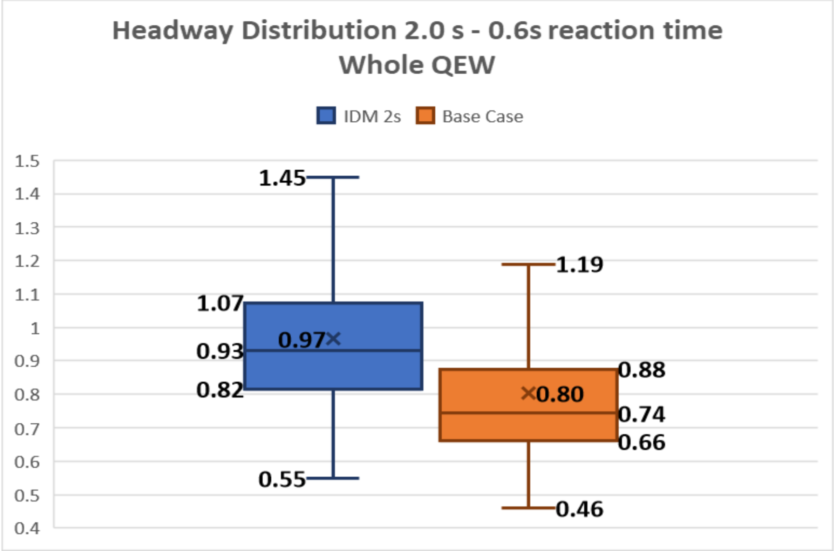
Q3: How does the headway distribution look like and how it relates to throughput?

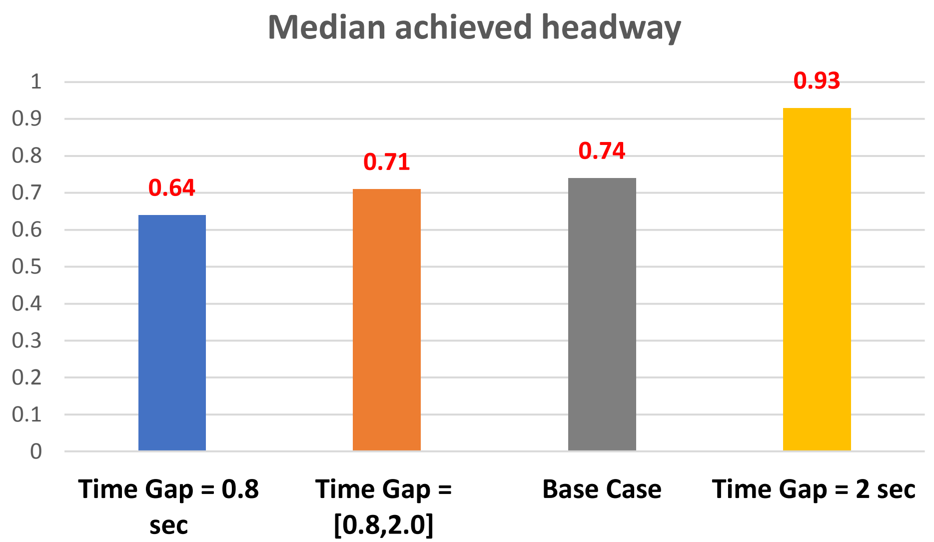
Q3: How does the headway distribution look like and how it relates to throughput?

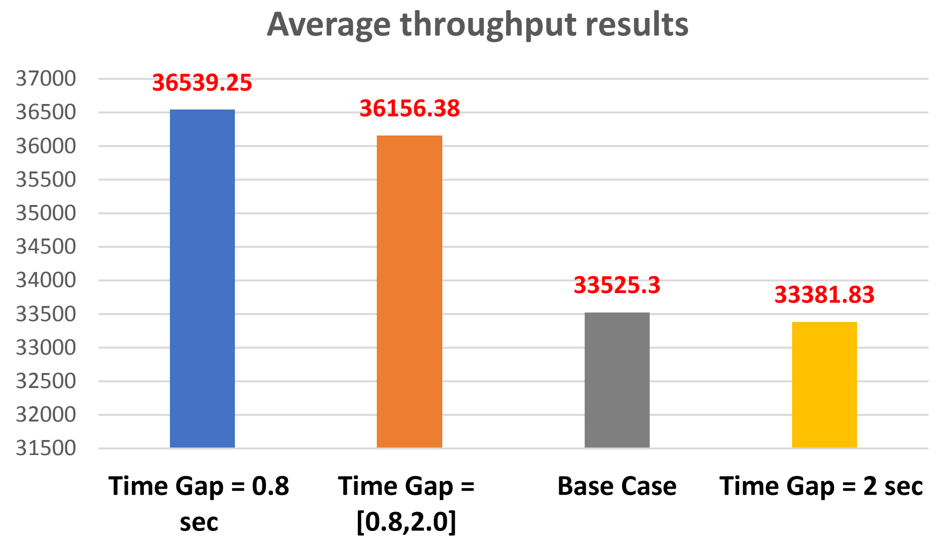
Headway distribution – 0.6s reaction time – 100% penetration





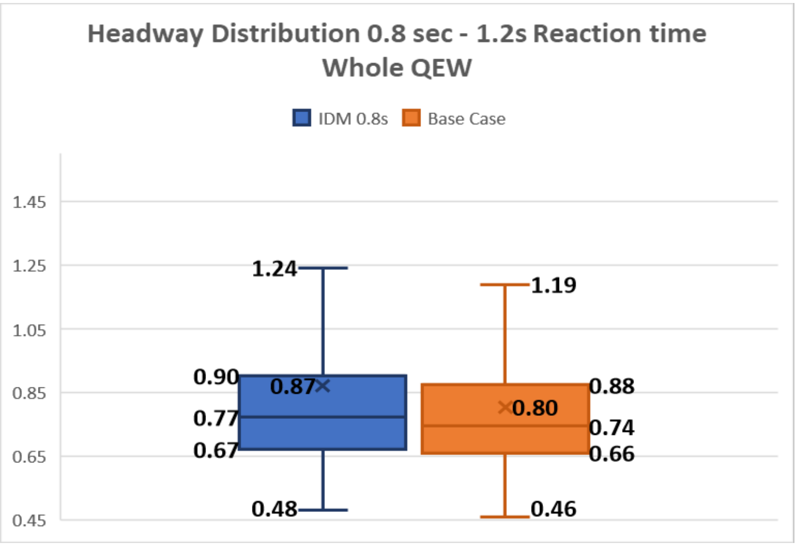


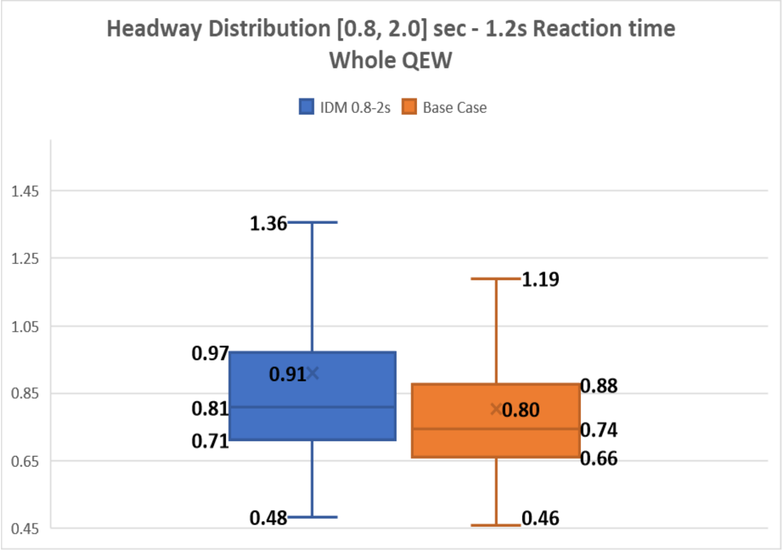


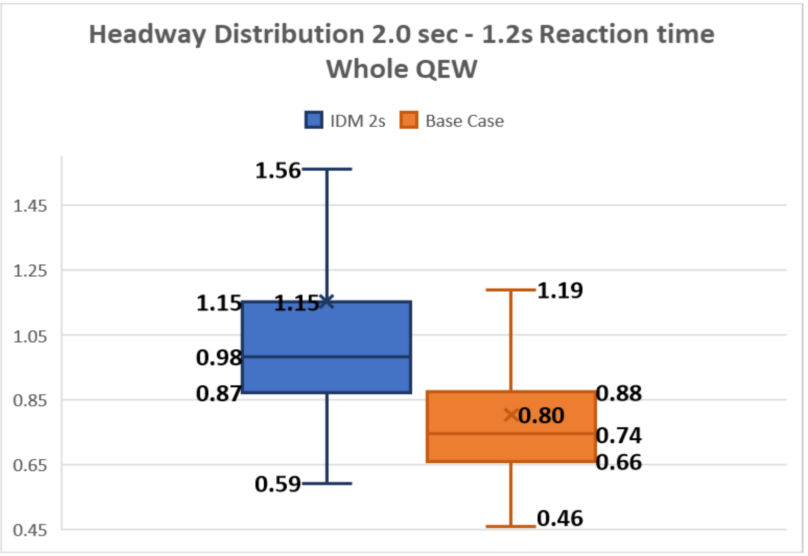


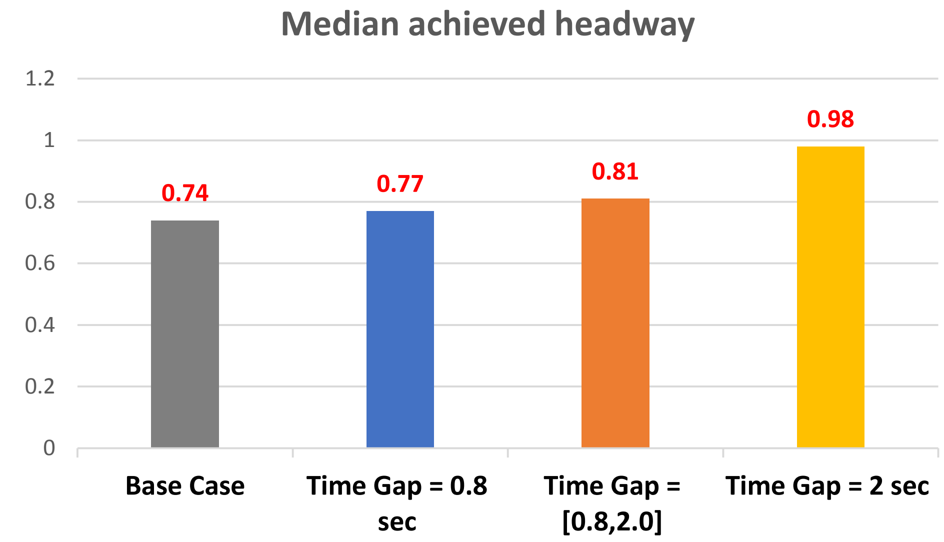
Q3: How does the headway distribution look like and how it relates to throughput?

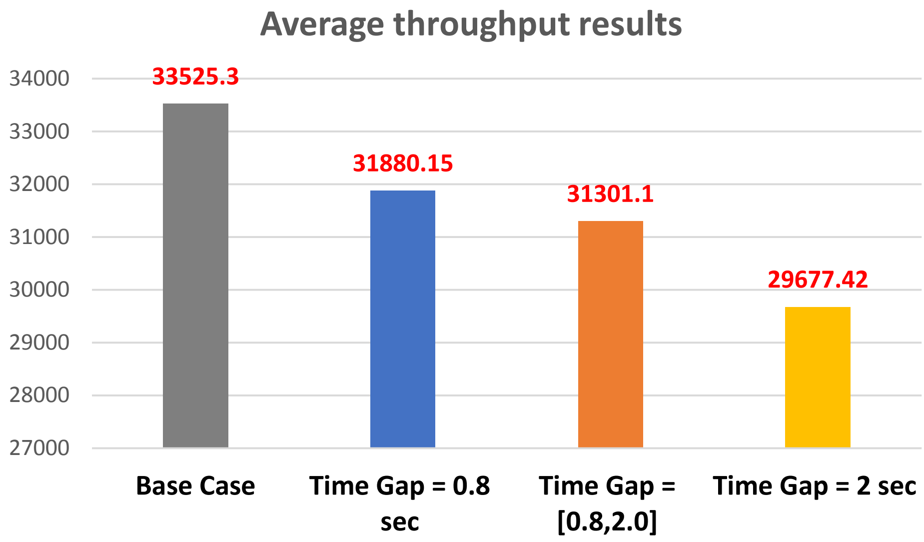
Headway distribution – 1.2s reaction time – 100% penetration











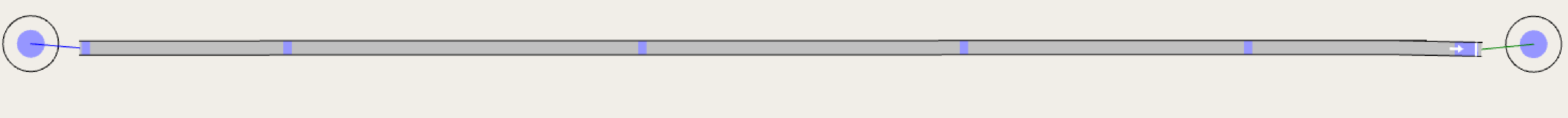
A deeper look into results

Q4: Why don't target headways materialize?
Under what conditions?

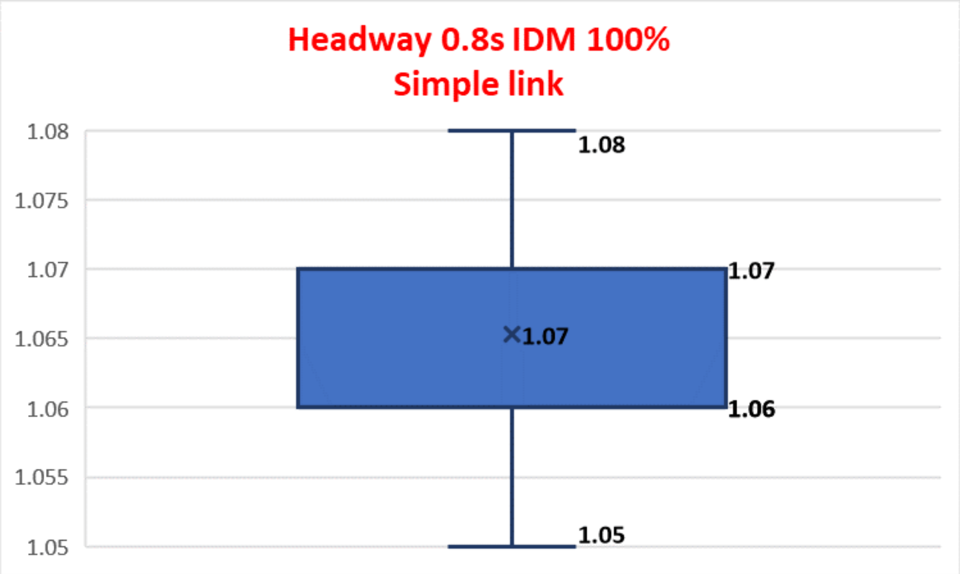
Q5: If target headways don't fully materialize, do they still impact performance?

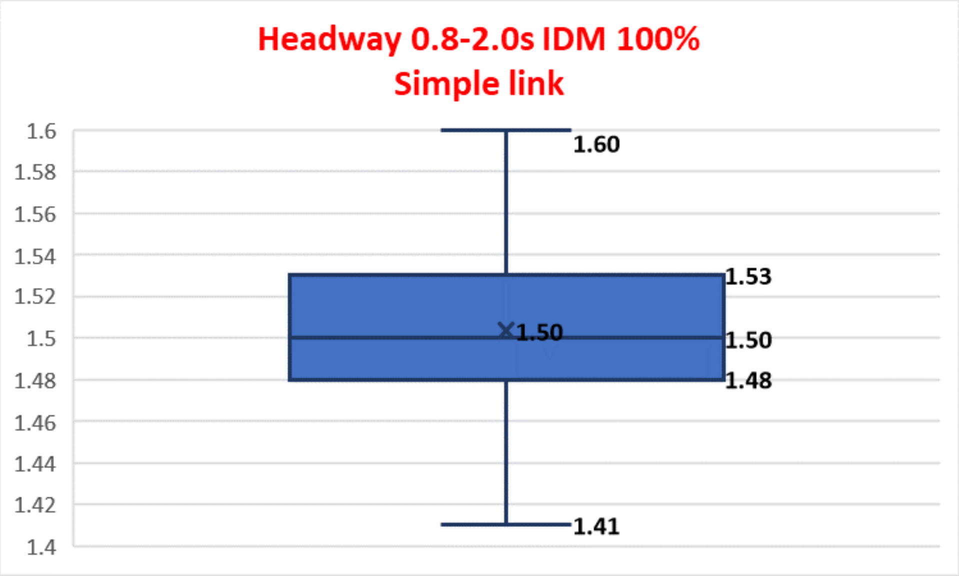
Simple Link

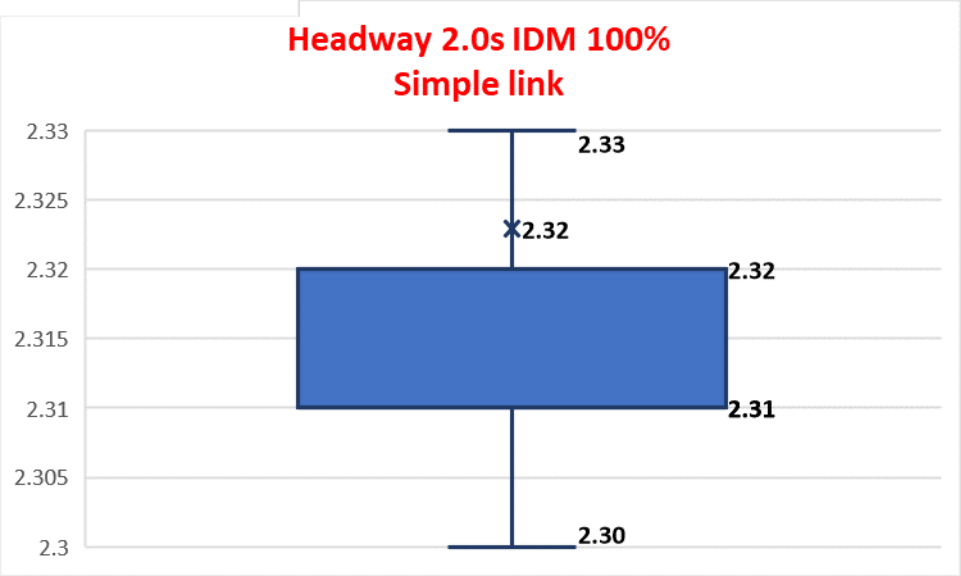
- Single-lane 5km stretch.
- No on-ramps or off-ramps
- For testing purposes.



Simple Link Headway distribution







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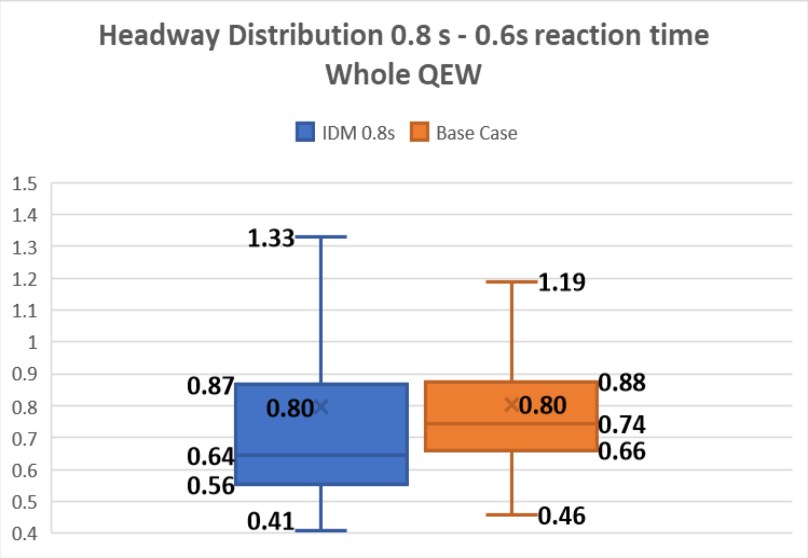
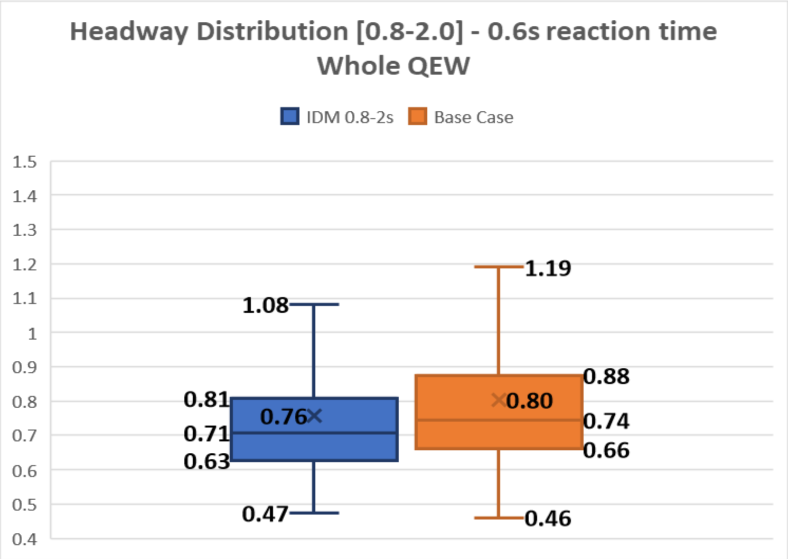
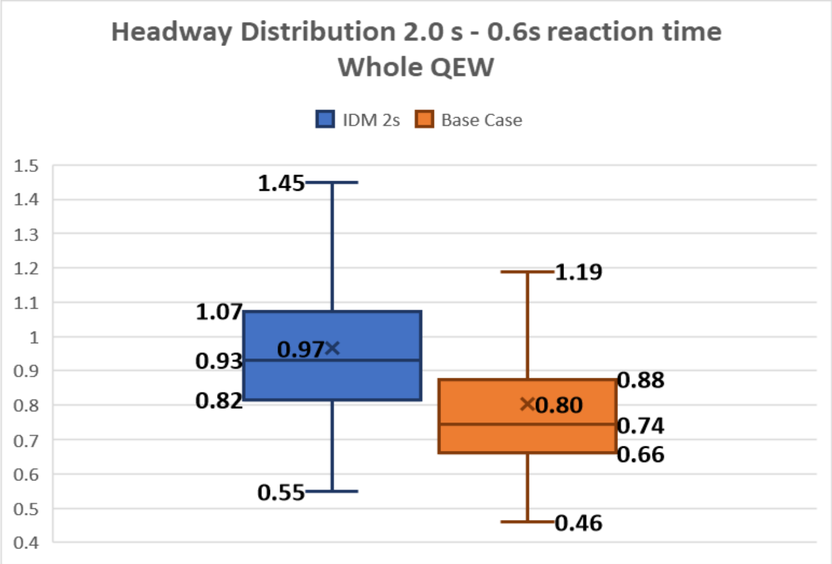
Full Congested Freeway

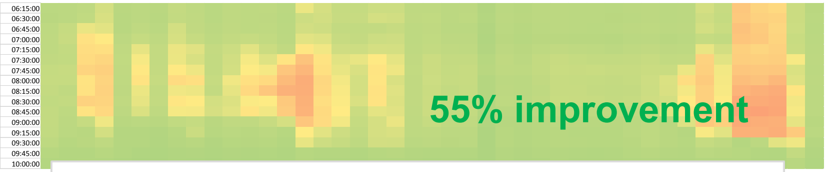
Q4: Why don't target headways materialize? Q5: Impact on performance?

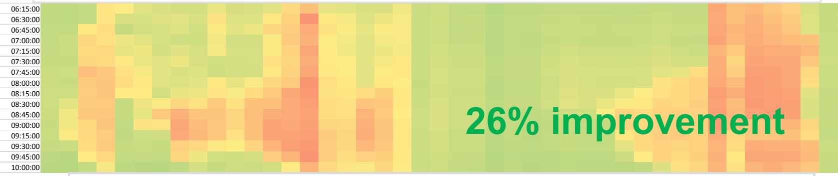
Headway distribution – 0.6s reaction time – 100% penetration

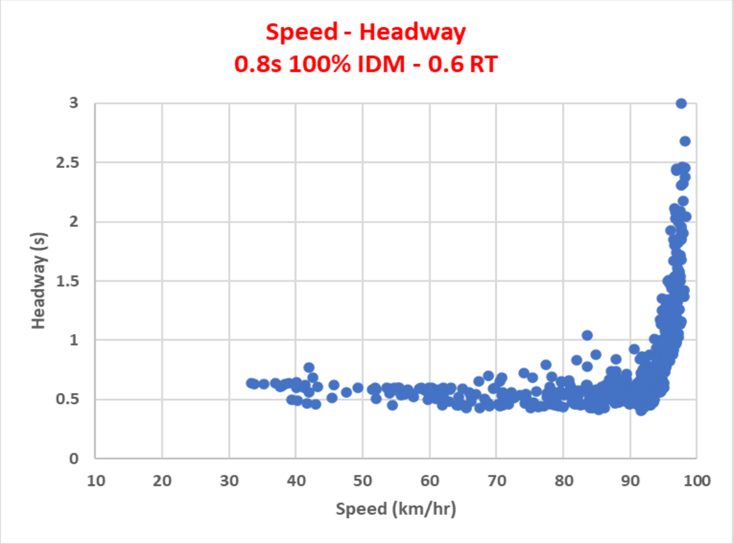


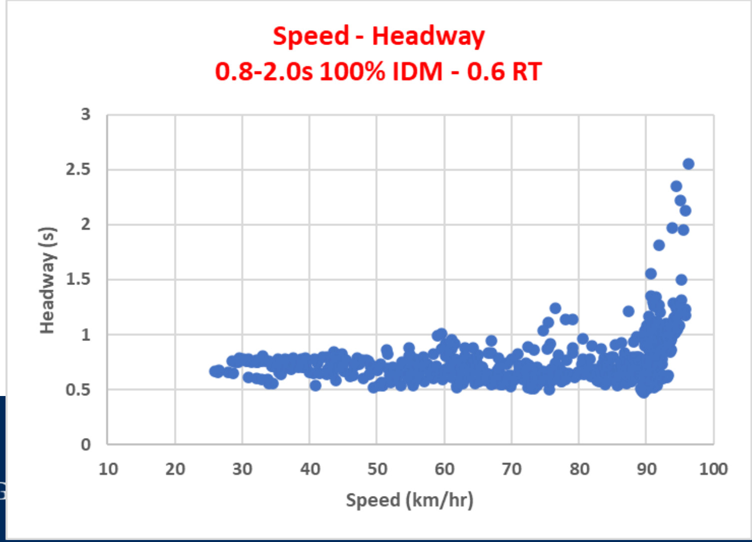


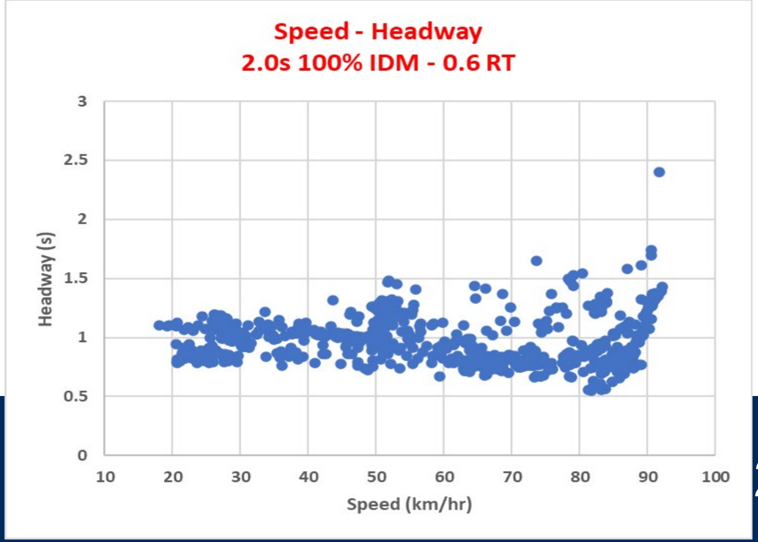












Observations and Insights (2)

- For small (0.6 sec) and high reaction time (1.2 sec) scenarios:
  - Throughput results are inline with the headway distribution results.
- On a simple link: target headways materialize.
- On full congested freeways:
  - Longer target headways don't materialize because of congestion + many back-to-back bottlenecks + on-ramps and off-ramps.
  - To be investigated next.

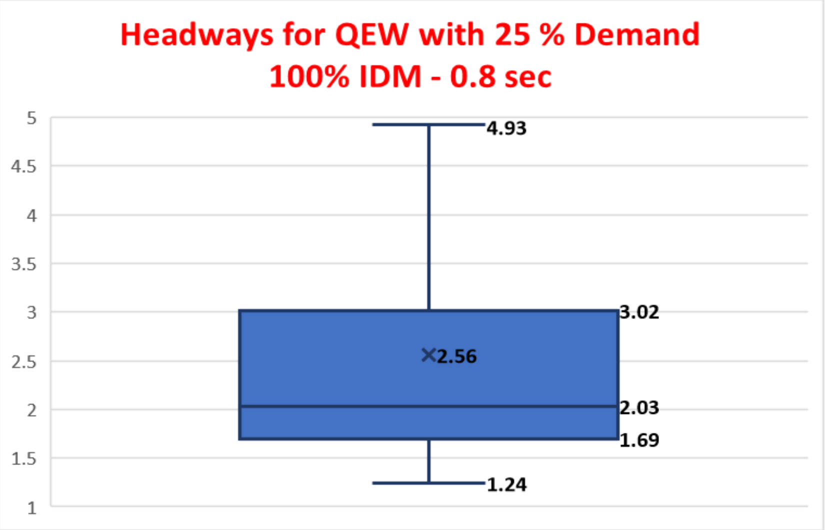
Full Uncongested Freeway

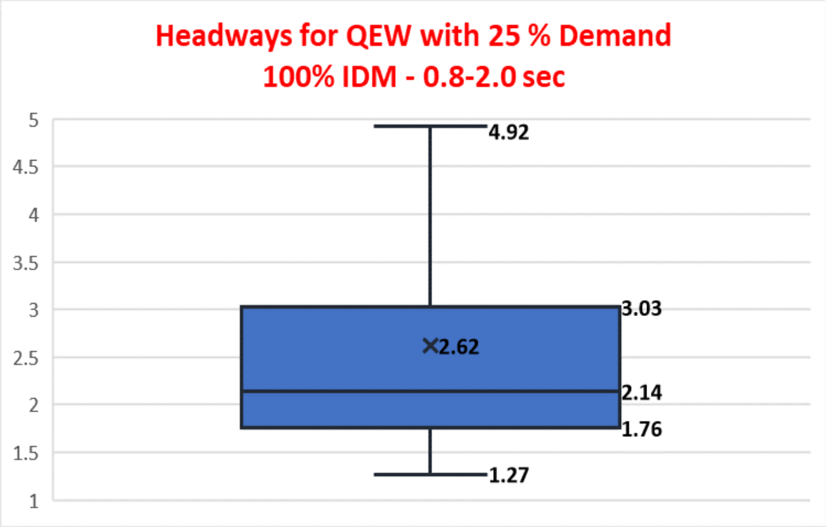
(Light Demand)

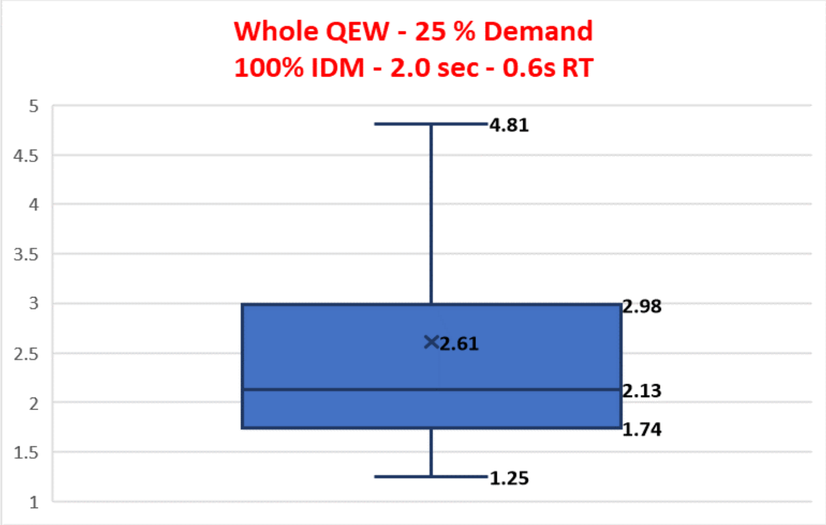
Q6: Impact of demand and prevailing congestion conditions.

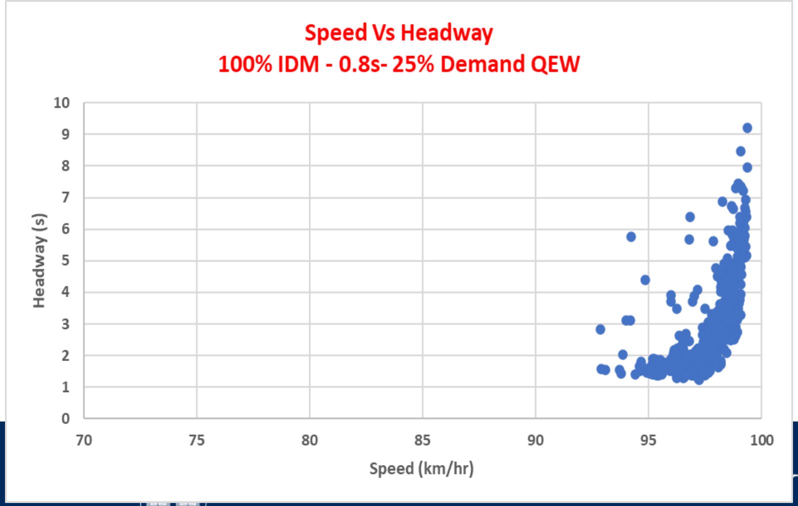
Q6: Impact of demand and prevailing congestion conditions

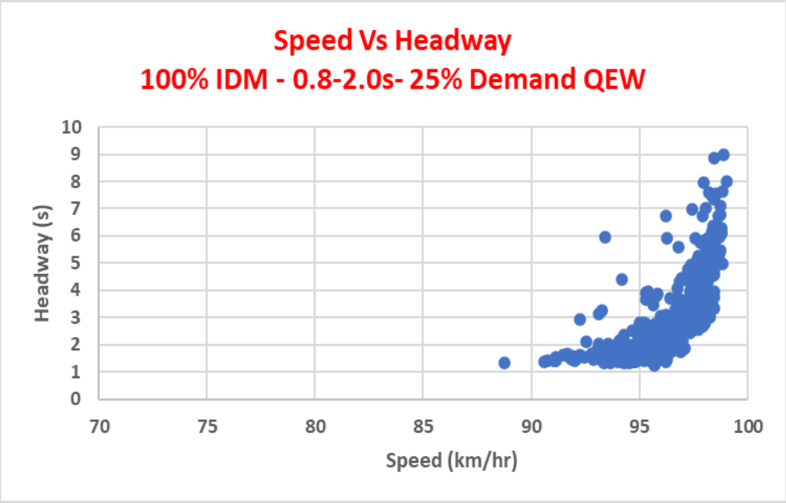
Headway Distribution- 25% Demand – 0.6s reaction time – 100% penetration

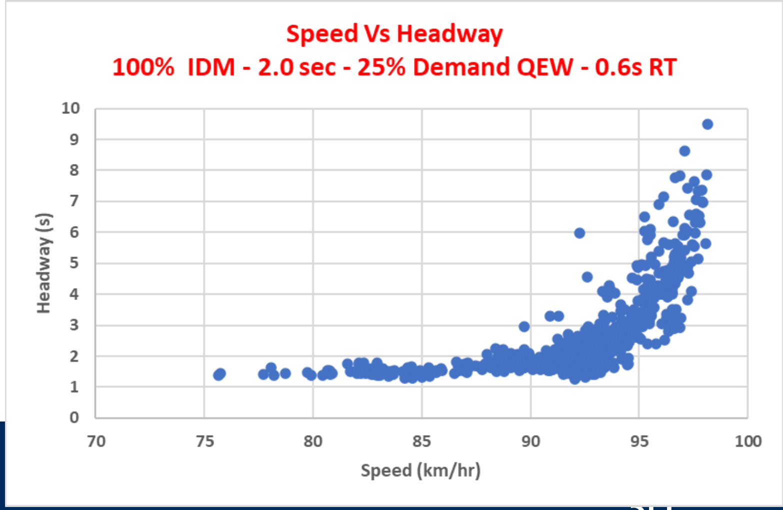






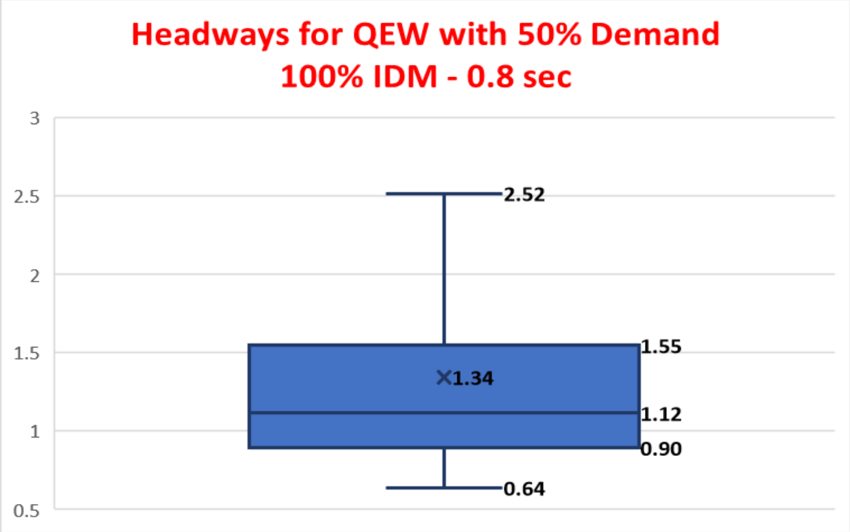


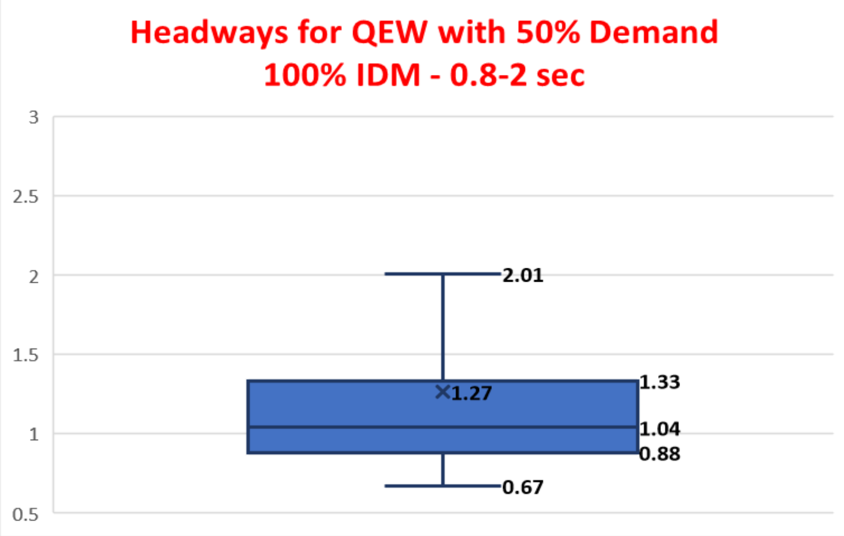


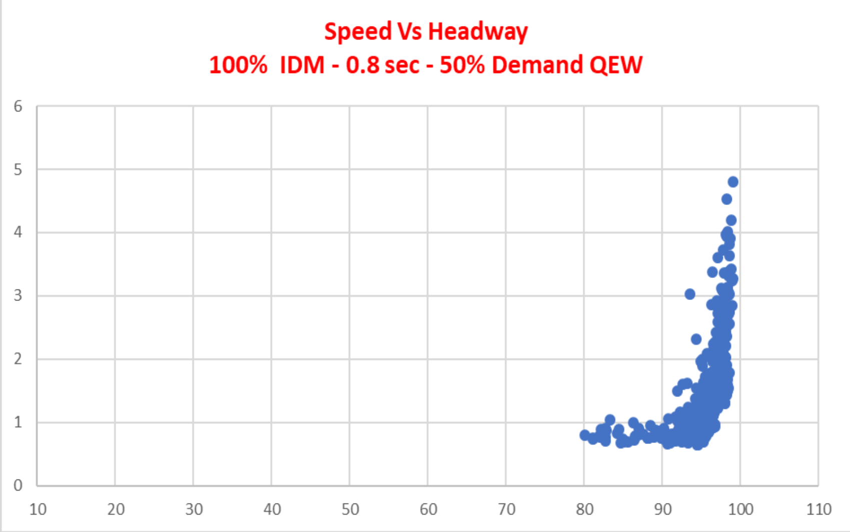


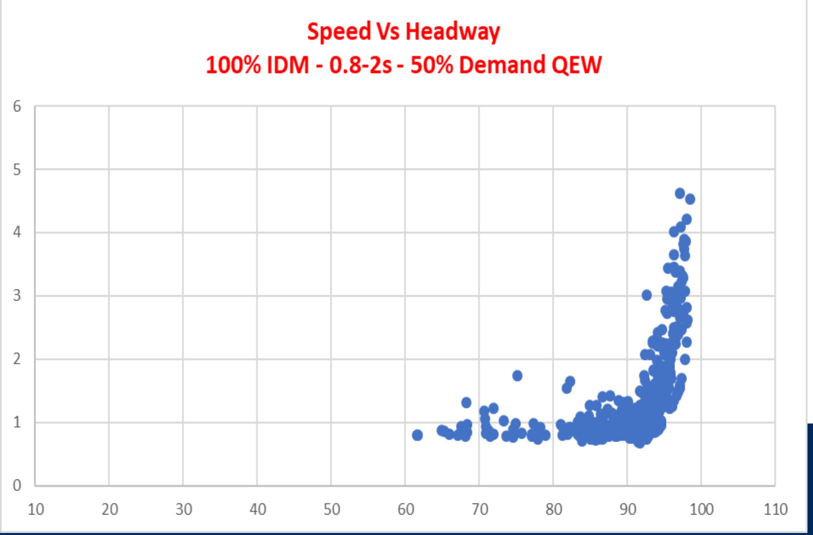
Q6: Impact of demand and prevailing congestion conditions

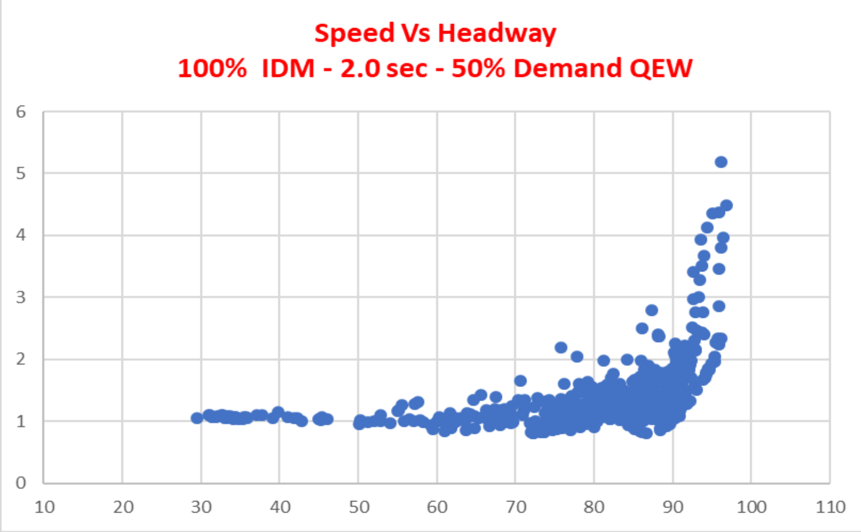
Headway Distribution- 50% Demand – 0.6s reaction time – 100% penetration











Observations and Insights (3)

- On full uncongested freeways:
  - Better chance to achieve long target headways.
  - Short target headways do not materialize (cars not in car-following mode).

- Regardless of the materialized headway:
  - Shorter headways lead to better performance.
  - Longer headways lead to worse performance.
  - Shorter reaction times lead to better performance.
    - The extent of performance improvement/deterioration depends on prevailing traffic conditions (demand)

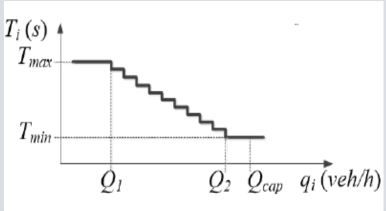
Summary: What has been addressed?

- ✓ Impact of desired headways of ACC-equipped vehicles.
- ✓ Impact of reaction times of ACC-equipped vehicles.
- ✓ Headway and throughput results are inline with each other.
- ✓ Headway distribution on a test link (simple link).
- ✓ Headway distribution on a congested freeway.
- ✓ Headway distribution on an uncongested freeway.

Next Steps: ACC Exploitation

Control and Exploitation of ACC

- Implement base case control (ACC exploitation).
  - On small stretch.
  - On whole QEW network.



Conclusions/Recommendations

- List limitations, insights and recommendations based on results.
- Benchmark for control strategy incorporating AI/DRL.

DRL control - Literature review

- ACC/Headway/longitudinal control.

Conceptualizing DRL approach

- Identify recommended methodologies and system architecture.

Q&A

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