# Determining Region of Influence of Ego-Vehicle on Roadways for Vehicle Decision Making

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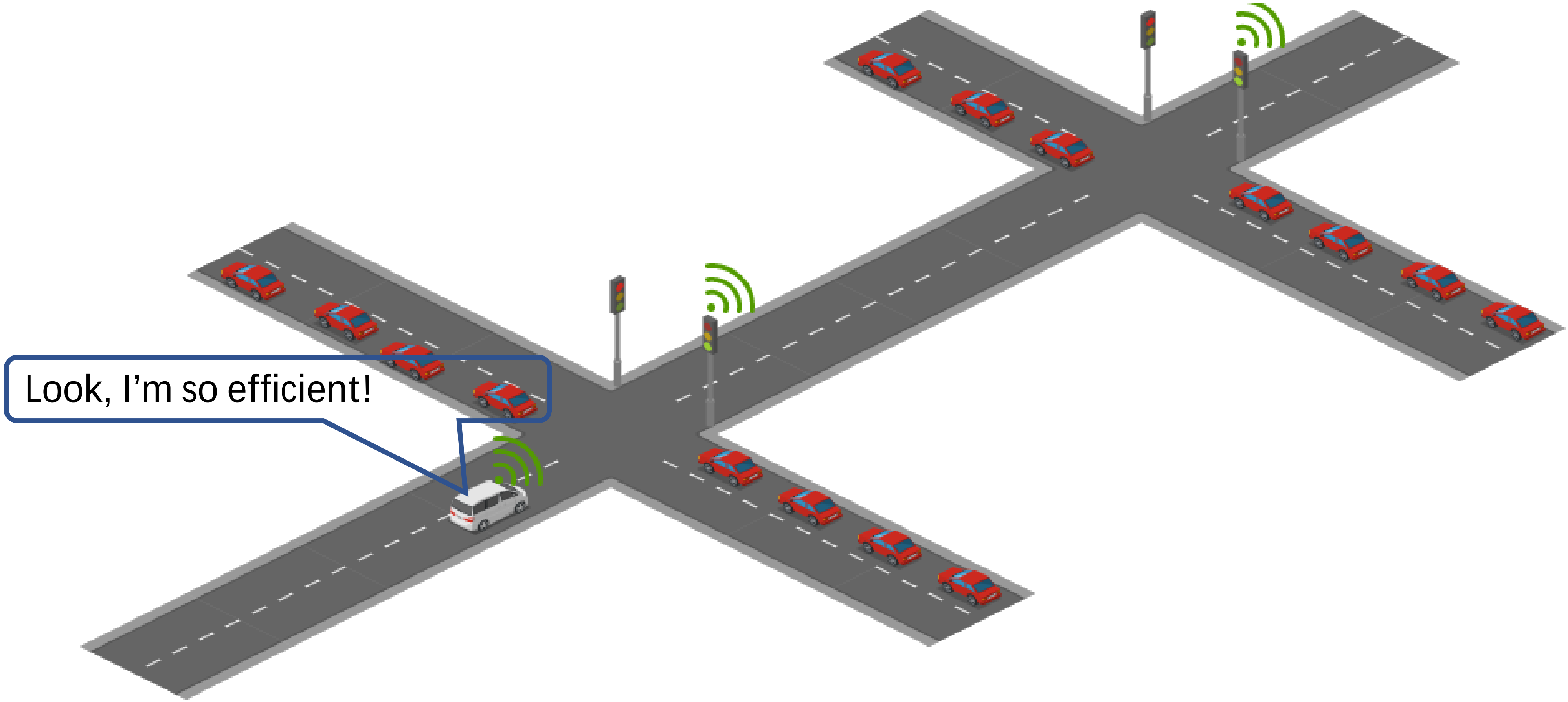
Figure from: Kan Z, Qiang Z, Haojun Y, Long Z, Lu H, Chatzimisios P (2015) Reliable and efficient autonomous driving: the need for heterogeneous vehicular networks. Commun Mag IEEE 53:72–79

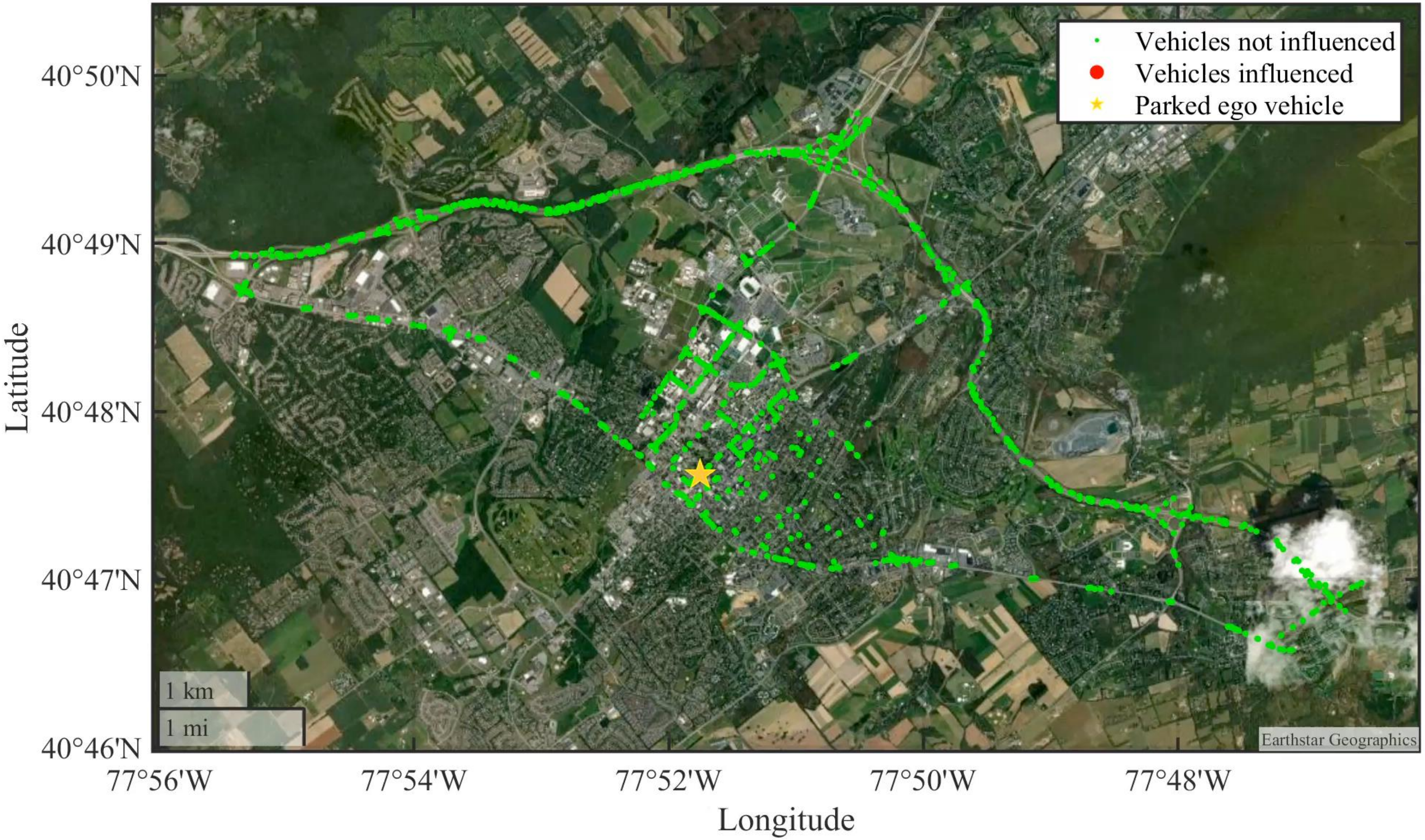
Connected and Autonomous Vehicles (CAVs) are an emerging and highly impactful technology on today's roads, with the **claimed** advantages of improved fuel economy, decreased congestion and improved safety etc.

# But the ego vehicle affects other vehicles and may decrease their performance.




One CAV might pass a smart traffic light while causing congestion in other roads.

Assessment of the vehicle's impacts on surrounding traffic is important, possibly even more important than the improvements enabled on the CAV itself. But what boundary, or factors, defines the vehicles, equipment, etc. "surrounding" a CAV?



# The process of simulation flows as below:

Run baseline simulations

Trajectories →

Run perturbed simulations

Trajectories →

Compare trajectories of traffic surrounding the ego vehicle

Difference in trajectories →

Evaluate the difference using following metrics:

- Vehicle trajectories
- Euclidian distance of each vehicle and its rate of change
- Total number of lane changes over the whole simulation VS. time
- Total number of lane changes over the whole simulation VS. surrounding vehicles' distance to the ego vehicle

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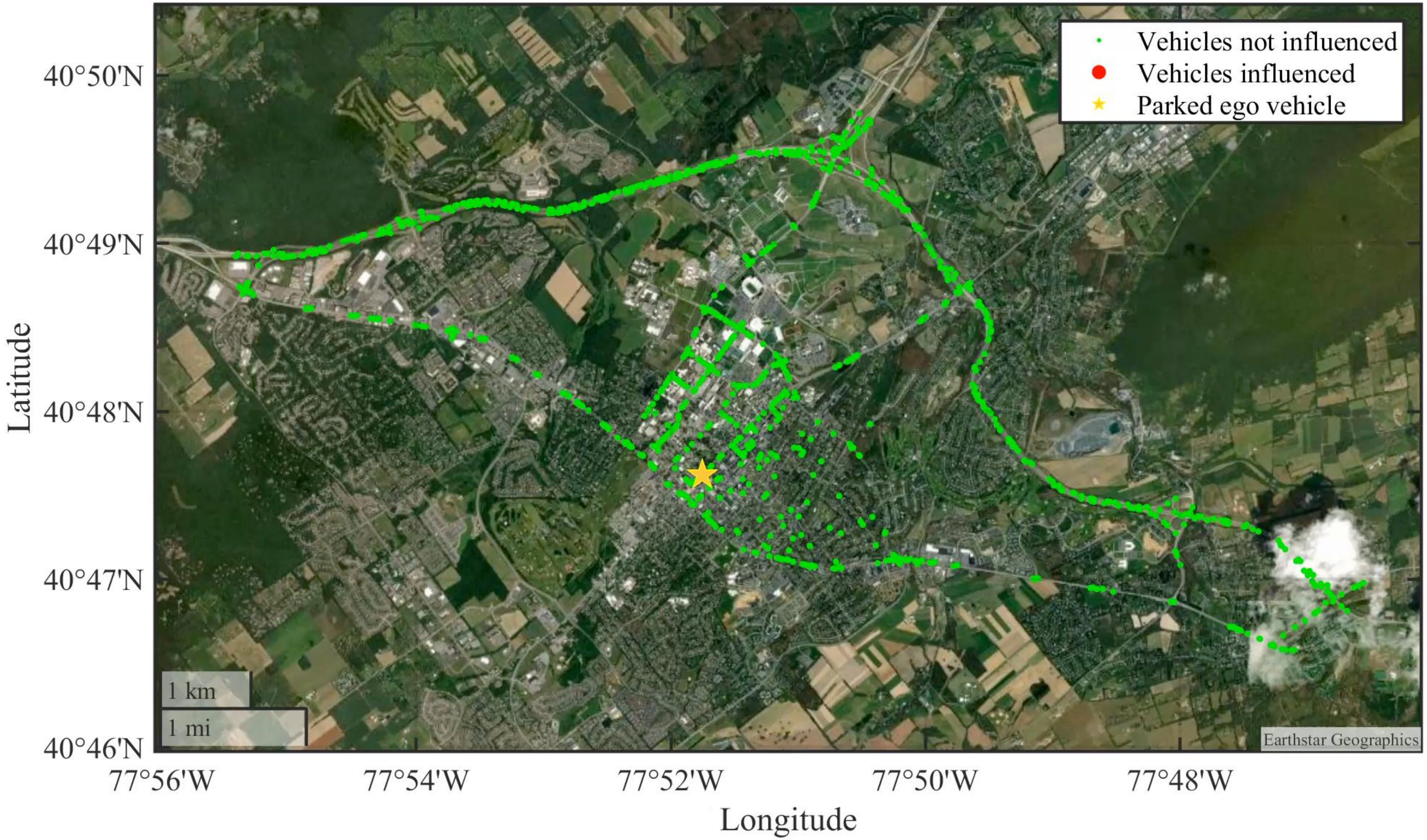


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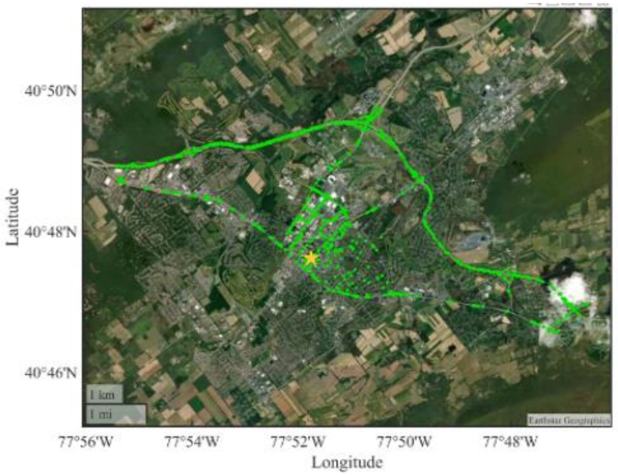
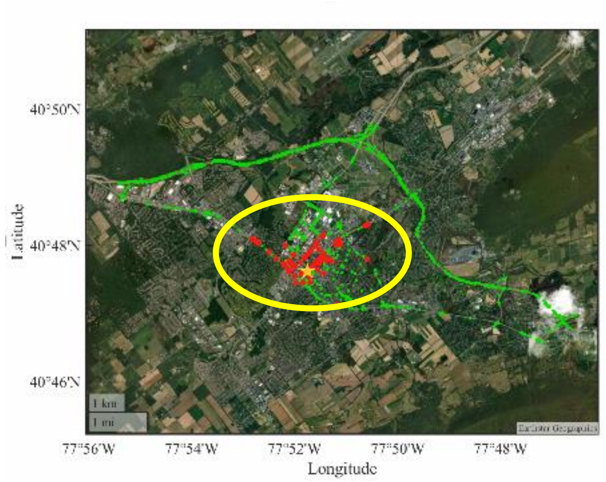
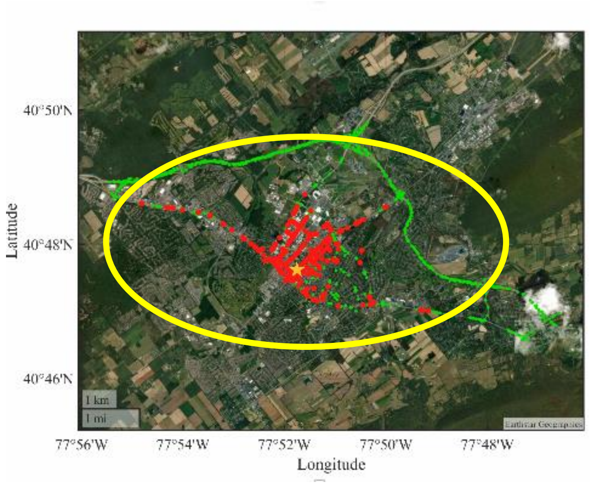
# The boundary of traffic “surrounding a CAV” is not static. Instead, the boundary of surrounding traffic, referred to as Region of Influence (ROI) changes as the simulation evolves.




Start of simulation




ROI is small



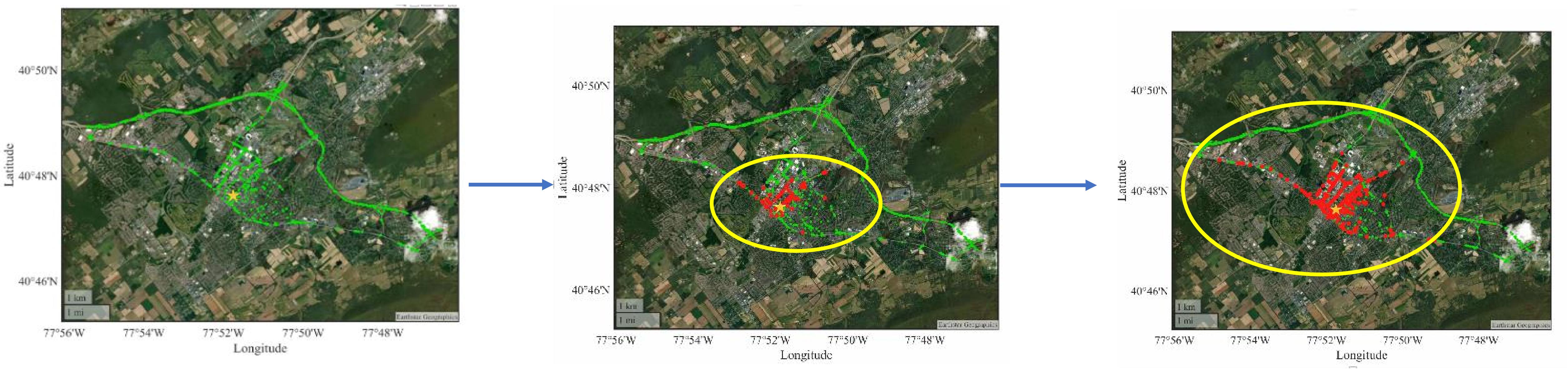

ROI gets bigger

The simulation environment needs to be bigger than this boundary. Otherwise, the influence of vehicle behavior changes is no longer captured by the simulation.

# Prior studies used traffic simulation to evaluate CAVs performance, while the selection of simulation area was mostly based on experience. The boundary of simulation area was still unclear.

| Main focus | Author | Year | Simulation boundary used in the paper |
|---|---|---|---|
| CAVs performance evaluation, algorithm validation. | Michal et al.<br>Christoph et al.<br>Assia et al.<br>Simone et al.<br>Marc et al.<br>Zhao et al.<br>Luise et al. | 2010<br>2010<br>2012<br>2015<br>2016<br>2017<br>2018 | Selected the simulation area based on experience |
| | Qiong et al. | 2020 | Early consideration given to simulation area selection, where a wider context was considered |

The objective of this work is to answer the question: “ what is the boundary of the domain we need to simulate to capture the impacts of ego vehicle on surrounding traffic? ” The boundary is referred to as Region of Influence, or ROI, in this study.

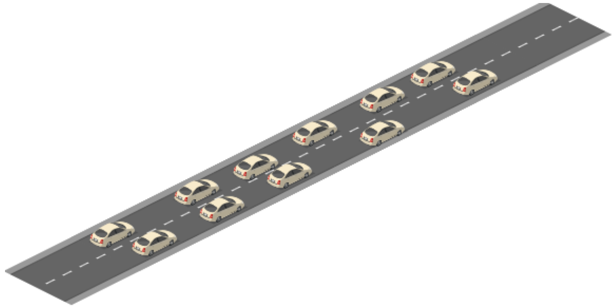



The simulation environment needs to be bigger than this boundary. Otherwise, the influence of vehicle behavior changes is no longer captured by the simulation.

To study ROI, the authors chose the simplest situation that involves traffic. This study uses AIMSUN traffic simulator to characterize ROI. The settings for simulations are as below:

Road type is double lane, straight highway, virtual road.


Mean speed is 60 mph.



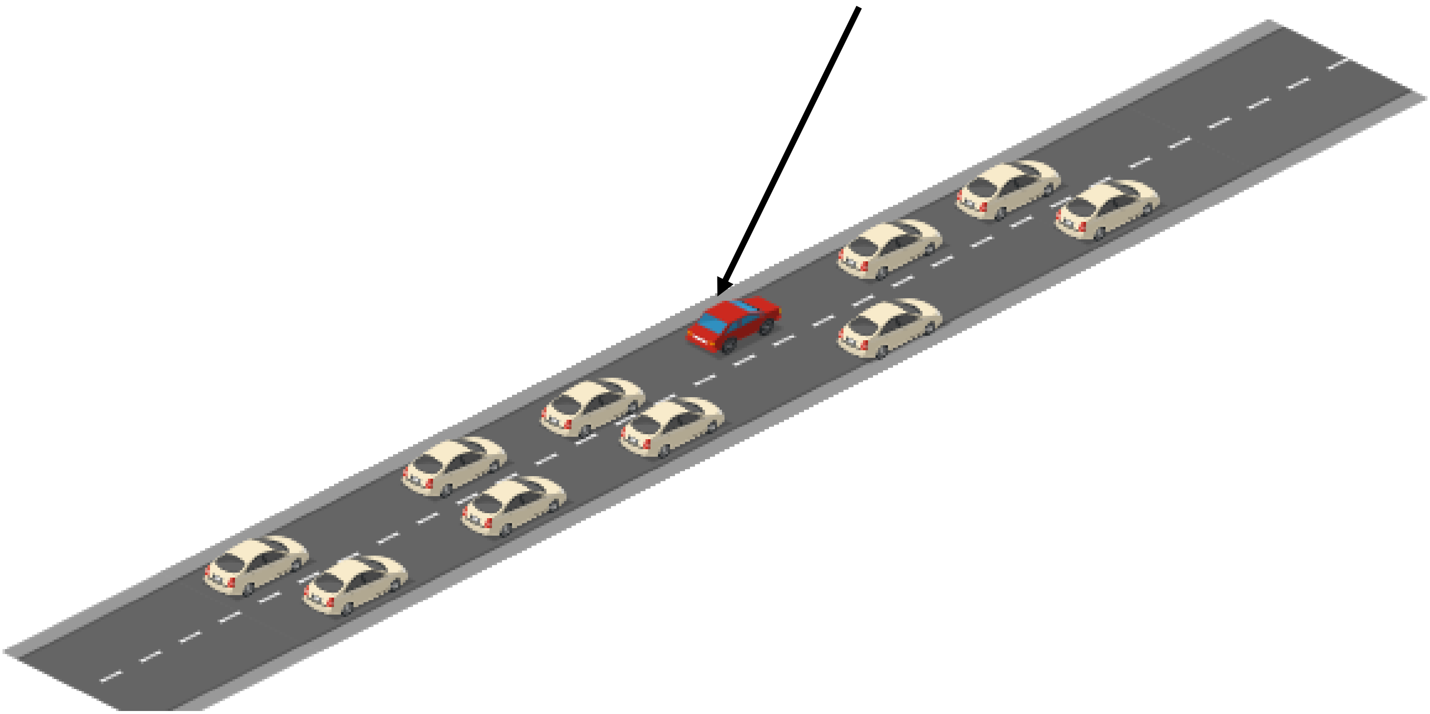
Traffic flow rate is 1800 veh/hr (high flow rate)[1,2], using passenger vehicles.

[1]Rios-Torres, J., & Malikopoulos, A. A. (2018). Impact of partial penetrations of connected and automated vehicles on fuel consumption and traffic flow. IEEE Transactions on Intelligent Vehicles, 3(4), 453-462.

[2]Aakre, E., Aakre, A., & Haugen, T. (2017). Enhancing driver performance: a closed track experiment. Transportation research procedia, 26, 22-31.

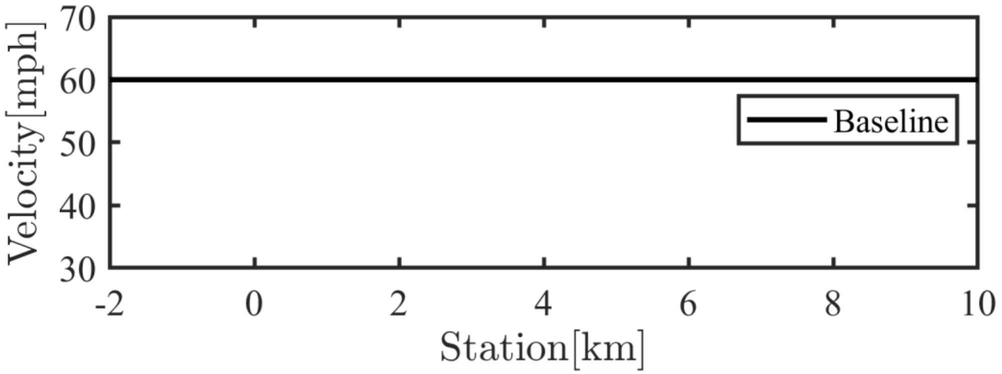
# The study is based on the concept of an ego vehicle.

Ego vehicle, or subject vehicle, the behavior of which is of primary interest

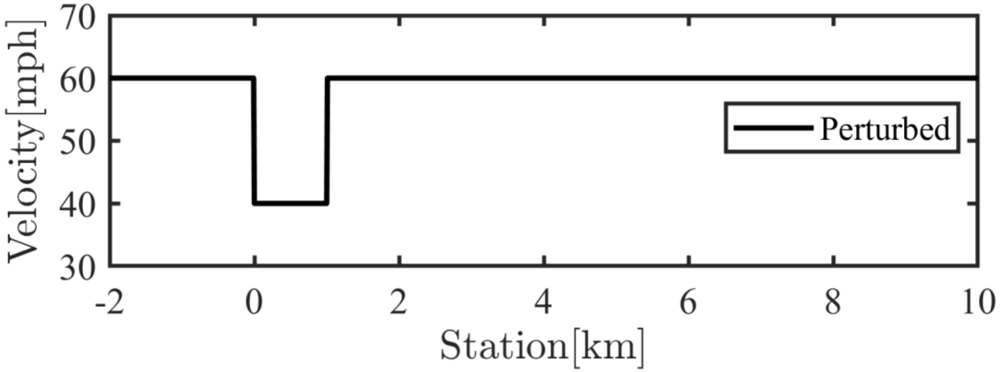


The perturbation in the simulation is slowing down the ego vehicle by 20 mph for only the first 1 km of simulation.  This is an user-defined relative large perturbation to approximate a (negative) impulse perturbation to the traffic system.

Baseline

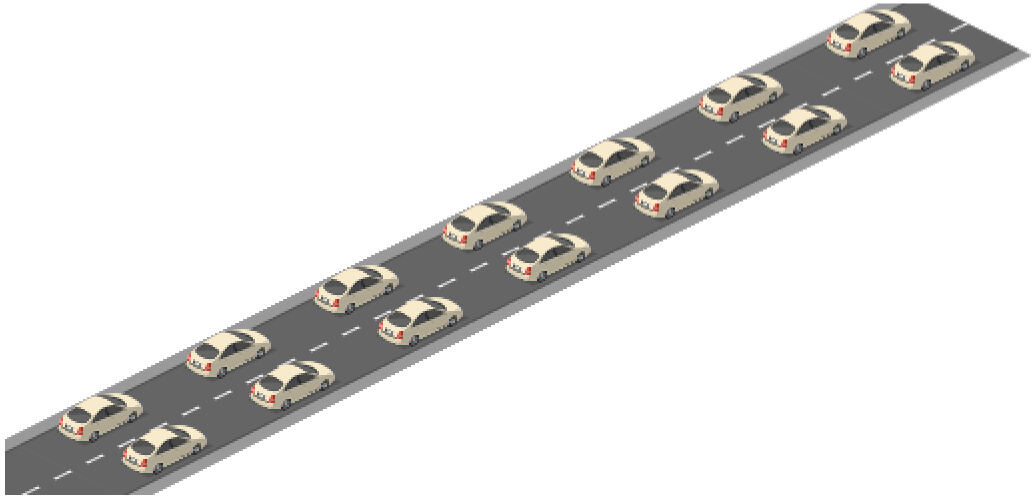



Perturbed

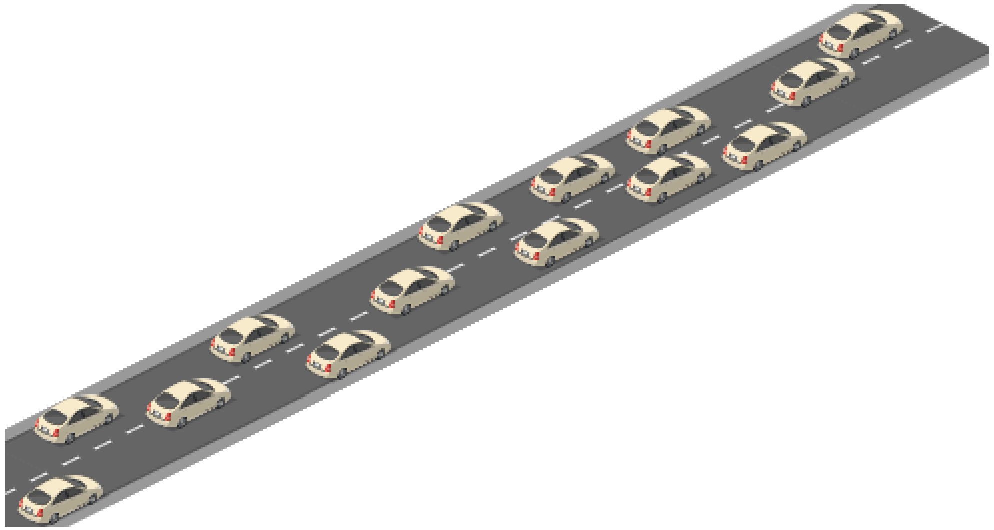



Velocity for ego vehicle in baseline and perturbed simulations

A key factor to investigate in this work is how the speed variance ($\sigma^2$) can affect ROI.

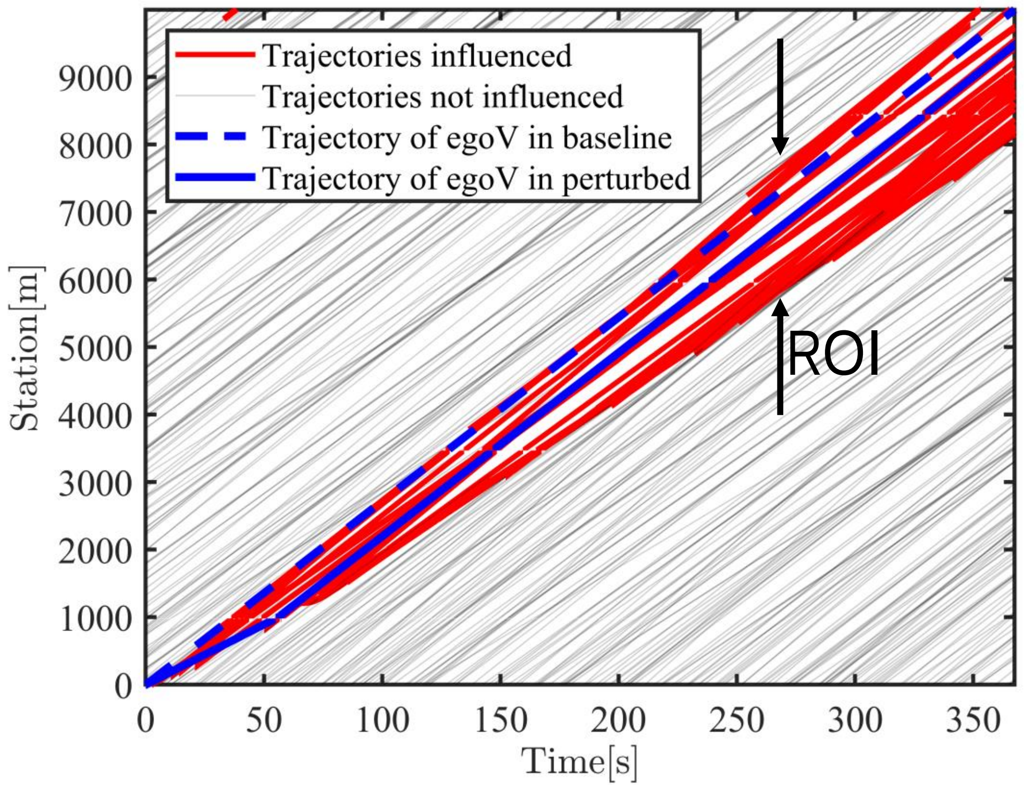


"Frozen" traffic: speed $\sigma$= 0 mph



"warm" traffic: speed $\sigma$ = 5 mph

# It’s difficult to compare the difference between baseline and perturbation trajectories. However, if we highlight where they are different, it becomes obvious.

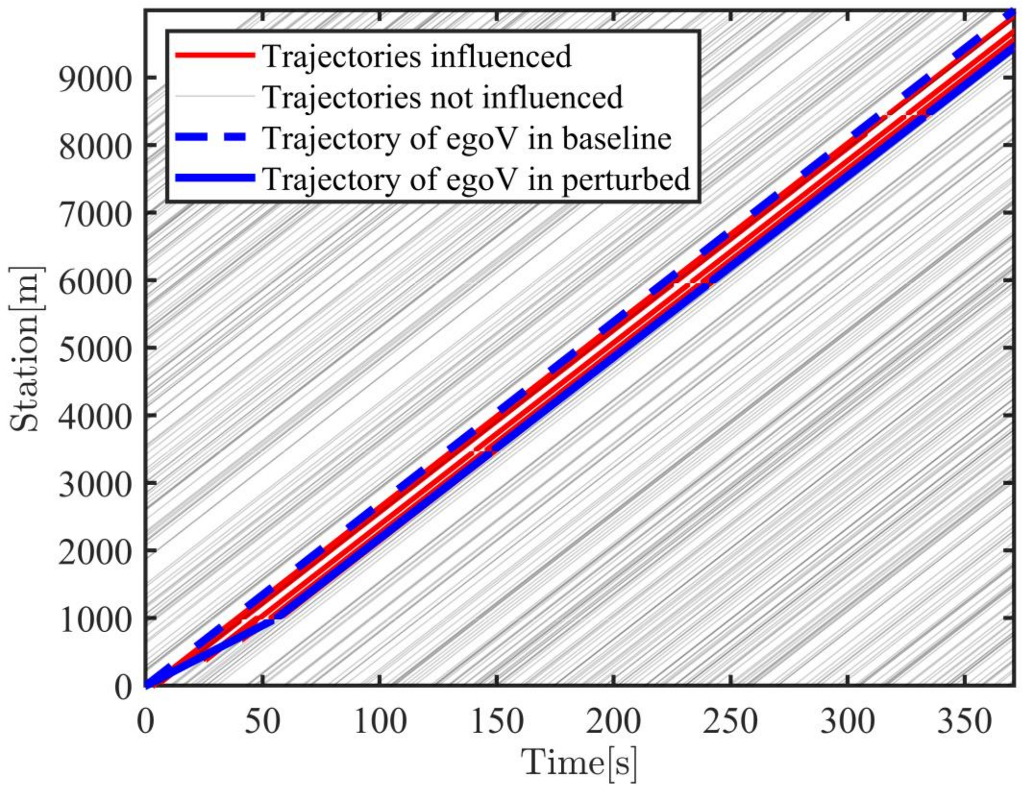



Traffic trajectories, warm mode

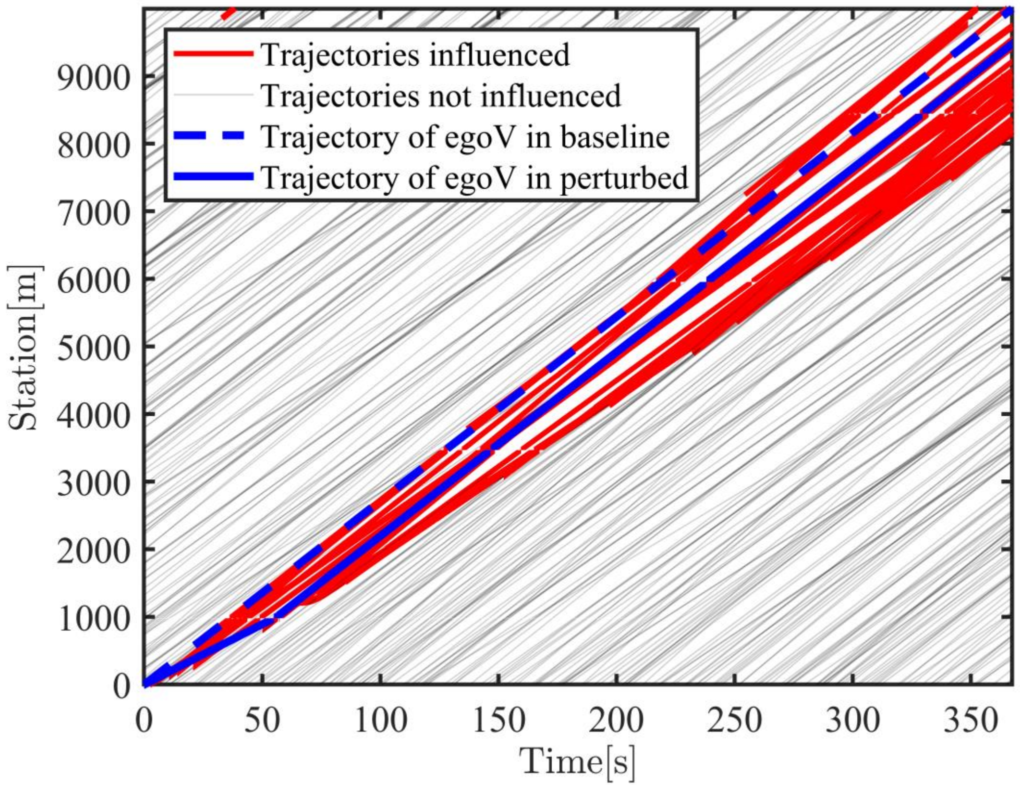
Traffic simulation settings

| Simulation parameters | Settings applied |
|---|---|
| Road type | Double lane, straight |
| Road length | 10 km |
| Perturbation | A speed change of -20 mph on the ego vehicle for 1 km |
| Mean velocity | 60 mph |
| Traffic temperature mode | “Frozen”: speed std = 0 mph; “warm”: speed std = 5 mph |
| Flow rate | 1800 veh/hr |

# ROI is smaller in frozen mode than in warm mode.

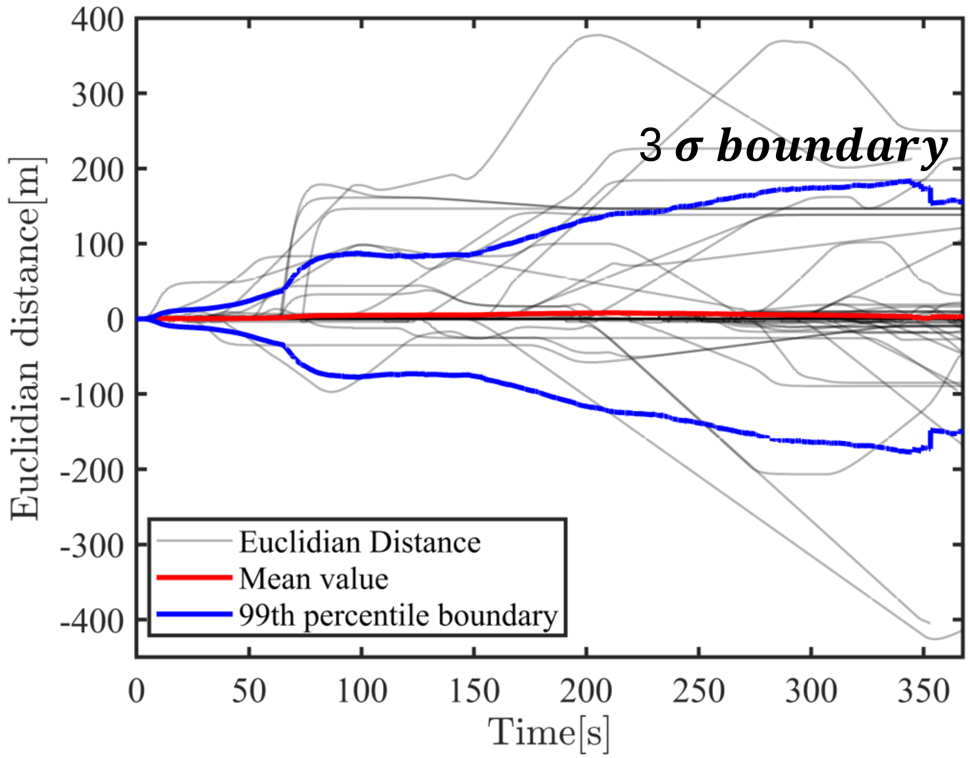



Traffic trajectories, frozen mode




Traffic trajectories, warm mode

# We use Euclidian distance as a metric to evaluate divergence of one vehicle’s trajectories in baseline and perturbed simulations.

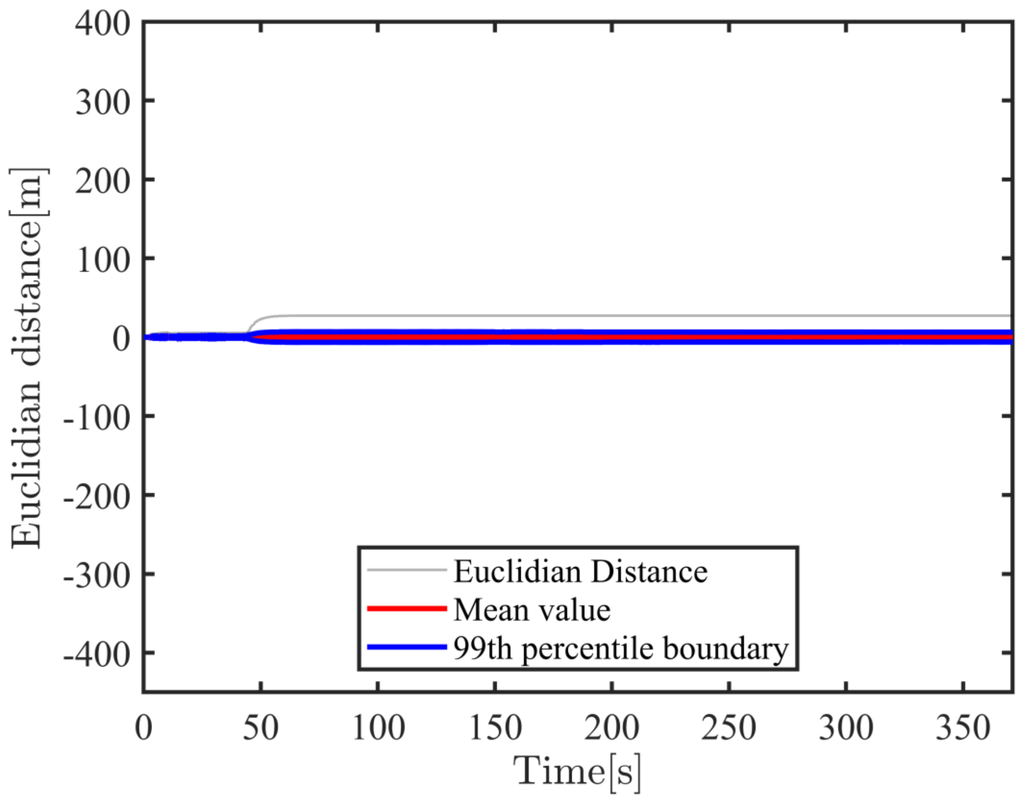



$$Euclidian\ Distance = \begin{cases} \sqrt{\left(x_{bl} - x_{per}\right)^2 + \left(y_{bl} - y_{per}\right)^2}, if\ S_{bl} \geq S_{per} \\ -\sqrt{\left(x_{bl} - x_{per}\right)^2 + \left(y_{bl} - y_{per}\right)^2}, Otherwise \end{cases}$$

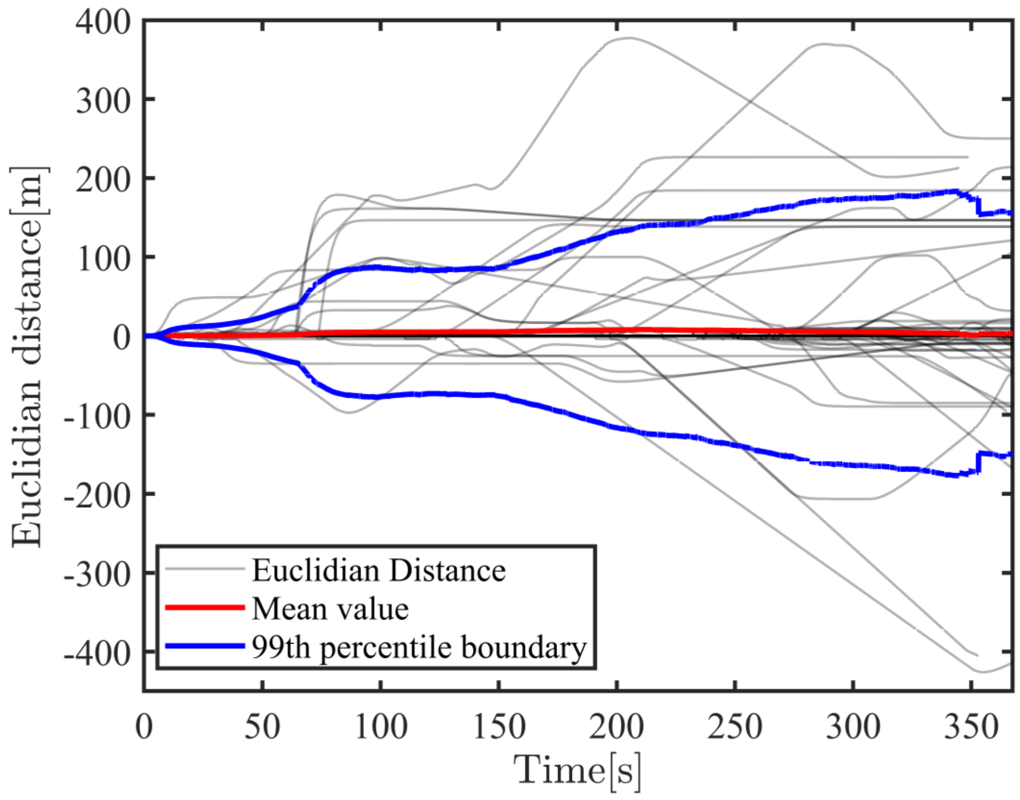
Where x and y are coordinates, S is station, the subscripts “bl” is baseline, and “per” is perturbed.

Euclidian distance, warm mode

# Frozen mode has smaller Euclidian distance than warm mode



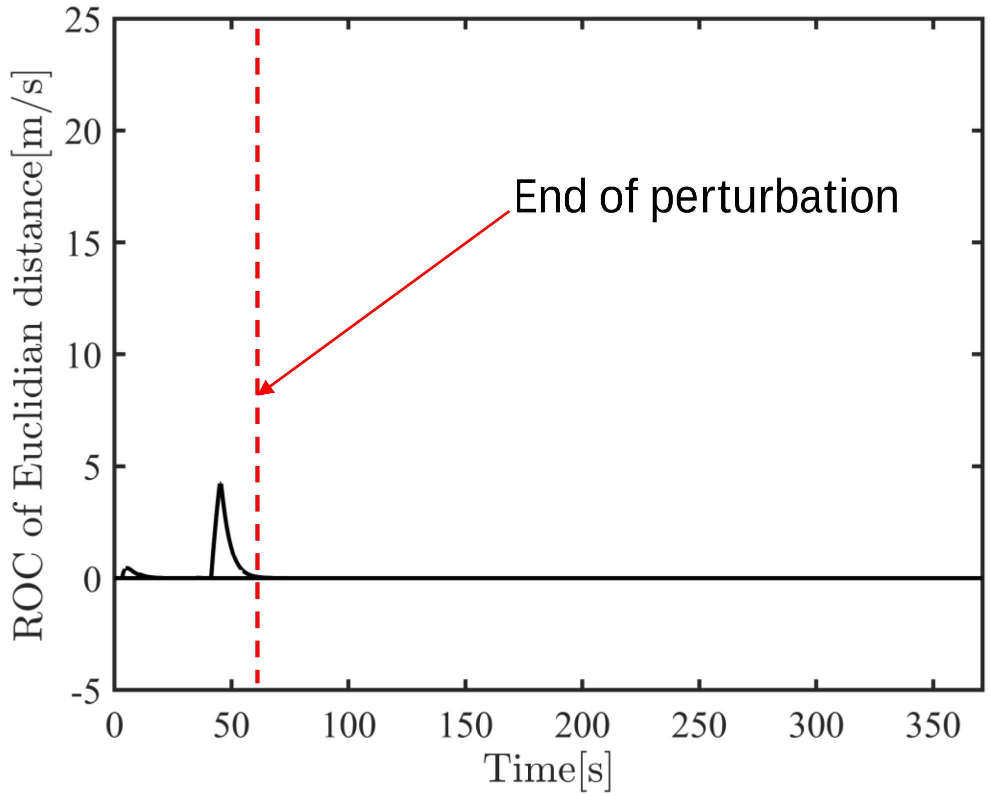

Euclidian distance, frozen mode



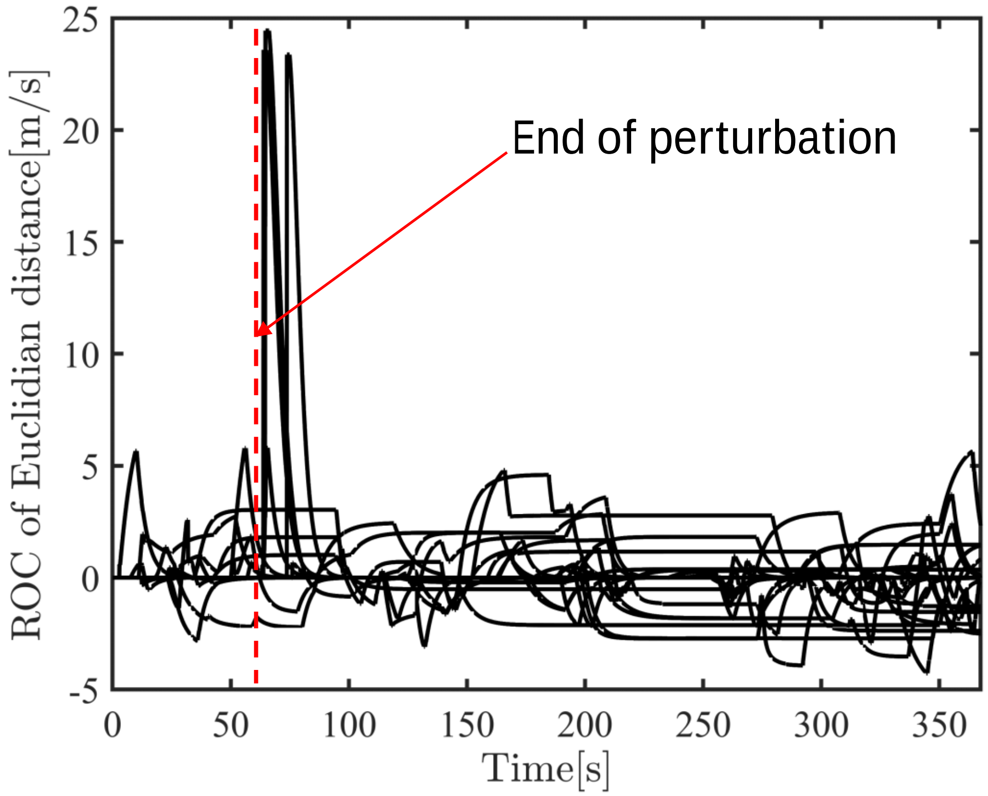

Euclidian distance, warm mode

The rate of change(ROC) of Euclidian distance is zero in “frozen” mode after the end of perturbation. While subplot in “warm” mode, it continues to grow after the end of perturbation.

$$Rate\ of\ Change = \frac{d\ EuclidianDistance}{dt}$$




Change rate of Euclidian distance, frozen mode




Change rate of Euclidian distance, warm mode

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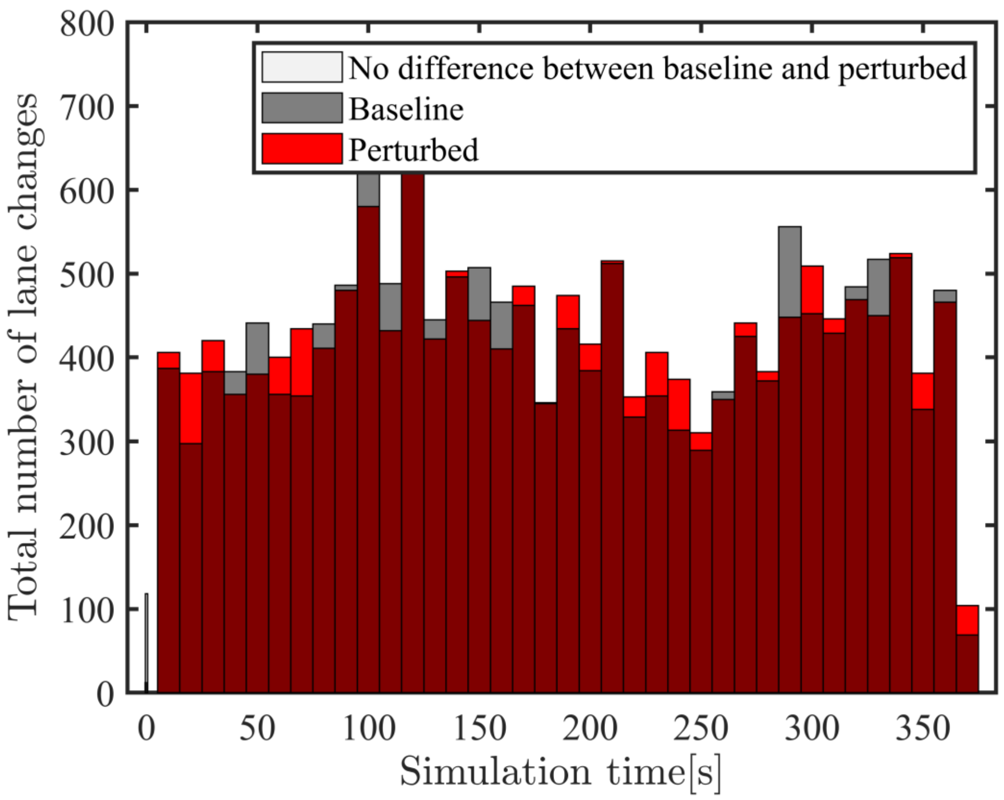
# We use the total number of lane changes over the whole simulation versus time to evaluate how long the perturbation affects lane changes of the surrounding traffic.



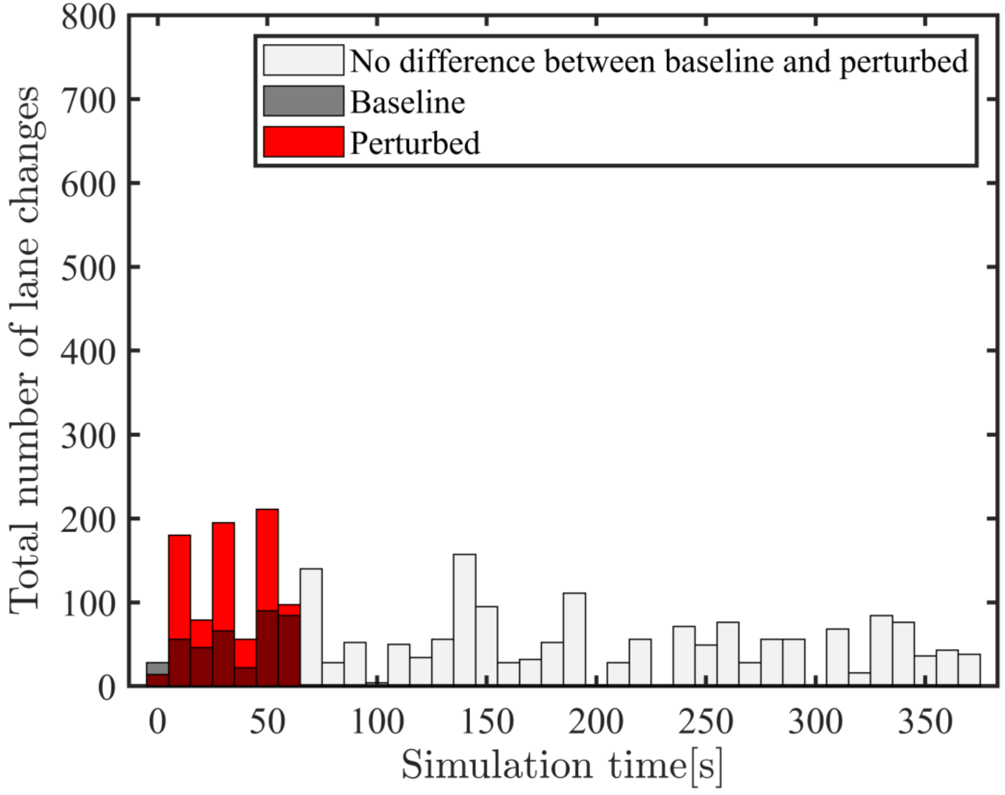

Total number of lane changes over the whole simulation space, warm mode

$$LaneChange(\Delta t)_i = \begin{cases} 1 & LaneChangeOccurs \\ 0 & Otherwise \end{cases}$$

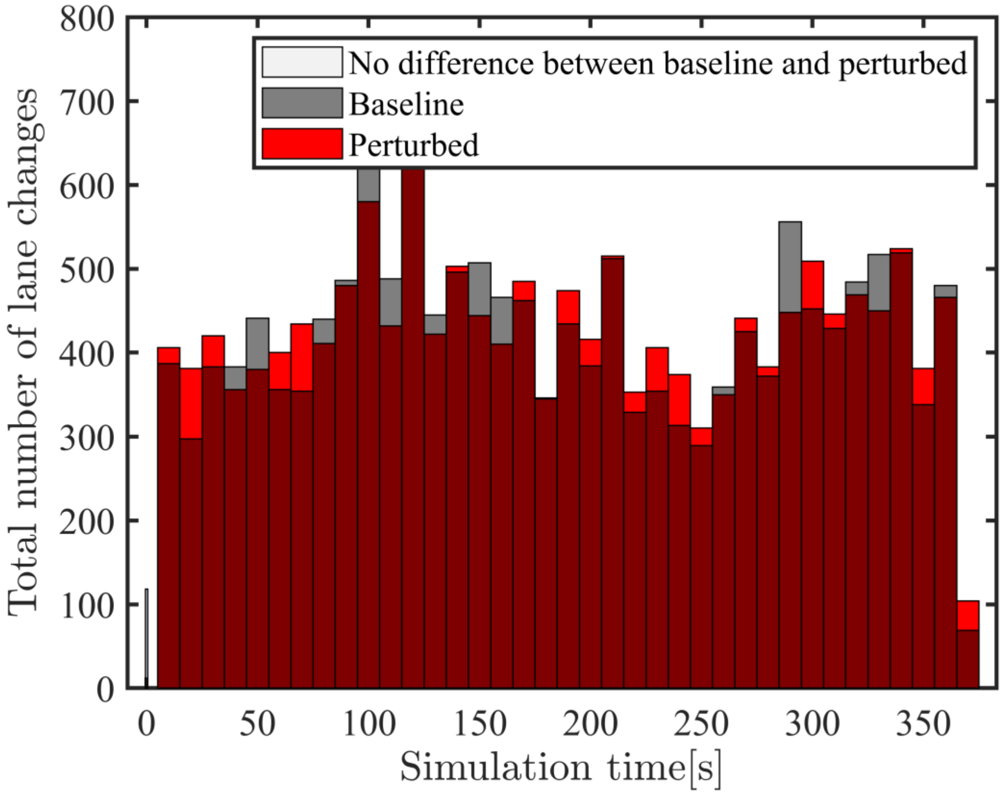
$$N_{LaneChange}(\Delta t) = \sum_{i=1}^{N} LangChange(\Delta t)_i$$

$where\ i\ is\ vehicle\ ID, N\ is\ maximum\ vehicle\ ID.$

# The ROI can disappear or persist, depending on whether the traffic is frozen or warm.

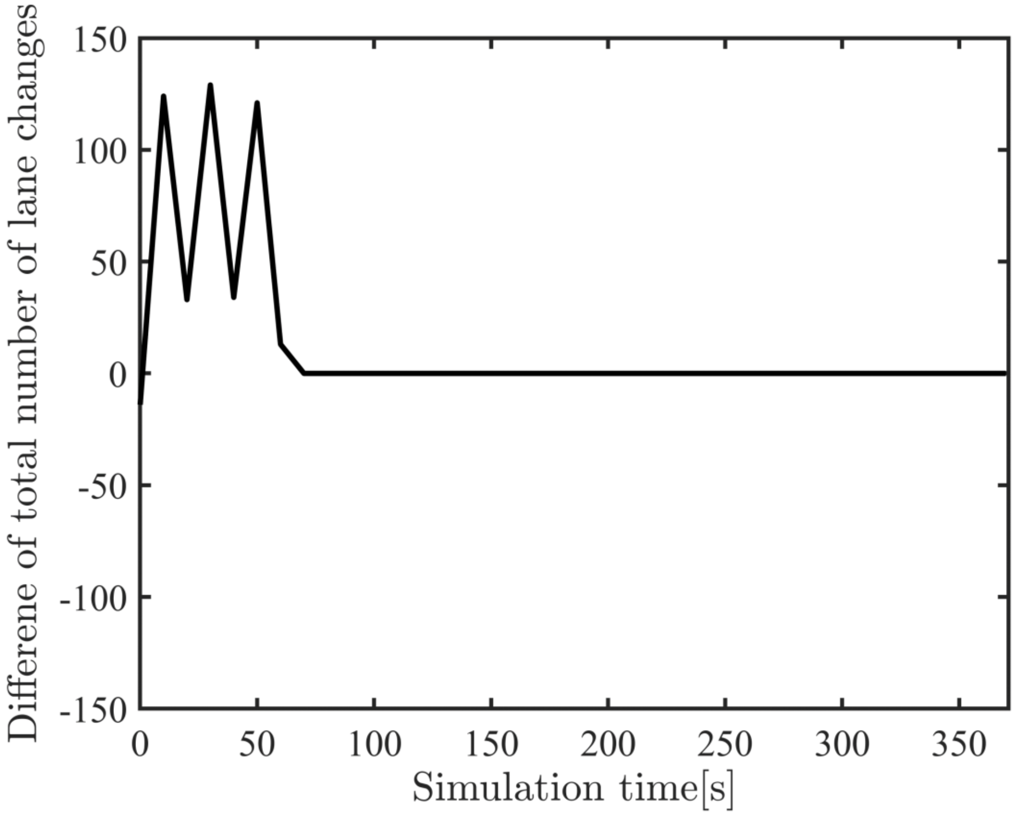



Total number of lane changes over the whole simulation space, frozen mode

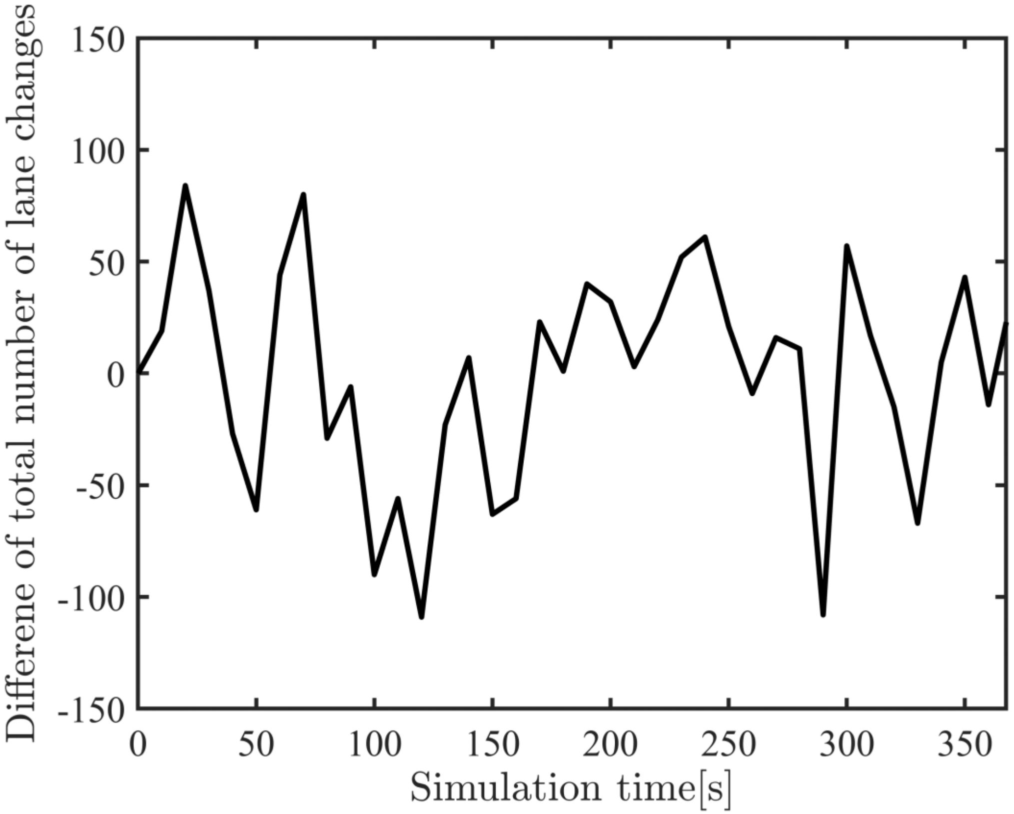



Total number of lane changes over the whole simulation space, warm mode

The ROI can disappear or persist, depending on whether the traffic is frozen or warm.




Difference of total number of lane changes over the whole simulation space, frozen mode




Difference of total number of lane changes over the whole simulation space, warm mode

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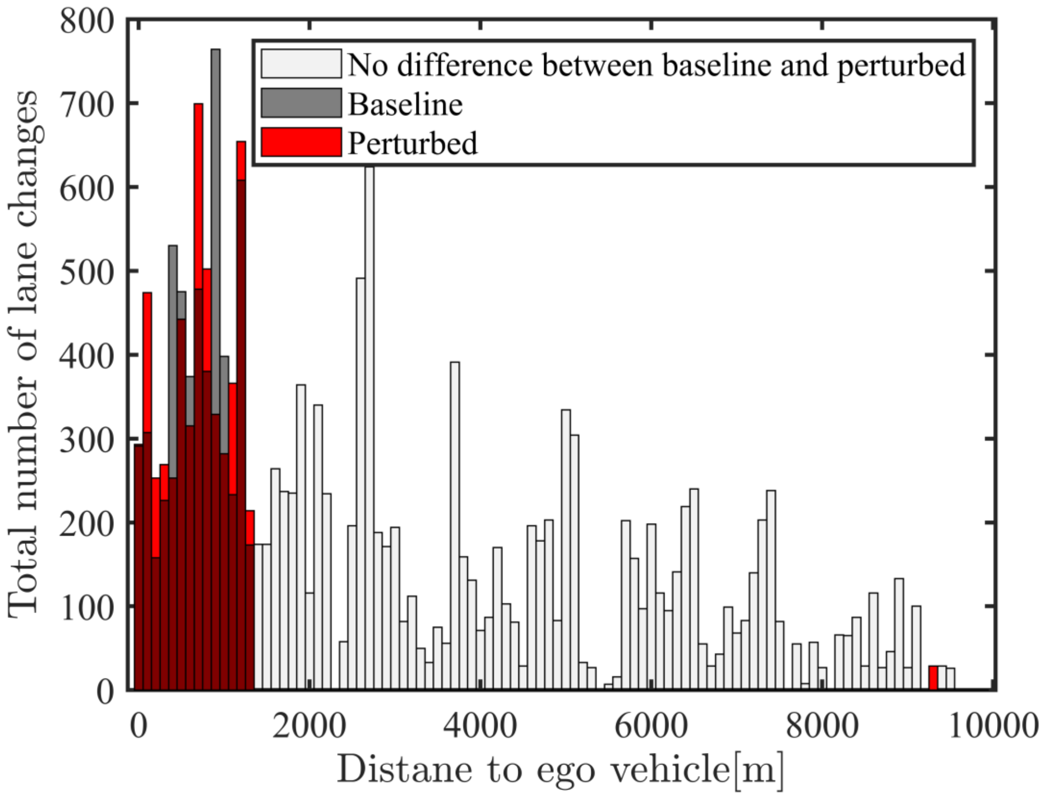
# We use total number of lane change over whole simulation versus distance to ego vehicle to evaluate how far the perturbation affects lane changes of surrounding traffic.

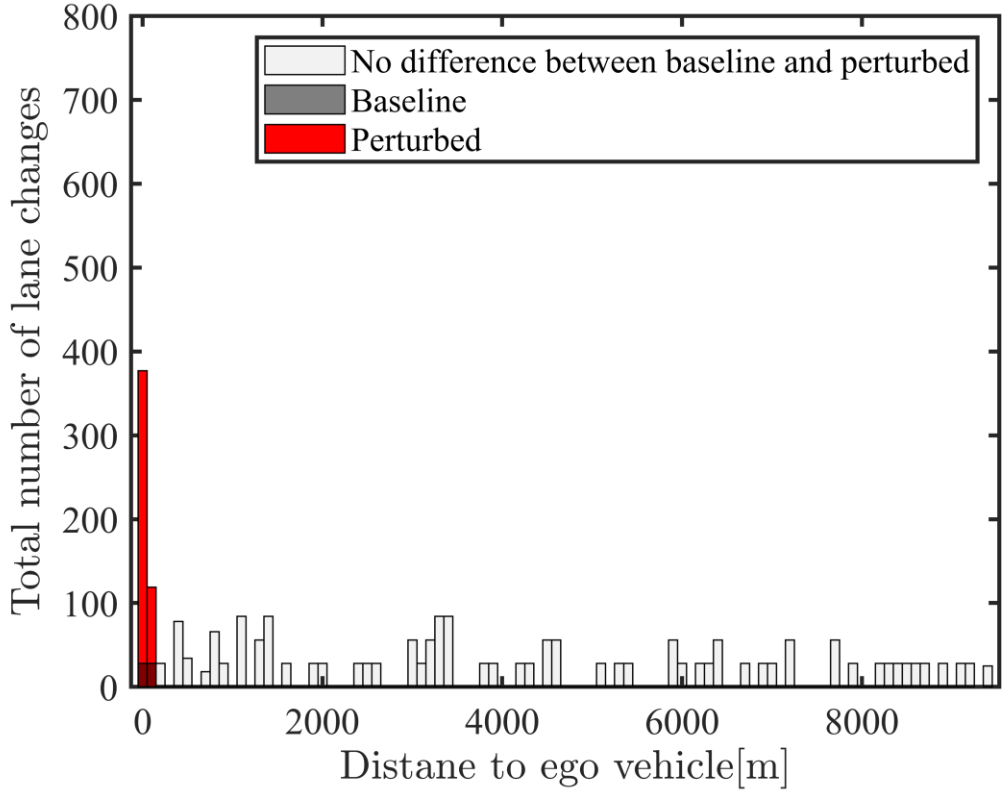


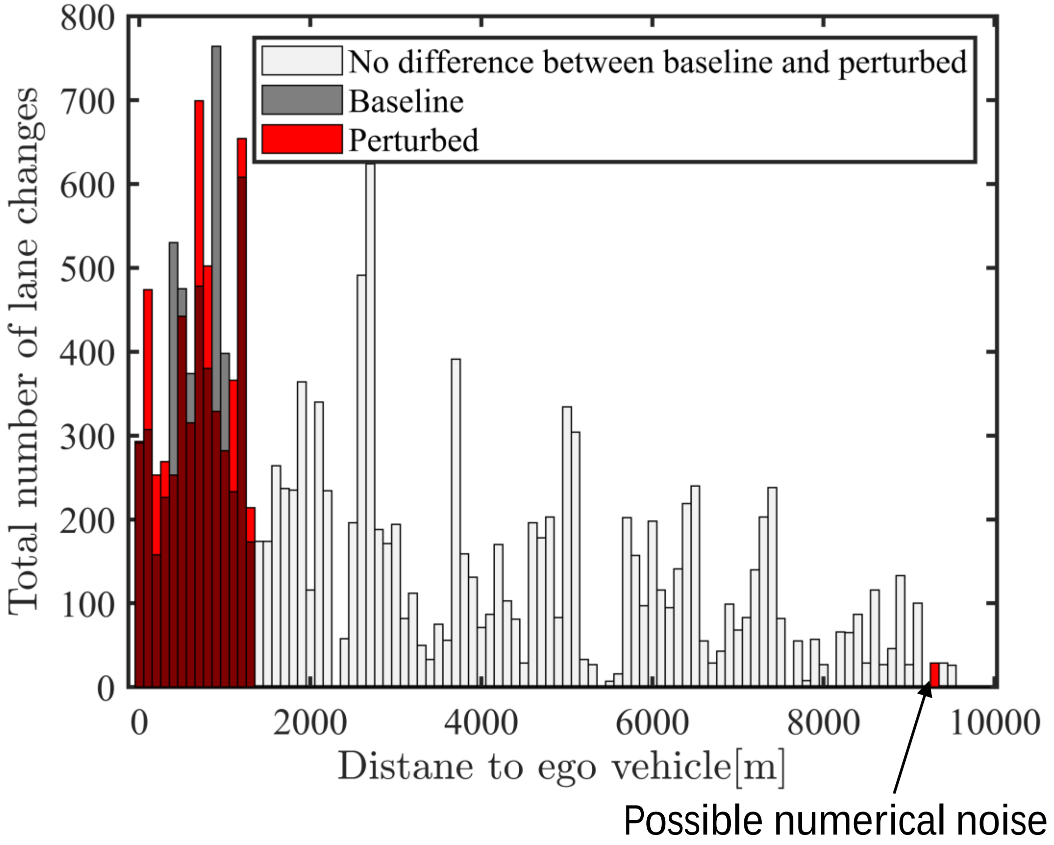

Total number of lane changes over the whole simulation time, warm mode

$$LaneChange(\Delta Dego)_i = \begin{cases} 1 & LaneChangeOccurs \\ 0 & Otherwise \end{cases}$$

$$N_{LaneChange}(\Delta Dego) = \sum_{i=1}^{N} LangChange(\Delta Dego)_i$$

ROI can be close or far from ego vehicle, depending on whether traffic temperature mode is frozen or warm.

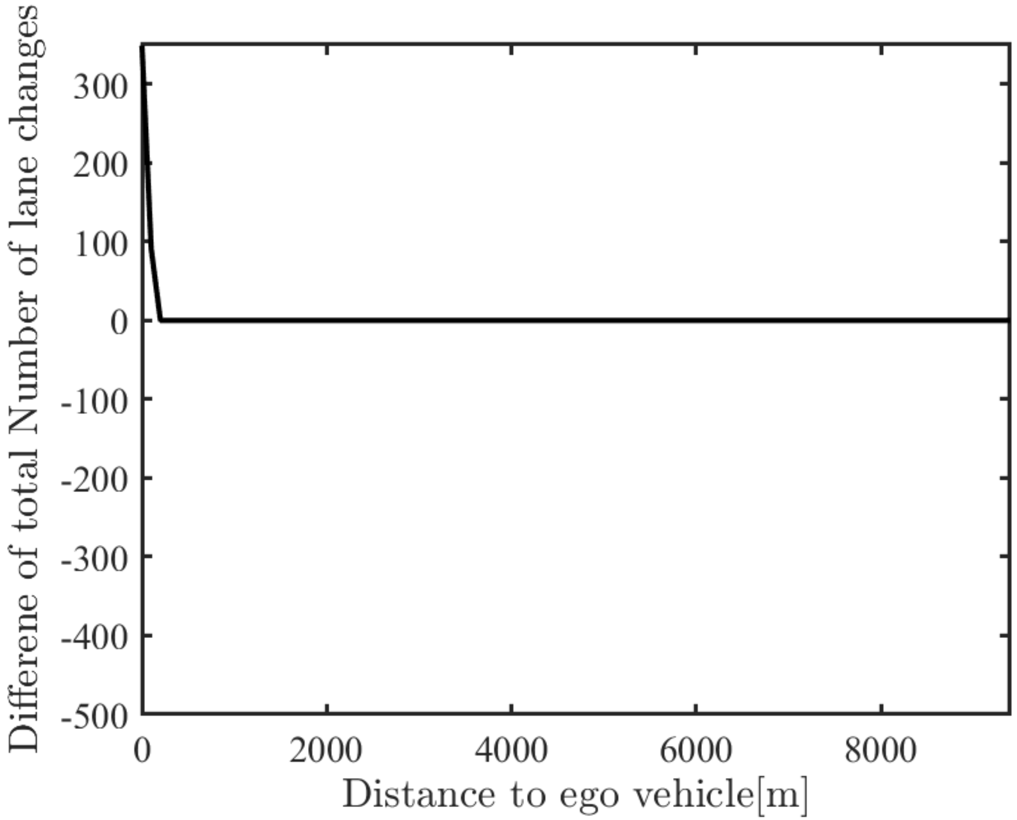


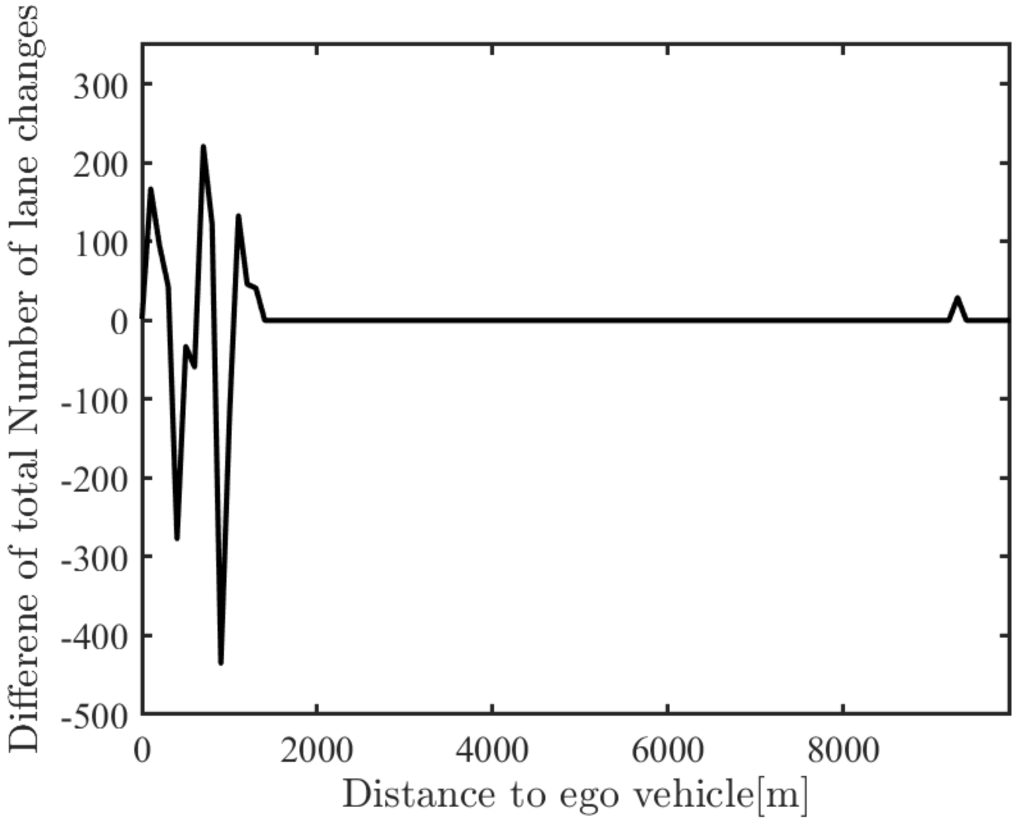

Total number of lane changes over the whole simulation time, frozen mode

Total number of lane changes over the whole simulation time, warm mode

# ROI can be close or far from ego vehicle, depending on whether traffic temperature mode is frozen or warm.

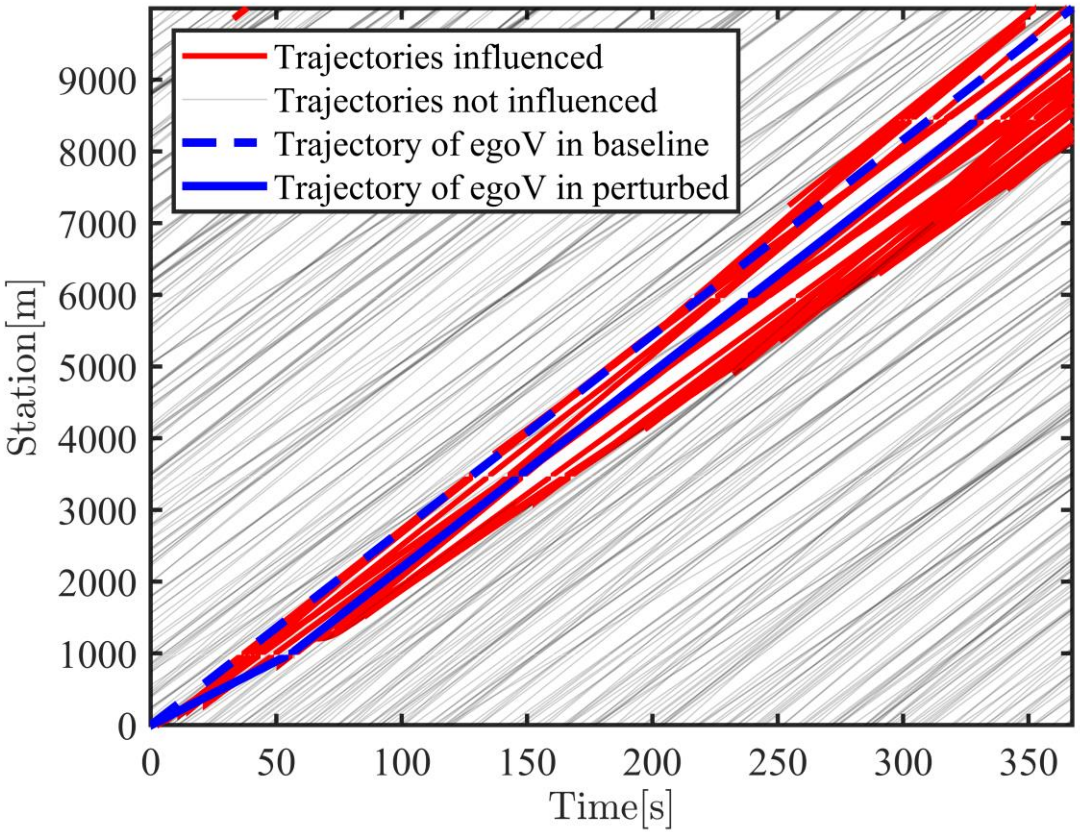


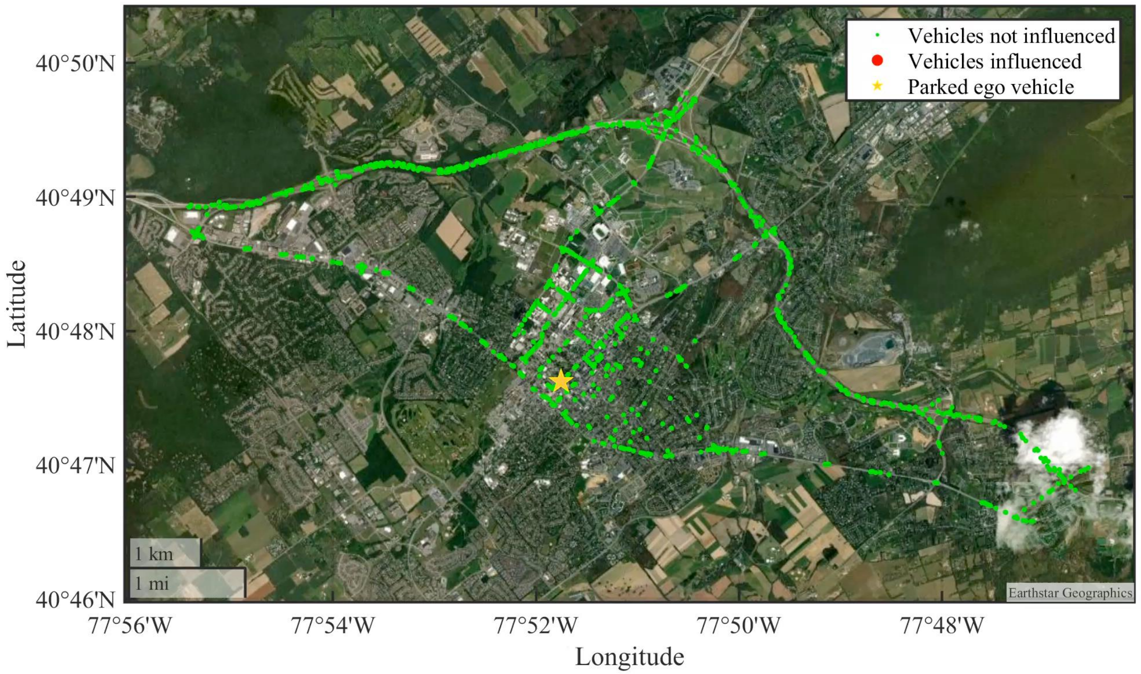

Difference of total number of lane changes over the whole simulation time, frozen mode




Difference of total number of lane changes over the whole simulation time, warm mode

In conclusion, this work presented a new concept, Region of Influence, or ROI, indicating the region over which a perturbation into the traffic as an input can influence the whole traffic system in time and space. This work introduced as well a method to characterize the ROI of one vehicle on the surrounding traffic. The results show that overall, speed variance has a strong influence on ROI. The results also show that ROI can have different values when using different metrics.




If you have questions, please contact me: Wushuang Bai,
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