Boxes-based Representation and Data Sharing of Road Surface Friction for Connected and Autonomous Vehicles (CAVs)

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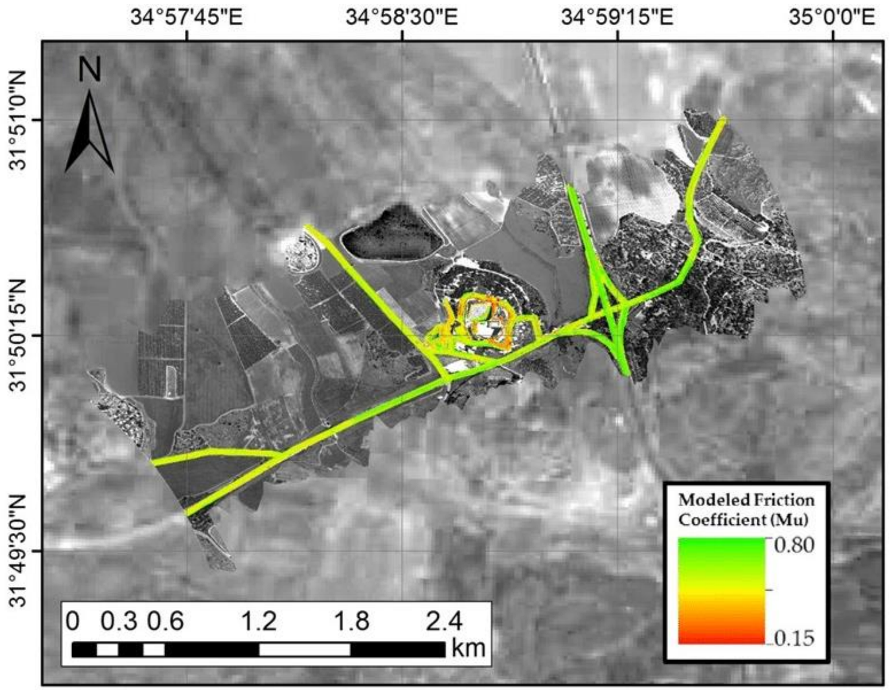
The unforeseen hazardous road surface friction conditions (snow, ice, rain, etc.) have a significant negative impact on vehicle safety and mobility.

https://www.youtube.com/watch?v=QyI4mjuGsQE

In impacting vehicle stability and safety, few data are as important as maps of the friction between tires and the road surface.

https://snowbrains.com/know-drive-winter-take-quiz/



- N. Carmon, and E. Ben-Dor, "Mapping Asphaltic Roads’ Skid Resistance Using Imaging Spectroscopy," Remote Sensing, vol. 10, no. 3, p. 430
- S. Chen, T. U. Saeed, and S. Labi, “Impact of road-surface condition on rural highway safety: A multivariate random parameters negative binomial approach,” Anal. Methods Accid. Res., vol. 16, pp. 75–89, 2017, doi: 10.1016/j.amar.2017.09.001.

This paper presents a road friction map generation strategy by aggerating the measured road-tire friction coefficients from a fleet of CAVs.

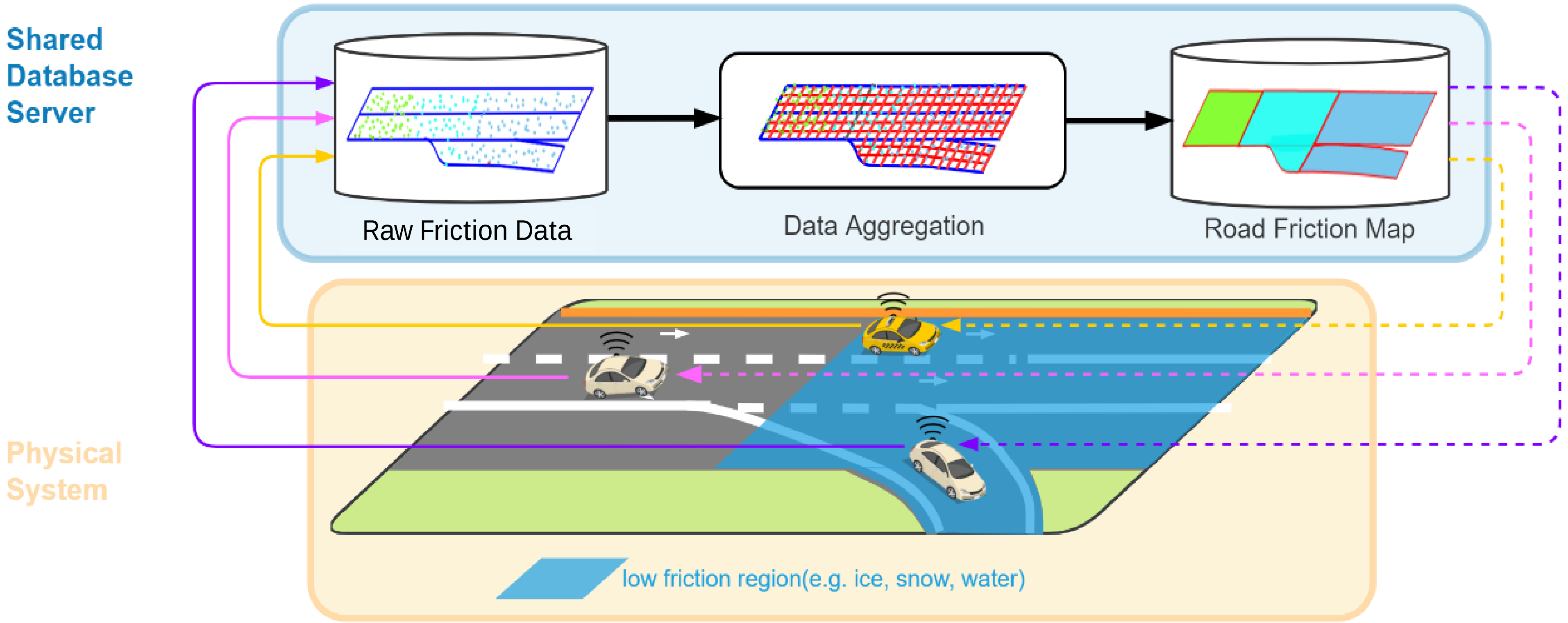
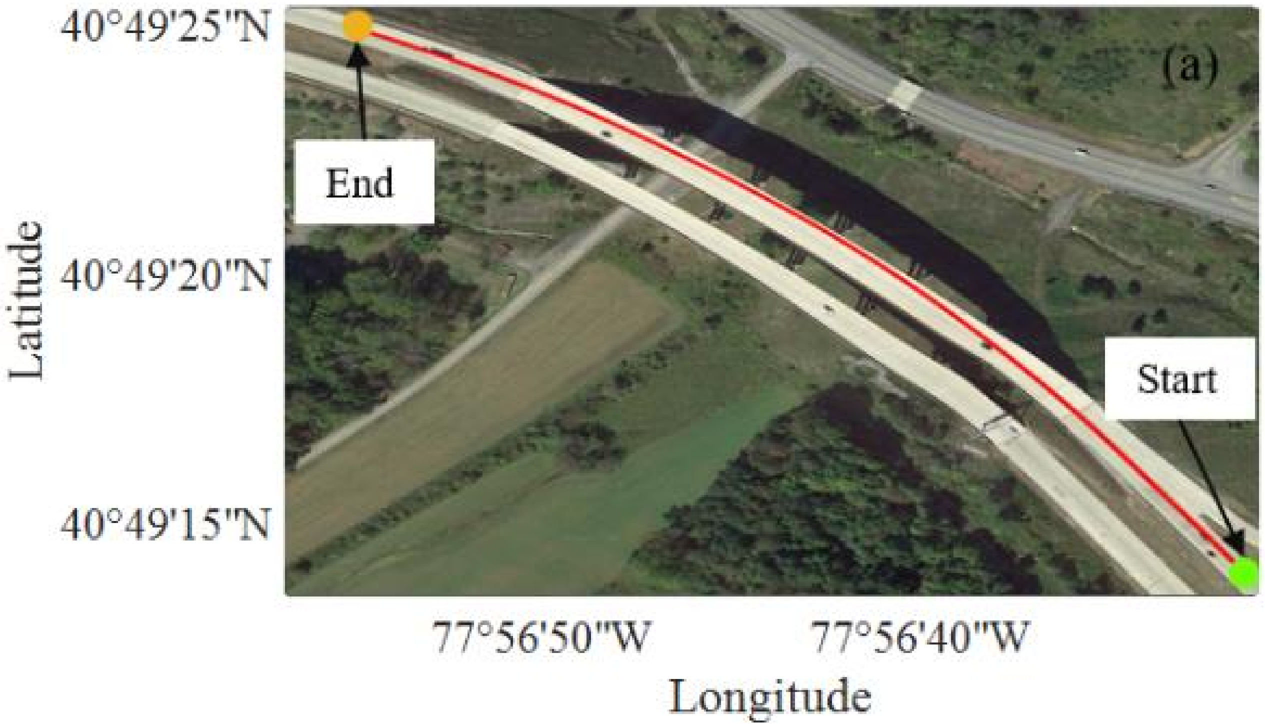
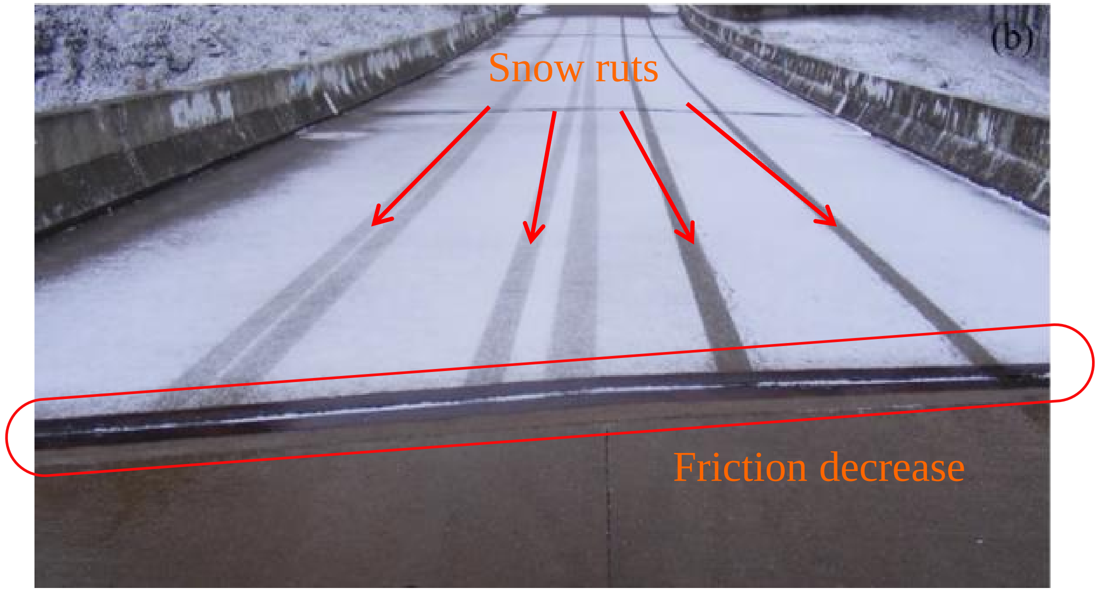


Figure: A road friction map generation strategy by aggerating the measured road-tire friction coefficients along the individual trajectories of CAVs through a shared roadside database.

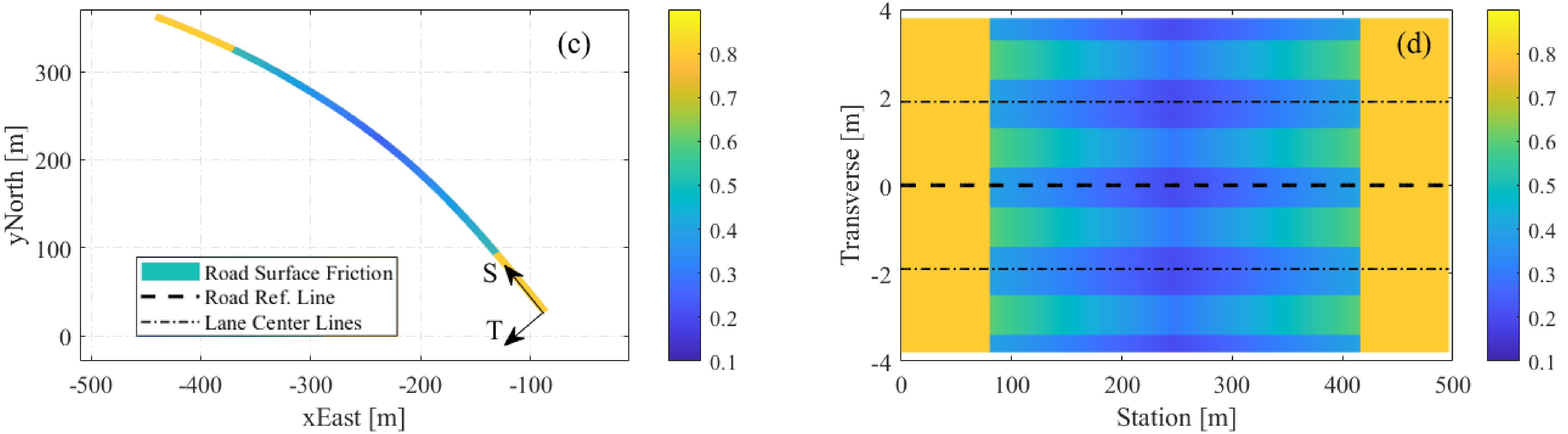
A highway bridge segment where friction changes in space is selected as a sample to demonstrate the friction map generation process.





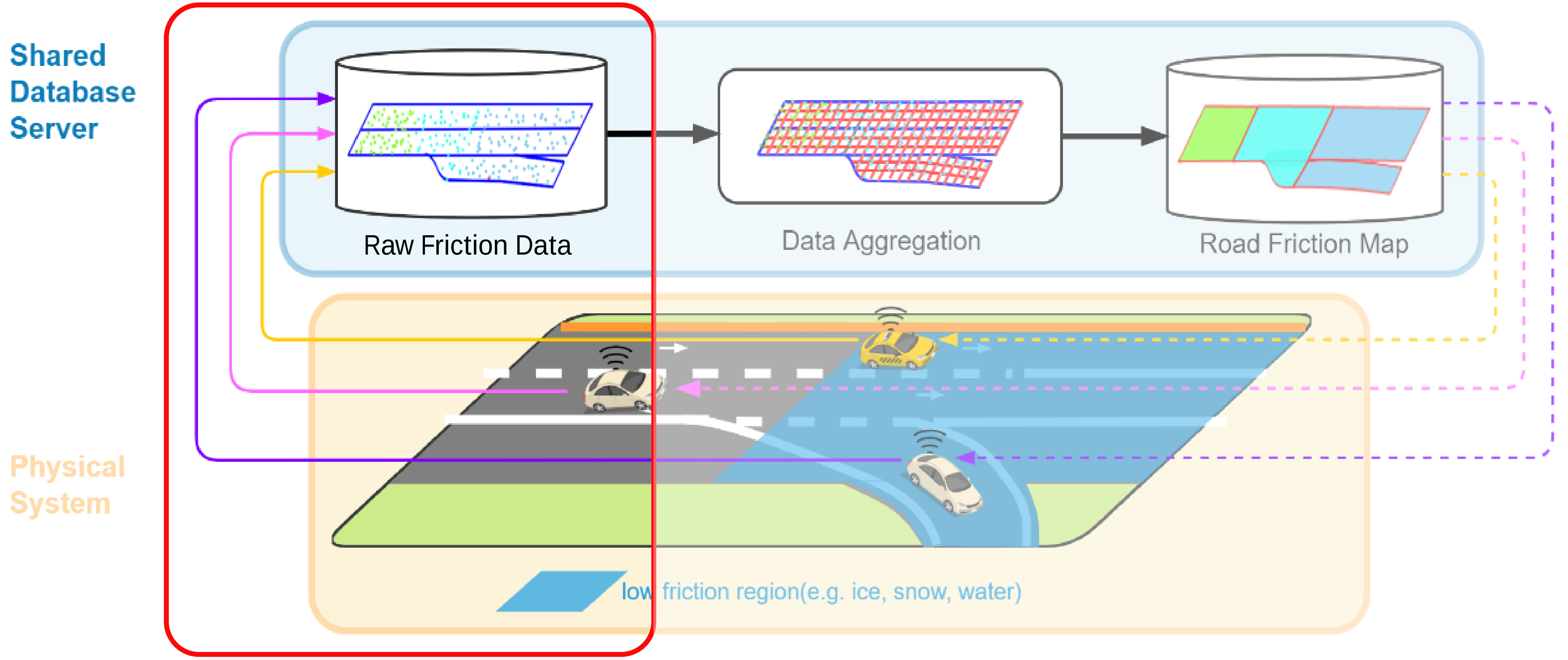
Sudden friction decrease with snow ruts

Without loss of the generality, to represent the snowy bridge and snow ruts, we synthetically generate a friction distribution numerically as the “true” road surface condition in this work.

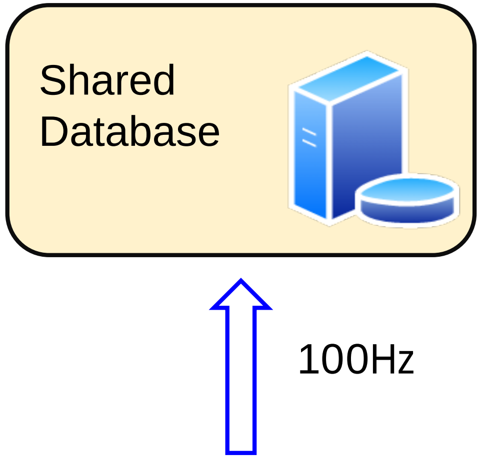


The numerical representation of the road surface friction pattern in east-north-up (ENU) cartesian coordinates and station-transverse-height (STH) curvilinear coordinates. The color bar indicates the friction coefficient values.

Friction coefficient data acquisition from a fleet of connected vehicles.



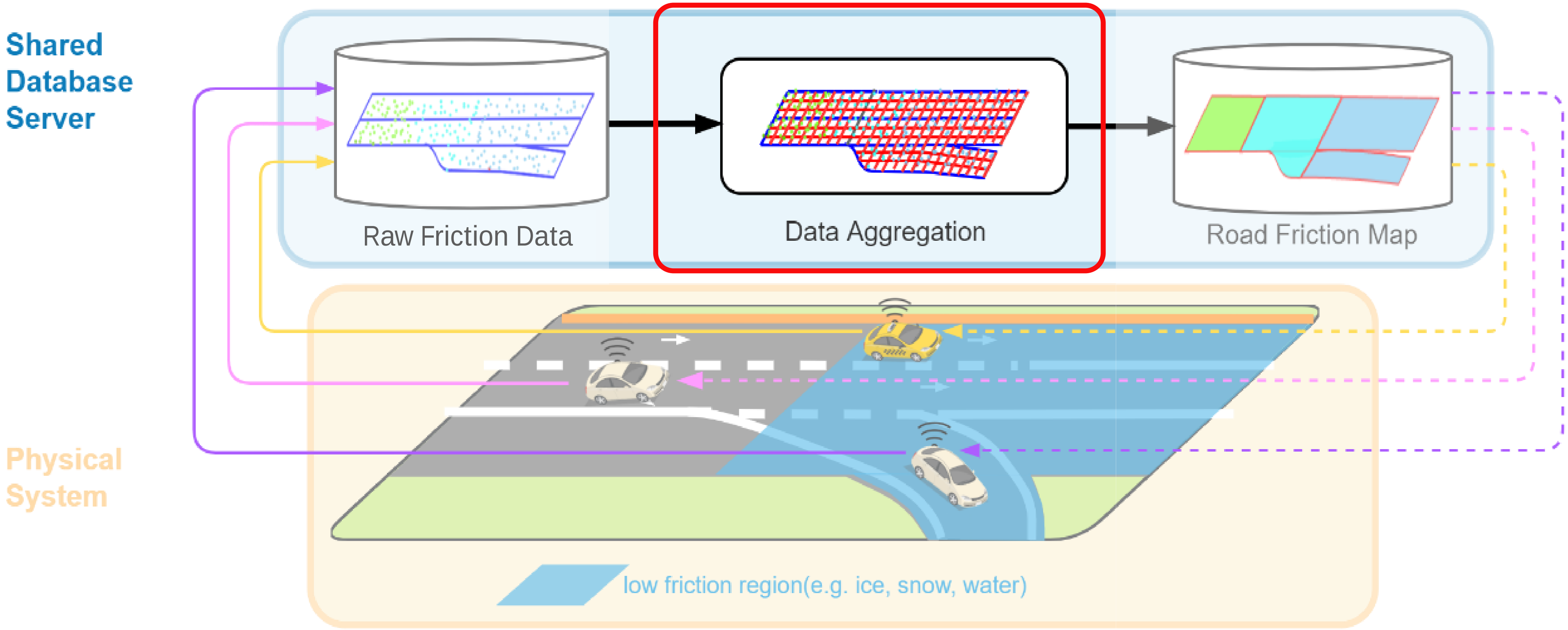
The measured data from each vehicle including the friction coefficient and the corresponding road-tire contact coordinates are pushed into a “raw data” database.



- ~10 million raw friction measurement data points

- 30 minutes
- 1038 vehicles

Aggregate the measured road-tire friction coefficients data based on static road surface grids.



The road surface is tiled into regular grids and coordinate system of the grids is carefully chosen as it plays an essential role in data aggregation.

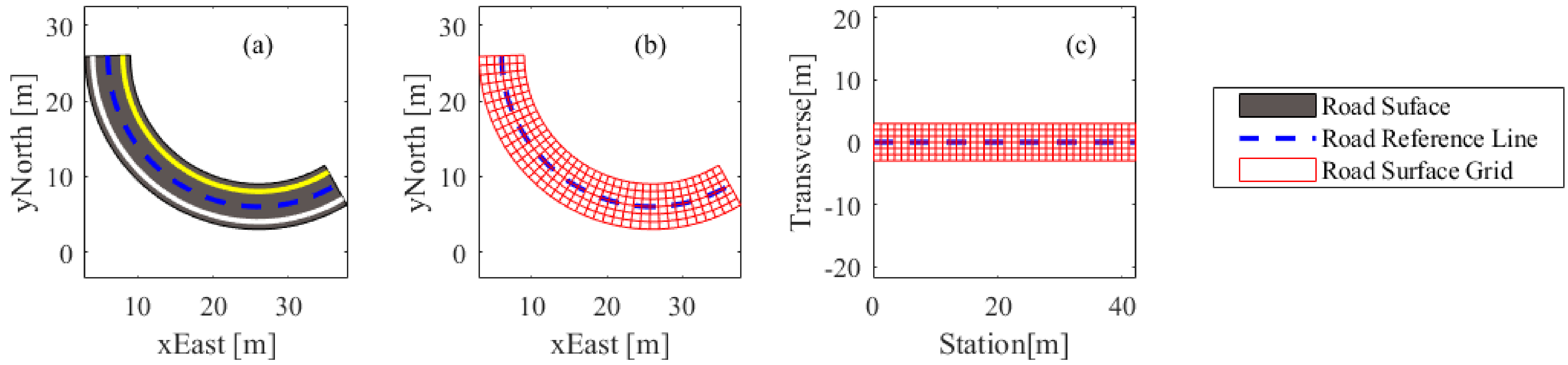
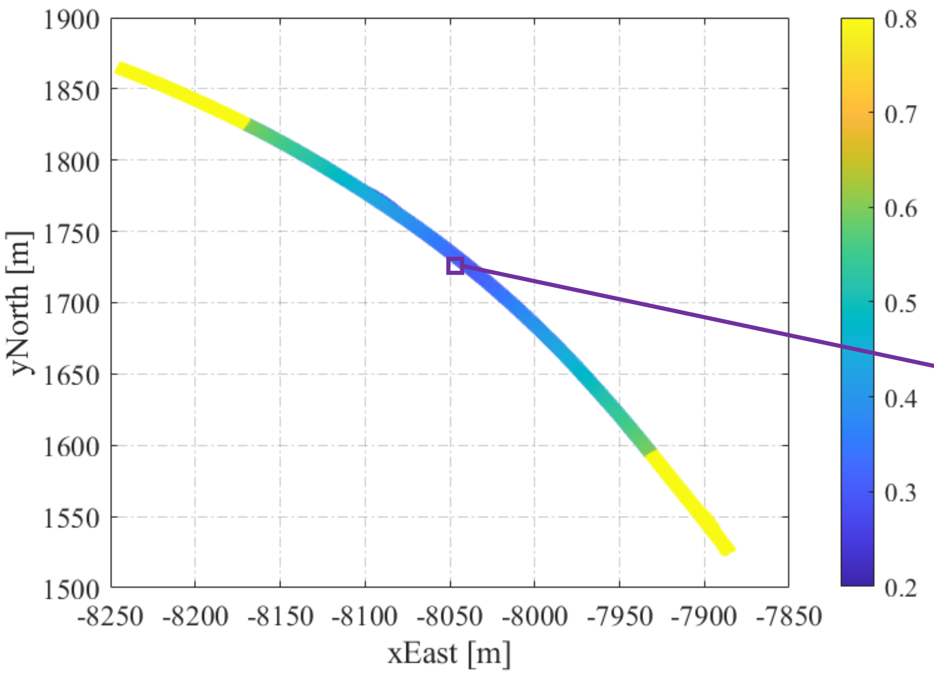
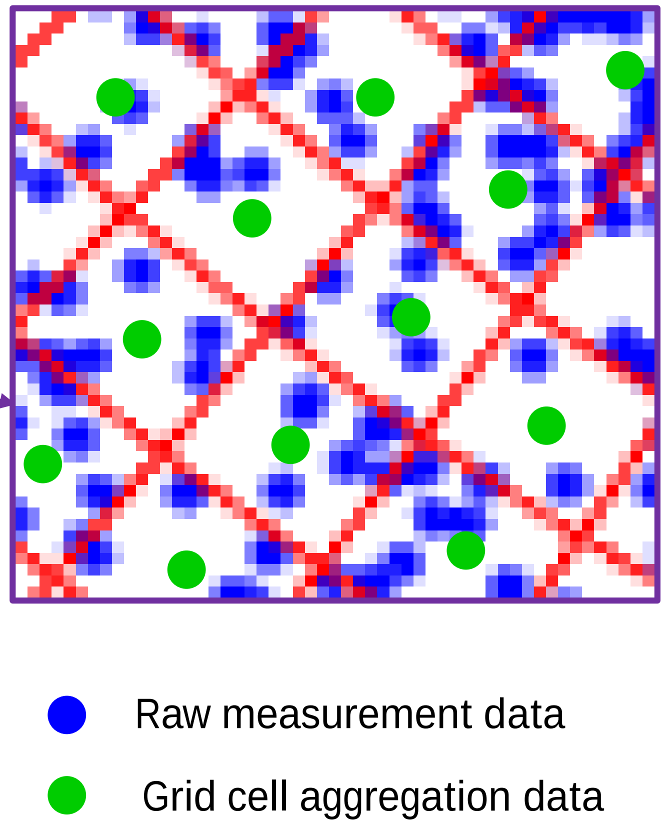


Figure: Grid-based road surface representation example. (a) a true road sample, (b) curved road grid in EN coordinates, (c) uncurved road grid in ST coordinates.

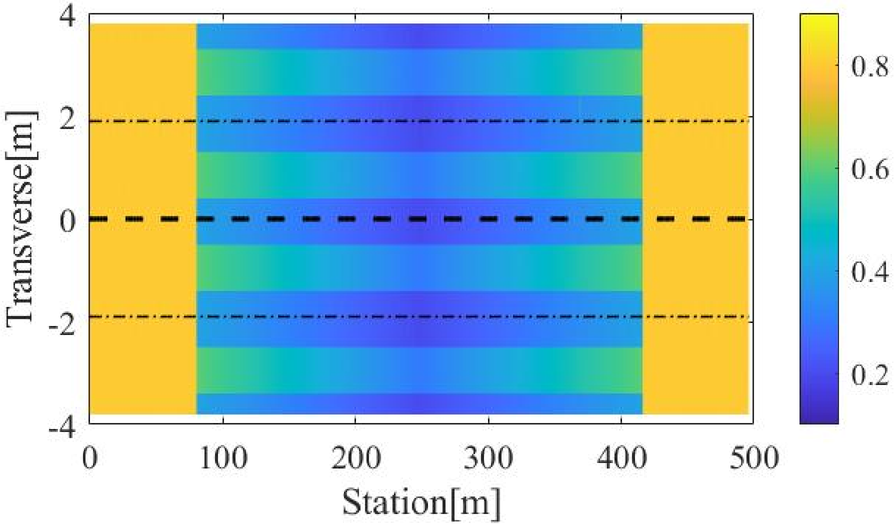
The measured raw friction data is associated with each grid cell and the friction value in each grid is represented statistical results of associated raw data.



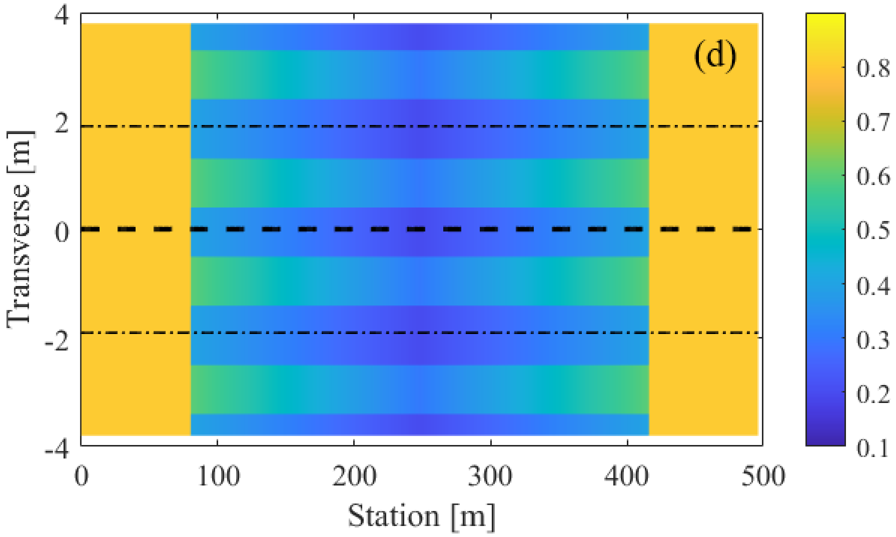
10cm by 10cm grid size



A grid-based road friction map with a high spatial resolution is generated. However, the data size of this friction map is still too large for fast sharing.



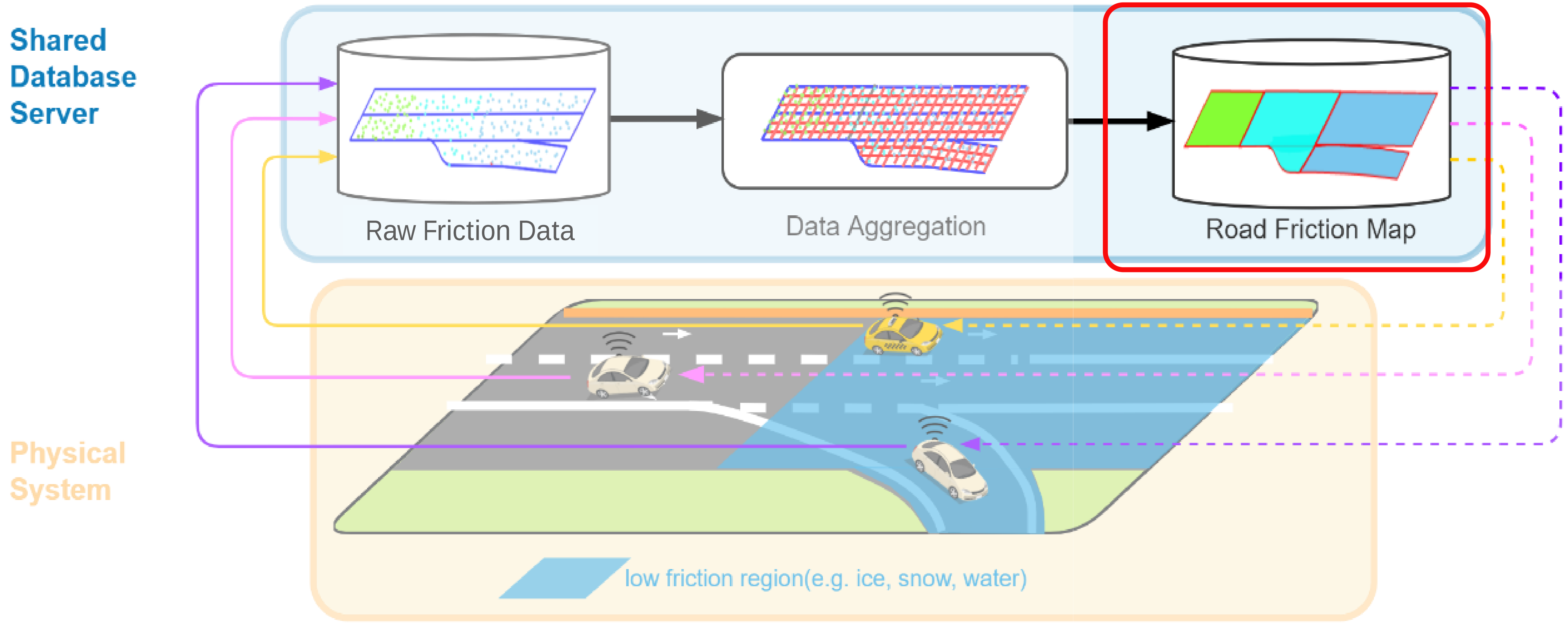
Mean friction coefficient value of each grid cell.



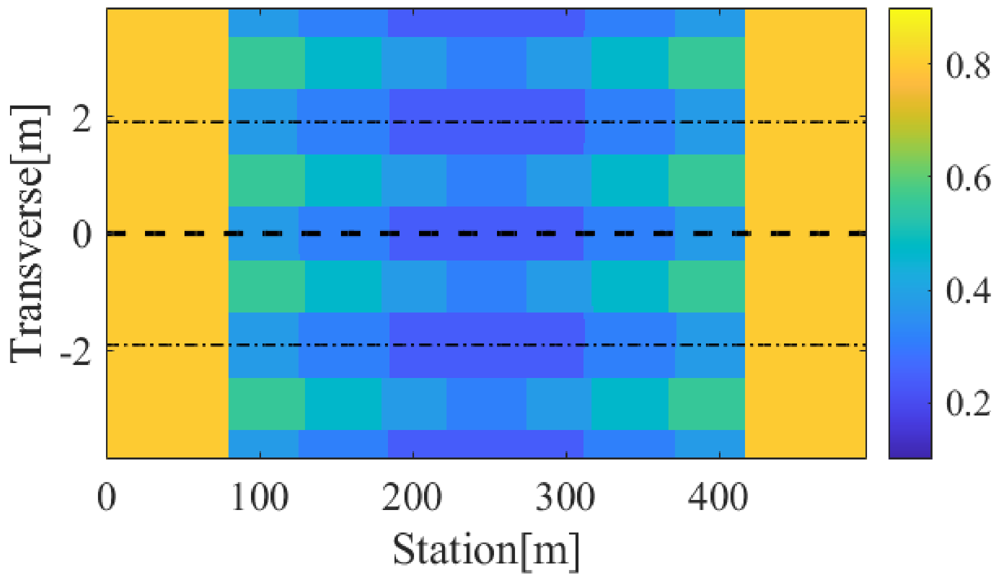
“True” friction distribution

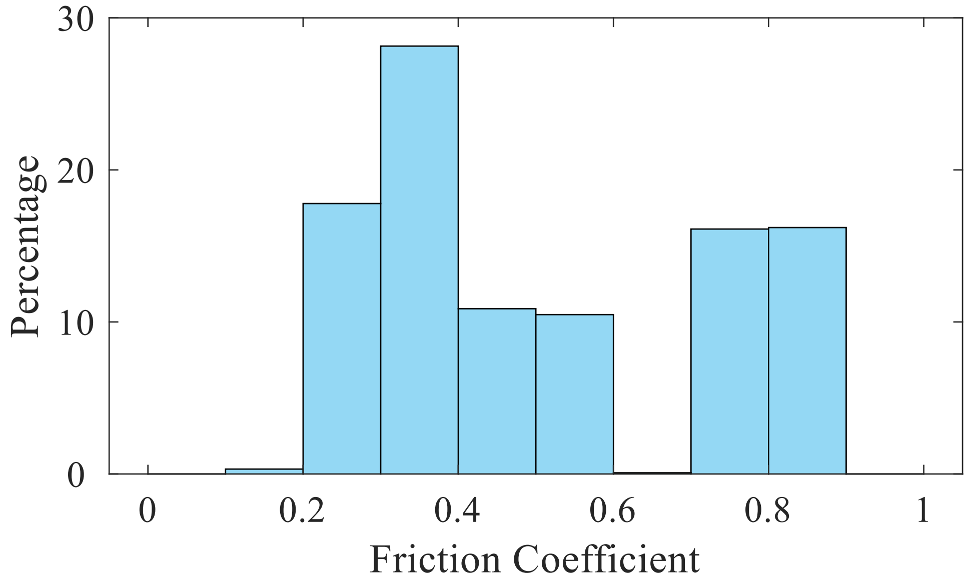
Aggregate 10 million raw data into 0.4 million grids data with ~130MB storage space

To produce a more compact representation, cells with similar friction value are clustered further.



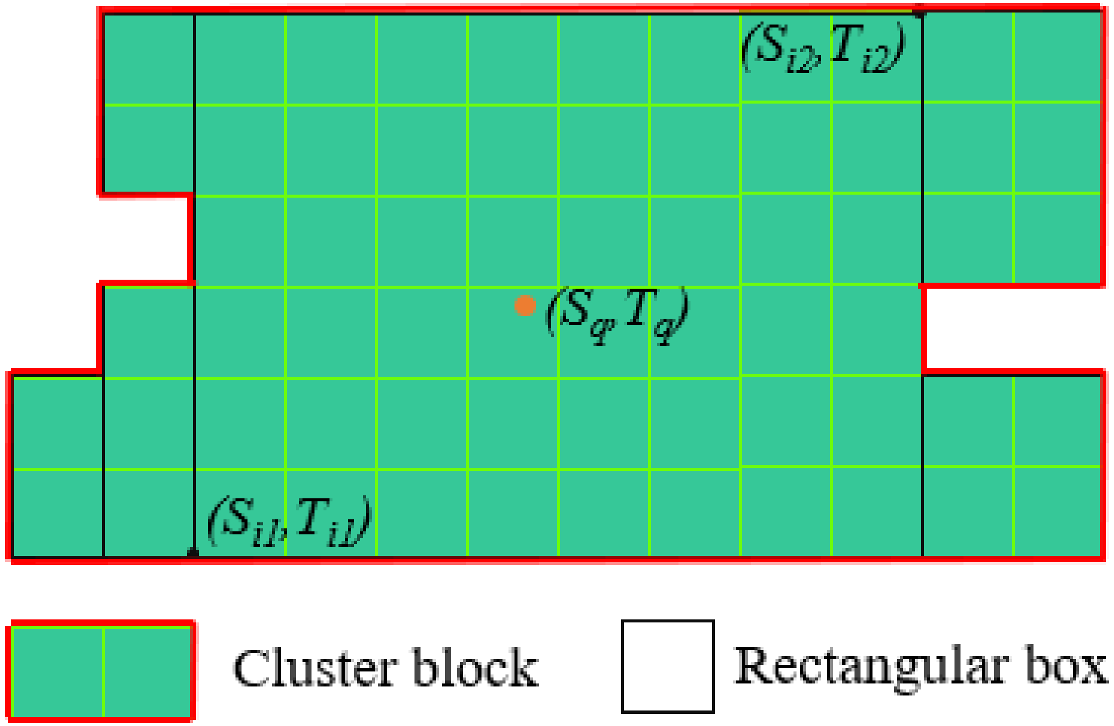
The cells with similar friction value can be grouped into clustered regions to reduce the data size. To achieve this, a spatial clustering method based on the K-Means clustering algorithm was used.





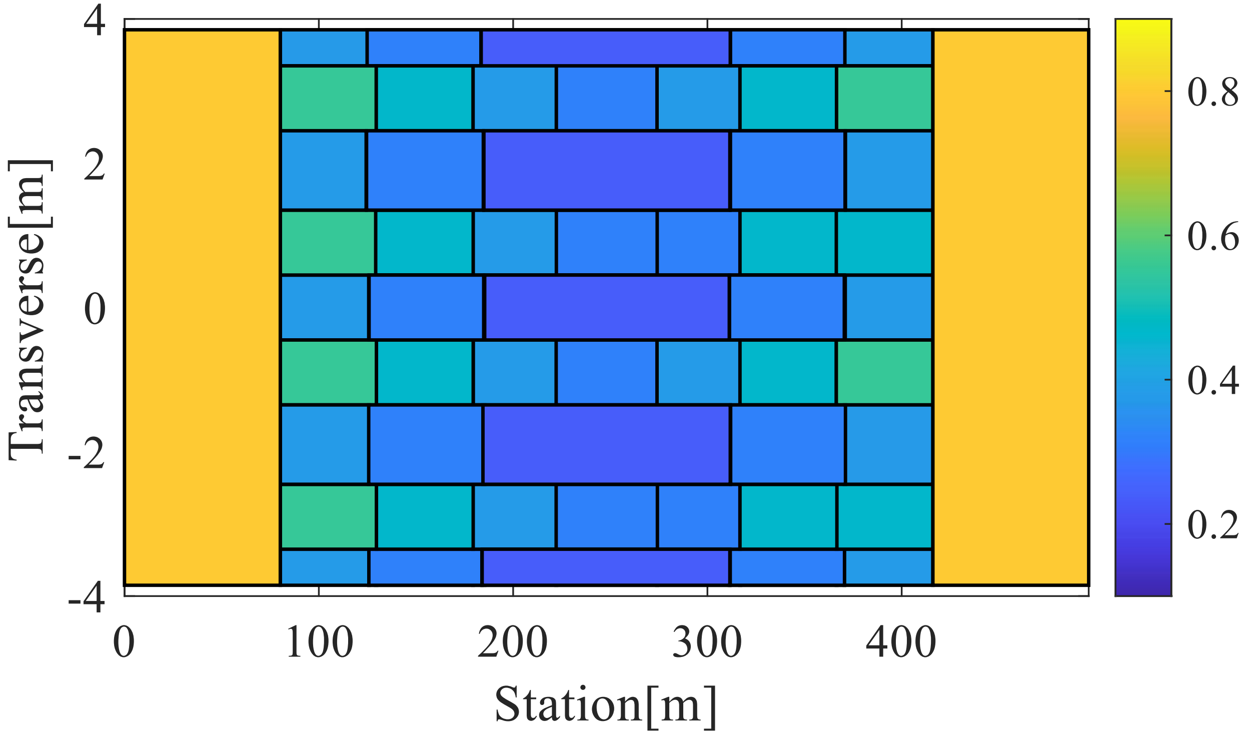
Note: The ST location values of grids are normalized into the same scale when conduct K-Means algorithm.

To represent friction regions efficiently, they are further partitioned into a collection of axis-aligned bounding boxes(AABB).



A partition example for one friction region

The road surface friction map can be represented compactly as the partition of AABB with associated friction coefficient values.



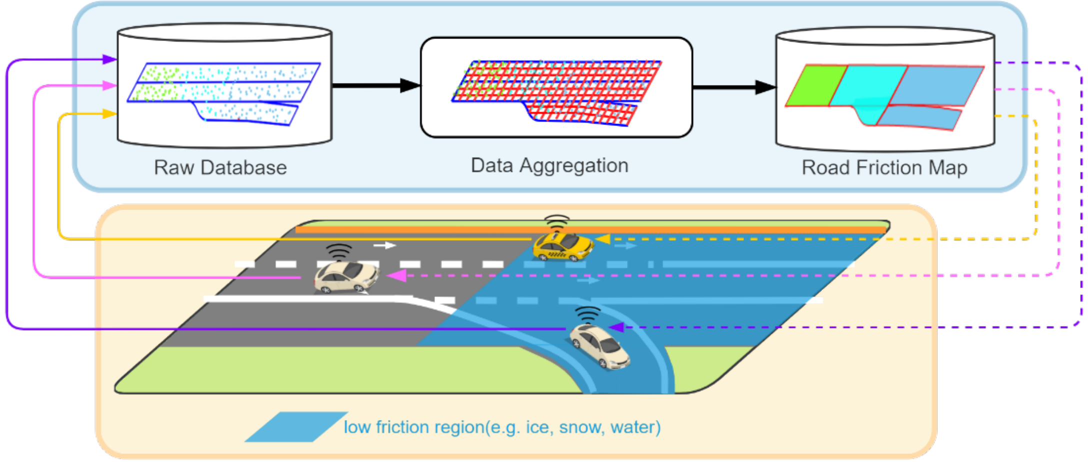
- 104 friction boxes with ~30KB of storage space
- root-mean-square percentage error(RMSPE): 5.36%

There is a trade-off between the partition granularity, i.e. the number of friction boxes, and mapping accuracy.

Interval	K	Number of friction boxes	Data size reduction percentage	Number of friction blocks	RMSE	RMSPE	MAE
0.03	15	285	99.9371%	136	0.00761	2.24%	0.019
0.05	10	177	99.9614%	91	0.0114	3.22%	0.0309
0.1	6	104	99.9771%	55	0.0180	5.36%	0.0453
0.15	5	85	99.9812%	47	0.0234	6.61%	0.0648
0.25	4	67	99.9852%	30	0.0302	8.90%	0.0779
0.3	3	54	99.9881%	12	0.0467	15.67%	0.113

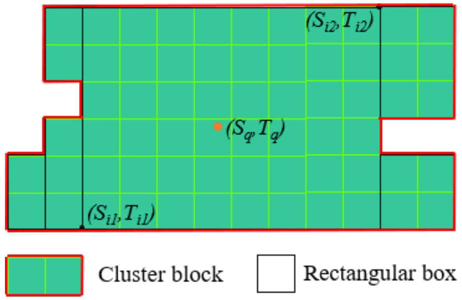
This paper presents a road friction map generation strategy by aggerating the measured road-tire friction coefficients from a fleet of CAVs.

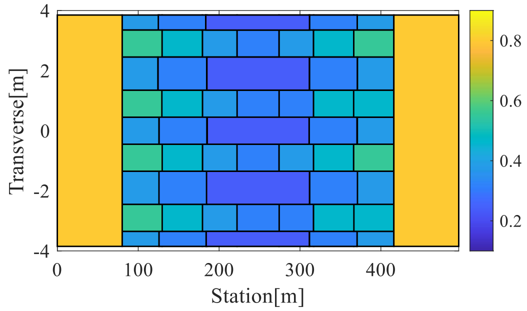
- We developed global road friction map generation strategy based on CAVs.
- The road surface condition map can be represented compactly as the partition of axis-aligned rectangular boxes with associated friction coefficient values.
- This road friction mapping strategy provides great potential for improving CAVs' control performance and stability via database-mediated feedback systems.



Thank you!

Please contact, Liming Gao, if you have further questions.
LUG358@psu.edu





Acknowledgment

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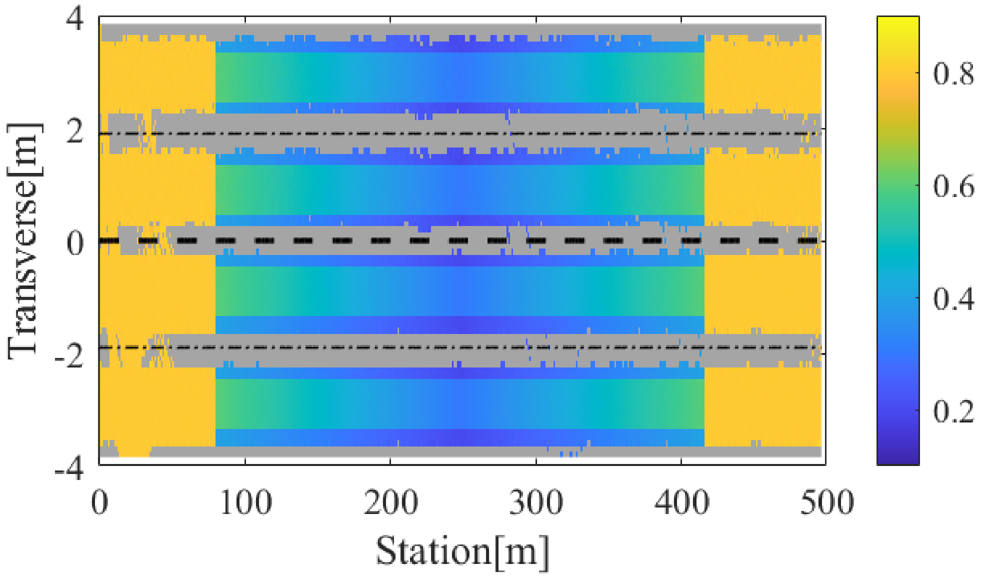
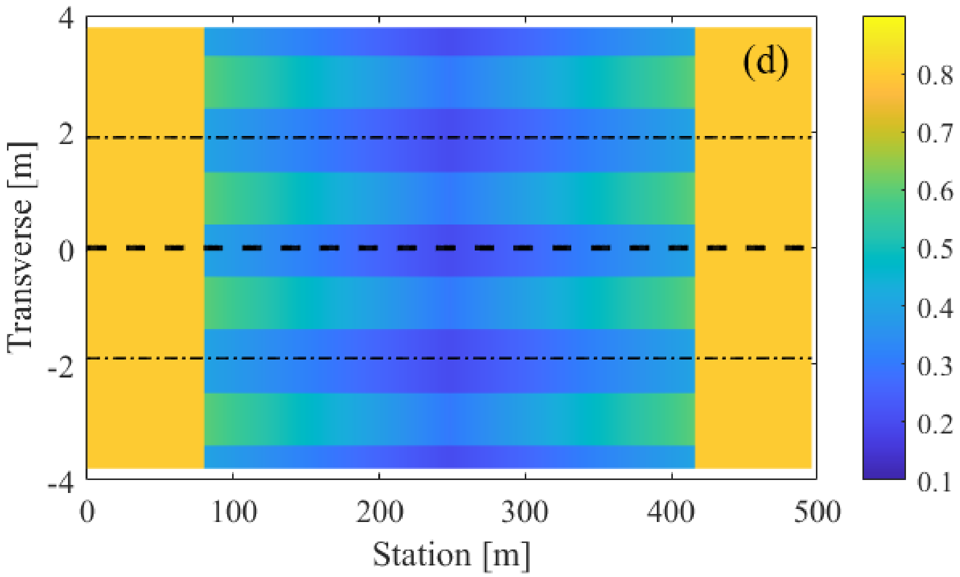
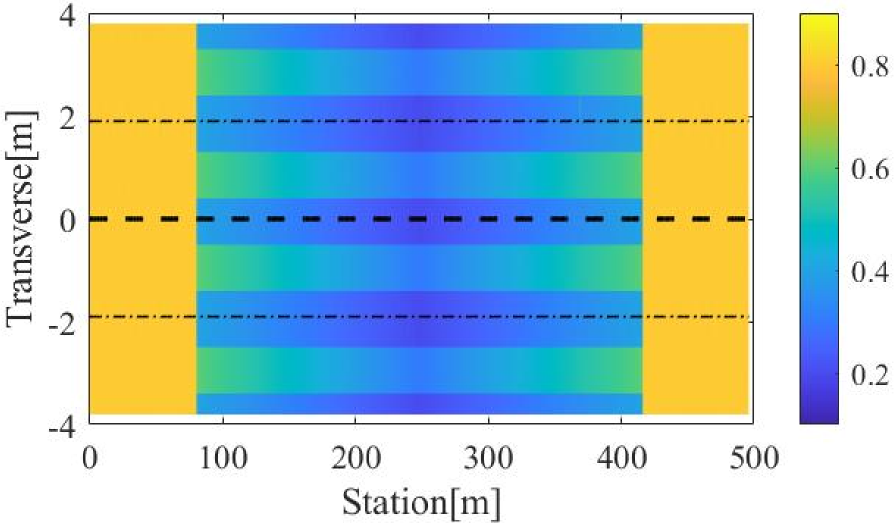


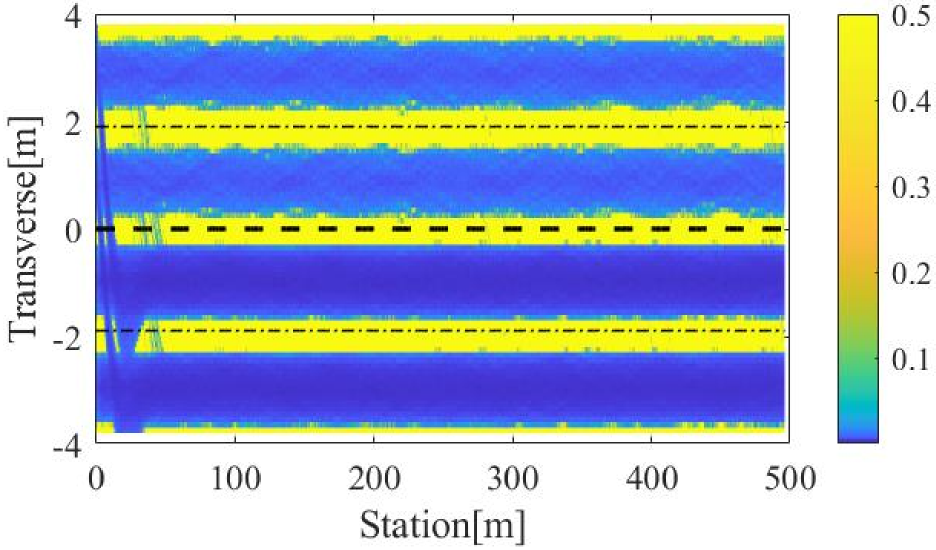
Mean of measurement data at each grid.
No measurement in grey area.



“True” friction distribution

Aggregate 10 million raw data into 0.4 million grids data fills the friction mean value to the missing data grids using its nearest non-missing grid data, and as well fills the confidence values for missing data with the worst confidence interval to indicate high uncertainty.





After correcting for missing data, the friction map is shown here and includes: (a) the friction coefficient value of each grid cell (on a scale of 0 to 1), and (b) the confidence interval magnitude of each grid cell.

The drawback of representing friction maps using boundary definitions rather than AABBs is that managing the polygon object, including data storage and the spatial query, is much less efficient in a database, especially for polygons with holes. Because most databases are designed to support AABB queries, such partitions have clear implementation advantages.