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A Novel Framework for Detecting Dangerously Slow Vehicle on Highway Corridor in a Partially Connected Environment

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Introduction

- Slow Vehicles in free flow conditions are affecting the global driving safety with required maneuvers for other drivers, like « mandatory lane changes ».
- We assume that such behaviour should affect the natural spatial distribution of lane-changes and be featured by a recognizable pattern.
- Main contributions :**
 - Introduction of a **lane change detection process with low requirements regarding the input data**, only requirement: the speed and heading time-series of Connected Vehicles (CVs) natively left by CVs through Cooperative Awareness Messages.
 - Introduction of a **slow vehicle detection process based on the weighted local density of lane changes** along a highway.

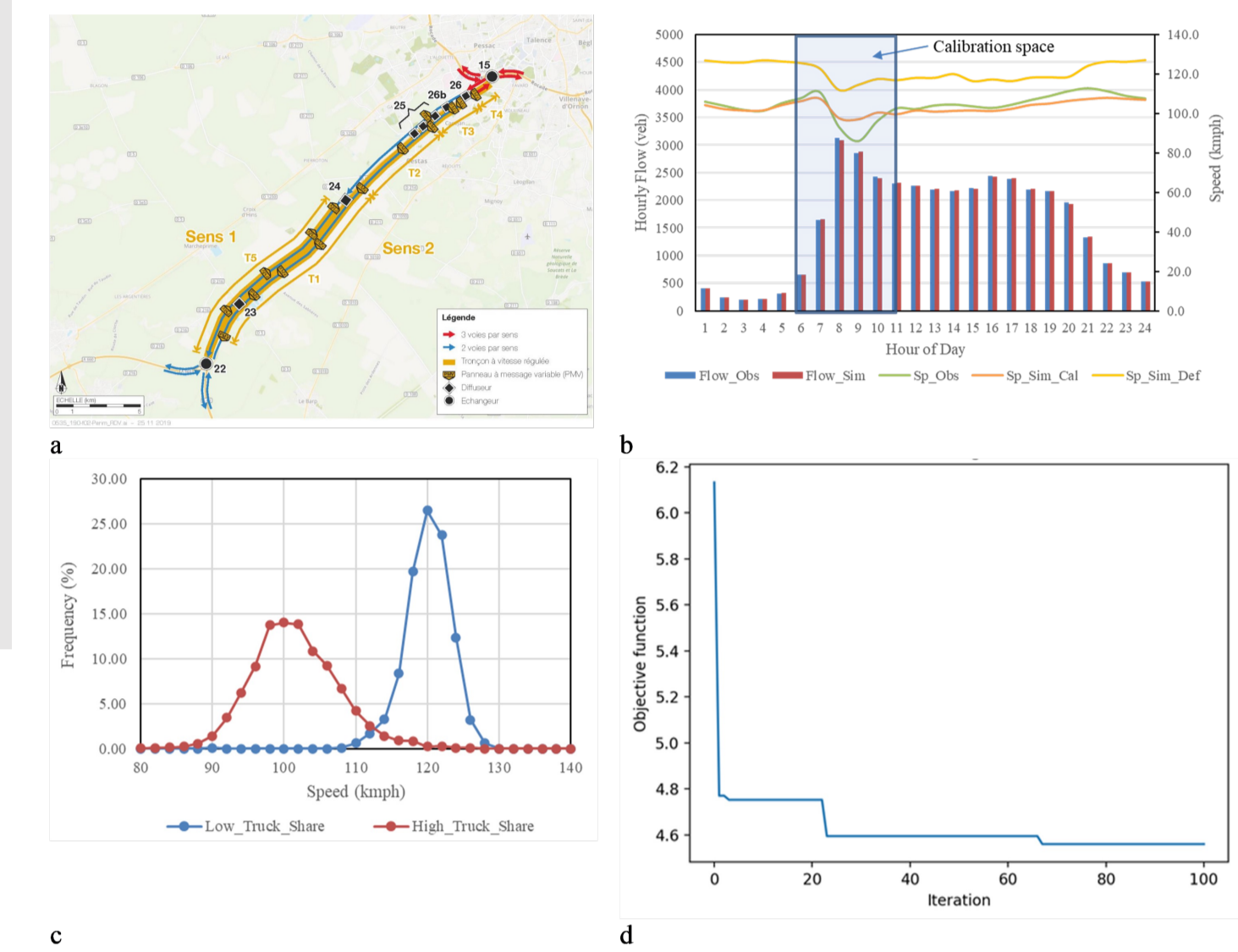
Experimental context

A fully simulated framework

- SUMO [1] is implemented with the default lane-change model [2] and a Krauss [1] car-following model calibrated thanks to a Genetic Algorithm.
- TraCI is used to dynamically collect data on Connected Vehicles with a refreshment period of 10 Hz.

TABLE 1: Default and calibrated values of selected parameters

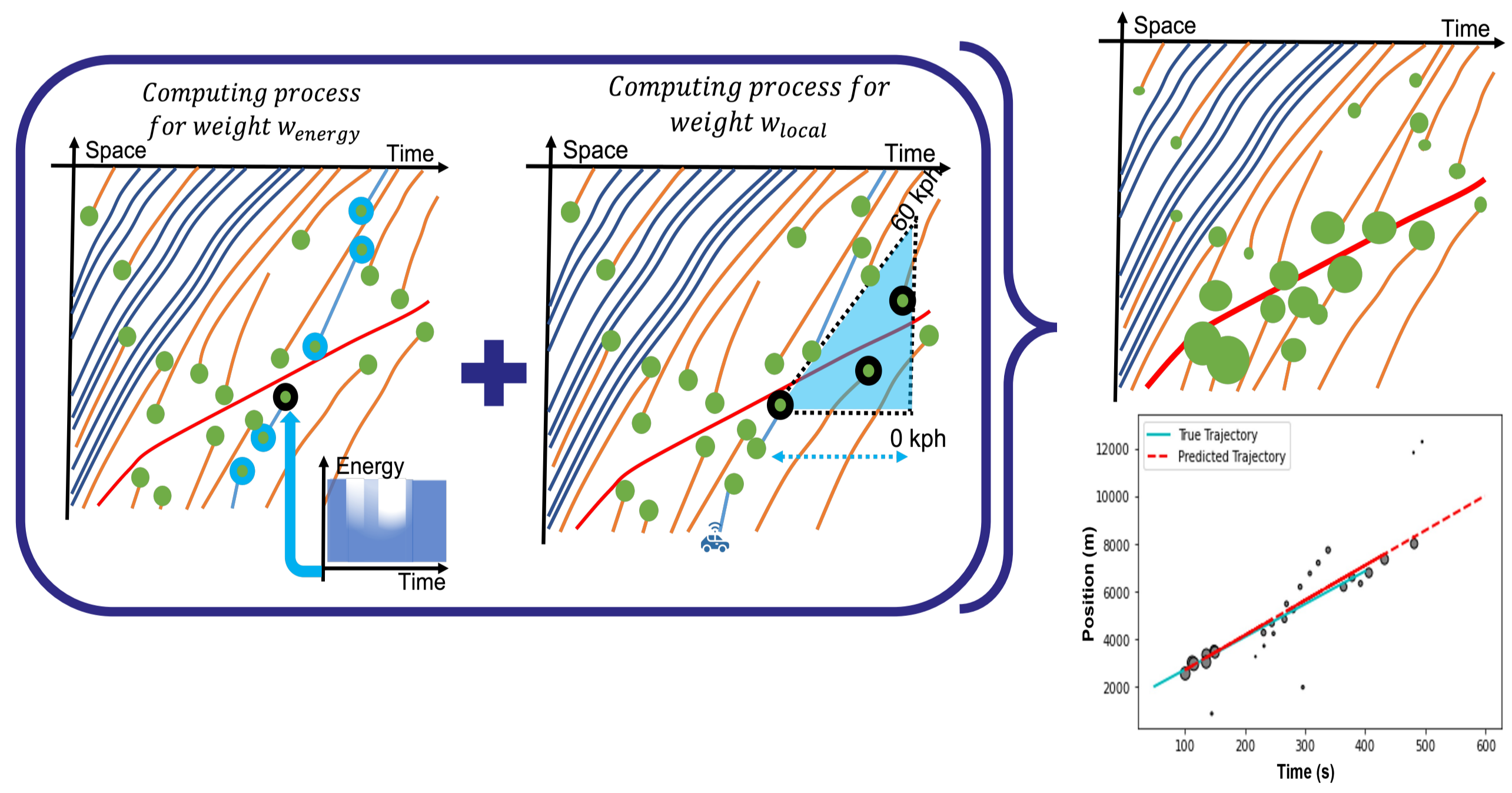
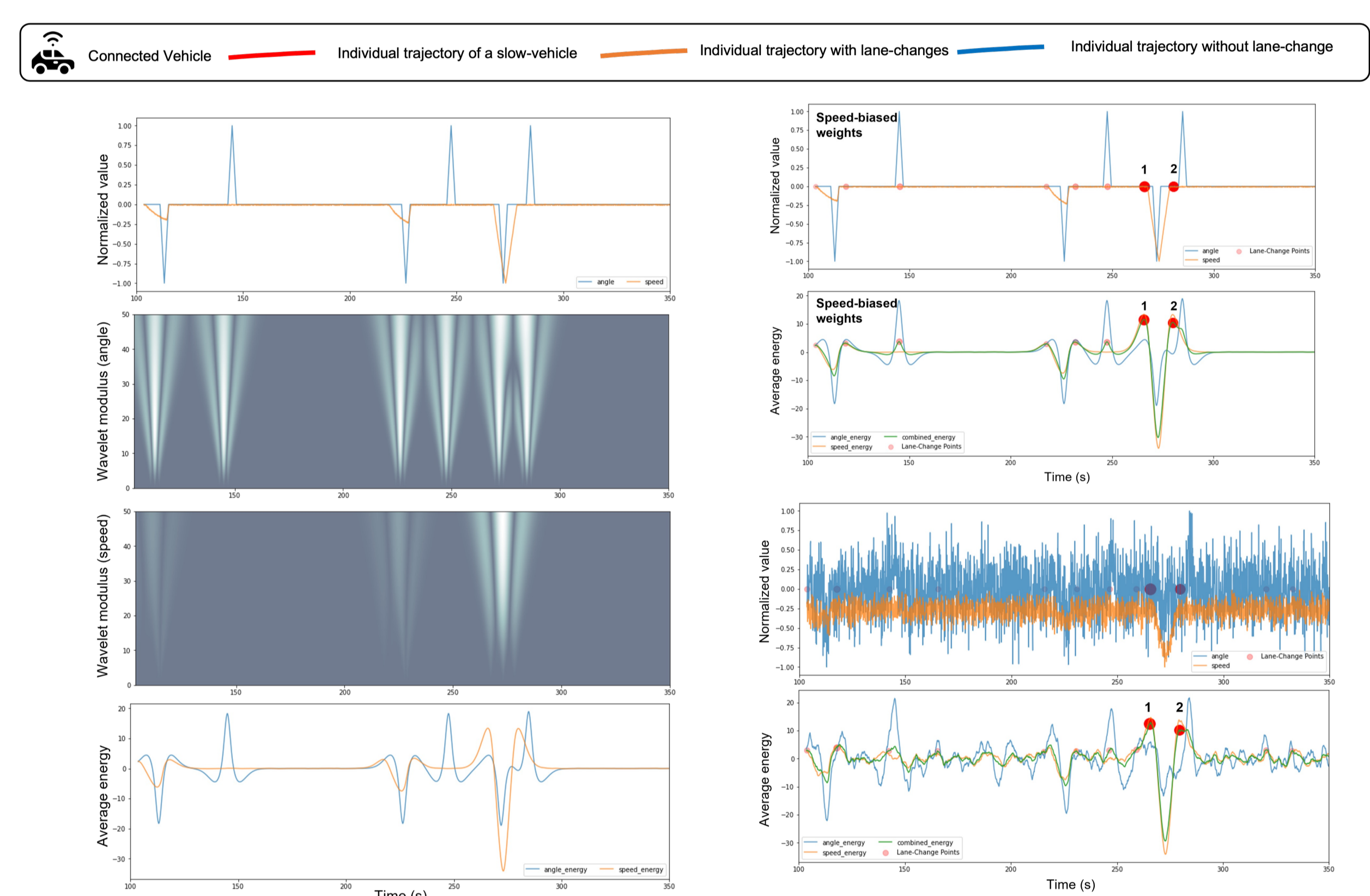
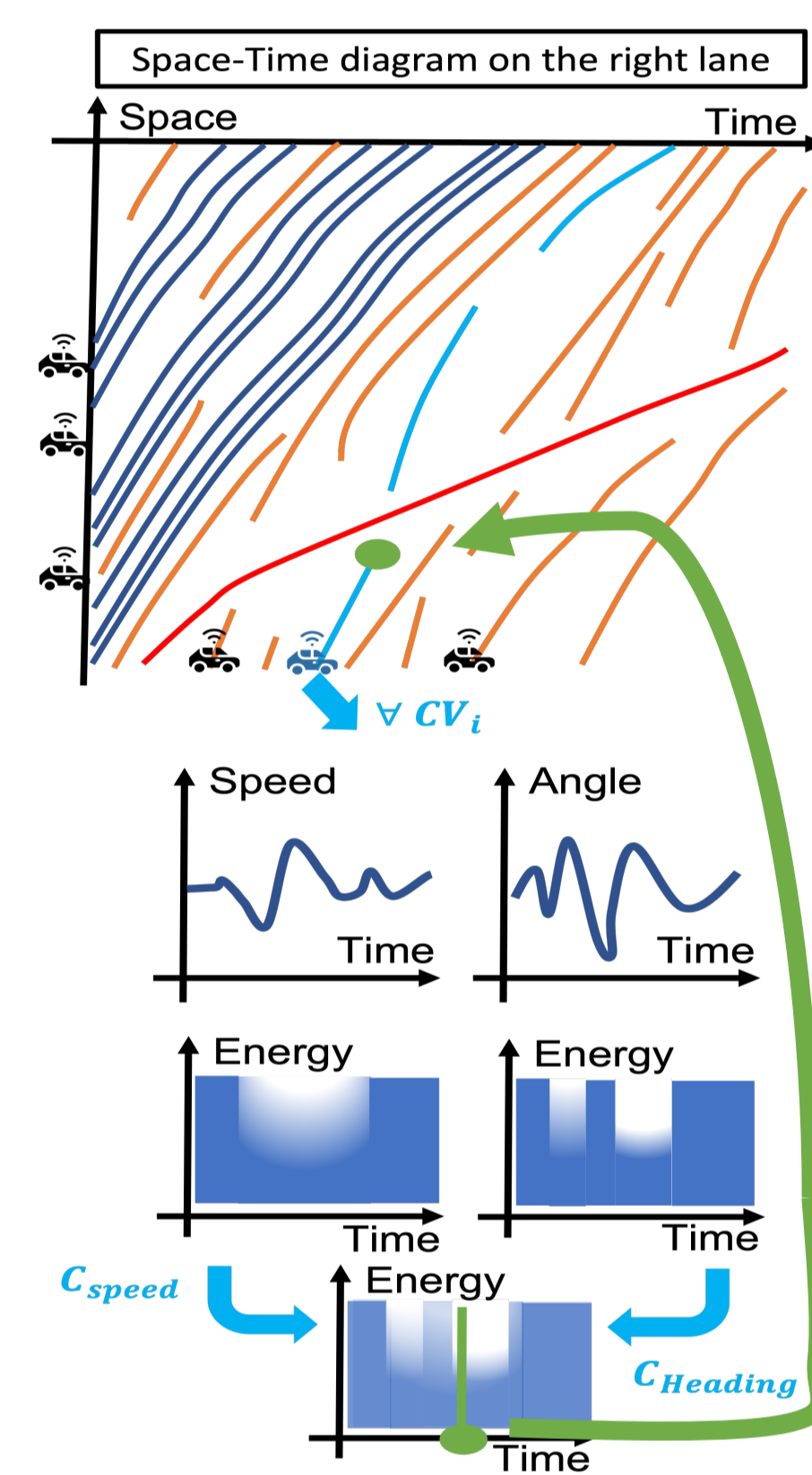
Parameter	Default Value	Calibrated Value
maxSpeed (m/s)	36.11	32.2 / 26.4
minGap (m)	2.5	2.4 / 3.15
accel (m/s ²)	2.6	2.5
decel (m/s ²)	4.5	4.65
sigma	0.5	0.7 / 0.75
tau (s)	1	1.3 / 1.5



Methodology

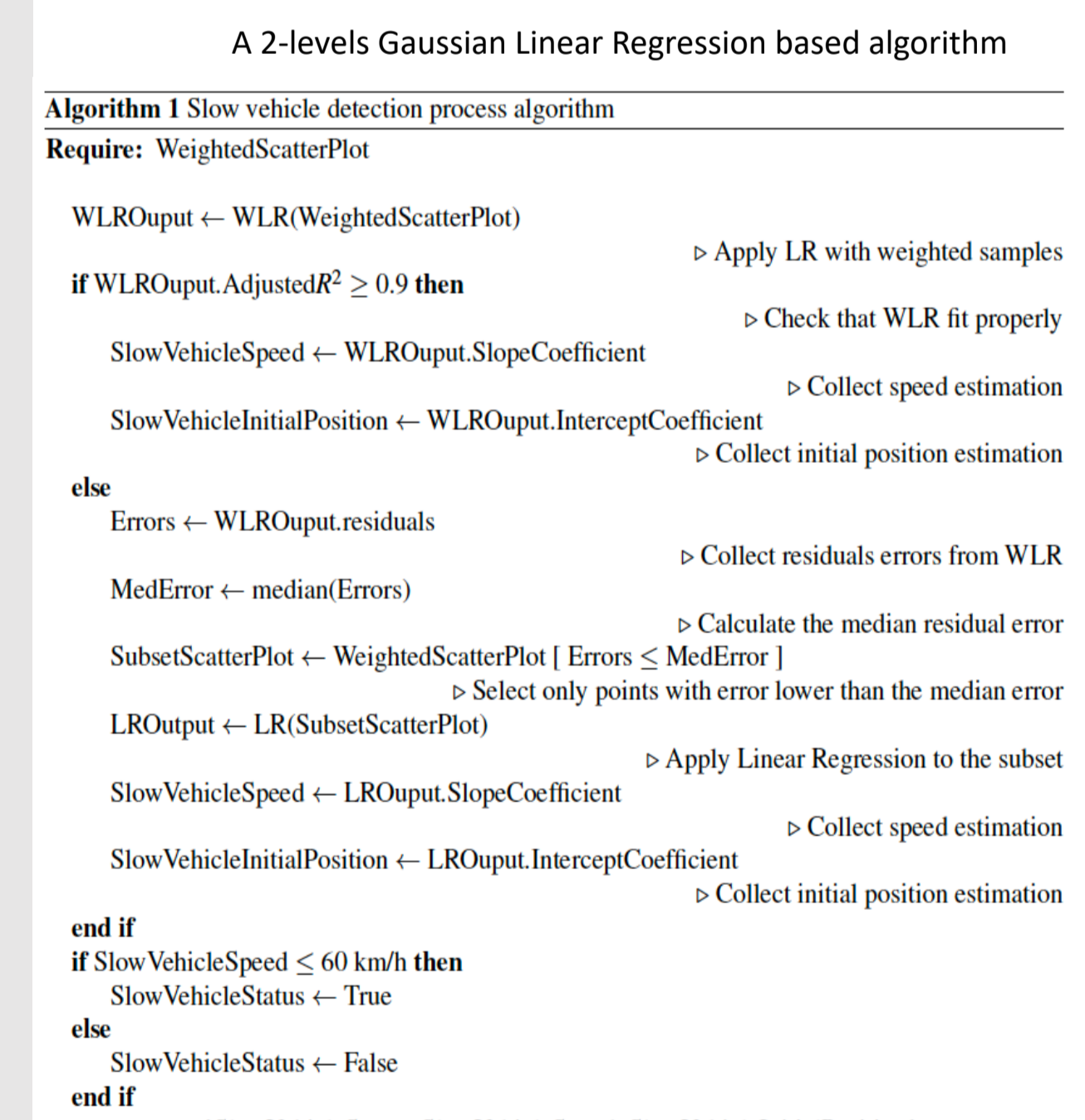
Step 1: Detecting lane-changes based on modifications of CV's energy computed by Wavelet Transform

- For a fixed time-window (60s long, updated every 30s),
 - For any Connected Vehicles (CVs),
 - The speed and steering angle profiles of Connected Vehicles (CVs) are collected and feed a Wavelet Transform (WT) analysis.
 - The energy resulting from the WT of speed and steering angle is combined into a global indicator E^{global} .
- $$\forall b, E^{global}(b) = C_{speed} \times E^{speed}(b) + C_{angle} \times E^{angle}(b)$$
- The global indicator E^{global} is compared to a threshold, when it is larger than 2.5, a lane-change is detected.



Step 2: Scatter plot analysis for slow-vehicles detection

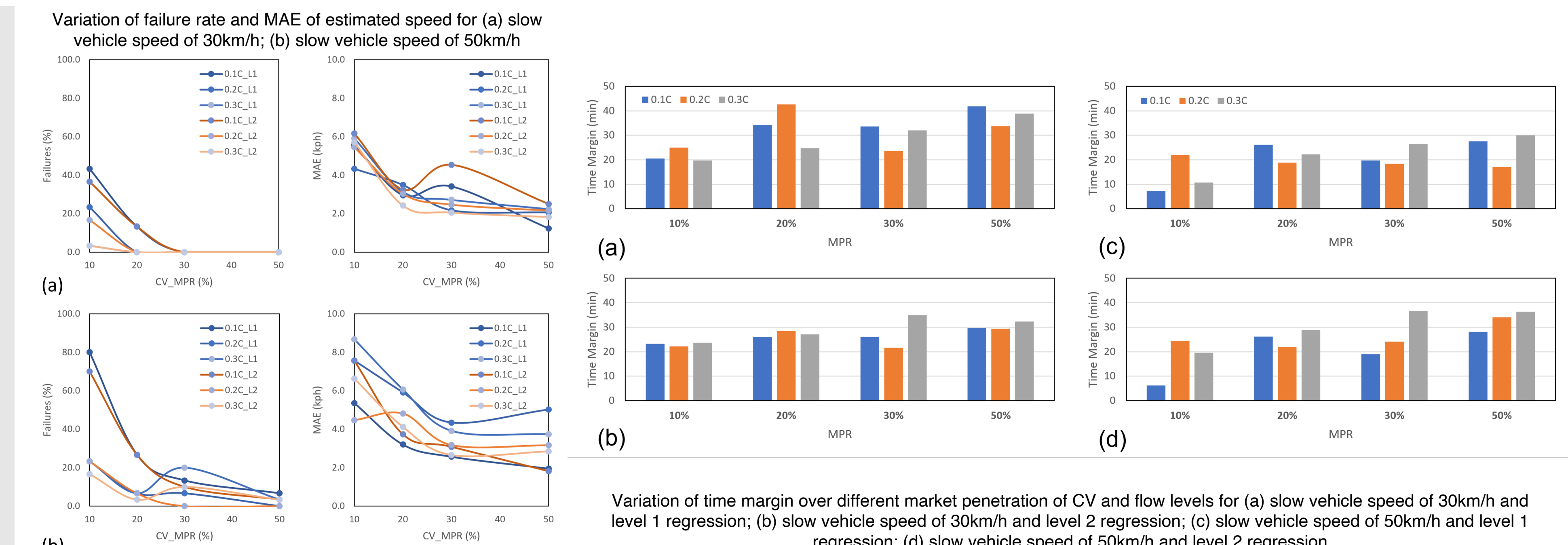
- Preliminary identified lane-changes are discriminated by computing two weights aiming at reinforcing the distinction between patterns related to slow-vehicles and other lane changes
- A weight related to the average WT energy
- A weight related to the local density of lane-changes
- A (combination of) Gaussian (Weighted) Linear Regression is then applied to approximate the potential trajectory of the slow vehicle and threshold-based criterion are set up to validate the existence of a slow vehicle.



Main results

Experimental Design

- Parameters under consideration**
 - Volume-to-Capacity ratio: 10%, 20%, 30%
 - CVs Market Penetration Rate: 10%, 20%, 30%, 50%
 - Speed of the slow vehicle: 30 kph, 50 kph
- Any unique combination of parameters was computed with 30 random seeds for stochasticity purpose
- Key Performance Indicators**
 - Failure Rate
 - Mean Absolute Error (MAE) of Estimated Speed of Slow Vehicle
 - Time Margin for Warning



Conclusions and Highlights

- The **performance** of the slow vehicle detection algorithm **stabilizes at a market penetration of 30%** which emphasizes that a high market penetration might not be necessary for deployment ;
- Globally, the **MAE is below 6km/h and 8km/h** for slow vehicle speeds of 30km/h and 50km/h respectively ;
- Because with a slow vehicle driving at 50 kph, its speed is **closer to the flow's speed**, the **failure rate is higher** ;
- Mostly, the 2-levels regression outperforms the 1-level in terms of reduced failure rates and estimated errors.

Bibliography

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- [2] Erdmann, J., SUMO's lane-changing model. In Modeling Mobility with Open Data. Springer, 2015, pp. 105–123.
- [3] Zheng, Z., S. I. Ahn, D. Chen, and J. Laval, Applications of wavelet transform for analysis of freeway traffic: Bottlenecks, transient traffic, and traffic oscillations. Transportation Research Part B: Methodological, Vol. 45, No. 2, 2011, pp. 372–384.