Exploring the impact of microscopic features of traffic on macroscopic patterns

Vincenzo Punzo

University of Naples Federico II, Italy

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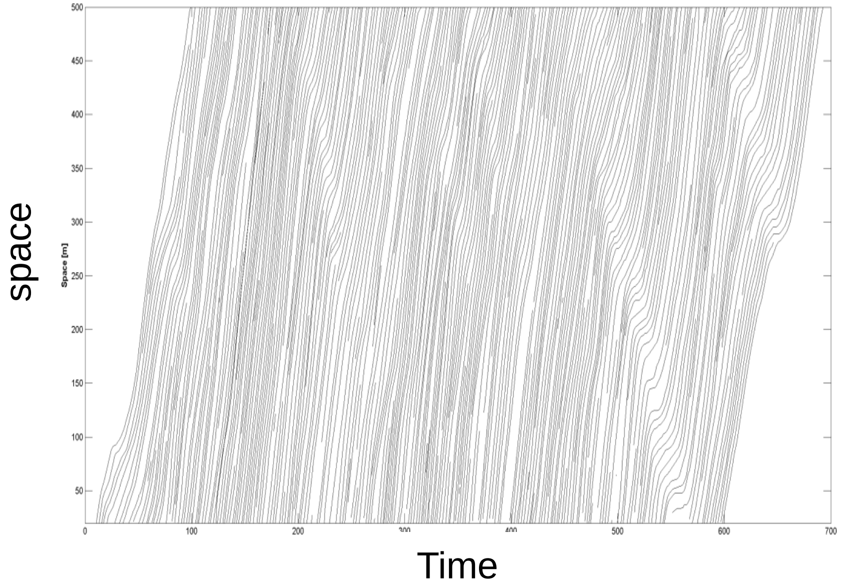
Contributors

- **Marcello Montanino**
- **Biagio Ciuffo** (now at the European Commission Joint Research Centre)

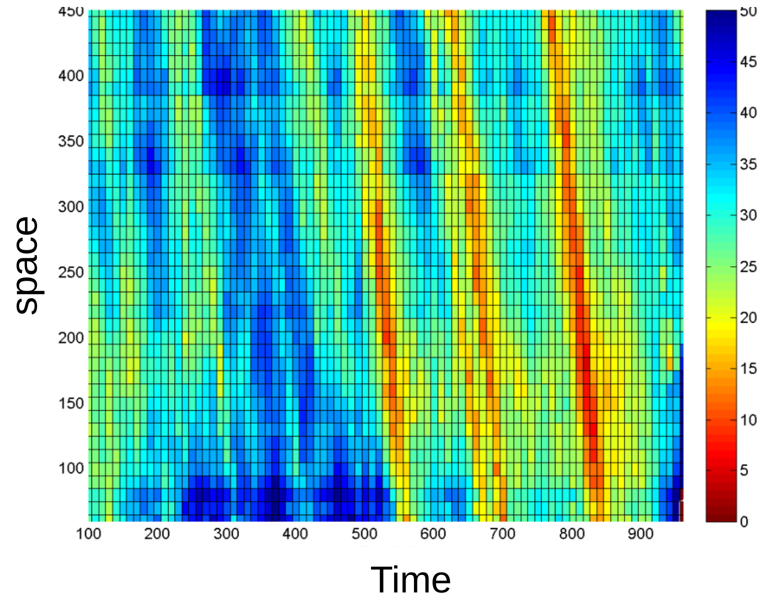
The twofold representation of traffic provided by NGSIM(-like) data

- NGSIM: trajectory of each single vehicle crossing the observed time-space domain → *spatiotemporal traffic patterns from microscopic data*
- Other traffic data: very partial view of the traffic phenomenon

Time-space trajectory plot



Time-space Edie's speed contour plot



- The traffic scientific community has not yet thoroughly exploited this twofold 'value' of NGSIM data

Twofold representation and TFT studies (1)

In microscopic modelling of traffic:

- We rather know how each single component works alone:
  - ✓ Theorethical investigations and empirical analyses of single 'driver' models (CF or LC models)
  - ✓ In car-following, most often single-lane, homogeneous-flow assumptions
  - ✓ Calibration and validation on disaggregate data focused on riproducing the single behaviour

- We do not really know what happens when single components interact in a stochastic traffic simulation environment:
  - ✓ Interaction effect of LC and CF decisions (i.e. of models output)?
  - ✓ Impact of parameter heterogeneity?
  - ✓ Impact of assumptions on the probabilistic model of parametric inputs?

Twofold representation and TFT studies (2)

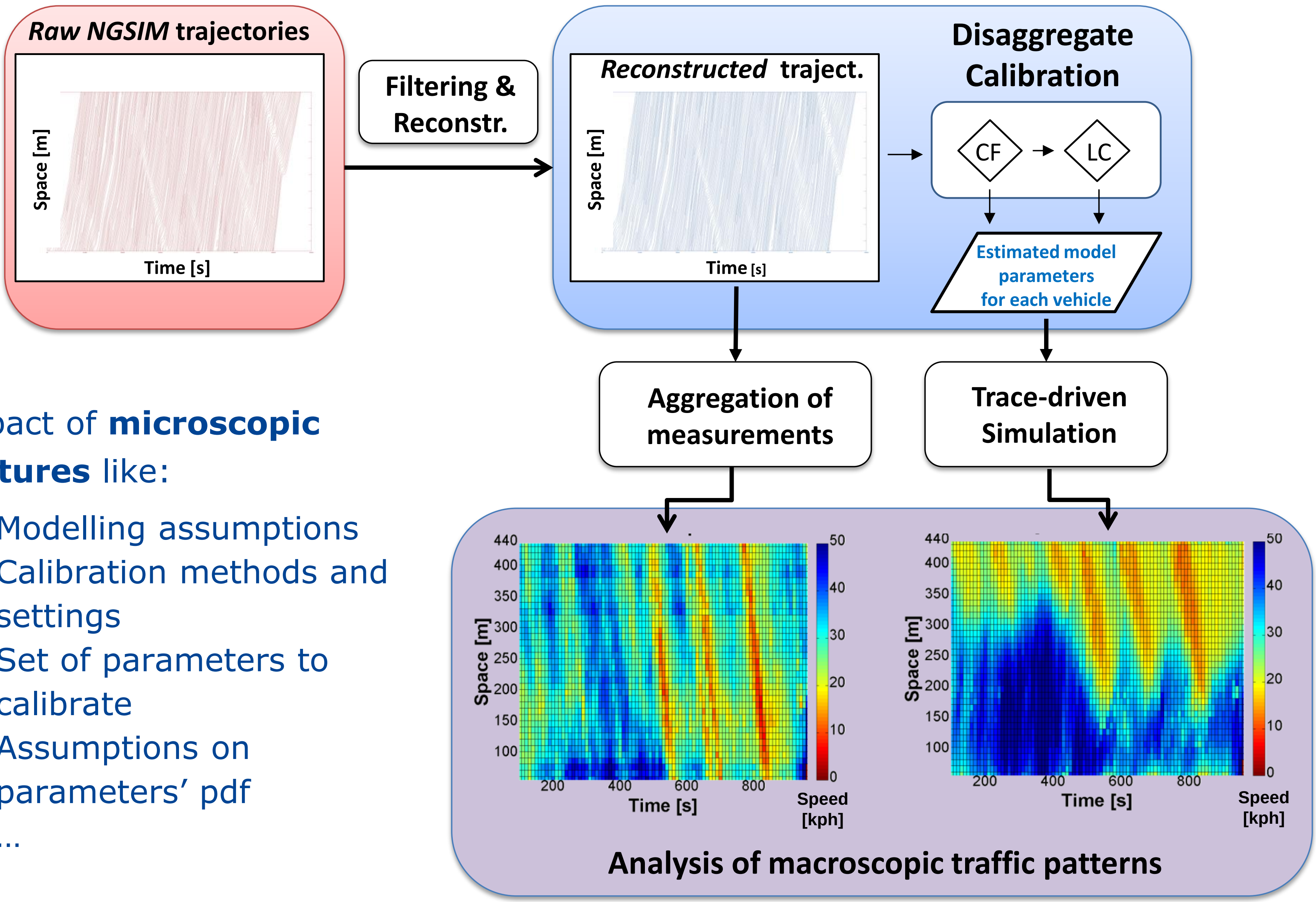
- What is the impact of microscopic features and assumptions on the collective behaviour of traffic? i.e. as captured by spatiotemporal congested patterns?
  - ✓ Spatiotemporal patterns are not the most often used measure to investigate microscopic models (often in simple settings like e.g. car-following only; Treiber & Kesting, 2012, *TR-C*)
- **Dichotomy** between microscopic TFT and traffic micro-simulation
  - ✓ Traffic simulation outcomes mostly investigated by means of time series or frequency plots

Methodology in extreme synthesis

- Using **measured and simulated** *macroscopic spatiotemporal traffic patterns* to investigate impact of *microscopic features*

- Calibrating on disaggregate data and validating on collective data

Analysis framework



Impact of **microscopic features** like:

- Modelling assumptions
- Calibration methods and settings
- Set of parameters to calibrate
- Assumptions on parameters' pdf
- …

Calibration of IDM and MOBIL

(Treiber et al., 2000, *Ph. Rev. E;* Kesting et al., 2007, *TRR*)

- **IDM**:
  - ✓ $\min_{\beta}\{\text{RMSE}(spacing)\}$
  - ✓ OptQuest Multistart *(Punzo et al. 2012, TRR)*
  - ✓ Uncertainty analysis and physical informed criteria to set parameters bounds *(Punzo et al. 2014, IEEE T-ITS)*

- **MOBIL** (no calibration attempts in literature; (*) Zheng, 2014, *TR-B*):
  - ✓ The lane-changing event is rare → not interested in the instant and its traffic conditions but in the prevailing traffic conditions that generate it
  - ✓ scenario → leaders & followers in current and target lanes do not change
  - ✓ $\min_{\beta}\left\{\frac{\#\text{LC}}{\sigma_{LC}}+\frac{\#\text{noLC}}{\sigma_{noLC}}\right\}$; where:

    #LC = number of unsuccessful LC scenarios (*1-detection rate*$^{(*)}$)

    #noLC = number of unsuccessful noLC scenarios (*false alarm rate*$^{(*)}$)

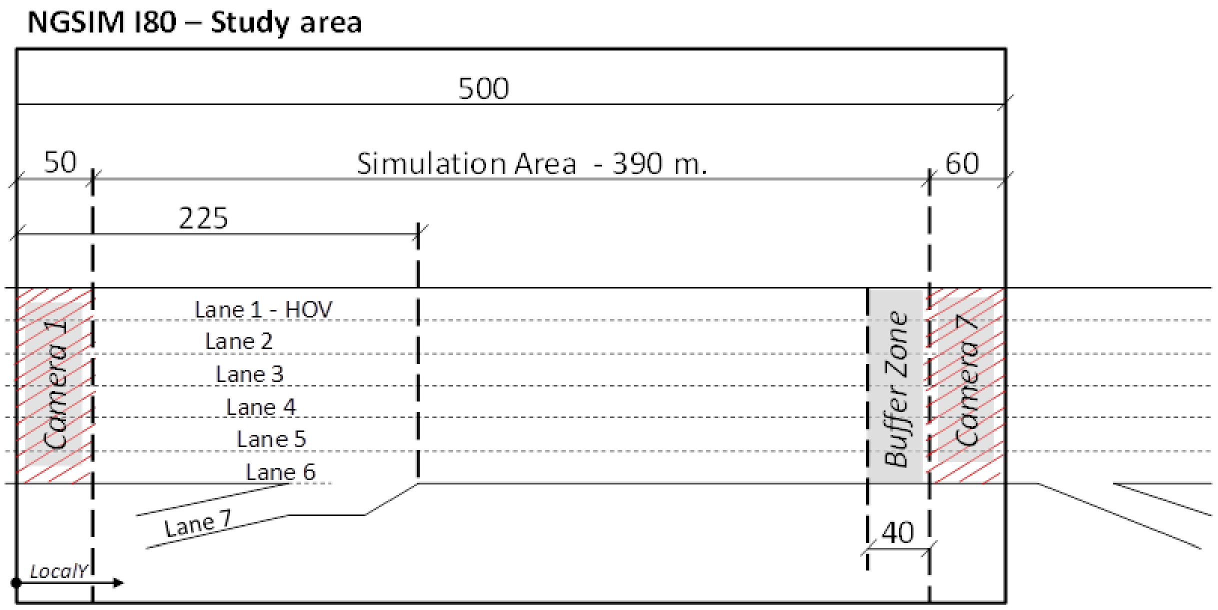
    σ_{LC} e σ_{noLC} computed through Monte Carlo uncertainty analysis

Calibration of MOBIL (2)

- ✓ MOBIL LC model calculates the potential advantage of all the vehicles involved in the LC maneuver in terms of acceleration, as given by the IDM model;
- ✓ MOBIL calibration is therefore conditional on the IDM calibration;
- ✓ In calibration:
  - ✓ vehicles are moved according to the NGSIM measurements (and not using the IDM).
  - ✓ The IDM is used to calculate accelerations yielding the potential advantage, by using for each vehicle its own IDM calibrated parameters;

Trace driven micro-simulation (NGSIM I80)

- **Trace-driven** traffic micro-simulation → *fair comparison*
  - Vehicle insertion as in measured data
  - Downstream conditions superimposed to exiting vehicles
  - …
  - *Car-following*: **IDM**
  - *Lane Changing*: **MOBIL**
  - *Merging*: mandatory lane-changing with MOBIL



NGSIM DATA ERROR ANALYSIS AND RECONSTRUCTION

Background on analysis of NGSIM data

Thieman, Treiber & Kesting, 2008, *TRR*

- Because of the noise in the positional data, velocity and acceleration information cannot be extracted directly
- Symmetric exponential moving average filter to be applied “to all trajectories before any further data analysis”

Punzo, Borzacchiello & Ciuffo, 2009, *TRB*; 2011, *TR-C*

- General methodology to quantify the degree of accuracy/bias in vehicle trajectory data
- Different criteria:
  - ✓ Analysis of accelerations, jerks, amplitude frequency spectrum
  - ✓ Internal consistency, platoon consistency
- Application to all the NGSIM datasets
- High level of measurement errors
- 4.0-12.4% of leader-follower couples show unphysical inter-vehicle spacing

Opened issues

- To which analyses can NGSIM data be reliably applied to without any processing?
- Which is the impact of such errors on analyses made on NGSIM data?
- Which the accuracy requirements for future data gathering?
- …

- Since 2012, 5 out of 19 studies published on journals(*) using NGSIM trajectories applied some kind of filter to data:
  - ✓ 2 out of 11 on car-following
  - ✓ 3 out of 8 on lane-changing

(*) source Scopus, accessed 28/07/2014

Filtering NGSIM data

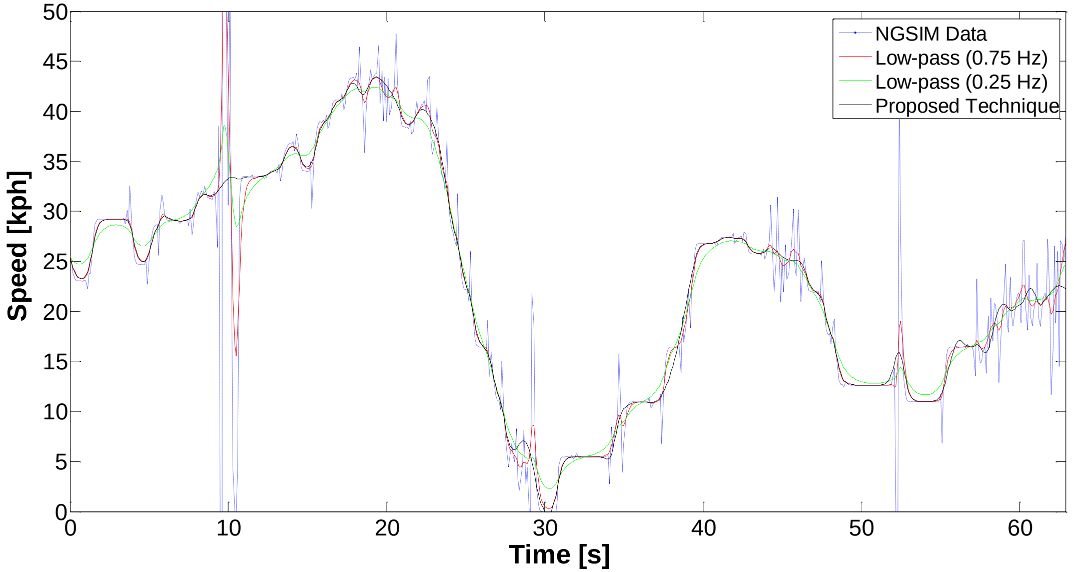
- Usual filtering techniques are inadequate (e.g. kernel smoothing)
- If you cannot filter the data, just throw them away...
- If the time window of eliminated points is short, lots of available information/constraints to reconstruct the missing trajectory:
  - ✓ space travelled within the window;
  - ✓ physical capabilities of cars;
  - ✓ car-following dynamics (inter-vehicle spacing integrity).

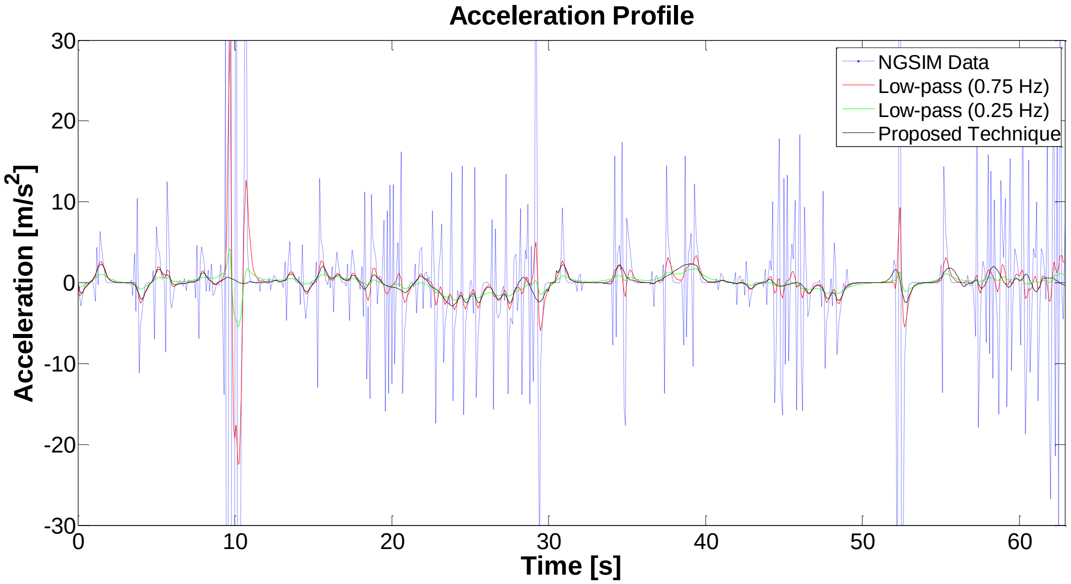
➔ **Multi-step reconstruction procedure**

Montanino and Punzo 2011, TRR
Montanino and Punzo 2015, TRB

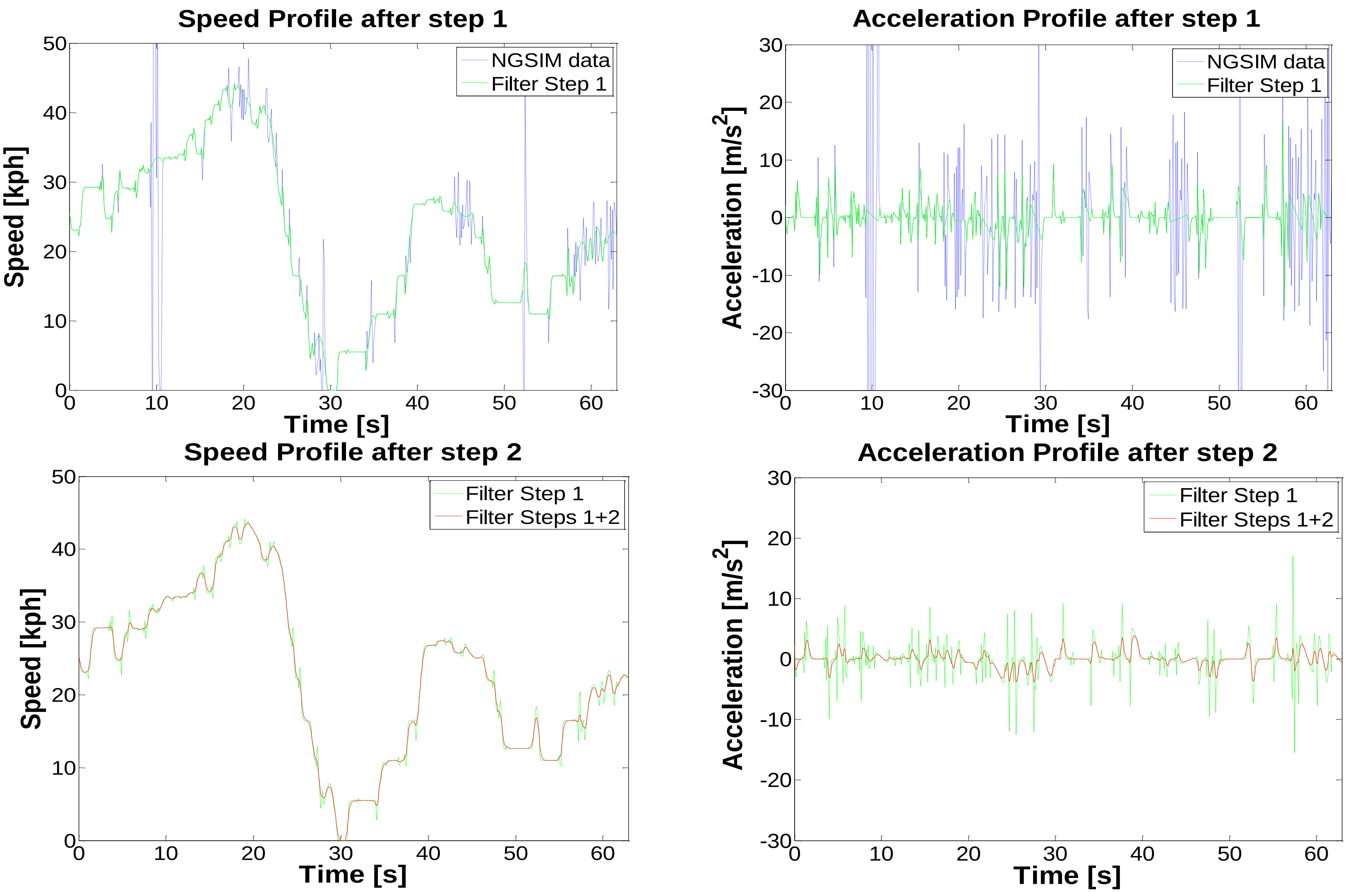
Application to I80-1 dataset (available at www.multitude-project.eu)

Inadequateness of low-pass filters

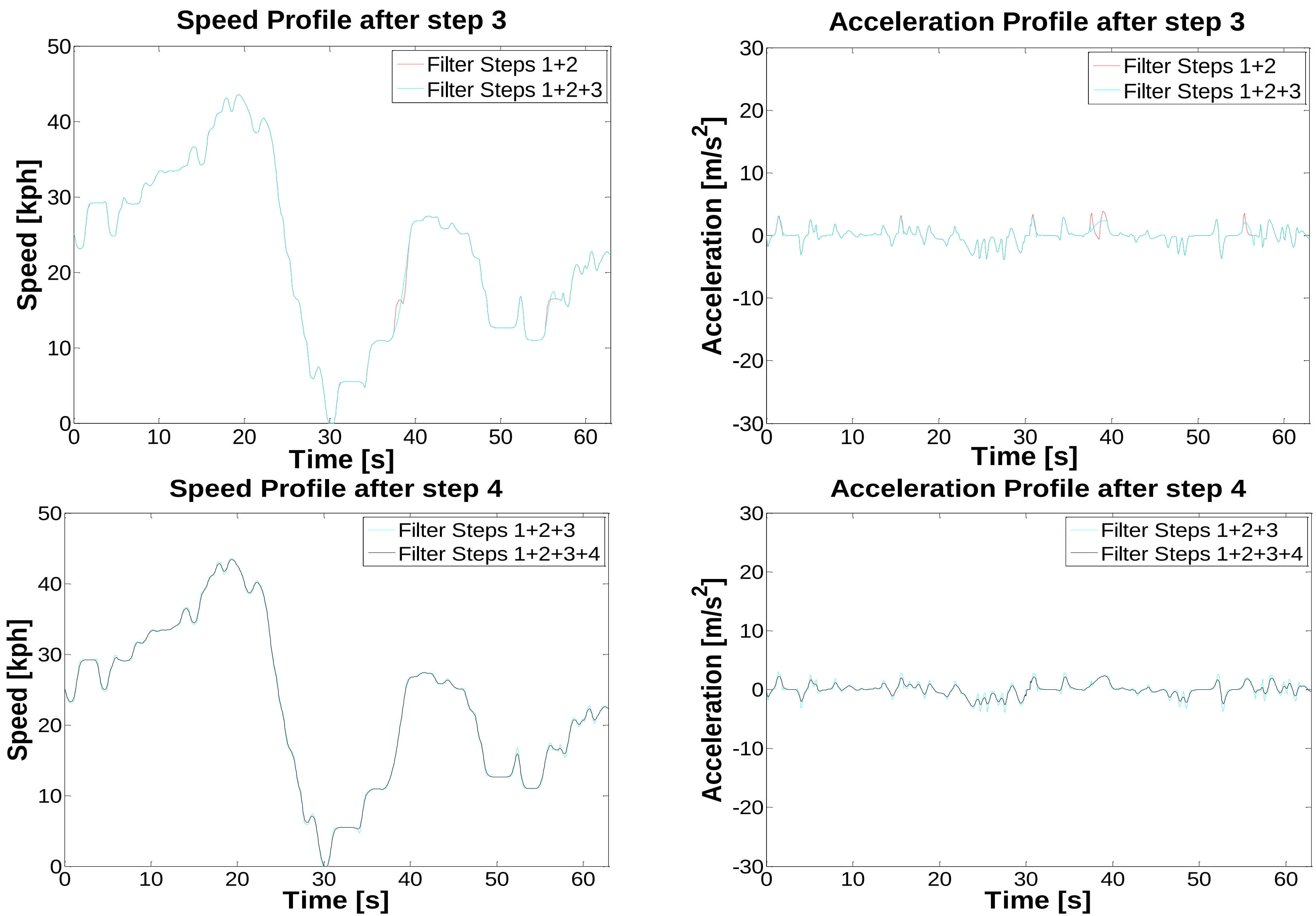




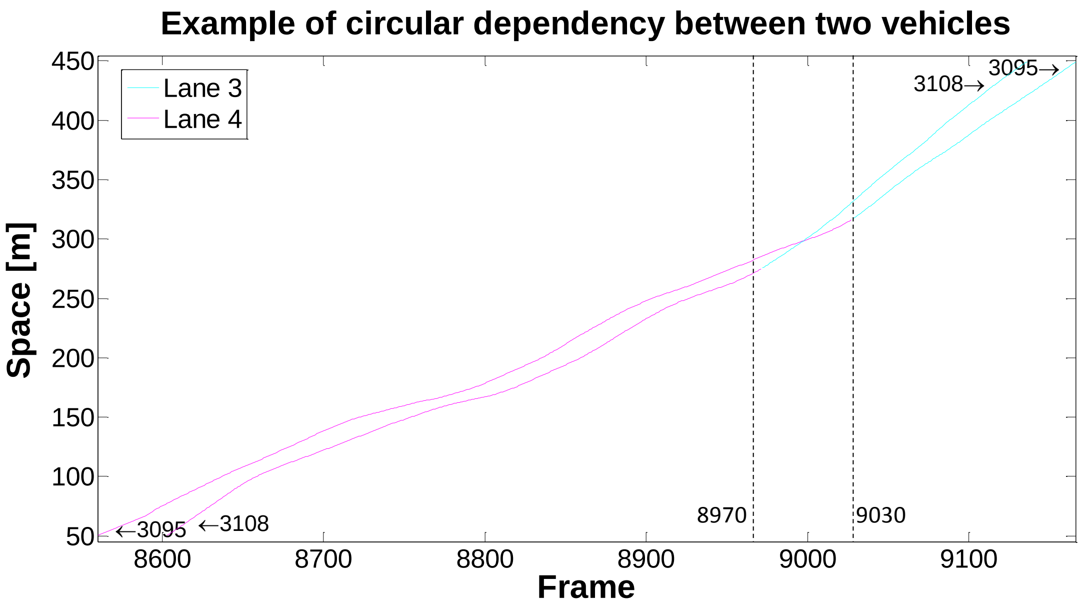
Removal of: *1)* outliers and *2)* noise

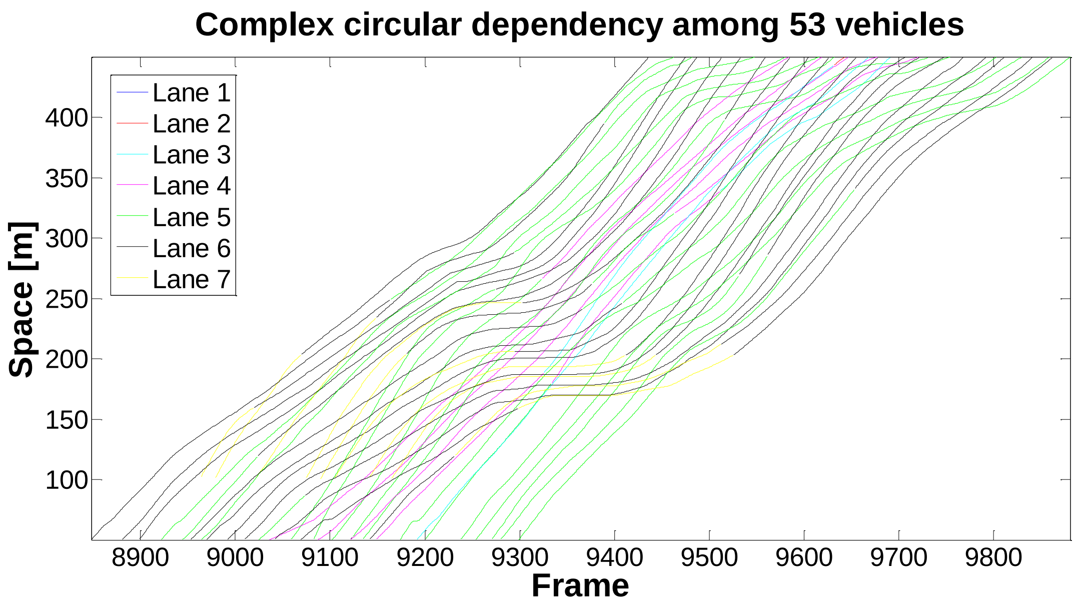


3) reconstruction *4)* residual noise removal

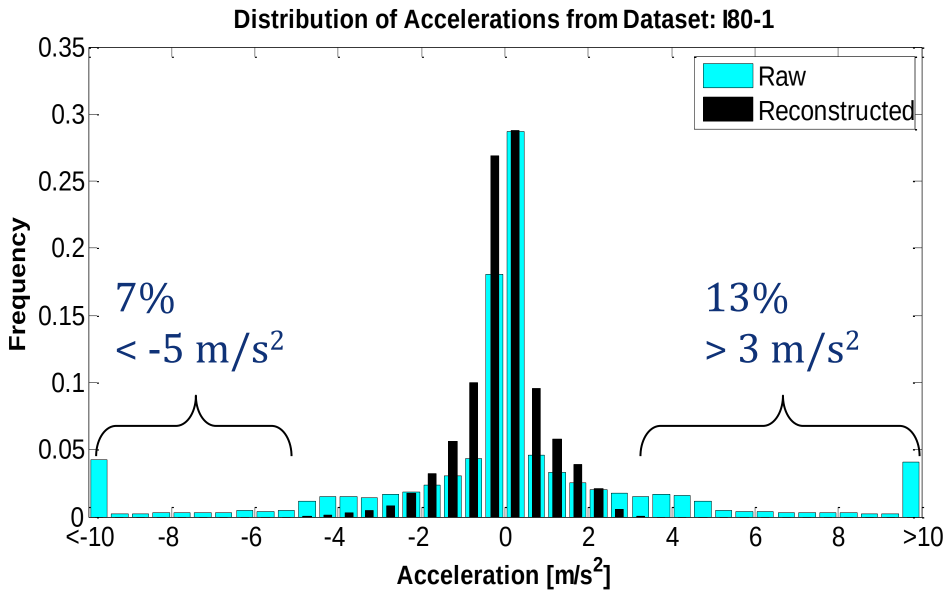


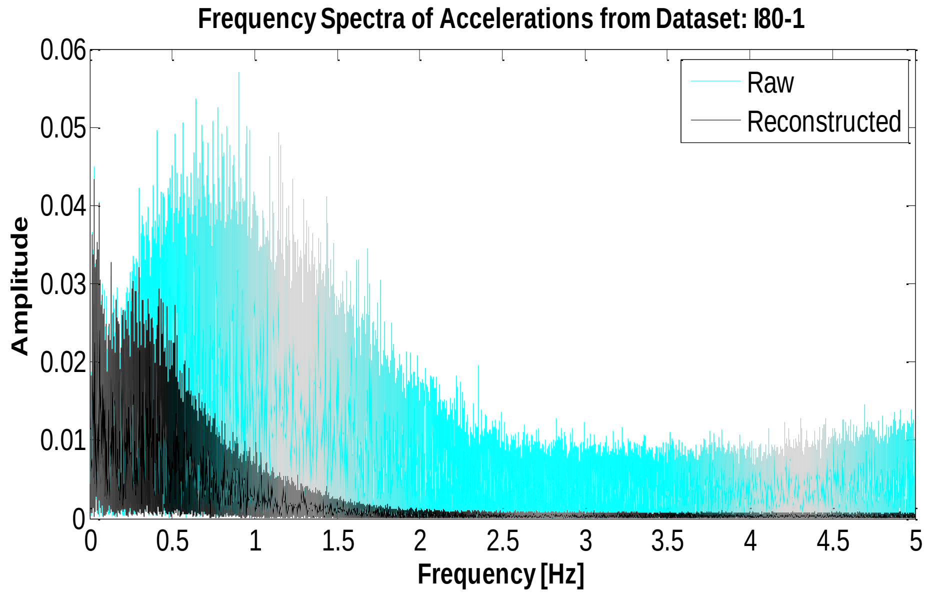
Imposing platoon consistency

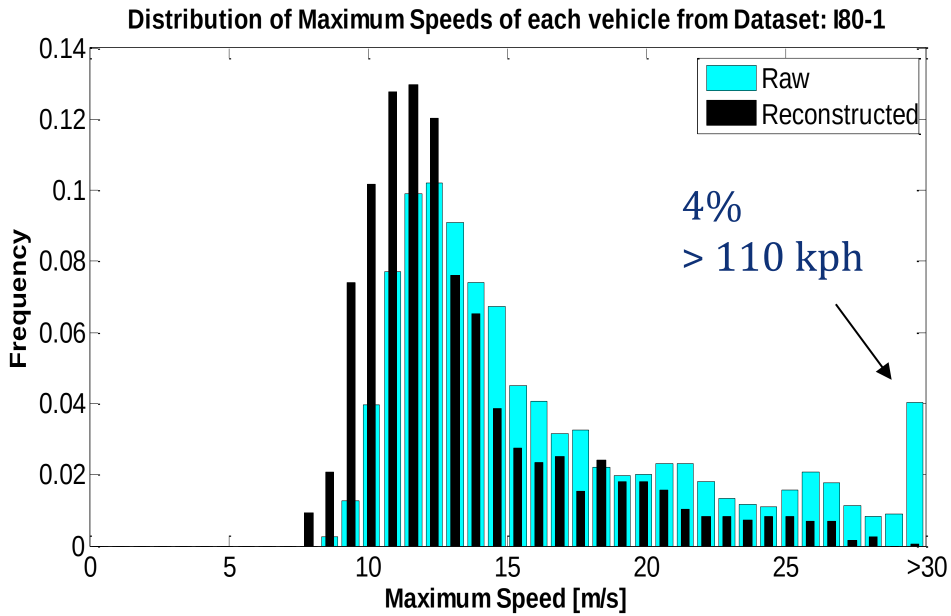


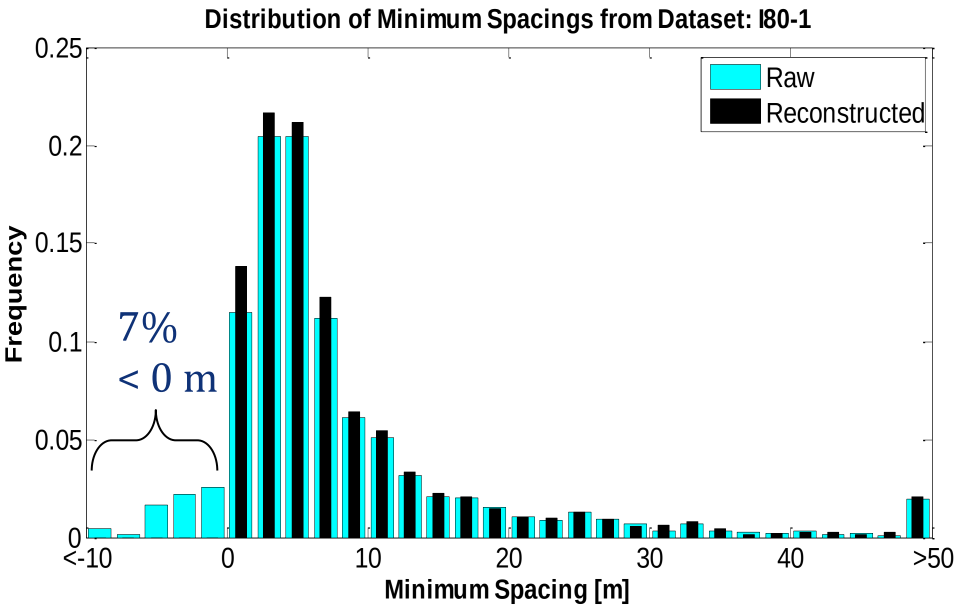


Raw vs. Reconstructed trajectories (I80-1)



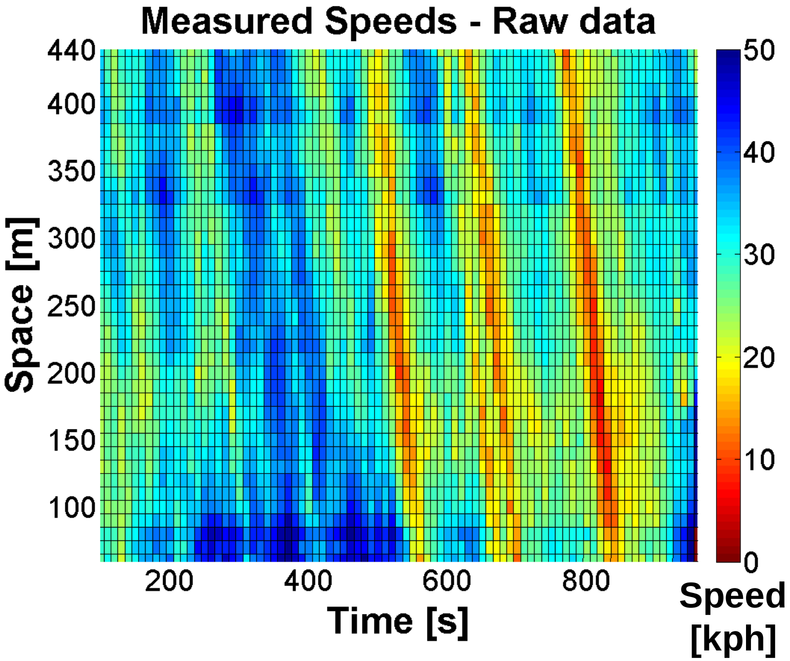


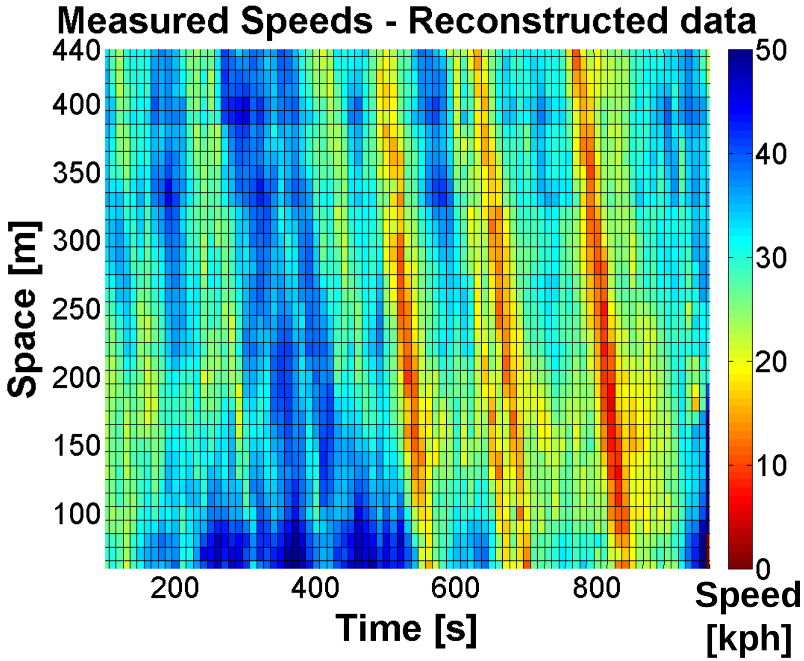




Raw vs. reconstructed macroscopic patterns

resolution 10m x 10s





Aggregating trajectory data, differences are barely visible

IMPACT OF MEASUREMENT ERRORS ON CALIBRATION OF DRIVER MODELS (CF AND LC)

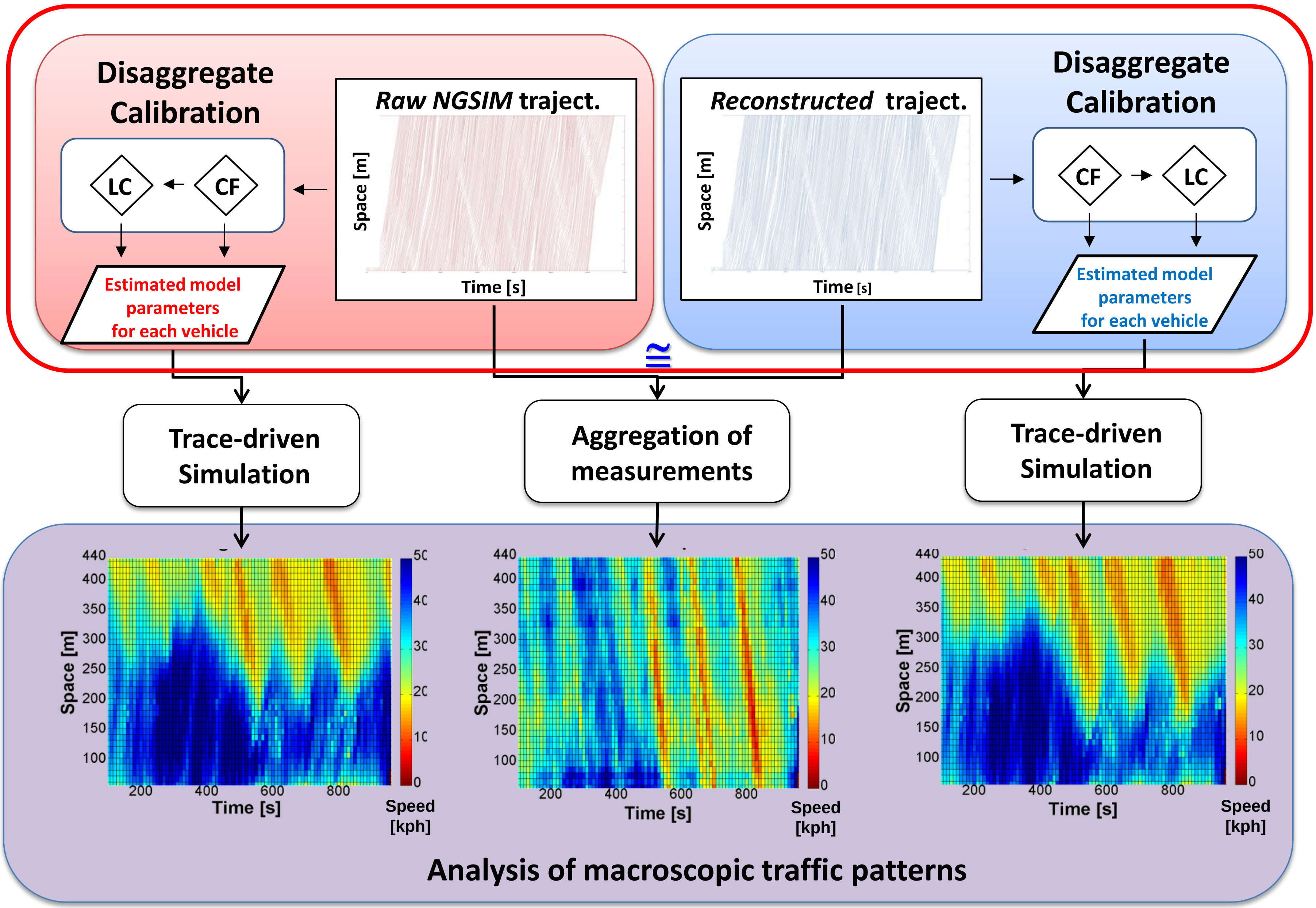
Impacts of trajectory measurement errors: background

- Ossen and Hoogendoorn, 2008, TRR
  - ✓ Impact of errors on calibration of car-following models
  - ✓ Experiment with synthetic data
  - ✓ white Gaussian noise assumption

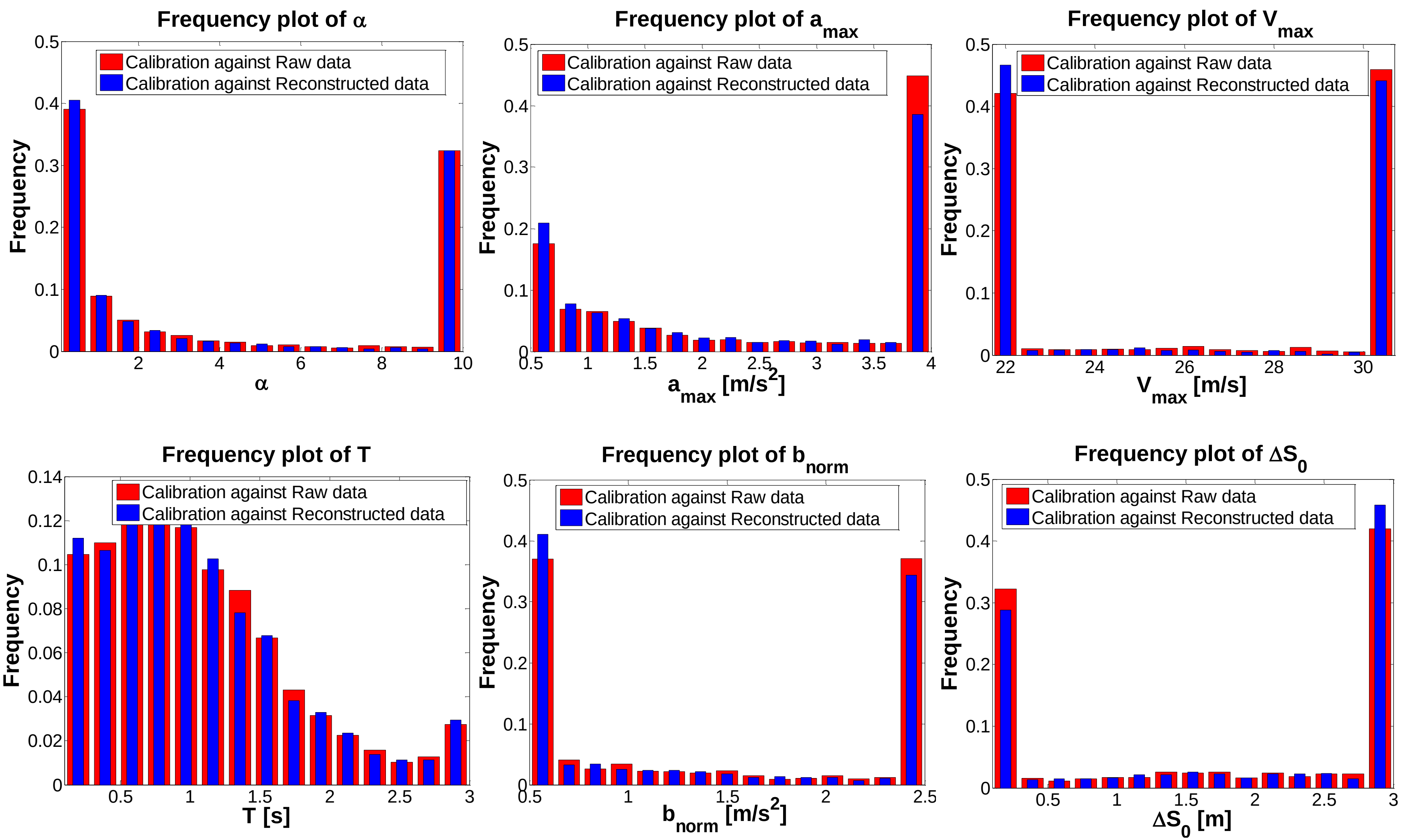
  ➔ **Significant impact of errors on calibration results**

- Only impact on calibration: no lane changing and no impact on aggregate results that is on traffic simulation outputs

Impact of measurement errors on simulation

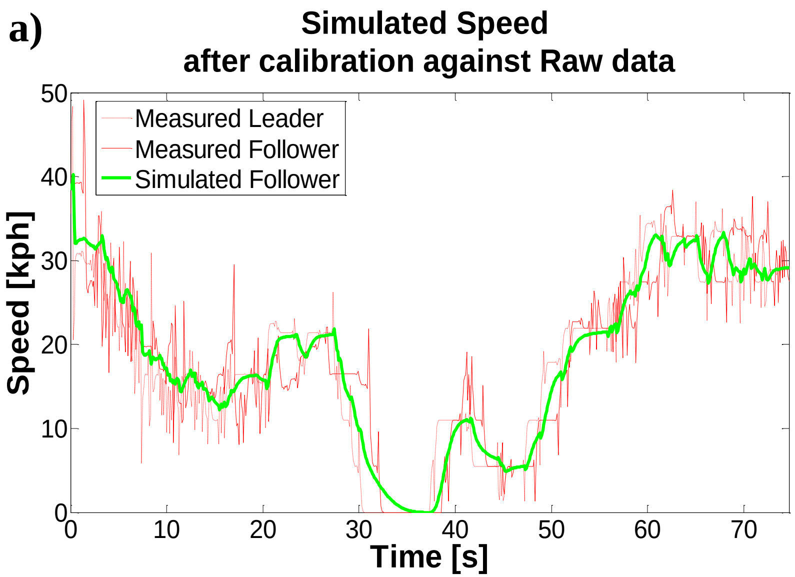


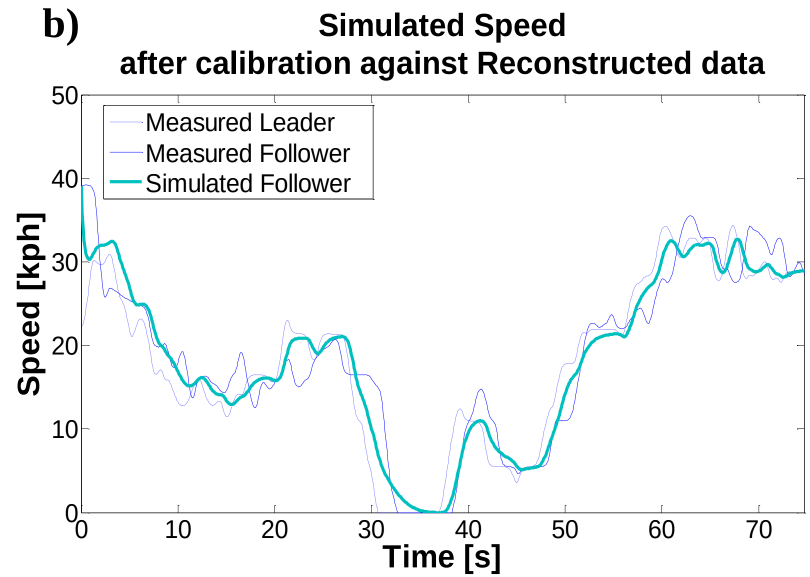
Frequencies of calibrated IDM parameters



H0(different distributions) rejected (5% level of significance)

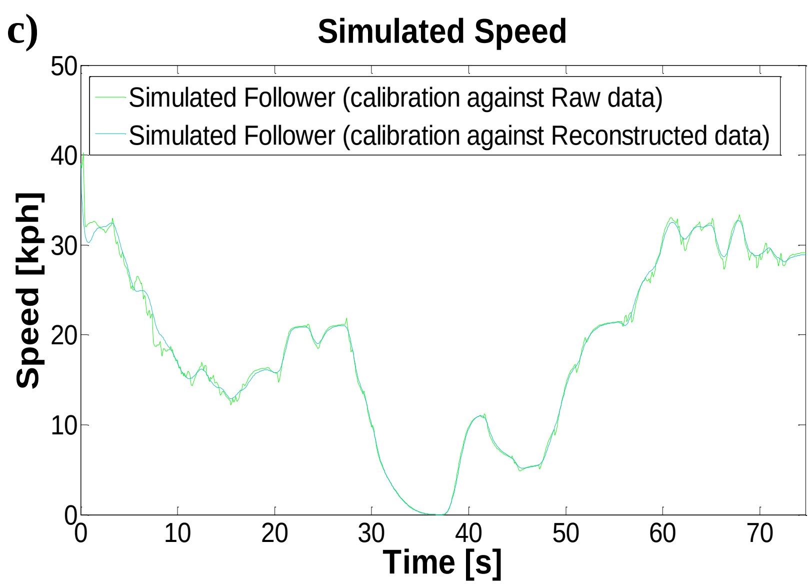
The car-following model acts as a filter



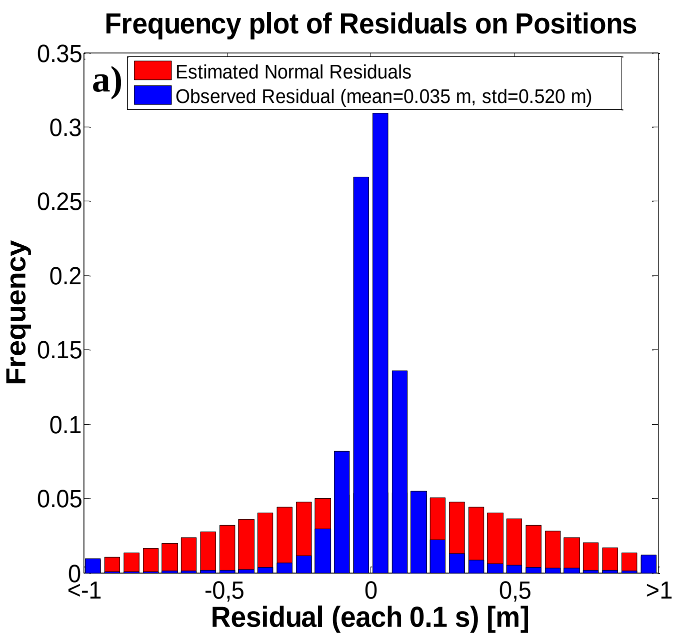


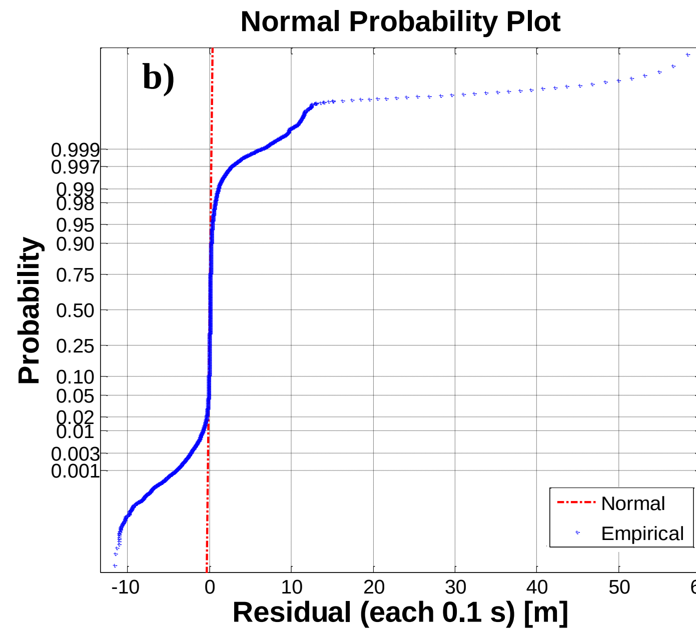
Negligible impact of errors on calibration results.

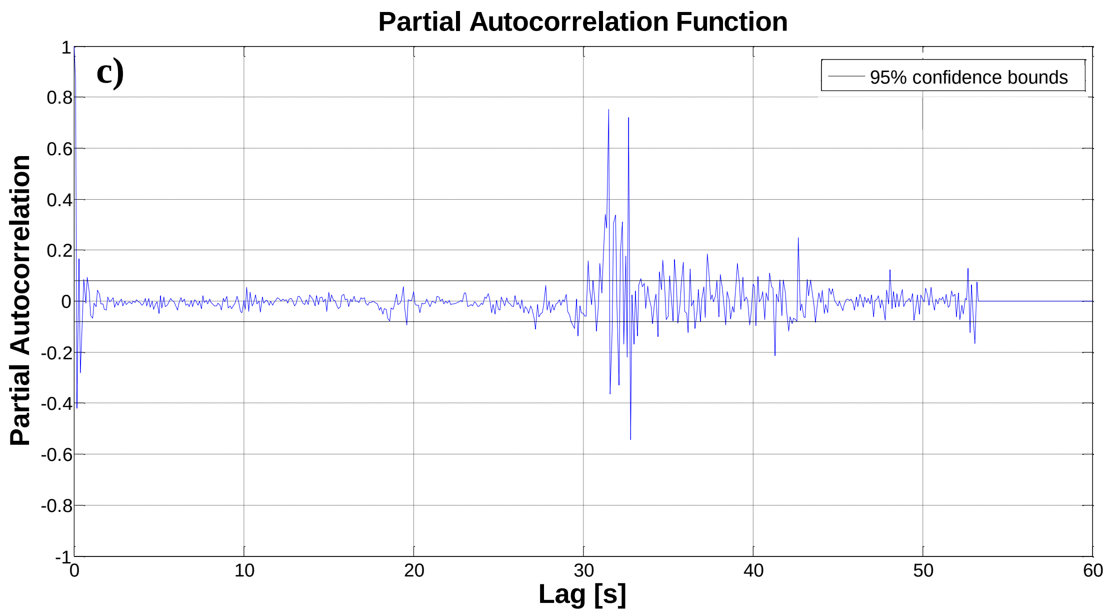
Ossen and Hoogendoorn, 2008?



Hp: Measurement errors = residuals between raw and reconstructed positions

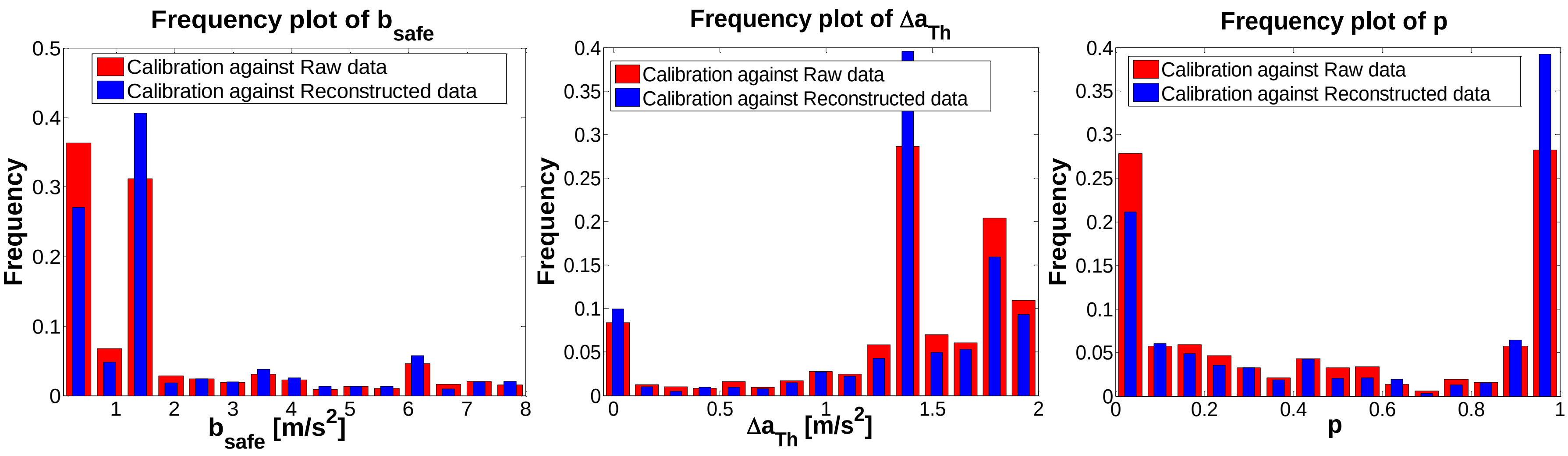






Residuals are not normal and are auto-correlated

Frequencies of calibrated MOBIL parameters

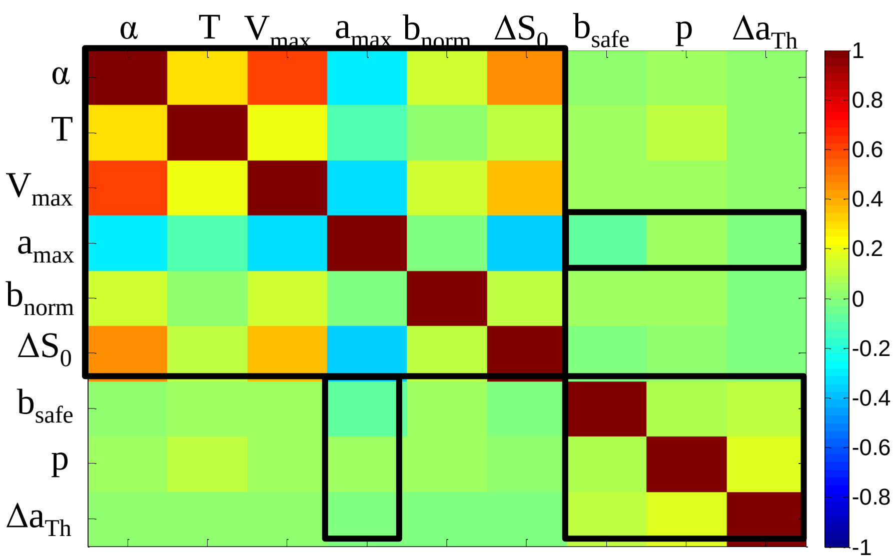


H0(different distributions) not rejected (5% level of significance)

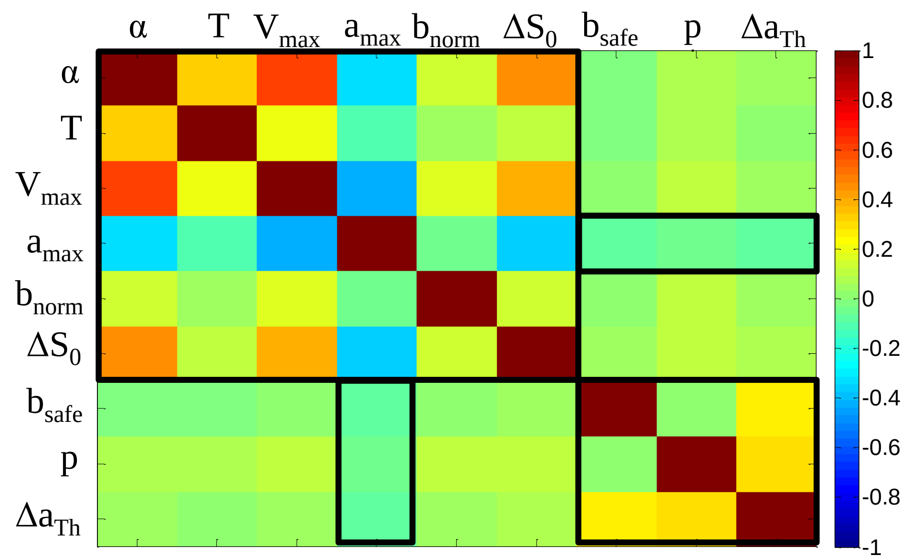
Correlation matrices of «raw and clean parameters» (i.e. parameters calibrated against raw and reconstructed data)

Analysis of parameters correlation (Kim and Mahmassani, 2012, *TRR*)

Calibration against Raw data



Calibration against Reconstructed data



- Correlation among CF parameters does not change;
- correlation of a_{max} CF parameter with LC parameters increases (in abs.);
- correlation among LC parameters increases.

- *Hp. explanatory capability of the LC model is reduced by errors*

Summary of impacts on calibration

- Not normal, auto-correlated residuals
- No impact on car-following calibration results (both on parameters PDF and correlation structure)
- Impact on Lane-changing calibration results (both on parameters PDF and correlation structure)
- …

- Analysis results not informative on the impacts on traffic simulation

Remarks

No car-following calibration possible on raw data without 'tricks' (negative inter-vehicle spacing)

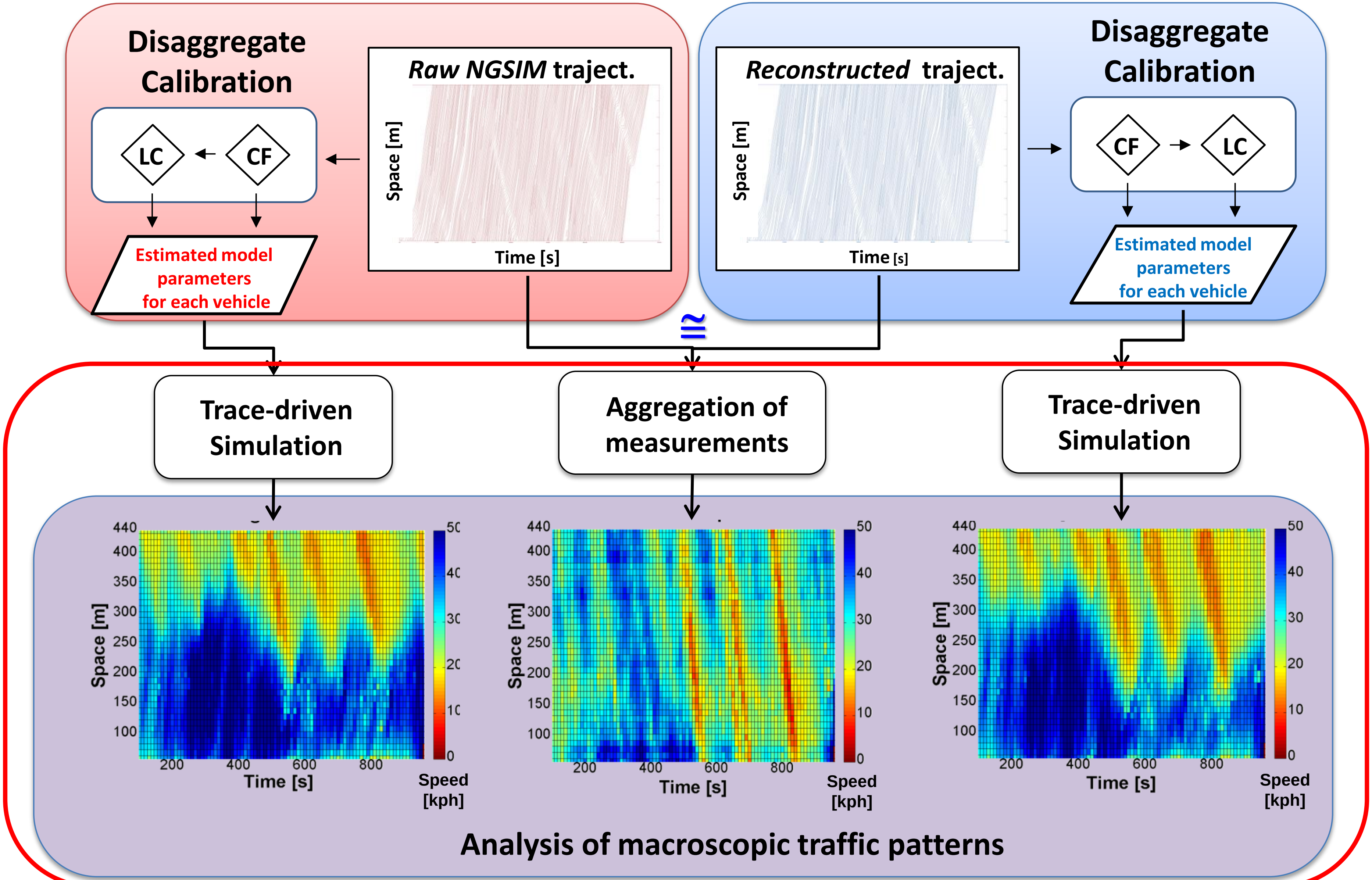
To calibrate a CF and LC model over a whole set of 2000 trajectories is not just running 2000 times an optimisation algorithm!

Major critical steps:

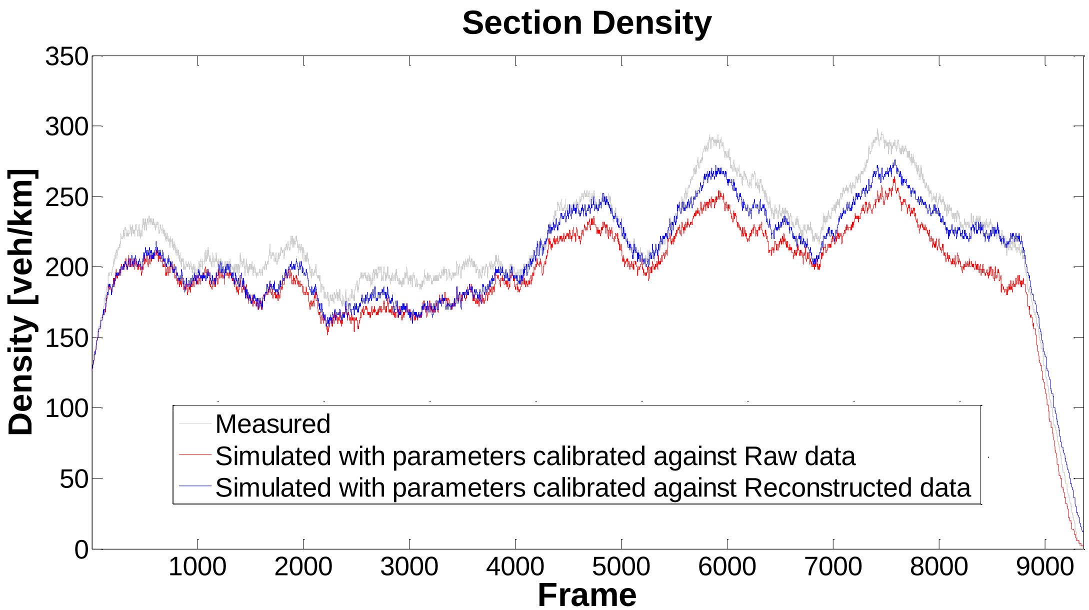
- To verify the calibration setting (MoP, GoF, algorithm)
- To set the bounds for the parameters *(Punzo et al. 2014, IEEE T-ITS)*
  - ✓ Uncertainty analysis
  - ✓ Physical criteria
  - ✓ Verification after simulation

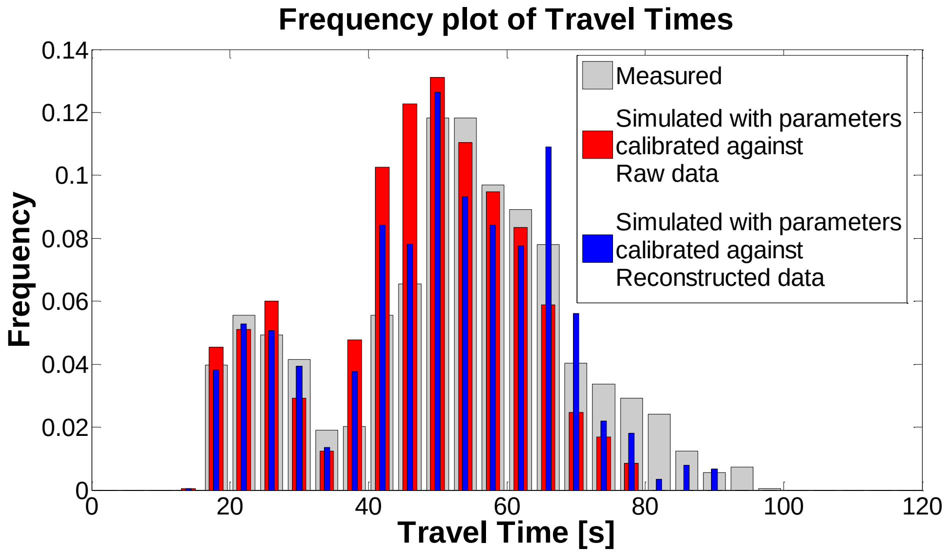
IMPACT OF MEASUREMENT ERRORS ON SIMULATION OUTPUTS AND MACROSCOPIC TRAFFIC PATTERNS

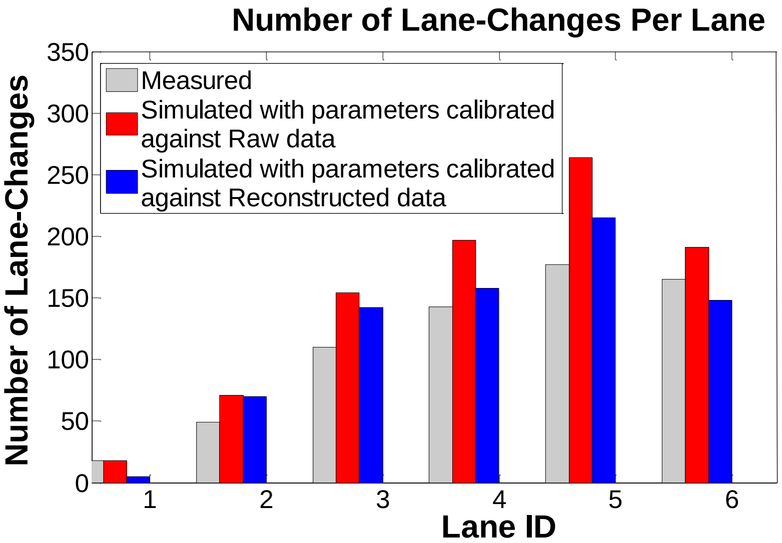
Impact of measurement errors on simulation



«Raw vs. clean parameters» simulations

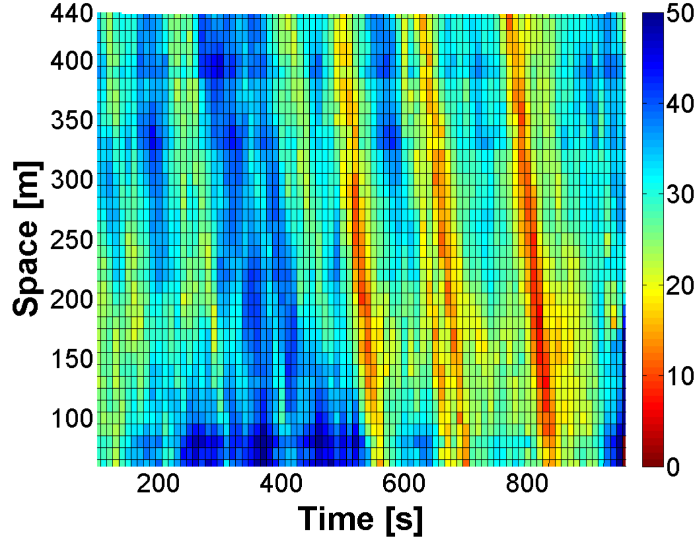




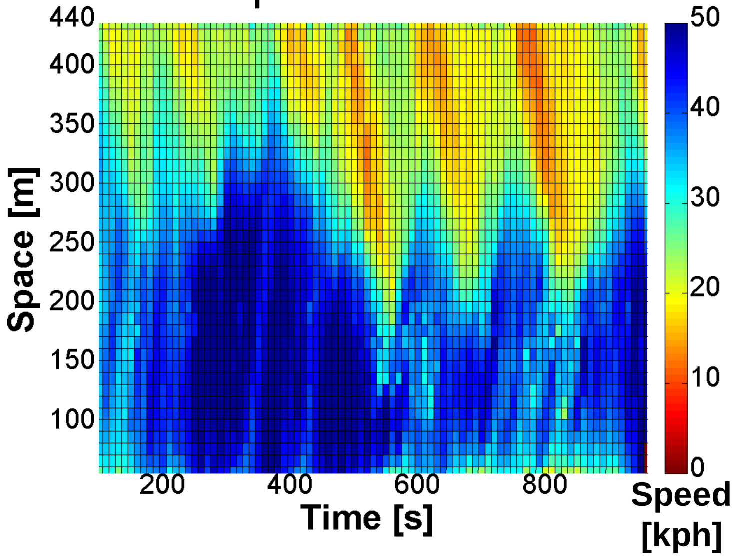


Measured vs. simulated Edie's speed

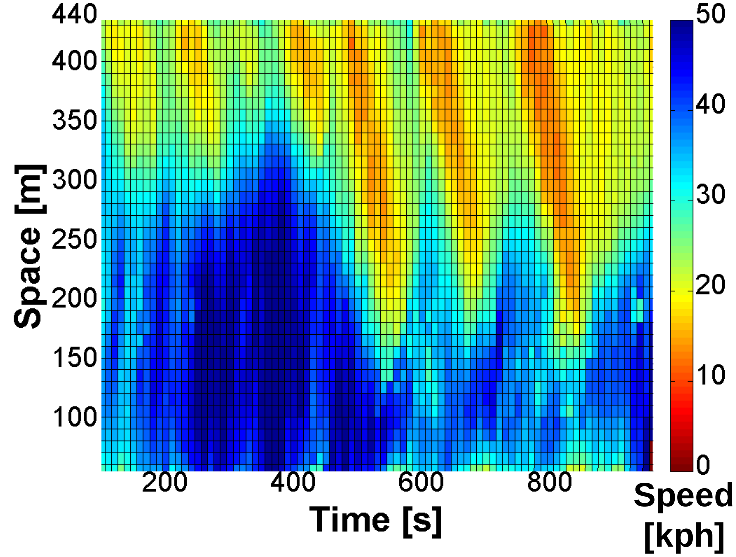
Real measurements



«Raw parameters» sim.



«Clean parameters» sim.

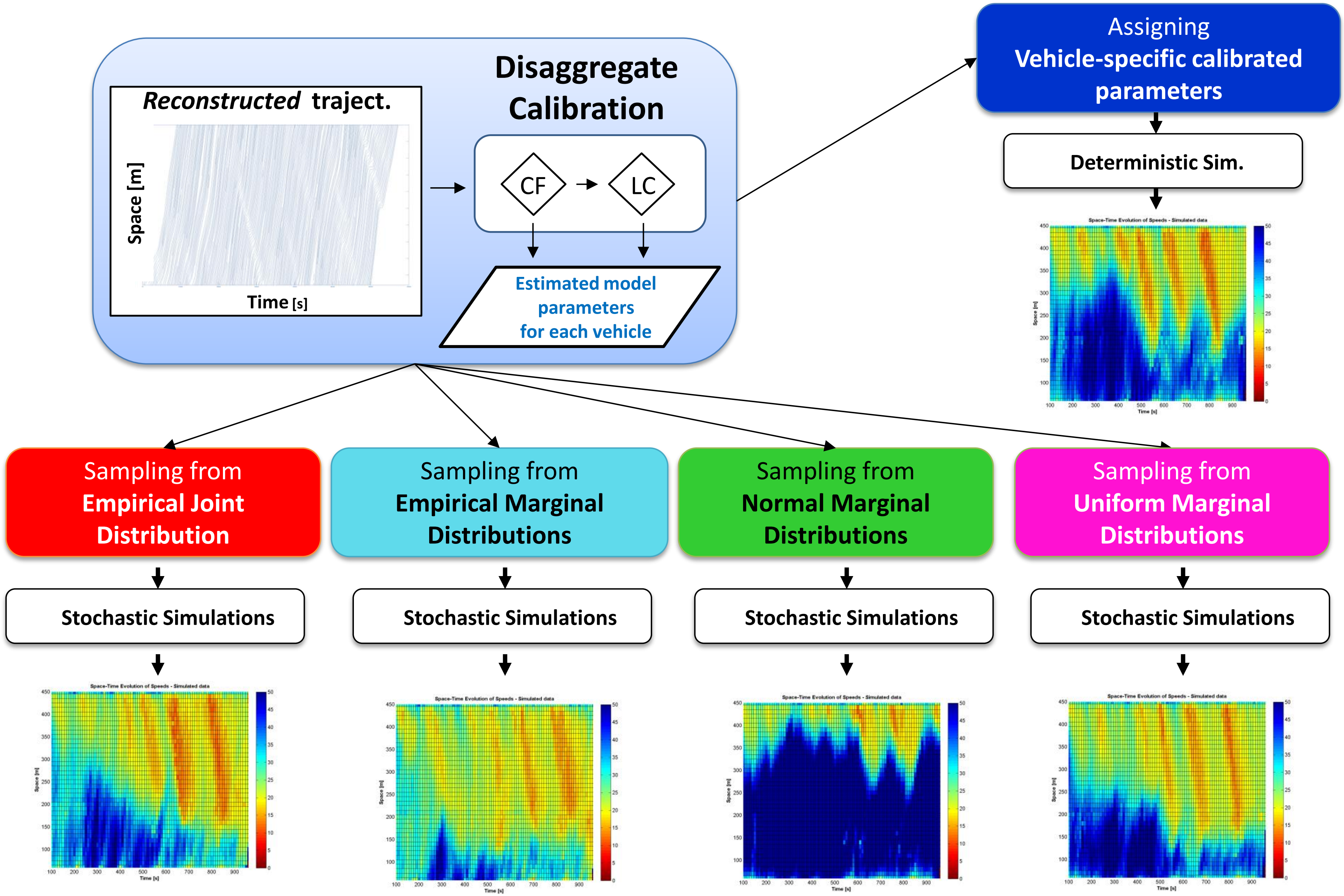


Remarks

- Impacts of errors on simulation less than expected, given the big errors in raw data
- Measures other than macroscopic patterns could not capture the true behavior of models
- In both the simulations congestion patterns are different from that measured:
  - ✓ congestion is lower at the beginning of the stretch, higher at the end.
  - ✓ Models are not able to reproduce the full upstream propagation of congestion
- Yet, the ‘clean data simulation’ provided slightly better description of traffic at both disaggregate and collective description

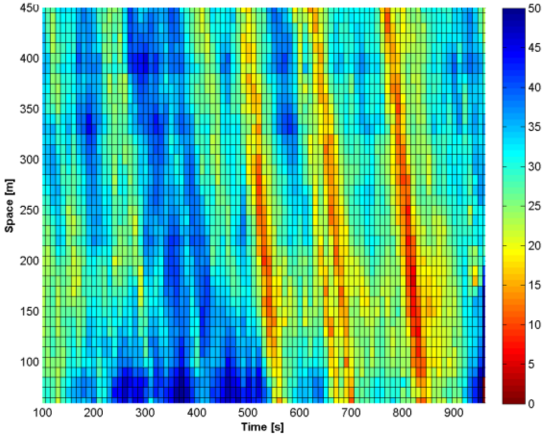
IMPACTS OF ASSUMPTIONS ON THE INPUT PARAMETER PROBABILITY DENSITY FUNCTIONS (PDF)

Assigning calibrated parameters to vehicles

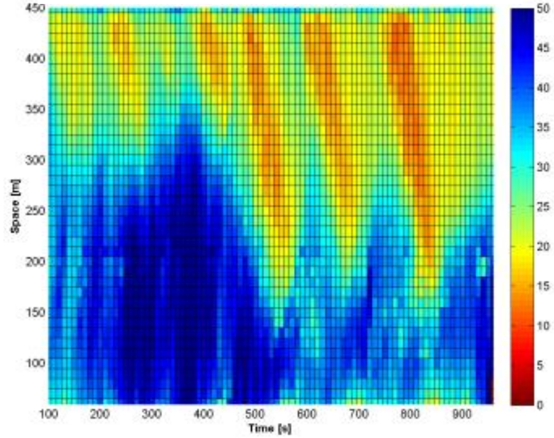


Real Measurements vs. best replication of scenarios

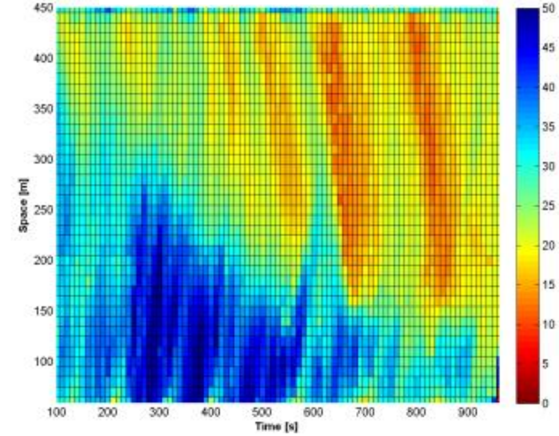
Real measurements



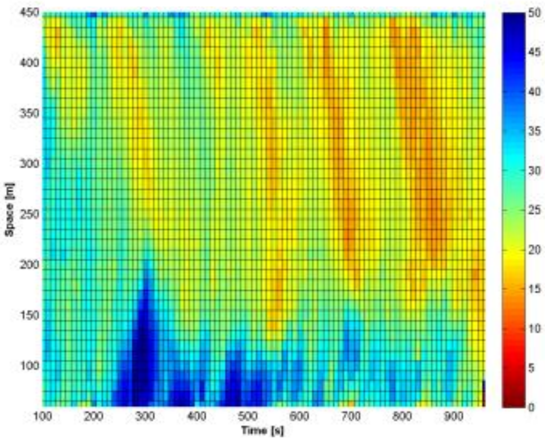
Veh-specific param.



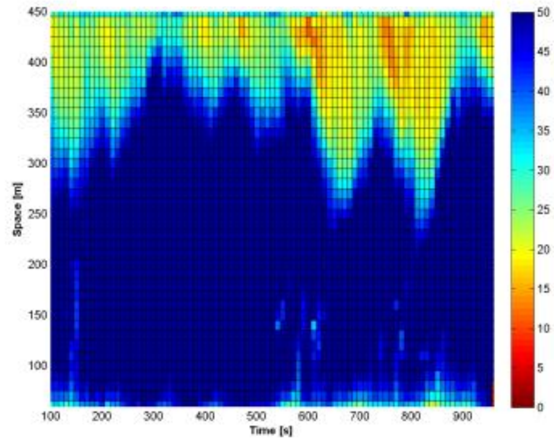
Empirical joint



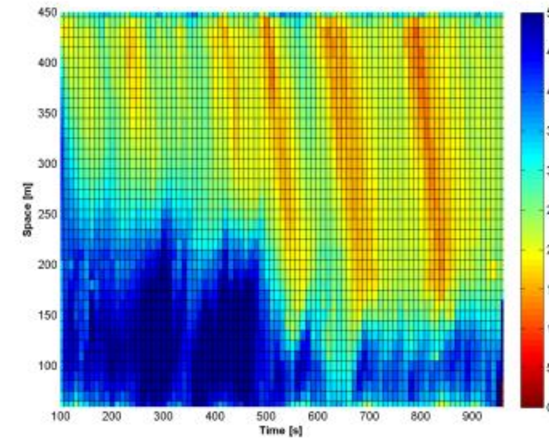
Empirical marginal



Normal marginal

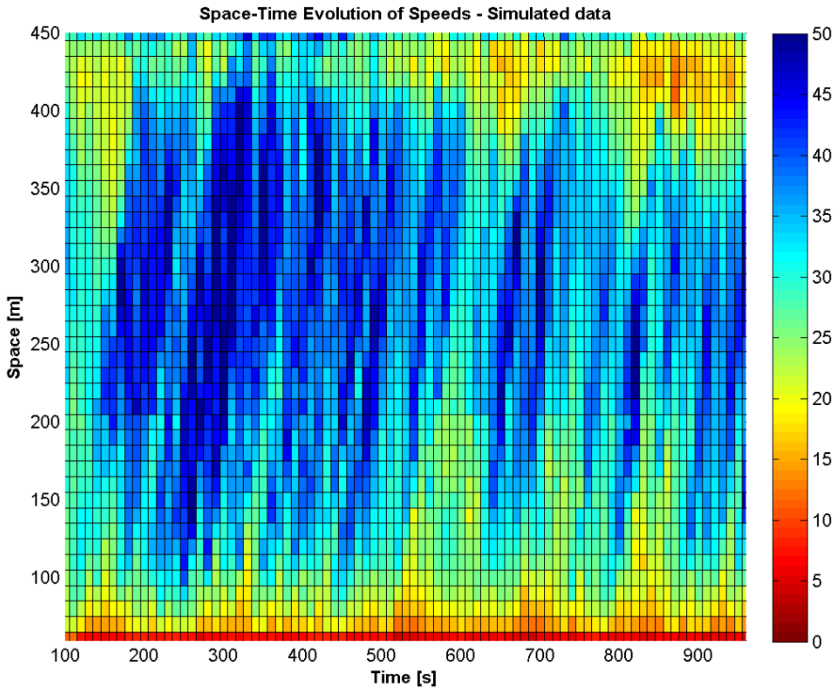


Uniform marginal

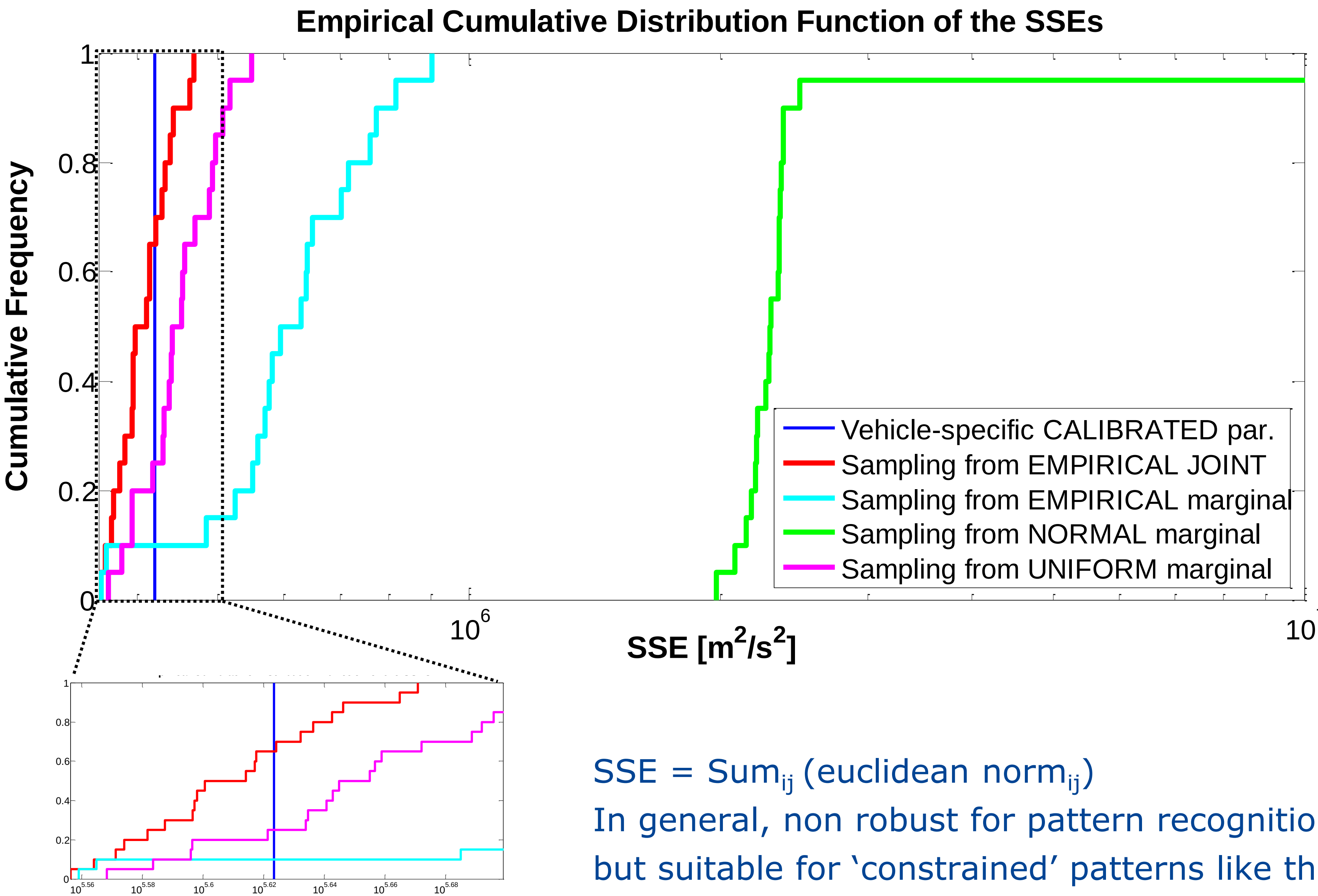


Virtual queue at the entrance

Empirical marginal



Empirical CDF of scenario replications' SSEs



SSE = Sum_{ij} (euclidean norm_{ij})

In general, non robust for pattern recognition

but suitable for 'constrained' patterns like these

Remarks

- Huge impact on results of the assumption on the input parameter PDFs
- CDFs on SSE offer a clear ranking of the performances of different input PDFs
- Sampling from ‘empirical marginal’ PDF (i.e. no correlation) yields ‘unrealistic’ parameters combinations (i.e. virtual queues at the entrance)
- Sampling from normal marginal, all the behaviours are averaged → no congestion propagation
- If the parameter correlation structure is unknown, the safest assumption is to sample the parameters from uniform PDFs (customary assumption in case of no prior information on the PDF)

Summary (1)

- Impact of measurement errors in trajectory data substantially neglected in the field literature.
- Enhanced methodology to reconstruct trajectory data, accounting for inter-vehicle spacing consistency;
- Application to the NGSIM I80-1 dataset;
- Straightforward methodology to evaluate the impacts of microscopic features on collective behaviour of traffic based on:
  - ✓ consistent calibration of individual driver models (lane changing and car-following) over the entire trajectory dataset
  - ✓ trace-driven traffic simulation over the same time-space domain of trajectory data.
- ✓ New methodology to calibrate rule-based lane changing models (e.g. MOBIL), based on the concept of lane-changing scenario.
- ✓ Quantification of measurement errors impact on both car-following and lane changing calibration:
  - ✓ Negligible impact on CF
  - ✓ Quantified impact on LC

Summary (2)

- Quantification of measurement errors impact on the collective behaviour of traffic;
- Analysis of the impact of assumptions on the probabilistic model of inputs on the simulation results, in terms of macroscopic spatiotemporal traffic patterns.

Conclusions

- Previous studies using NGSIM-like data rarely made use of collective description of traffic, as resulting from macroscopic spatiotemporal traffic patterns, to corroborate models and model assumptions
- NGSIM-like data open up new horizons in researching traffic flow theory and simulation, enabling the study of the collective behavior of traffic resulting from single driver models (i.e. car-following and lane-changing)
- Investigations made on NGSIM-like data will hopefully contribute to solve the dichotomy between TFT and traffic simulations as well as micro/macro dualism
- New data gathering efforts of NGSIM-like data are needed around the world

Main work references

Montanino M. and Punzo V. 2015. Errors in vehicle trajectory data and their impact on simulated spatiotemporal traffic patterns. Submitted for presentation to the *2015 TRB Annual meeting*, Washington D.C.

Punzo V., M. Montanino and Ciuffo B., 2014. Do we really need to calibrate all the parameters? Variance-based sensitivity analysis to simplify microscopic traffic flow models. *IEEE Transactions on Intelligent Transportation Systems* (in press)

M. Montanino, V. Punzo, 2013. Making NGSIM data usable for studies on traffic flow theory: a multistep method for vehicle trajectory reconstruction. *Transportation Research Record* 2390, p.99-111, TRB.

Punzo V., Ciuffo B. and Montanino M. 2012. Can results of car-following model calibration based on trajectory data be trusted? *Transportation Research Record* 2315, p. 11-24. "Greenshields prize 2012"

Punzo V., Borzacchiello M., Ciuffo B., 2011. On the assessment of vehicle trajectory data accuracy and application to the Next Generation SIMulation (NGSIM) program data. *Transportation Research Part C* 19 (2011), 1243–1262.

www.multitude-project.eu

Contacts:

Vincenzo Punzo

University of Naples Federico II, Italy

vinpunzo@unina.it