Mikromodellering av cykeltrafik – så kan du planera för framtidens cykling

Guillermo Pérez Castro

Foto Hejdlösa bilder, VTI

Agenda

- Background
- The role of microscopic traffic simulation.
- MTS of bicycle traffic.
- MTS support for bicycle traffic analysis.

Background

- Bicycling as a valuable mode of transport.
  - Benefits in health, and a pathway for lowering CO_2 emissions.
  - Targeted/intended increase in bicycle demand.
    - Utilitarian bicycle travel concentrates at specific time periods.

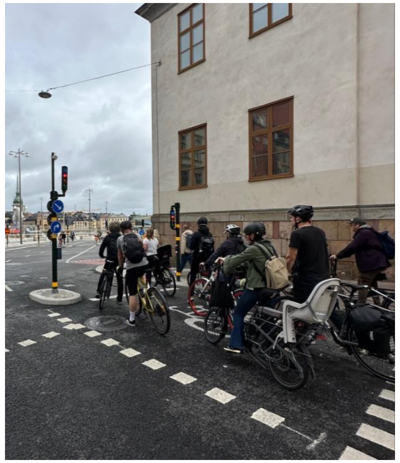

Photo by Guillermo Pérez Castro

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svt NYHETER Nyheter Lokalt Sport SVT Play Barn

/ STOCKHOLM

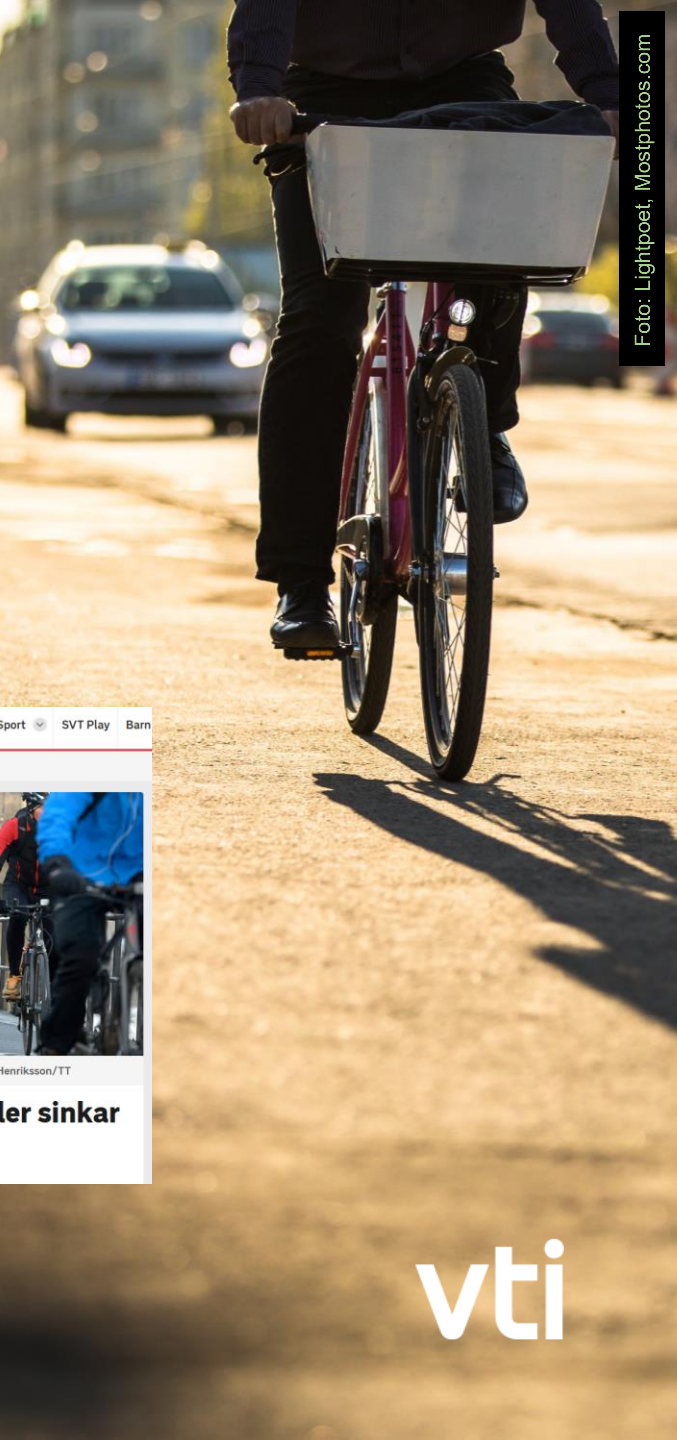
Trafikreglerna är för dåligt anpassade till cyklister Foto: Janerik Henriksson/TT

Stockholms trafiksignaler sinkar cyklister

PUBLICERAD 8 MAJ 2019

- Plan for attractive bicycle traffic → evaluations of traffic performance.

(in-)efficiency and (dis-)comfort



Traffic models and simulation

- To support the planning of well-functioning traffic.
  - Most traffic systems are too complex to evaluate analytically.
  - Simulation offers the possibility to imitate traffic systems.
    - Via mathematical models.
    - Cost-effective.

Traffic models

Macroscopic

Collective properties of a group of traffic entities (e.g., mean speed, flow, density)

↓

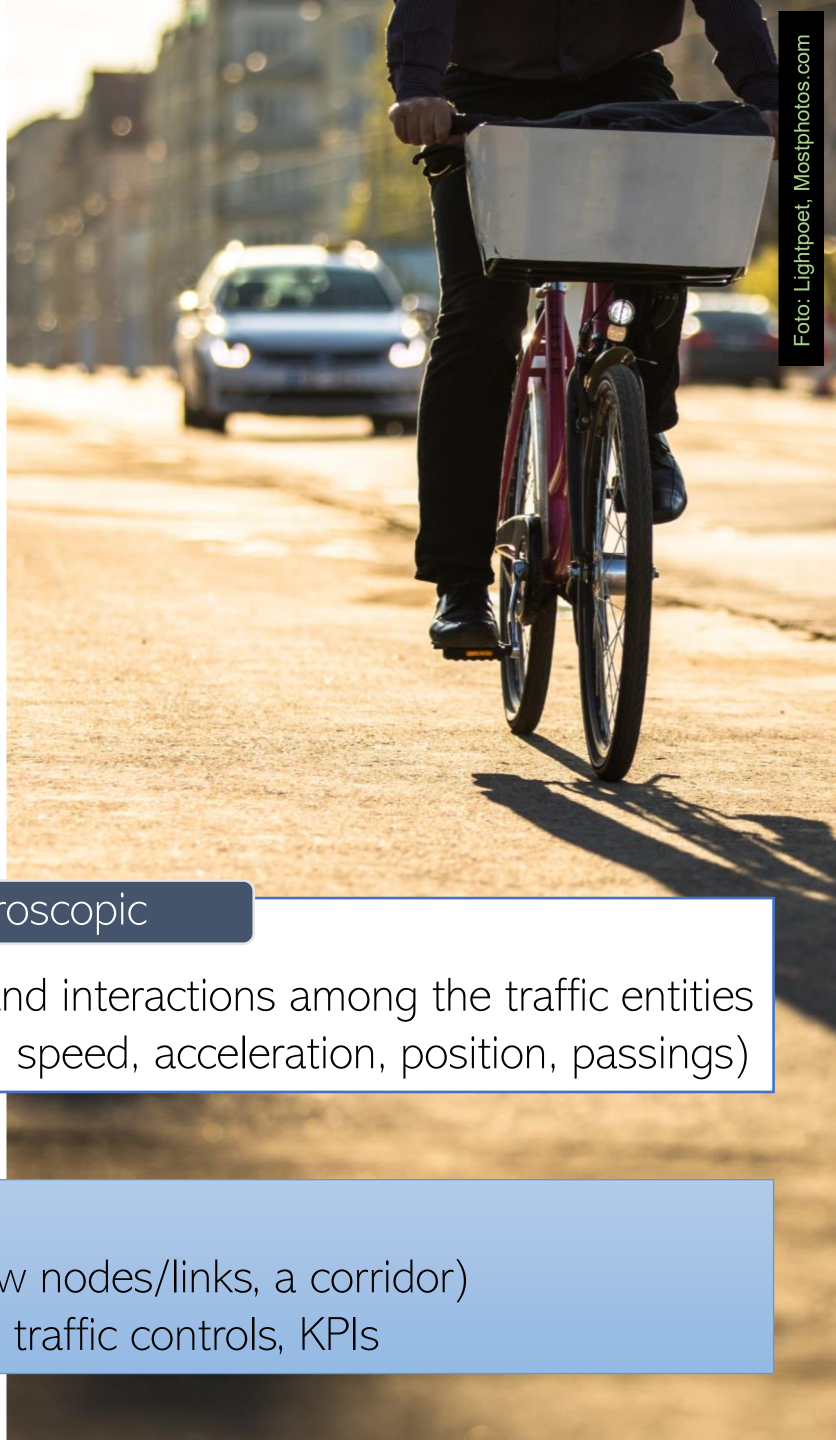
Transportation planning
Large scale (regional/city networks)
E.g., demand modeling, route choice

Microscopic

Individual properties, and interactions among the traffic entities (e.g., speed, acceleration, position, passings)

↓

Traffic flow dynamics
Small/medium scale (a few nodes/links, a corridor)
E.g., infrastructure design, traffic controls, KPIs



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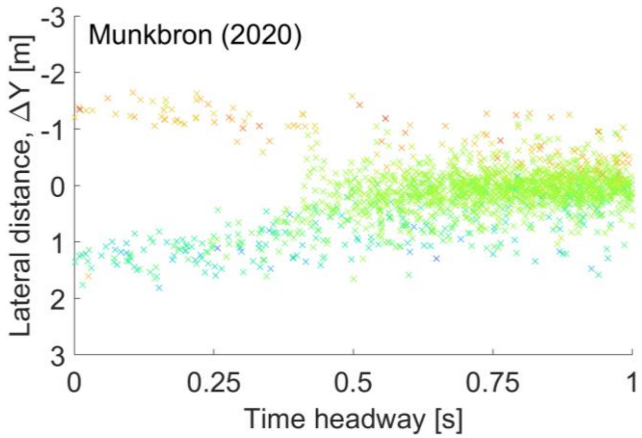
Microscopic Traffic Simulation

- To evaluate the effects of changes in the traffic system on traffic performance,
  - e.g., delays, queue lengths, overtaking frequency, platooning, etc.,
  - when
    - traffic demand increases,
    - traffic composition changes: conventional bikes, e-bikes, cargo bikes, other micromobility vehicles, etc.,
    - infrastructure (incl. traffic controls) changes (redesign).
- Suitable for highly heterogenous populations (as in micromobility).
  - Captures a wide range of physical and behavioral characteristics: various needs.
- Suitable for localized problems.
  - Captures detailed properties of the infrastructure and its relationships to road user behavior
  - Captures upstream and downstream infrastructure that influence traffic flow dynamics

Microscopic Traffic Simulation

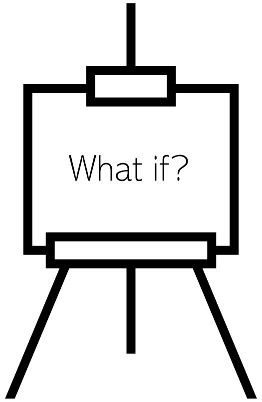
Research
Traffic theory



Model and software development

Calibration and validation

Evaluation of traffic performance



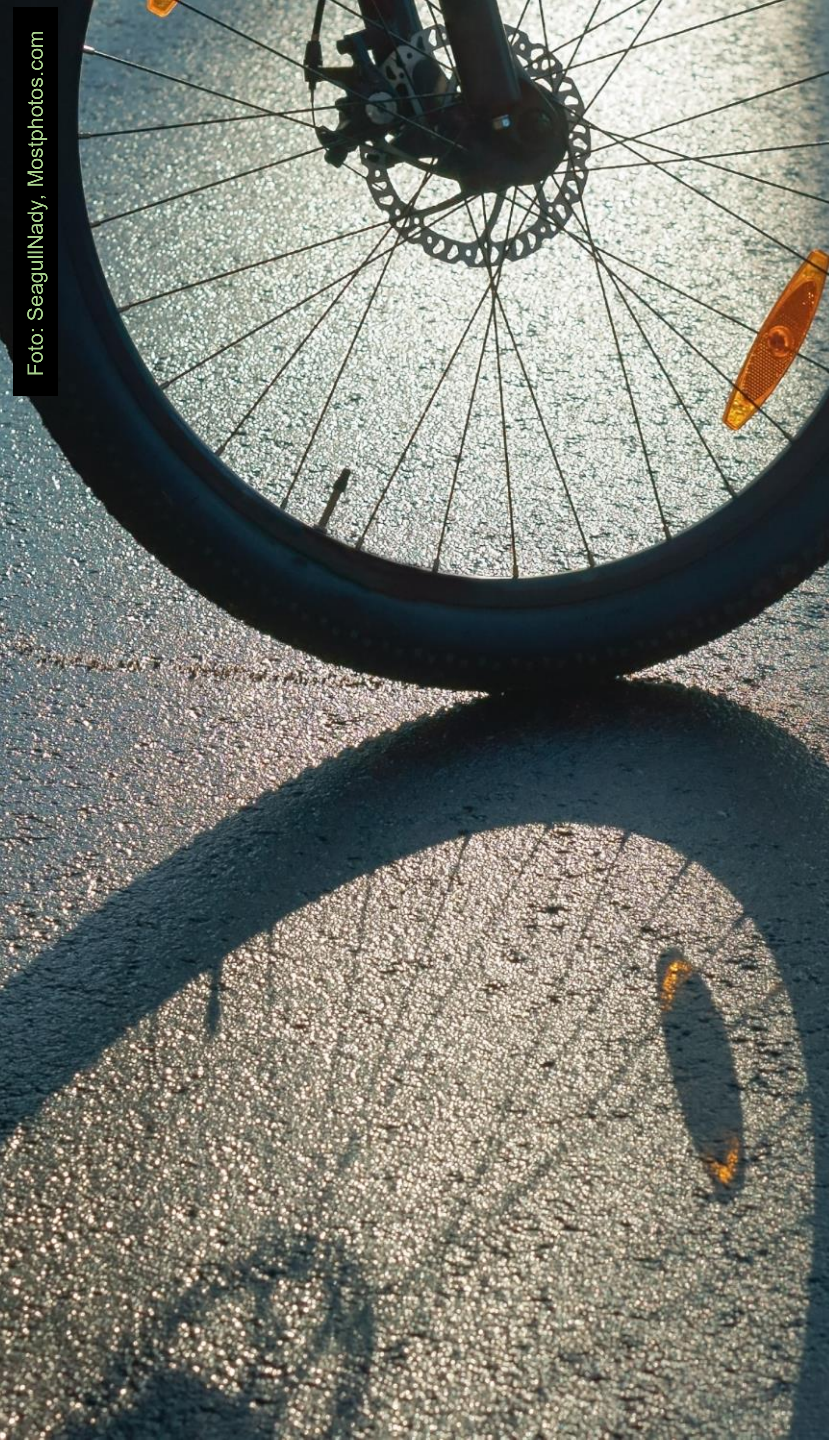
Evaluations of traffic performance

- Metrics to describe the quality of traffic: efficiency and comfort.
  - With respect to e.g.:
    - geometric design (path width, gradient, curvature)
    - intersection layouts and traffic controls,
    - type of infrastructure:
      - one-directional vs bidirectional paths,
      - separated traffic vs mixed traffic (incl. shared paths with pedestrians),
  - Standards for acceptable performance.

- Valuable input for CBAs of bicycle investments:
  - Quantification of travel time savings (delay), energy expenditure.
  - Mostly missing today.

- Valuable input for macroscopic analysis:
  - E.g., accurate travel times / energy expenditure → route choice.
  - Flow-mean speed relationships.

Foto: Mostphotos.com



MTS of bicycle traffic (micromobility)

- Mostly missing in the planning of bicycle traffic.

Modeling support

- Mostly using models developed for other road users.
  - As car drivers:
    - Commercial software: Vissim, SUMO, Aimsun
  - As pedestrians:
    - Social-force models.
- May limit the representation of unique characteristics of bicycle traffic.
- Few bicycle-specific models, but generally not implemented in commercial traffic simulators.

Data

- Lack of empirics on bicycle traffic characteristics.
  - Required for
    - calibration of existing models,
    - and development of new models.
- Challenges in data collection of bicycle traffic.
  - Quantity and quality.

Methods for evaluation of bicycle traffic performance

- Existing (comfort) methods,
  - e.g., Bicycle Level-Of-Service,
  - oversimplify bicycle traffic dynamics,
    - e.g., overtaking maneuvers do not account for platoon formation.
- Delay functions are mostly missing.

Focus during PhD project

MTS of bicycle traffic (micromobility)

Interactions with the infrastructure and/or the environment

- E.g., gradient, curves, wind.

Free riding

Speed choices [highly contextual]

Interactions between bicyclists

- E.g., following process, passing maneuvers

Interactions with other road users

- E.g., cars, scooters, mopeds, pedestrians.

- High heterogeneity among bicyclists.
- Non-lane based.
- Human-powered motion.

*Focus on bicycle paths (separated from motorized traffic) during PhD project

Data

- Data collection and validation – Trajectory data:

Large data sets.
Low-spatial coverage.
Anonymized.
Prone to tracking errors.

Small data sets.
High(er) spatial coverage.
No personal characterization.
Prone to tracking errors.

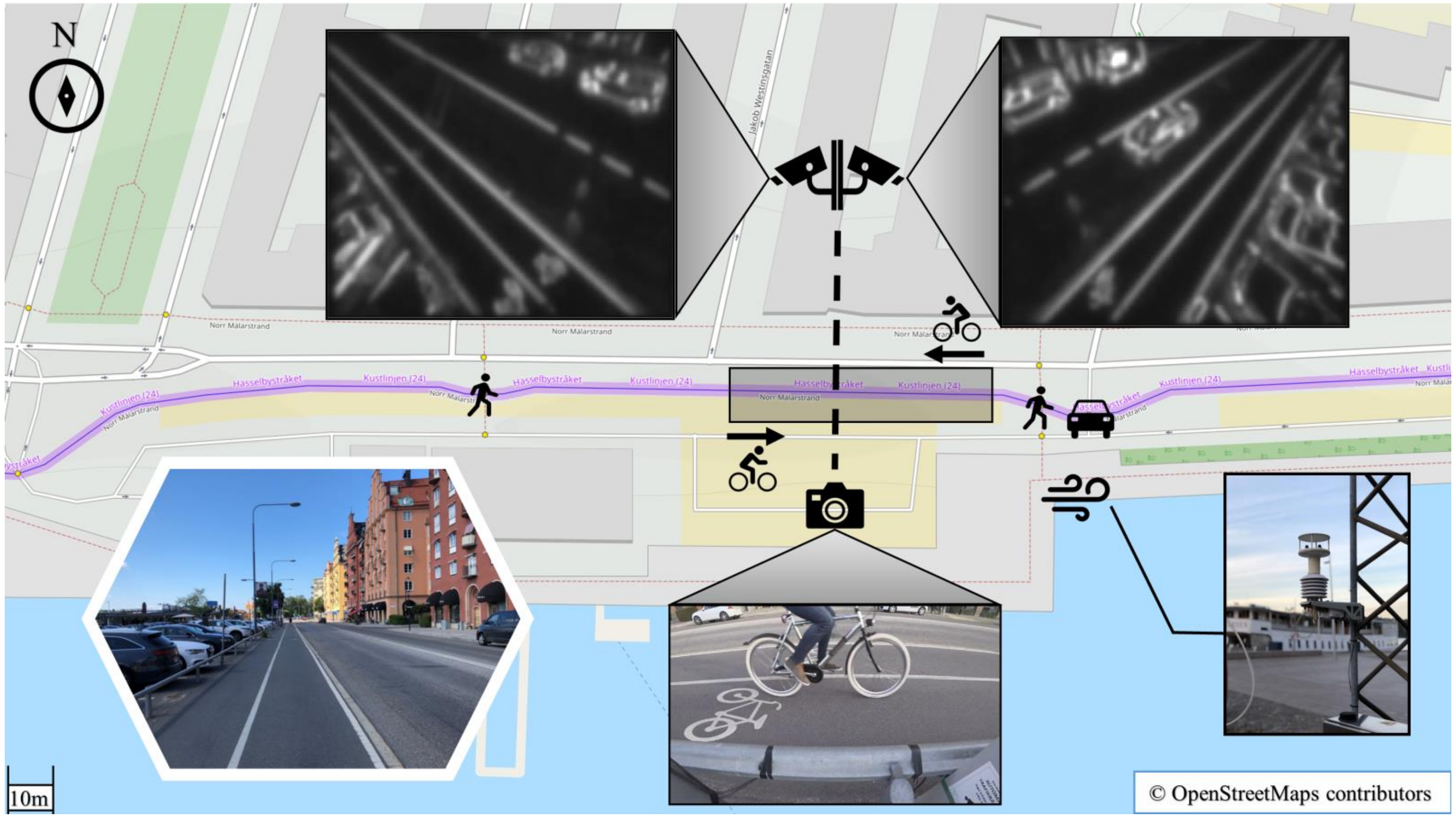
Small data sets.
Rich(er) and long(er) trajectories.
Possible to get info on bicyclists.

Naturalistic studies
- Bidirectional bicycle paths
- High-demand periods

Semi-controlled studies for free riding behavior

- Several locations: Stockholm, Gothenburg, Lund, Linköping, and Wuppertal (Germany)

Data collection methods



Video-based
Viscando OTUS3D System
Norr Mälarstrand Stockholm (2021)

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Data collection methods

Event button, alt. microphone

Accelerometers

Ultrasound distance-to-the-side sensor

Rearview radar for approaching vehicles

Bicycle computer

Dual power meter pedals

Aerometer

Front and back cameras

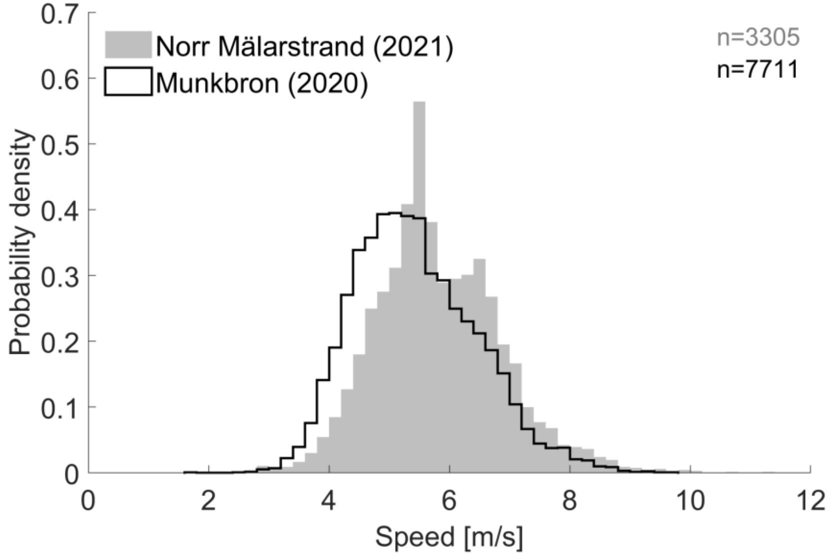
Cadence sensor

Heart-rate armband

Speed sensor

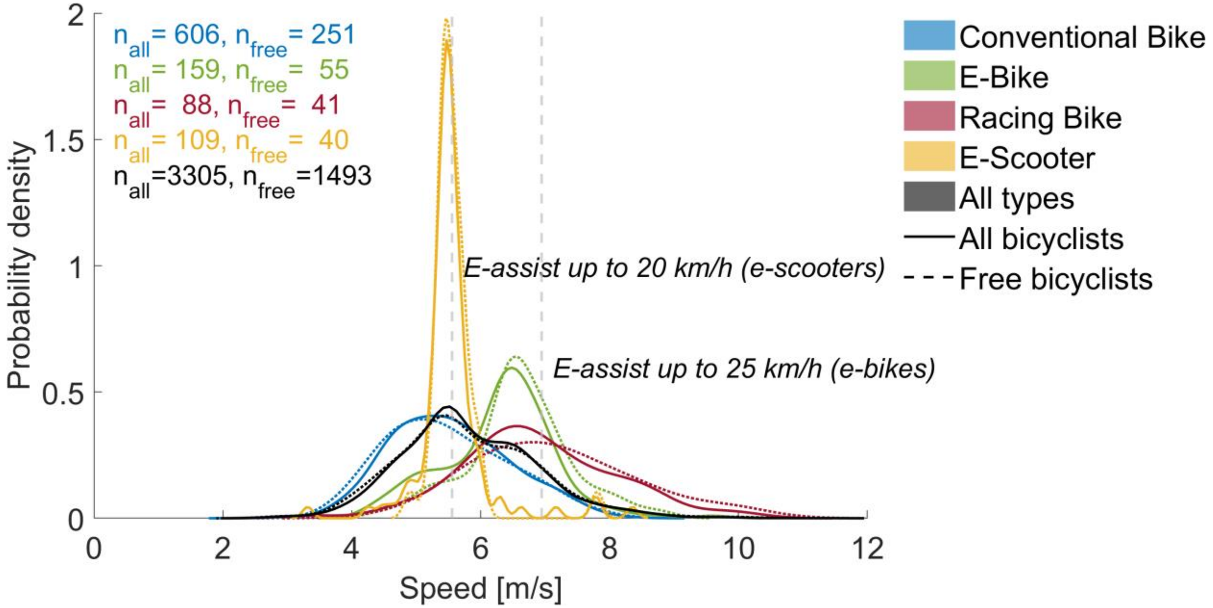
Semi-controlled experiment with IBs
Linköping, Sweden (2023)

Speed



Data source: Viscando fixed detectors.

Norr Mälarstrand (2021)



- Bimodal distribution of speed.
  - High heterogeneity in preferences of bicyclists.
- Small differences (~0.5 m/s) can trigger overtakings.
- Higher speeds during morning peak period, despite highest flows.

Distribution of bike types

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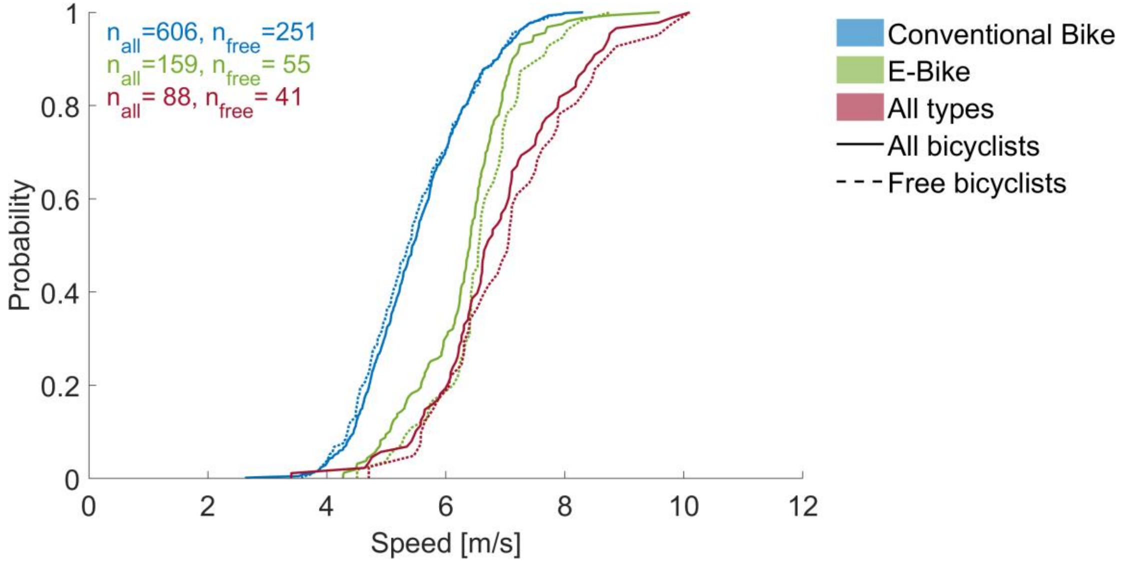
Speed

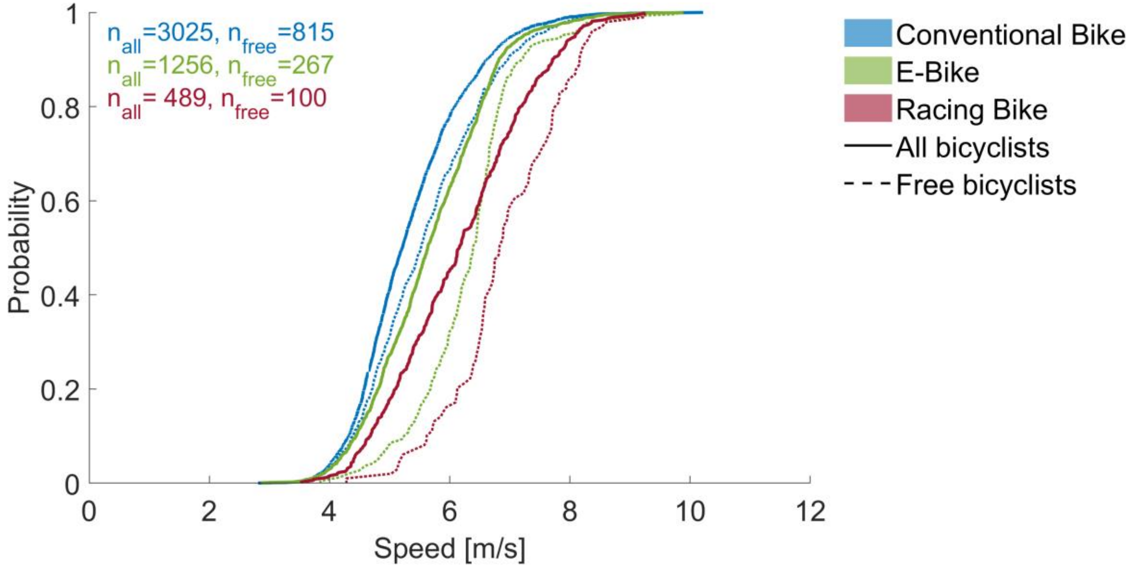
Bicycle type as a good proxy for desired speeds.

Norr Mälarstrand, Stockholm (2021)



- AM peak
- ~1100 bicycles/h
- 15% e-bikes, 10% racing bikes

Munkbron, Stockholm (2024)



- AM peak
- ~2000 bicycles/h
- 25% e-bikes, 10% racing bikes
- Limited overtaking possibilities

Data source: Viscando fixed detectors.

New research project:
Estimation of interaction delay on bicycle paths (DelBiP)

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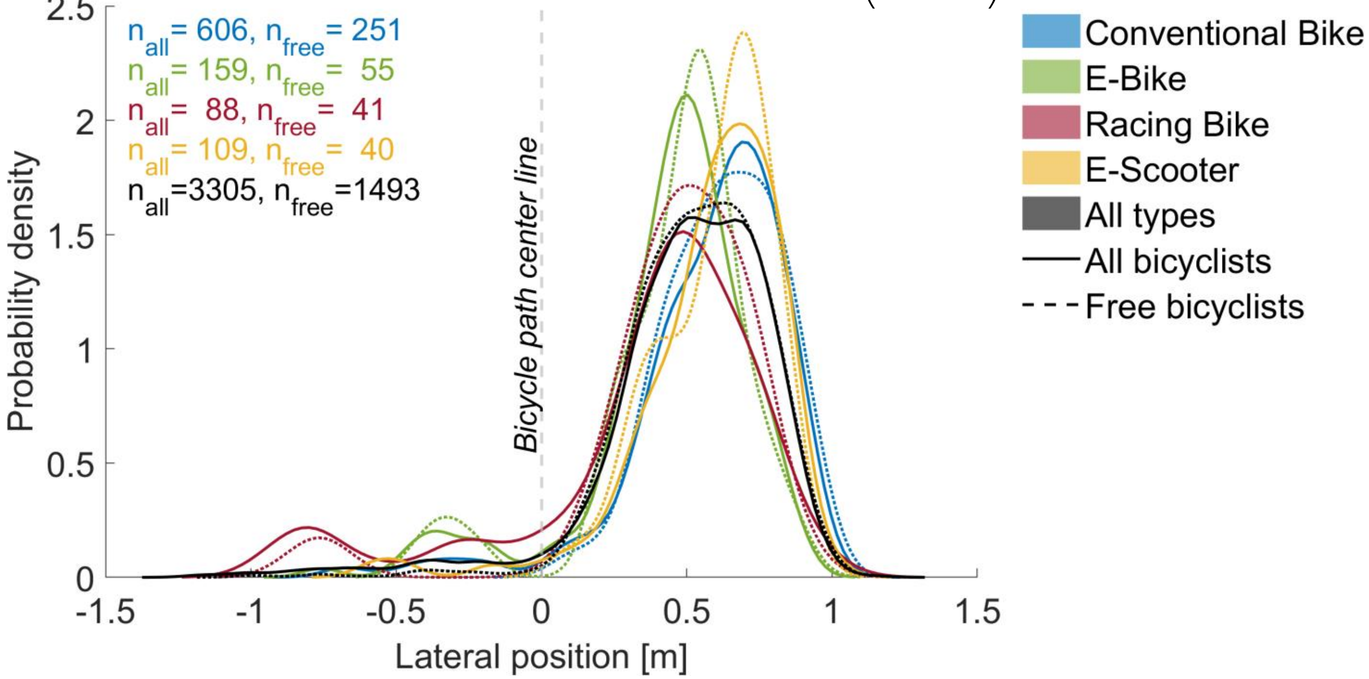
Lateral position

Norr Mälarstrand (2021)



Distribution of bike types

Data source: Viscando fixed detectors.

Ability to describe lateral positioning in MTS is key:

- Dependence on path width.
- Tactical positioning and desired speed.
- Lateral spacing to
  - other road users (meetings vs passings).
  - fixed objects on the side (e.g., barriers, poles).
- Self-organization.
  - Dominant flow in one direction.
    - Opposite direction yields space.
  - Merging.
- Effective path width.

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Free riding

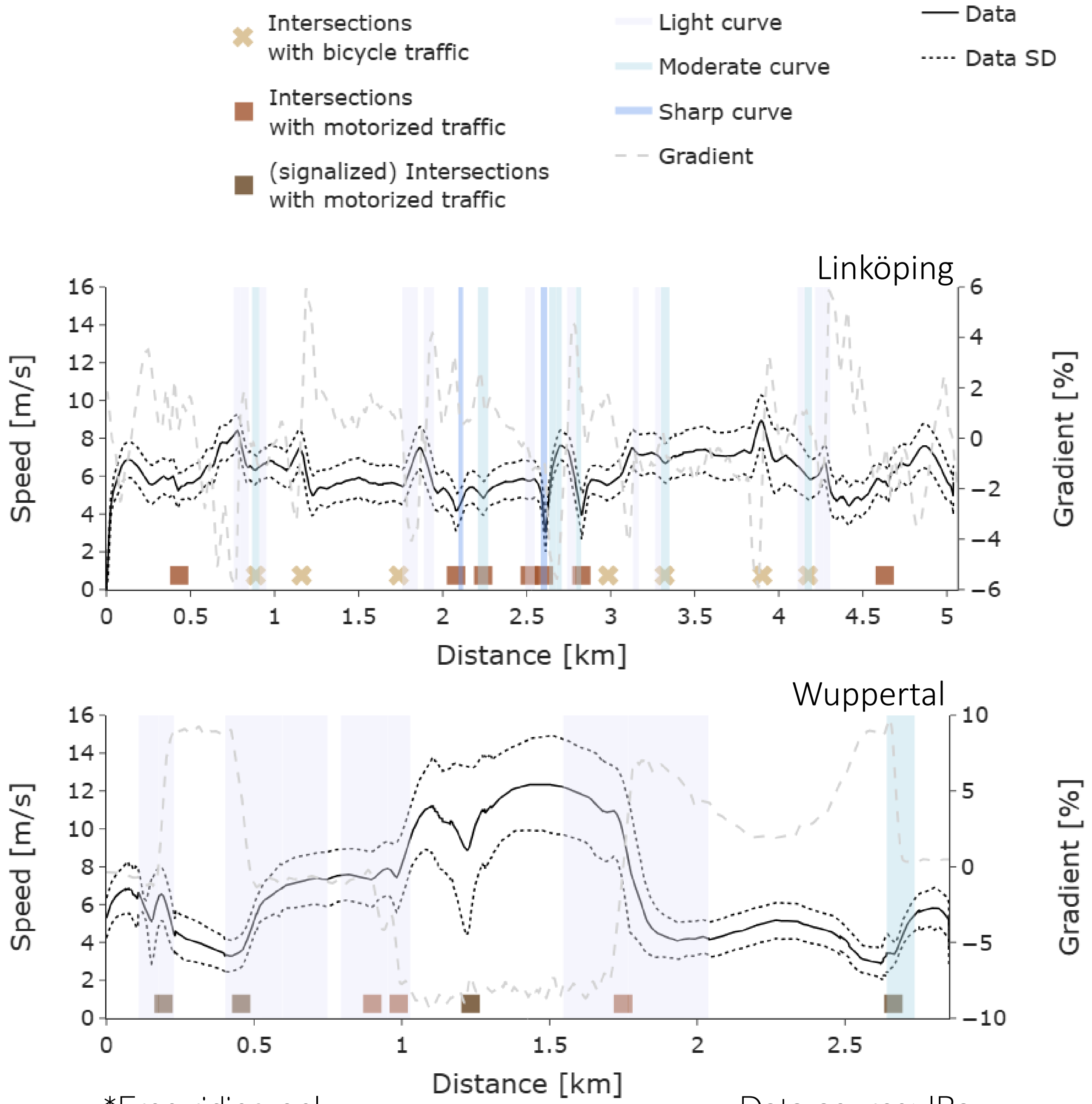
Significant variability in speed/power throughout the trip:

- 70%-85% explained by trip features (topography, curvature, intersections and wind) and differences among bicyclists.

Bicyclists adapt power output in relation to gradient, and wind.

- Trade-off between minimizing travel time and managing physical exertion.
- Linear correlation between power and gradient/(low/moderate)wind.

Mean over the population, along the routes



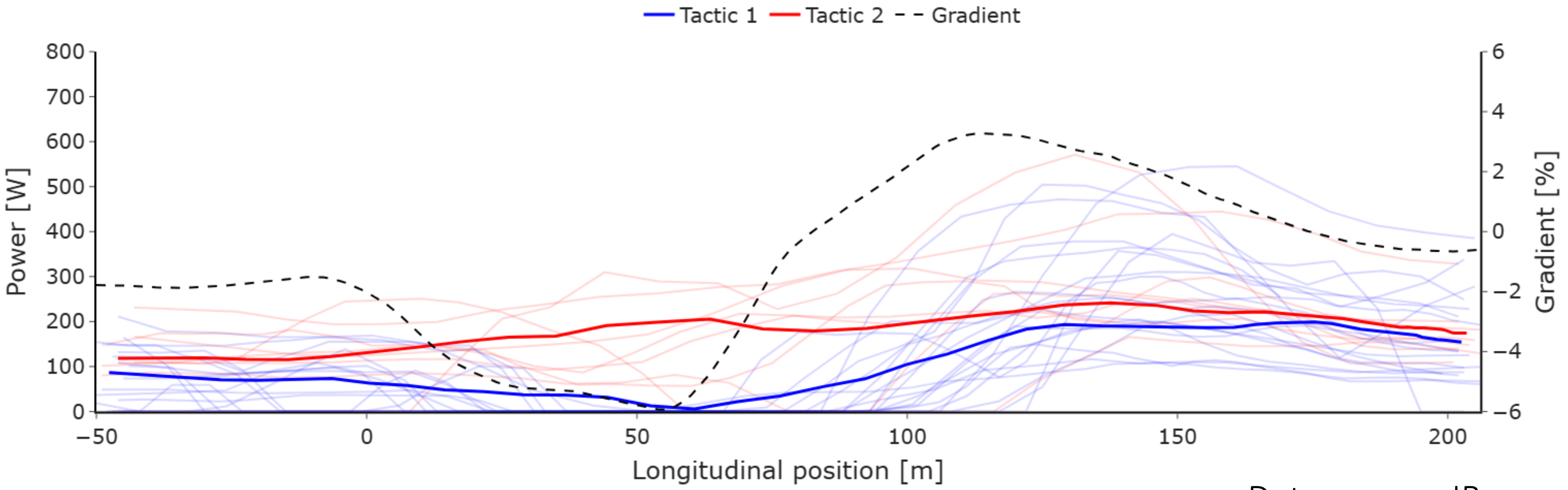
*Free riding only

Data source: IBs

Tactical behavior on uphills

Downhill-to-Uphill transition

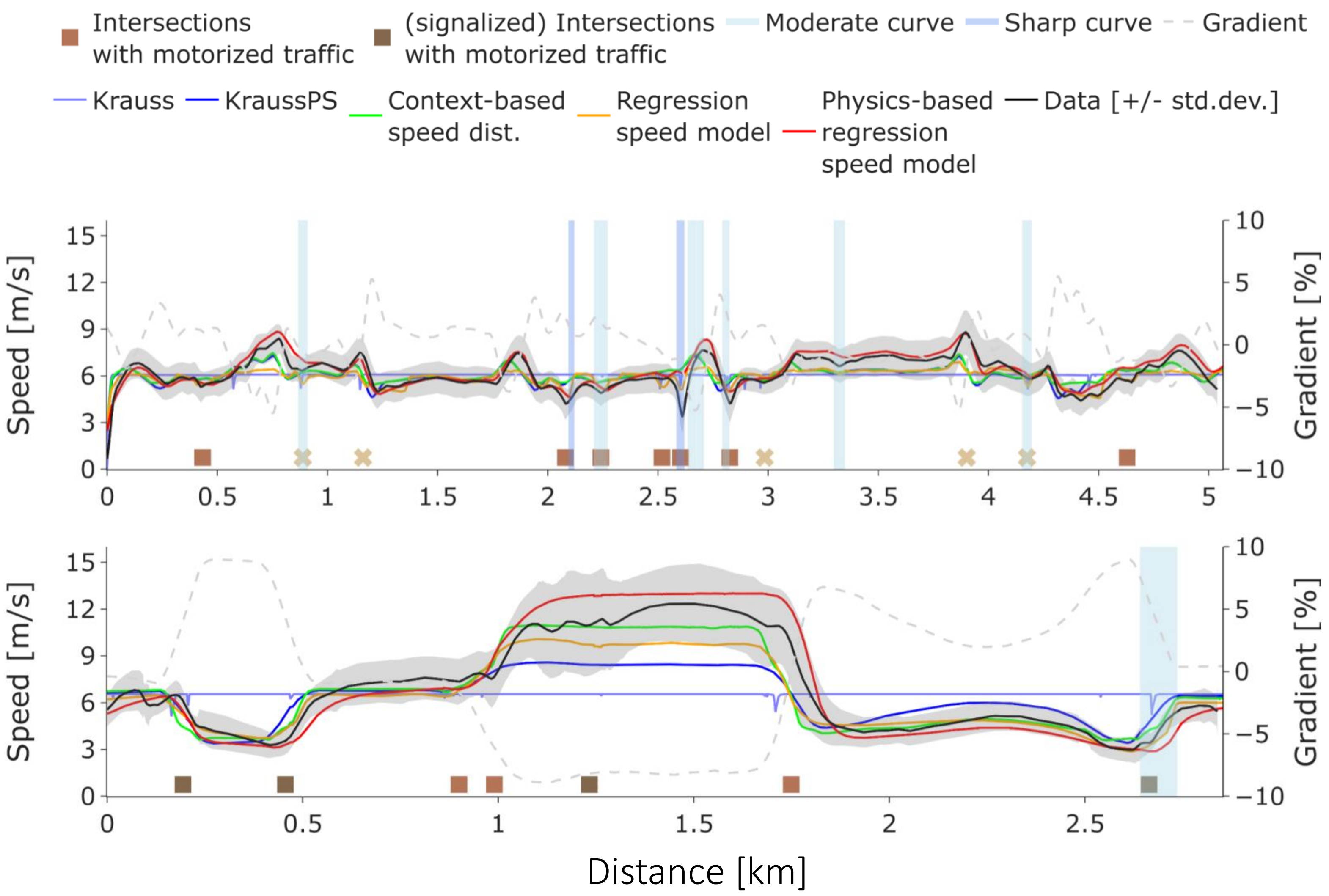
- (Linköping)



Data source: IBs

- The length of the hill further influence power output.

Simulation of free riding



Mean over the population, along the route

[Linköping]

Mean over the population, along the route

[Wuppertal]

- Models differ in accuracy, complexity and data requirements.

Data source: IBs
Implementation in SUMO

Simulation of free riding

- Advanced free riding models improve simulation accuracy in speed.
- Reliable
  - travel times,
  - geometric delays,
  - energy expenditure.
- Useful for uncongested/congested bicycle traffic.

Applications:
- Analysis of infrastructure standards.
  - e.g., acceptable gradients for bridges, curve radii.
- Analysis of speed/acceleration at intersections (uphill/downhill approaches).
- Analysis of travel times savings / energy expenditure.

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Intersections

- Significant delays.
- Simulation of
  - Desired pathways at intersections.
    - Twaddle, H. (2017). Development of tactical and operational behaviour models for bicyclists based on automated video data analysis. https://doi.org/10.1007/s11116-012-9399-4
  - Bicycle boxes.
    - Grigoropoulos et al. (2022). Traffic flow at signalized intersections with large volumes of bicycle traffic. Transportation Research Part A: Policy and Practice Vol 155. https://doi.org/10.1016/j.tra.2021.11.021
  - Acceleration from standstill.

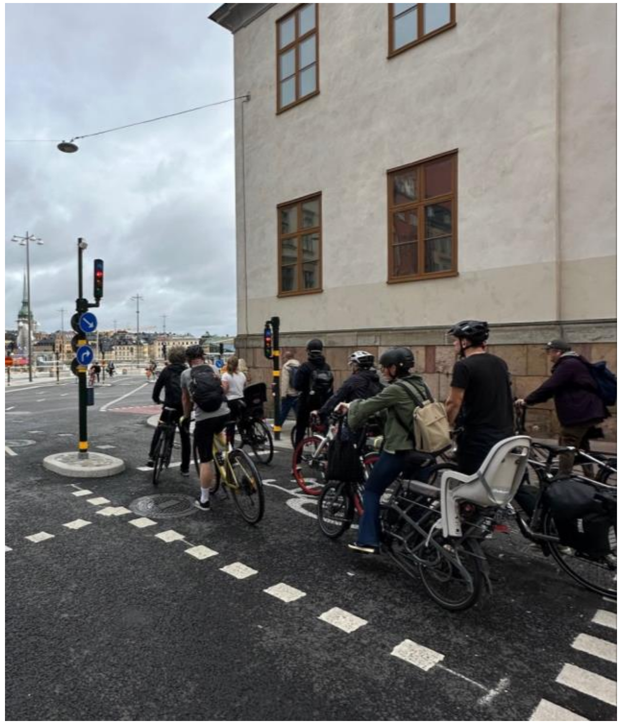

Photo by Guillermo Pérez Castro

New research project:
The impact of signalized intersections on downstream bicycle traffic: queueing behavior and platoon formations (CykelTAKO)

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Overall…

- MTS of bicycle traffic (micromobility) under active development.
  - Important to be aware of modeling specifications and current limitations.
  - Calibration efforts are essential.
- Relevant for calibrating existing MTS models and developing bicycle-specific modeling approaches.
  - The role of “good” bicycle data.
- MTS contributes to incorporating traffic performance criteria into micromobility planning across demand levels.
  - Make sure it works for all bicyclists.

Publications

- Pérez Castro, G., Johansson F., Olstam, J., 2022. How to Model the Effect of Gradient on Bicycle Traffic in Microscopic Traffic Simulation. Transportation Research Record: Journal of the Transportation Research Board, Vol. 2676, No. 11, 2022, pp. 609–620.
- Pérez Castro, G., Johansson, F., Olstam, J., 2023. A Power-Based Approach to Model the Impact of Gradient in Bicycle Traffic Simulation, in 102nd Transportation Research Board Annual Meeting, Washington D.C., U.S.A.
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- Pérez Castro, G., 2023. Towards microscopic models for bicycle traffic simulation. Licentiate Thesis No. 1972. Linköping Studies in Science and Technology. Linköping University,
- Belikhov, D., Pérez Castro, G., Titgemeyer, M., Johansson, F., Heather, K., Olstam, O., 2025. Exploring free riding behavior: An instrumented bicycle study on the impact of infrastructure and wind on bicycling. Journal of Cycling and Micromobility Research 5.
- Pérez Castro, G., Belikhov, D., Johansson, F., Heather, K., Olstam, O., 2025. Microscopic simulation of free riding speed dynamics in bicycle traffic: modeling heterogeneous context-dependent effects. Working paper.
- Pérez Castro, G., Johansson, F., Olstam, O., 2025. The role of advanced free riding behavior models in microscopic simulation of congested bicycle traffic. Working paper.
- Pérez Castro, G., 2025. Microscopic simulation of bicycle traffic: Analysis of heterogeneity and free riding on bicycle paths. PhD Dissertation No. 2494, Linköping University Electronic Press. https://doi.org/10.3384/9789181183627

Thank you!

guillermo.perez.castro@vti.se

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