Road operating speed estimation

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Outline

- Problem definition
- Applications
- Model Classification
- Model examples
- Obtaining data
- Our Research area
  - Problems
  - SOTA
- Our solution
  - Ideas
  - Preliminary results

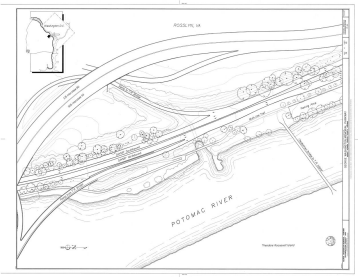
Road speed classification

- Design speed
  - Determined before the building of the infrastructure
  - Does not change in time
- Posted speed
  - Speed limit
  - Limited by the law and safety concerns
- **Operating speed**
  - The real speed of the vehicle on the road

Problem: Estimating the operating speed on the road segment

Estimating speed

- Design speed
  - We can look up the designed speed in the project documentation
  - Can be inferred from curvature, lane width, grade
- Posted speed
  - Is determined by law and traffic signs
- **Operating speed**
  - ??
  - Can we extract the operating speed from design speed and/or posted speed?



Operating speed?

Extracting operating speed

Can be greater than design speed

Can be greater than posted speed

Can be lower than design speed

Can be lower than posted speed

Applications - Routing

We need the road operating speed to find the shortest time path, which is the main task for navigation applications

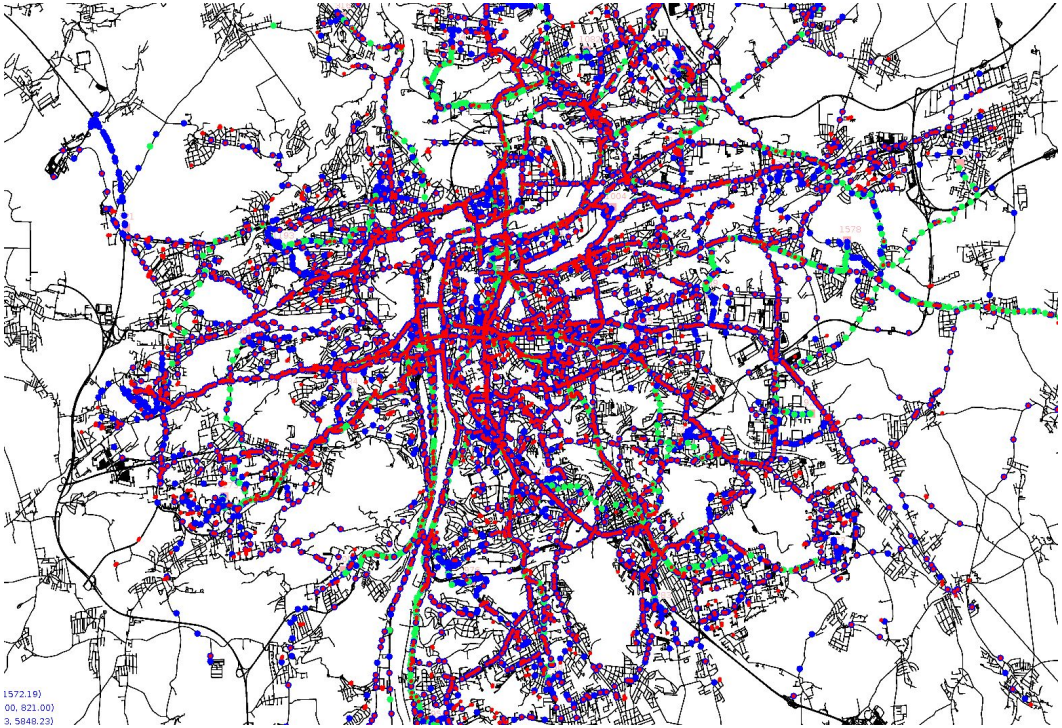
Applications - Safety

Car navigation can recommend the operating speed for the upcoming segments to driver.

Applications - Traffic simulations

Traffic simulations need to configure the operating speed in order to deliver high fidelity.

- This was our motivation to accept this challenge
- Currently, posted speed is used as operating speed in simulations



Operating speed models classification

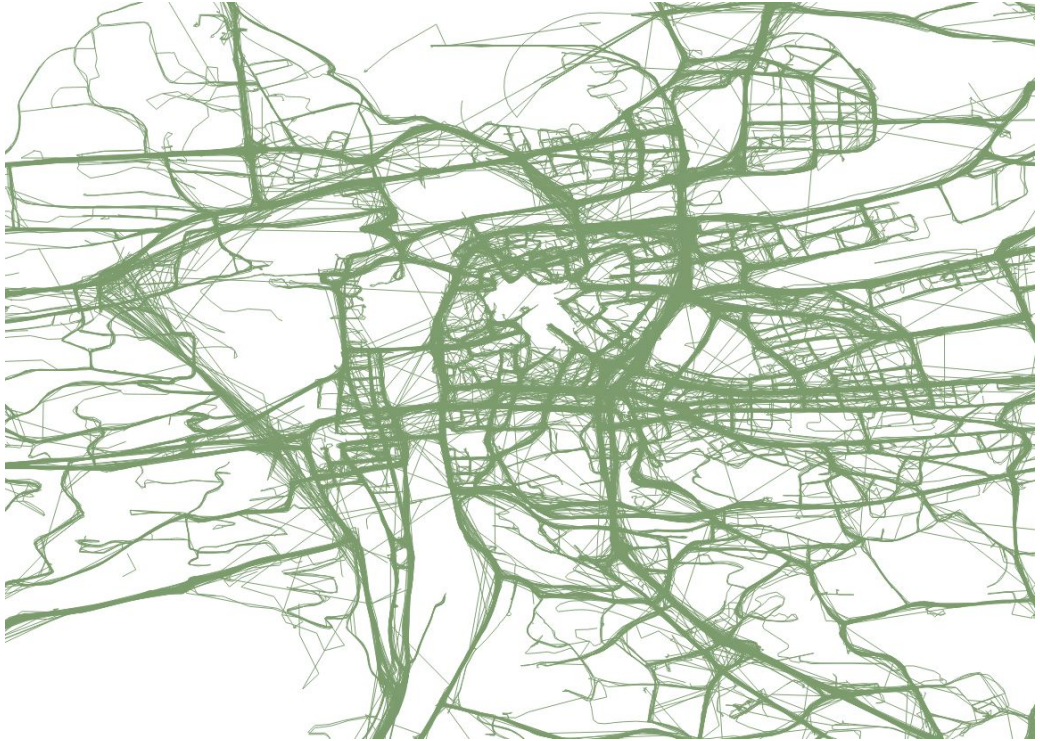
Classification is non-hierarchical, almost all combination exists. Categories:

- per road segment vs parametric
- Free-flow vs congested flow
- Online vs offline

Models - per road segment

We measure the operating speeds on each road segment and build a speed model for each segment

- Google maps, waze
- Usually combined with online data
- Requires a sufficient amount of data for each segment



Models - parametric

We measure the operating speed on part of the segments and build some abstract model on top of that

- Traffic theory
- Can be based on many different parameters: physical, psychological, spatial, temporal
- Does not require data for each road segment

$$S_f = (25.6 + 0.47S_{pl} + f_{cs} + f_A) * f_L$$

$$V85 = 31.565 + 6.491\ \text{lane.num} - 0.101\ \text{roadside} - 0.051\ \text{driveway} - 0.082\ \text{intersection} + 3.01\ \text{curb} - 4.265\ \text{sidewalk} - 3.189\ \text{parking} + 3.312\ \text{land.use1} + 3.273\ \text{land.use2}$$

$$S_f = S_{pl} + 5$$

$$V_{85} = 51.520 + 1.567\ \text{ST} - 2.795\ \text{MT} - 4.001\ PT - 2.150\ \text{AG} + 2.221\ \ln(\text{LC})$$

Online vs Offline estimation

Online: we can use **current car** data

- Uses speed on previous segment to predict current speed
- Speed can be inferred from driver behaviour

Offline: we can use only **average car** data

- Speeds on consecutive segments do not have to be related
- No individual driver behaviour

Models - free flow

Operating speed is not affected by traffic flow (number of cars using the road network)

- Samples have to be measured during the periods of low traffic flow (at night)
- Same free-flow speed during the whole day

Models - congested flow

- Operating speed is affected by traffic flow - number of cars using the road network
- Has to be sampled with some rate to cover the traffic flow variation

Model examples - Google maps

- Per road segment
- Congested flow
- Online

Model examples - Highway Capacity Manual

- Parametric
- Free-flow
- Offline

$$S_{fo} = S_0 + f_{CS} + f_A$$

$S_0 = 25.6 + 0.47 S_{pl}$ where S_{pl} = posted speed limit (mi/h).
$f_{CS} = 1.5\ p_{rm} - 0.47\ p_{curb} - 3.7\ p_{curb}\ p_{rm}$ where p_{rm} = proportion of link length with restrictive median (decimal) and p_{curb} = proportion of segment with curb on the right-hand side (decimal).
$f_A = -0.078\ D_a / N_{th}$ with $D_a = 5{,}280\ (N_{ap,s} + N_{ap,o})/(L - W_i)$ where D_a = access point density on segment (points/mi); N_{th} = number of through lanes on the segment in the subject direction of travel (ln); $N_{ap,s}$ = number of access point approaches on the right side in the subject direction of travel (points); $N_{ap,o}$ = number of access point approaches on the right side in the opposing direction of travel (points); and W_i = width of signalized intersection (ft).

Model examples - Austrian Institute of Technology

- Parametric
- Congested-flow
- Offline

$$\mathrm{sp}_i = c_{f(i)} + \beta_{f(i)}\mathrm{mxsp}_i + v_i$$

$$y_i = \mathrm{sp}_i = c_{f(i)} + \gamma_{t(i),f(i)} + \beta_{f(i)}\mathrm{mxsp}_i + u_i \quad \text{and} \quad (1a)$$

$$y_i' = \frac{\mathrm{sp}_i}{\mathrm{mxsp}_i} = c'_{f(i)} + \gamma'_{t(i),f(i)} + \beta'_{f(i)}\mathrm{mxsp}_i + u'_i\ , \quad (1b)$$

$$\gamma_{t,i} = \bar{\gamma}_{t,j} \text{ for all } i \in F_j \text{ with } \sum_{t=1}^{96} \bar{\gamma}_{t,j} = 0,\ j = 1, \ldots, g, \quad (2)$$

$$\hat{y}_i(p\,|\,q) = \hat{c}_{f(i)|q} + \hat{\gamma}_{t(i),f(i)|q} + \hat{\beta}_{f(i)|q}\mathrm{mxsp}_i \quad \text{or} \quad (3a)$$

$$\hat{y}_i(p\,|\,q) = \hat{c}_{f(i)|q} + \hat{\gamma}^r_{t(i),f(i)|q} + \hat{\beta}_{f(i)|q}\mathrm{mxsp}_i\ , \quad (3b)$$

$$\tilde{\mathbf{r}}^r_q = \sum_{i \le r} \hat{\boldsymbol{\sigma}}_{i|q}\hat{\mathbf{u}}_{i|q}\hat{\mathbf{v}}^{\mathsf{T}}_{i|q}$$

Obtaining speed data - field measurement

- Small datasets
- Expensive
- Time consuming
- Can bring speed-enforcement bias

Obtaining speed data - traffic infrastructure

- Acceptable time requirement
- Cheap
- Limited to existing infrastructure

Obtaining speed data - GPS traces

- Cheap
- Almost complete datasets
- Requires map matching

Our Research Area

- We can't gather data for all roads -> **parametric model**
- We have our own congestion model -> **free-flow model**
- We don't model drivers behaviour -> **offline model**
- GPS traces as the source data
- Also, we focus on urban models, which brings some difficulties

Our Research Area - Urban Models

Many types of roads

Our Research Area - Urban Models

Lot of roads with small utilization

SOTA - limitations

The main problem is interdisciplinarity

Traffic researchers does not have the necessary ML background

- Cannot overcome high-dimensionality
- Chooses field measurements over data-mining

ML researchers are not interested

- No article in ML conference or journal even in applications (ICMLA)
- Focus on statistical models

SOTA - limitations

- Only linear regression as a ML model
- Mostly, only one feature at a time is fitted
- Models uses features that have to be measured in the field
  - When we measure the feature in the field, we can measure the speed instead and build the statistical model
- Cherry picking of testing sites - only simple standardized segments are included in most studies
- Radar gun measurment
- Models are evaluated on a very limited - statistically insignificant number of roads

Our model - ideas

- Use only parameters that can be obtained or computed from public resources worldwide (length, curvature, road type, elevation…)
- Use machine learning methods to create models that leverage many different parameters
- Choose relevant parameters based on the efficiency of the model
- Compute geometric features from the map and try if they are related to speed

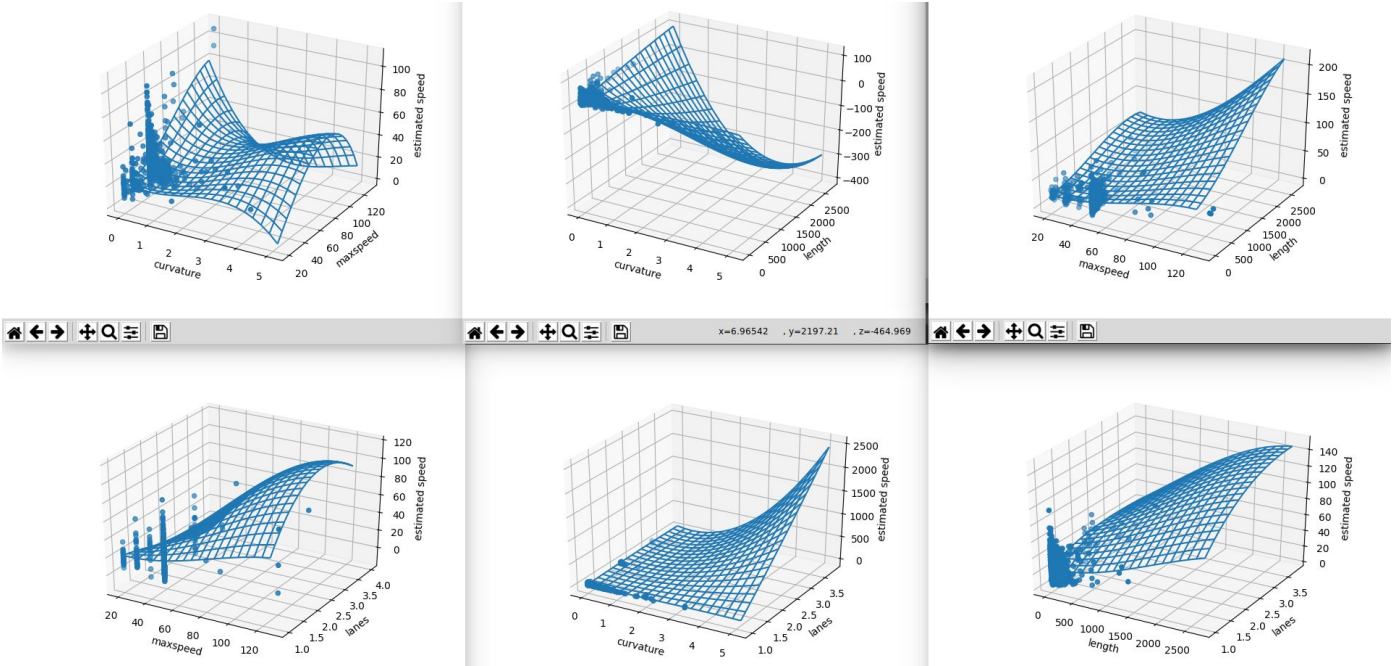
Our model - current features

	Expected value	Standard deviation	p-value
Curvature	0.14	0.31	<< 0.001
Max curvature	0.31	0.7	<< 0.001
Posted speed	48.8	9.17	<< 0.001
Length	124	162.5	<< 0.001
Lane count	1.23	0.91	<< 0.001
Road type	10.16	1.93	<< 0.001

Our model - Baseline

- Polynomial regression for all parameter combinations

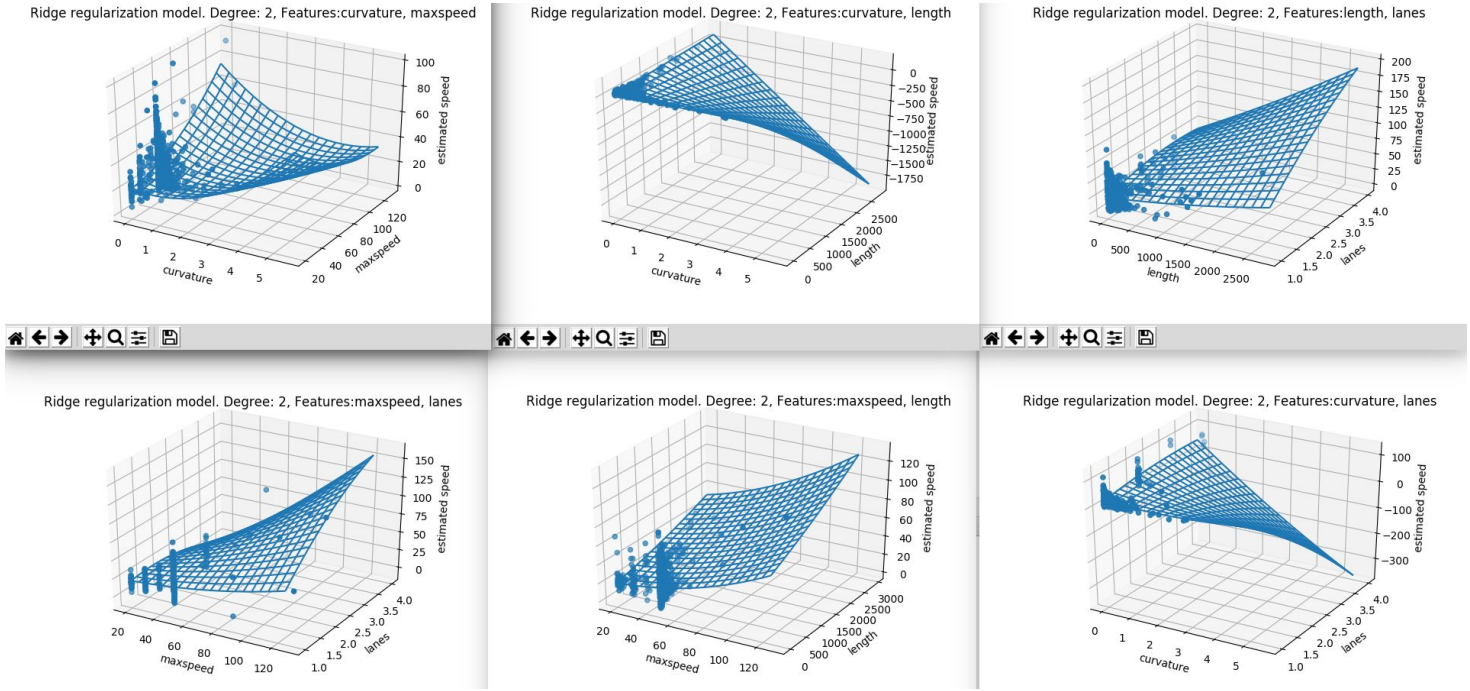
$$\min_{w} ||Xw - y||_2^2$$



Our model - Ridge regression

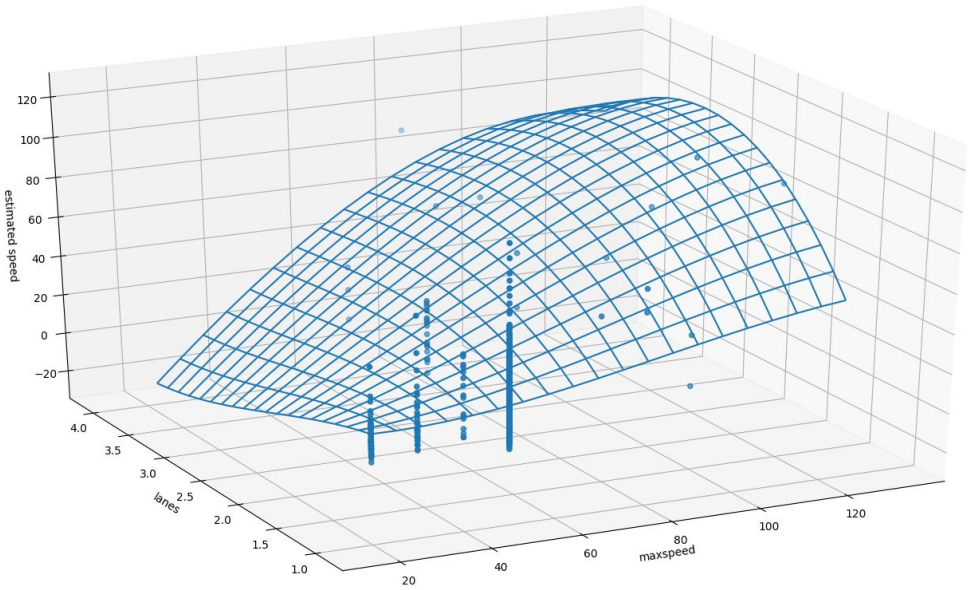
- Regularized regression for all parameter combinations

$$\min_{w} ||Xw - y||_2^2 + \alpha ||w||_2^2$$



Our model - preliminary results

- With only five parameters, we reached **average error ~7.1 km/h** compared to ~23.9 km/h error when using posted speed as free-flow operating speed (current procedure in most simulations).
- The share of explained variance **(R^2) is 0.48**



Our model - challenges

- We need to come up with more features/parameters that helps to classify streets
  - Each parameter has significant impact to model accuracy - lastly added road type increased the accuracy by 25%
- We have both continuous and discrete parameters
  - So the model should not be pure regression
- High dimensionality prevent us from visualising the results

Thank you!

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