Microscopic Calibration and Validation of Car-Following Models

Motivation

- What is the minimum quantitative data requirement for a given calibration task in terms of minimum number of vehicles, minimum length of time interval, or minimum temporal resolution?
- Is it possible to formulate qualitative data requirements by defining a minimal set of traffic states which must be contained in the data?
- To which degree does data noise or the sampling rate influence the calibration result?
- Is it possible to distinguish noise from intra-driver and inter-driver variations?
- To which degree does the result differ when calibrating a given model on given data with different methods such as least squared errors (LSE) or maximum-likelihood?
- How does the result depend on the objective function?
- Is it necessary to smooth trajectory data before calibration?
- Finally: Why there so little difference when comparing LSE calibration results of the "best" with that of the "worst" models?

Data Preparation

- check for discontinuities, negative speeds, negative gaps
- ensure internal and platoon consistency
- data resampling (if needed) and smoothing (if desired)

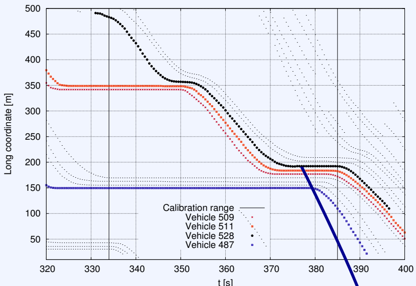
Consistency requirements:

internal consistency

$$\frac{dx}{dt} = v(t), \quad \frac{dv}{dt} = \dot{v}(t)$$

platoon consistency:

$$s(0) = x_l(0) - x(0) - l_l, \quad \frac{ds}{dt} = v_l(t) - v(t).$$

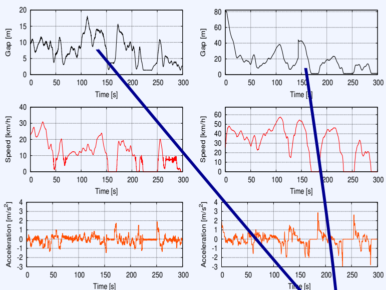


Primary NGSIM quantities

Positions x_i and x_{li}

Dependent NGSIM quantities:

$$s_i = x_{li} - x_i - l_i, \quad v_i = \frac{x_{i+1} - x_{i-1}}{2\Delta t}, \quad v_{li} = \frac{x_{l,i+1} - x_{l,i-1}}{2\Delta t}, \quad \dot{v}_i = \frac{x_{i+1} - 2x_i + x_{i-1}}{(\Delta t)^2}$$



Primary xFCD quantities

Positions x_i and gaps s_i at times $t_i = i\Delta t$

Dependent xFC quantities:

$$v_{li} = v_i + \frac{s_{j+1} - s_{j-1}}{2\Delta t}, \quad \dot{v}_i = \frac{v_{j+1} - v_{j-1}}{2\Delta t}, \quad \dot{v}_{li} = \dot{v}_i + \frac{s_{j+1} - 2s_i + s_{j-1}}{(\Delta t)^2}.$$

Calibration Approaches

Local ML Calibration

Maximum-Likelihood:

$$\tilde{L}(\beta) = \ln[\,\text{prob}\,(\hat{y}_1(\beta) = y_1, \ldots, \hat{y}_n(\beta) = y_n)] = -\frac{n}{2}\ln(\det\Sigma) - \frac{1}{2}\sum_{i=1}^{n} e_i^{\top}(\beta)\,\Sigma^{-1}\,e_i(\beta)$$

System Equation:

$$\frac{dv}{dt} = a_{\text{mic}}(s, v, v_l;\, \beta) + \epsilon, \quad \epsilon \sim iid\; N(0, \sigma^2)$$

Calibration Prescription:

$$\hat{\beta} = \arg\min S_{\text{ML}}(\beta), \quad S_{\text{ML}}(\beta) = \sum_{i=1}^{n} (\dot{v}_i - a_i^{\text{mic}}(\beta))^2$$

Global LSE Calibration

One evaluation of the objective function
⇒ complete simulation!

Absolute-Gap Objective Function:

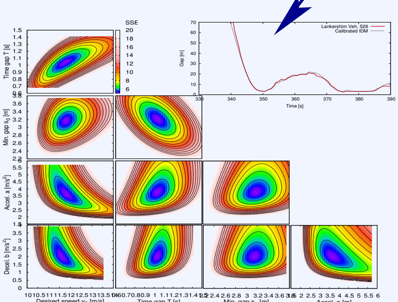
$$S_s^{\text{abs}}(\beta) = \sum_{i=1}^{n} (\hat{s}_i(\beta) - s_i)^2$$

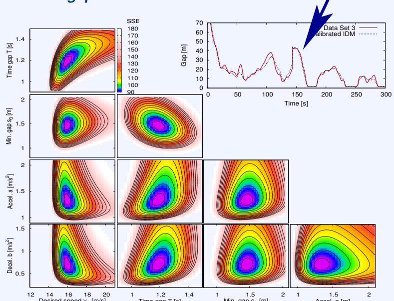
Relative-Gap Objective Function:

$$S_s^{\text{rel}}(\beta) = \sum_{i=1}^{n} (\ln \hat{s}_i(\beta) - \ln s_i)^2$$

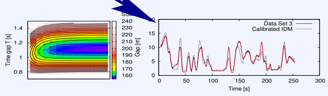
Results

Global calibration of the IDM to relative gaps





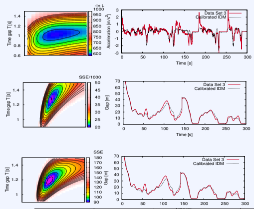
Data Incompleteness: FCD Set 1



No free traffic!

Regime	xFCD Set 1	xFCD Set 3
cruising	0 %	5 %
free acceleration	16 %	8 %
approaching	2 %	3 %
standing	4 %	15 %
following	72 %	65 %
inconsistent	3 %	4 %

Influence on Calibration Method and Objective



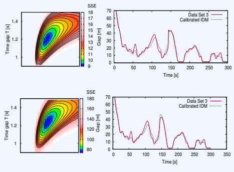
Local Calibration

Global Calibration to log (gaps)

Global Calibration to gaps

IDM parameter	local calibration	global calibration to gap	global calibration to ln(gap)
v_0[m/s]	16.9	16.1	16.1
T[s]	1.02	1.27	1.20
s_0[m]	1.56	1.44	1.53
a[m/s^2]	0.51	1.46	1.39
b[m/s^2]	1.47	0.63	0.65

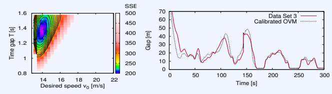
Influence of Data Rate and Smoothing



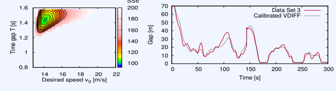
	local calibration w.r.t. $S_{\text{ML}}(\beta)$					global calibration w.r.t. $S_s^{\text{rel}}(\beta)$				
sampling interval Δt	0.1 s	0.5 s	1.0 s	2.0 s	5.0 s	0.1 s	0.5 s	1.0 s	2.0 s	5.0 s
v_0[m/s]	16.9	16.8	16.8	16.6	16.1	16.1	16.2	16.3	15.8	14.8
T[s]	1.02	1.01	1.00	1.02	0.90	1.20	1.21	1.22	1.12	0.87
s_0[m]	1.55	1.56	1.57	1.58	1.72	1.53	1.54	1.58	2.05	3.12
a[m/s^2]	0.52	0.51	0.49	0.43	0.31	1.39	1.38	1.37	1.35	1.24
b[m/s^2]	1.47	1.47	1.52	1.90	2.77	0.65	0.65	0.66	0.76	0.28
error [m/s^2 or %]	0.45	0.42	0.40	0.38	0.36	17.4	17.2	17.7	19.9	32.2

	local calibration w.r.t. $S_{\text{ML}}(\beta)$				global calibration w.r.t. $S_s^{\text{rel}}(\beta)$			
smoothing kernel width w	0.5 s	1.0 s	2.0 s	5.0 s	0.5 s	1.0 s	2.0 s	5.0 s
v_0[m/s]	16.9	17.1	17.5	18.3	16.2	16.2	16.2	15.9
T[s]	1.02	1.03	1.05	1.08	1.21	1.22	1.22	1.24
s_0[m]	1.56	1.57	1.58	1.69	1.54	1.54	1.57	1.67
a[m/s^2]	0.51	0.51	0.48	0.40	1.37	1.32	1.21	1.00
b[m/s^2]	1.41	1.29	1.03	0.62	0.69	0.69	0.68	0.58
error [m/s^2 or %]	0.41	0.38	0.33	0.25	17.1	16.6	16.1	14.9

Influence of the Car–Following Model



Optimal Velocity Model



Full Velocity Difference Model

parameter	OVM, Set 1	OVM, Set 3	FVDM, Set 1	FVDM, Set 3
v_0[m/s]	170	14.0	12.8	14.1
T[s]	1.09	1.38	1.08	1.44
s_0[m]	2.75	2.86	2.76	1.52
a[m/s^2]	182	16.4	12.0	9.03
γ[s^{-1}]	-	-	0.08	0.65

Conclusions

Often, little difference of the fitting quality between models has been reported. In order to discriminate between "good" and "bad" models, one needs a *complete* EFC or trajectory test data set including the following driving regimes:

- free acceleration
- free cruising
- steady-state following
- dynamic following
- approaching a standing object
- stopped traffic

Here, we obtained a squared-sum error of log(gaps) of 200 for the OVM, 110 for the FVDM, and 85 for the IDM.

Furthermore, we have found:

- a global calibration based on the logarithms of the gaps is most distinctive,
- a data sampling rate of 10 Hz is unneccessarily high and 1 Hz suffices,
- in contrast to intuition, data smoothing has no significant influence on the calibration result as long as internal and platoon consistency are fulfilled
- data completeness, and also a minimum total time interval of the order of 300 s are crucial.

References

- E. Brockfeld, R. D. Kühne, P. Wagner, Transportation Research Record 1876 (2004) 62–70.
- V. Punzo, B. Ciuffo, Transportation Research Record 2124 (2009) 249–256.
- M. Treiber, A. Kesting, Traffic Flow Dynamics: Data, Models and Simulation, Springer, 2013.