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Calibrating the Local and Platoon Dynamics of Car-following Models on the Reconstructed NGSIM Data

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Outline

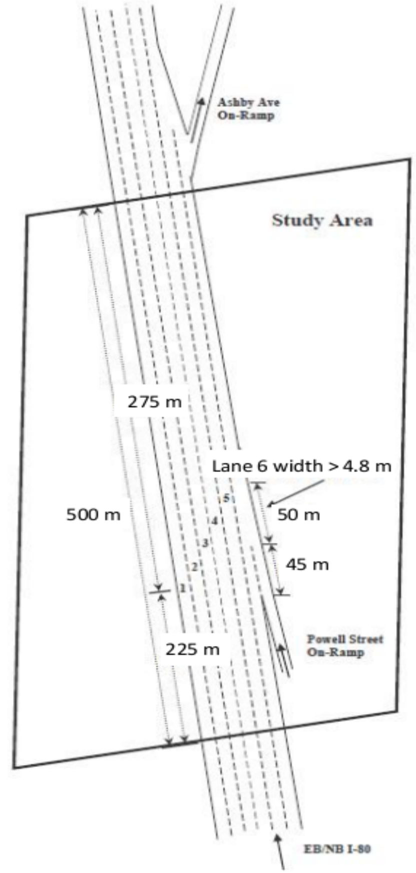
- The reconstructed NGSIM trajectory data (“I80-1”)
- Car-following models under investigation
- Calibration methodology
- Results
- Intra- and inter-driver variations
- Future work

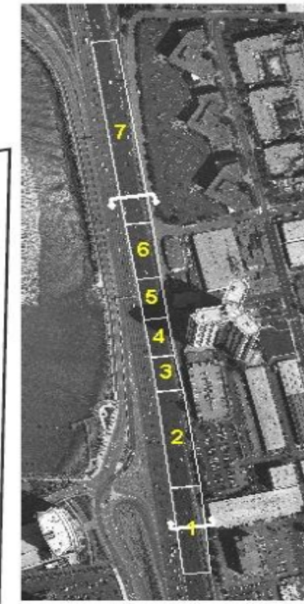
The reconstructed NGSIM trajectory data ("I80-1")

- 500 m, 6 lanes (California)
- 4:00 p.m. – 4:15 p.m., April 13, 2005
- 5648 trajectories (motorcycles, cars, trucks)

#NGSIM I80, error corrected and averaged according to TechnicalReport.pdf

#vehID	frameID[100ms]	laneID	longCoord[m]	v[m/s]	acc[m/s^2]	vehLen[m]	vehClass{b,c,t}	leaderID (-1=none)	followID
1	147	2	50.08315	2.84104	1.46320	4.35910	2	-1	-1
1	148	2	50.38612	3.02972	1.88680	4.35910	2	-1	-1
1	149	2	50.69421	3.08086	0.51134	4.35910	2	-1	-1
1	150	2	51.00658	3.12377	0.42912	4.35910	2	-1	-1
1	151	2	51.32203	3.15445	0.30681	4.35910	2	-1	-1
1	152	2	51.63942	3.17391	0.19455	4.35910	2	-1	-1
1	153	2	51.95797	3.18549	0.11588	4.35910	2	-1	-1
1	154	2	52.27720	3.19236	0.06865	4.35910	2	-1	-1
1	155	2	52.59686	3.19659	0.04227	4.35910	2	-1	-1
1	156	2	52.91681	3.19947	0.02881	4.35910	2	-1	-1
1	157	2	53.23700	3.20191	0.02444	4.35910	2	-1	-1
1	158	2	53.55747	3.20470	0.02786	4.35910	2	-1	-1
1	159	2	53.87834	3.20871	0.04014	4.35910	2	-1	-1
1	160	2	54.19987	3.21529	0.06576	4.35910	2	-1	-1
1	161	2	54.52254	3.22666	0.11372	4.35910	2	-1	-1
1	162	2	54.84719	3.24656	0.19900	4.35910	2	-1	-1
1	163	2	55.17530	3.28113	0.34566	4.35910	2	-1	-1
1	164	2	55.50924	3.33941	0.58283	4.35910	2	-1	-1
1	165	2	55.85238	3.43133	0.91919	4.35910	2	-1	-1
1	166	2	56.20856	3.56184	1.30509	4.35910	2	-1	-1
1	167	2	56.58099	3.72433	1.62489	4.35910	2	-1	-1
1	168	2	56.97093	3.89935	1.75025	4.35910	2	-1	-1
1	169	2	57.37711	4.06180	1.62452	4.35910	2	-1	-1
1	170	2	57.79633	4.19224	1.30442	4.35910	2	-1	-1





Data filtering

- trajectories of more than 30 s length are taken
- eliminate the first and last 5 s of each trajectory
- filter out all active and passive lane changes and 5 s before and after such changes
- filter out all trajectories on the first and last lanes
- distinguish the trajectories by lane and vehicle type

Car-following models under investigation

Intelligent driver model	*Velocity difference model*
$\dot{v}_{IDM}(v, \Delta v, s) = a\left[1 - \left(\frac{v}{V_0}\right)^4 - \left(\frac{s^*(v, \Delta v)}{s}\right)^2\right]$ $s^*(v, \Delta v) = s_0 + max\left(0, Tv + \frac{v\Delta v}{2\sqrt{ab}}\right)$	$\dot{v}_{VDIFF}(v, \Delta v, s) = \frac{v_{opt}(s) - v}{\tau} - \lambda \Delta v$ $v_{opt}(s) = \frac{V_0}{2}\left[tanh\left(\frac{s}{l_{int}} - \beta\right) - tanh(-\beta)\right]$
Model parameters to calibrate	
a V_0 s_0 T b	β V_0 l_{int} τ λ

5 parameters to calibrate

Calibration methodology

CF model calibration problem = a nonlinear optimization problem with constraints (numerically)

I. Initial condition for the simulated speed: $v^{sim}\left(t=0\right)=v^{data}\left(0\right)$

Initial condition for the simulated gap: $s^{sim}\left(t=0\right)=s^{data}\left(0\right)$

II. Calibration methods:

Method	**Details**	**Simulations**
Local calibration	Model's acceleration function is fitted directly to the observed accelerations	No
Global calibration	The simulated trajectory of the follower with prescribed leader is compared to the data	Yes
Platoon calibration	A platoon of several vehicles following a data-driven leader is simulated and compared to the observed dynamics	Yes

III. Dynamic variables:

- acceleration (local calibration)
- velocity and gap (global and platoon calibration)

Calibration methodology (2)

IV. Objective functions = the deviation between the measured and simulated dynamic variables

$$S_s^{abs} = \frac{\sum_{i=1}^{n} \left(s_i^{sim} - s_i^{data}\right)^2}{\sum_{i=1}^{n} \left(s_i^{data}\right)^2}$$

$$S_s^{rel} = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{s_i^{sim} - s_i^{data}}{s_i^{data}} \right)^2$$

$$S_s^{mix} = \frac{\sum_{i=1}^{n} \left(s_i^{sim} - s_i^{data}\right)^2 / \left|s_i^{data}\right|}{\sum_{i=1}^{n} \left|s_i^{data}\right|}$$

$$S_v^{abs} = \frac{\sum_{i=1}^{n} \left(v_i^{sim} - v_i^{data}\right)^2}{\sum_{i=1}^{n} \left(v_i^{data}\right)^2}$$

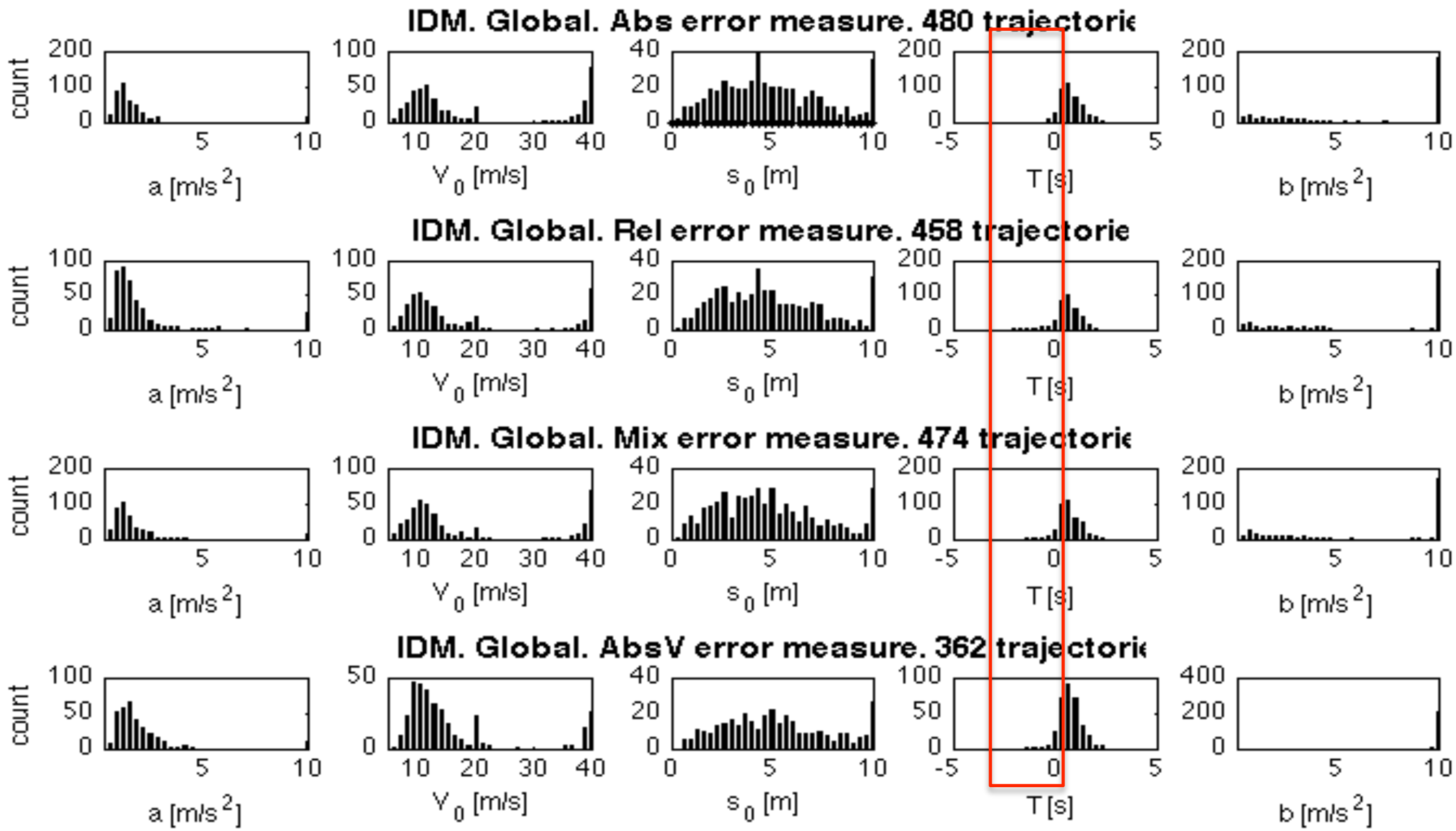
V. Numerical algorithm – the interior-point algorithm (MATLAB optimization toolbox)

VI. Parameter constraints = box constraints

IDM	$V_0 \in [5,40]$ *m/s*	$s_0 \in [0,10]$ *m*	$T \in [-5,5]$ *s*	$a \in [0.01,10]$ *m/s²*	$b \in [0.01,10]$ *m/s²*
VDIFF	$V_0 \in [0,70]$ *m/s*	$l_{int} \in [0.1,100]$ *m*	$\tau \in [0.05,20]$ *s*	$\beta \in [0.1,10]$	$\lambda \in [0,3]$ *1/s*

Results. Global calibration. The IDM

Data filtering procedure – 876 trajectories to calibrate



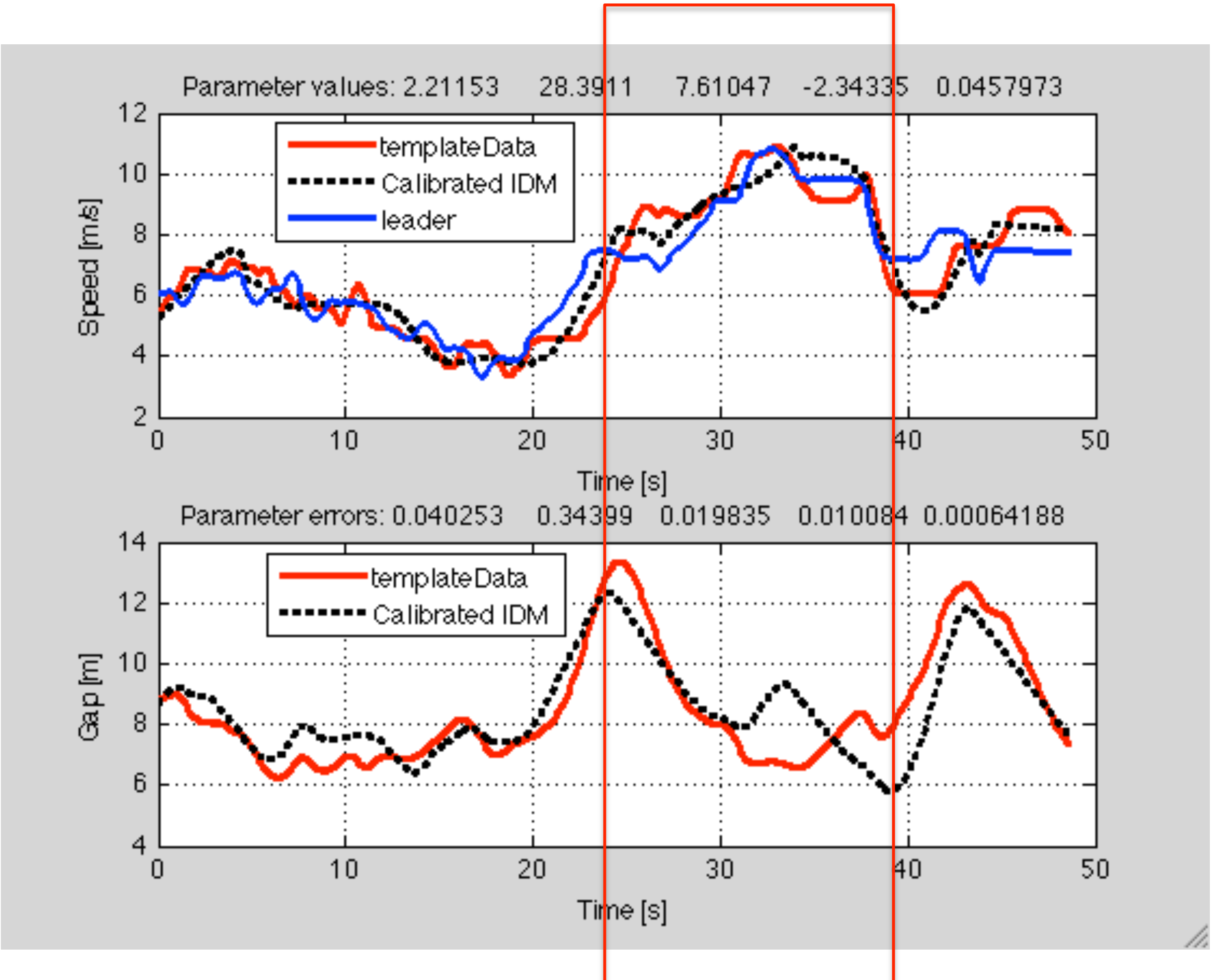
		Kolmogorov-Smirnov statistic					
		$abs_s - rel_s$	$abs_s - mix_s$	$rel_s - mix_s$	$abs_s - abs_v$	$rel_s - abs_v$	$mix_s - abs_v$
IDM	$a[m/s^2]$	0.06	0.04	0.05	0.16	0.12	0.16
	$V_0[m/s]$	0.09	0.06	0.06	0.17	0.09	0.13
	$s_0[m]$	0.05	0.05	0.02	0.08	0.10	0.09
	$T[s]$	0.10	0.07	0.07	0.05	0.11	0.07
	$b[m/s^2]$	0.04	0.03	0.04	0.27	0.26	0.26
	mean	0.07	0.05	0.05	0.15	0.14	0.14

Calibration errors

	IDM	
	global	super-global
abs_s	0.098	0.256
rel_s	0.125	0.324
mix_s	0.111	0.296
abs_v	0.086	0.131

Global calibration. The IDM. Negative reaction times

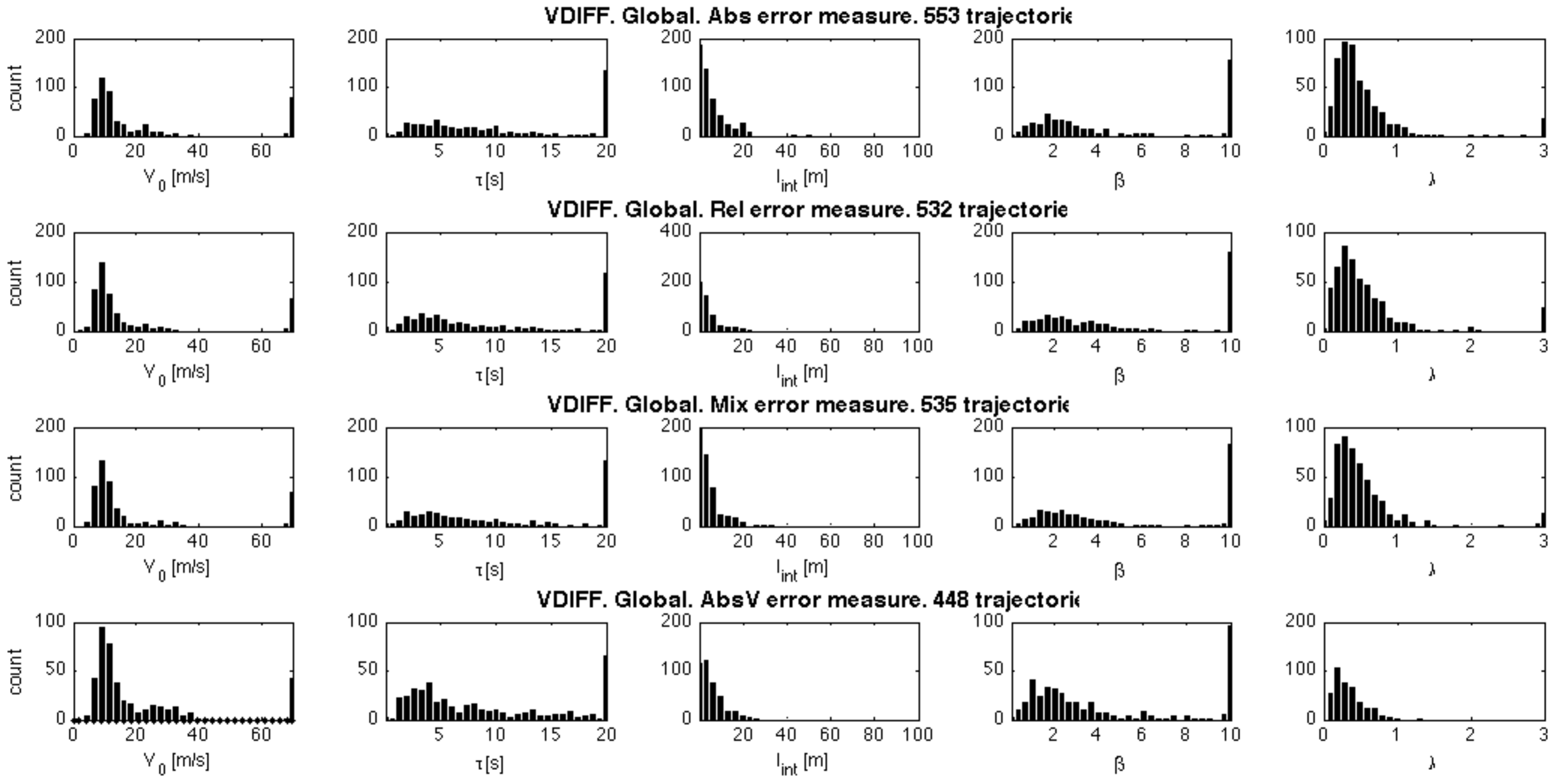
Speed increasing and gap decreasing simultaneously



$$T = -2.34s$$

Results. Global calibration. The VDIFF

Data filtering procedure – 876 trajectories to calibrate



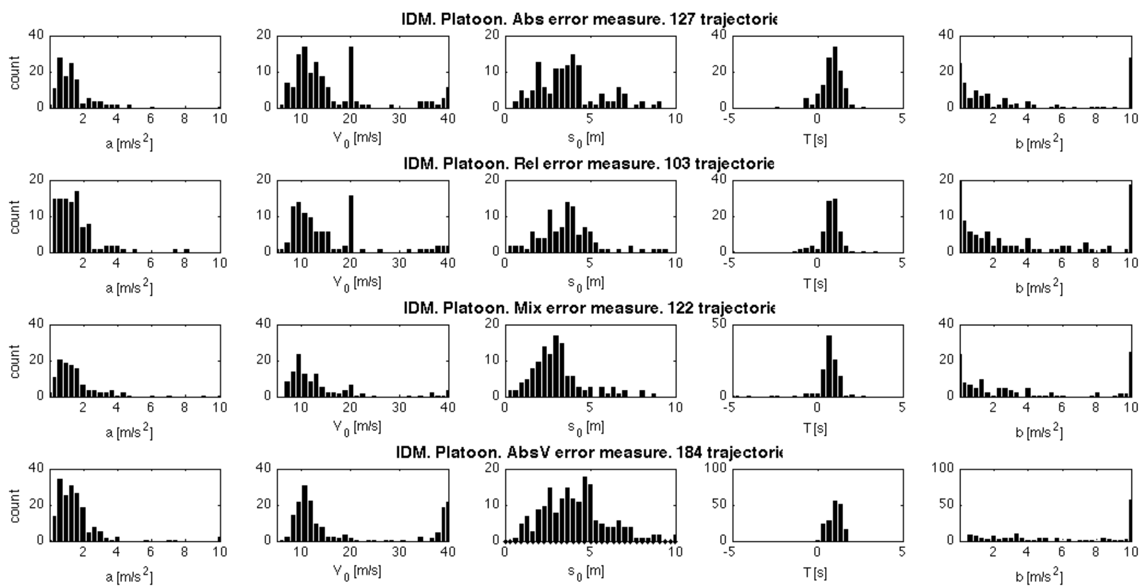
		Kolmogorov-Smirnov statistic					
		$abs_s - rel_s$	$abs_s - mix_s$	$rel_s - mix_s$	$abs_s - abs_v$	$rel_s - abs_v$	$mix_s - abs_v$
VDIFF	$V_0\,[m/s]$	0.08	0.07	0.04	0.08	0.14	0.13
	$\tau\,[s]$	0.08	0.04	0.06	0.13	0.11	0.12
	$l_{int}\,[m]$	0.09	0.06	0.03	0.09	0.15	0.13
	$\beta\,[m]$	0.07	0.06	0.04	0.11	0.15	0.14
	$\lambda\,[1]$	0.07	0.02	0.05	0.18	0.21	0.19
	mean	0.08	0.05	0.04	0.12	0.15	0.14

Calibration errors

	VDIFF	
	global	super-global
abs_s	0.097	0.239
rel_s	0.112	0.303
mix_s	0.105	0.279
abs_v	0.083	0.128

Results. Platoon calibration. The IDM

At least 5 vehicles following each other – 251 data sets to calibrate

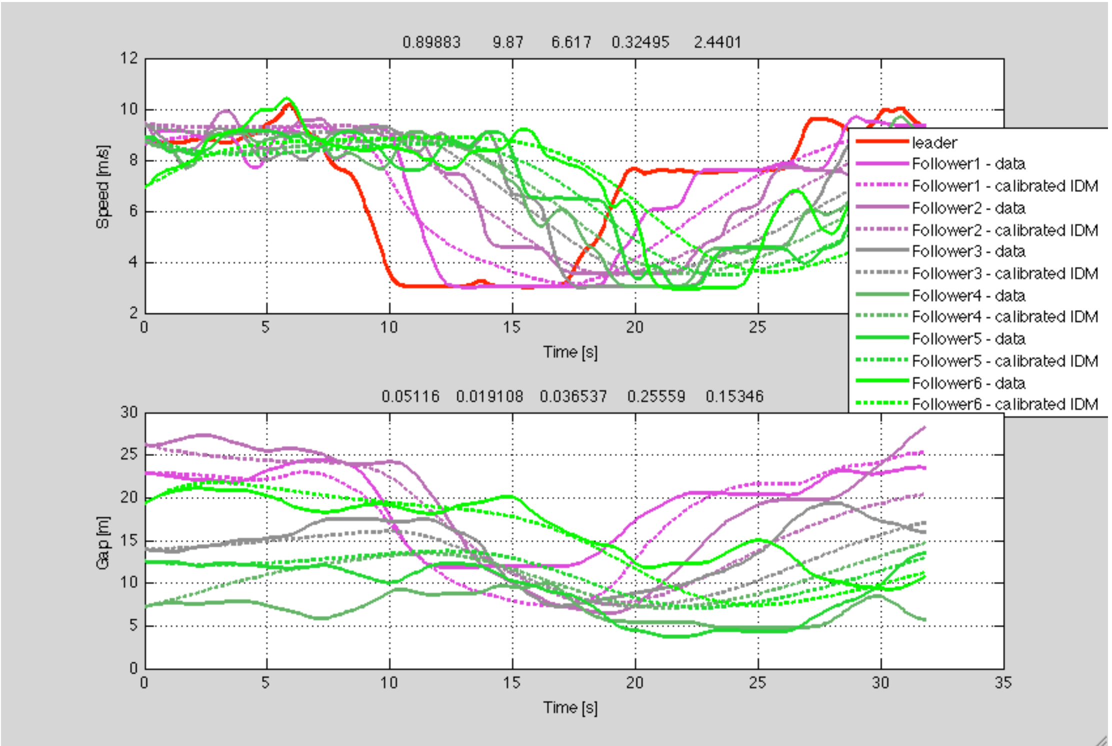


Calibration errors

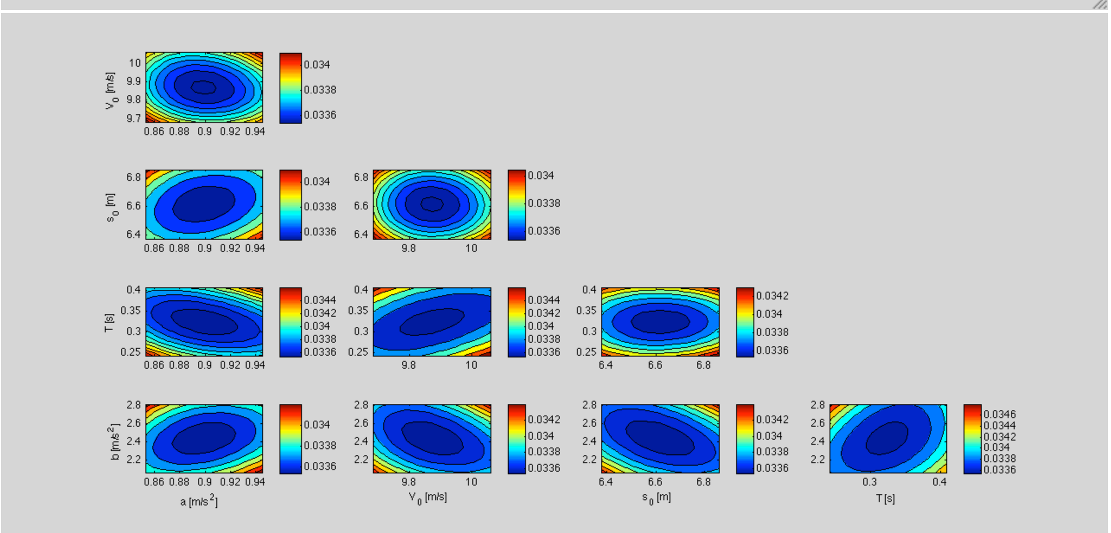
	IDM	
	global	super-global
abs_s	0.098	0.256
rel_s	0.125	0.324
mix_s	0.111	0.296
abs_v	0.086	0.131

		Kolmogorov-Smirnov statistic					
		$abs_s - rel_s$	$abs_s - mix_s$	$rel_s - mix_s$	$abs_s - abs_v$	$rel_s - abs_v$	$mix_s - abs_v$
IDM	$a[m/s^2]$	0.10	0.08	0.08	0.09	0.07	0.09
	$V_0[m/s]$	0.10	0.18	0.12	0.18	0.20	0.21
	$s_0[m]$	0.10	0.29	0.31	0.19	0.19	0.36
	$T[s]$	0.16	0.20	0.16	0.19	0.25	0.36
	$b[m/s^2]$	0.09	0.08	0.05	0.38	0.32	0.31
	mean	0.11	0.17	0.14	0.21	0.21	0.26

Results. Platoon calibration. The IDM



Leader + 6 followers



Objective function – absolute error measure (gap)

Intra- and inter-driver variations

Variations in driving behavior

- Inter-driver – differences between the driving styles of different drivers
- Intra-driver – a single individual can change their behavior over time

Global calibration: $\varepsilon^{global} = \varepsilon_{intra}$

Platoon calibration: $\varepsilon^{platoon} = \varepsilon_{intra} + \varepsilon_{inter}$

$\varepsilon_i = s_i^{sim} - s_i^{data}$ – absolute gap error for specific trajectory at time t_i

$Var(\varepsilon) = \frac{1}{N}\sum_{i=1}^{N} \varepsilon_i$, N - the number of the trajectory data points

$Var(\varepsilon_{inter}) = Var(\varepsilon^{platoon}) - Var(\varepsilon^{global})$

	IDM		VDIFF	
	abs_s	abs_v	abs_s	abs_v
$Var(\varepsilon^{global}), [m^2]$	1.74	0.35	1.83	0.32
$Var(\varepsilon^{superglobal}), [m^2]$	12.01	0.57	10.42	0.54
$Var(\varepsilon_{inter}), [m^2]$	10.27	0.22	8.59	0.22
$Var(\varepsilon_{inter})/Var(\varepsilon_{intra}), [1]$	5.9	0.6	4.7	0.7

Benchmarking of car-following models

Calibration errors:

	IDM		VDIFF	
	global	super-global	global	super-global
abs_s	0.098	0.256	0.097	0.239
rel_s	0.125	0.324	0.112	0.303
mix_s	0.111	0.296	0.105	0.279
abs_v	0.086	0.131	0.083	0.128

Calibration with four objective functions demonstrates the same stability properties of two models considered

		Kolmogorov-Smirnov statistic					
		$abs_s - rel_s$	$abs_s - mix_s$	$rel_s - mix_s$	$abs_s - abs_v$	$rel_s - abs_v$	$mix_s - abs_v$
IDM	$a[m/s^2]$	0.10	0.08	0.08	0.09	0.07	0.09
	$V_0[m/s]$	0.10	0.18	0.12	0.18	0.20	0.21
	$s_0[m]$	0.10	0.29	0.31	0.19	0.19	0.36
	$T[s]$	0.16	0.20	0.16	0.19	0.25	0.36
	$b[m/s^2]$	0.09	0.08	0.05	0.38	0.32	0.31
	mean	0.11	0.17	0.14	0.21	0.21	0.26
VDIFF	$V_0[m/s]$	0.10	0.09	0.12	0.21	0.26	0.22
	$\tau[s]$	0.18	0.10	0.13	0.33	0.16	0.26
	$l_{int}[m]$	0.14	0.05	0.14	0.29	0.35	0.29
	$\beta[m]$	0.13	0.09	0.15	0.32	0.35	0.28
	$\lambda[1]$	0.07	0.06	0.10	0.30	0.26	0.33
	mean	0.13	0.08	0.13	0.29	0.27	0.27

Future work

- consider data containing longer trajectories to increase the occuracy of results obtained during the calibrating procedure
- consider data containing trajectories with stops due to traffic lights to study stop-and-go waves occurring in traffic flow
- develop more elaborate deviation measure to take into account aspects of driving style with higher precision
- choose the most suitable optimization algorithm