

Measuring and Modelling Crowd Flows - Fusing Stationary and Tracking Data

Martin Treiber

TGF 15, Nootdorp, Holland







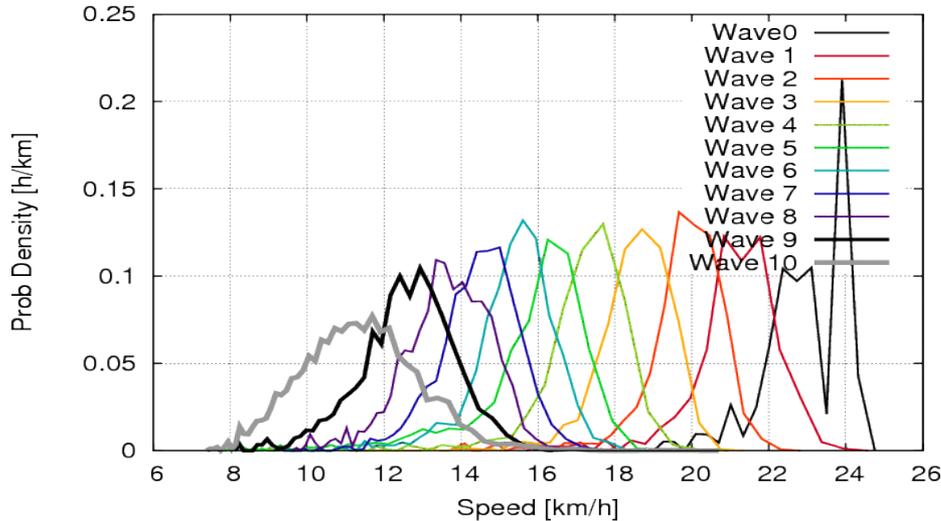




- ▶ Each athlete has an RFID chip
- ▶ When passing the starting line, the start time will be recorded
- ▶ When passing stations (refreshments), split times are taken
- ▶ At the finish, the final time is recorded

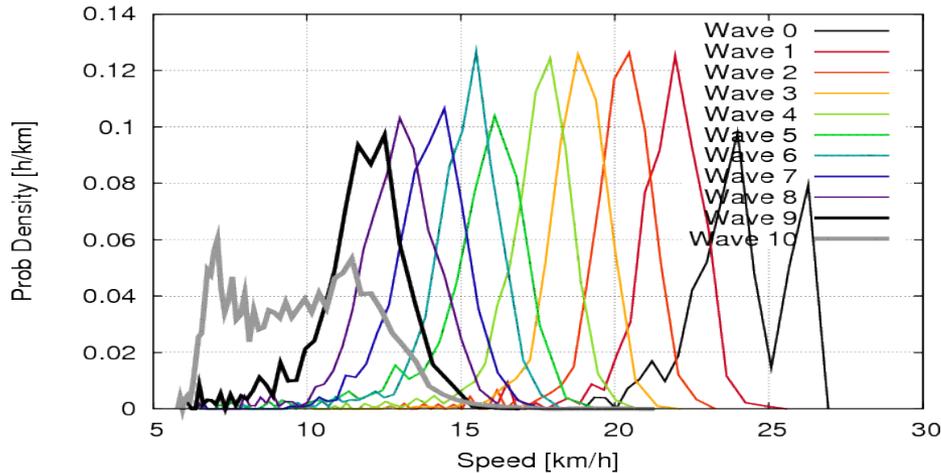
=> Passage times (and some socioeconomic data and the starting wave) are known at fixed locations x_{Det_i}

Average speed between Stations S12



► Between stations 1 and 2: Gaussian

Average speed between Stations S23



► Between stations 2 and 3: the slowest wave 10 is not Gaussian: evidence for congestion!

Live GPS-Tracking for Events

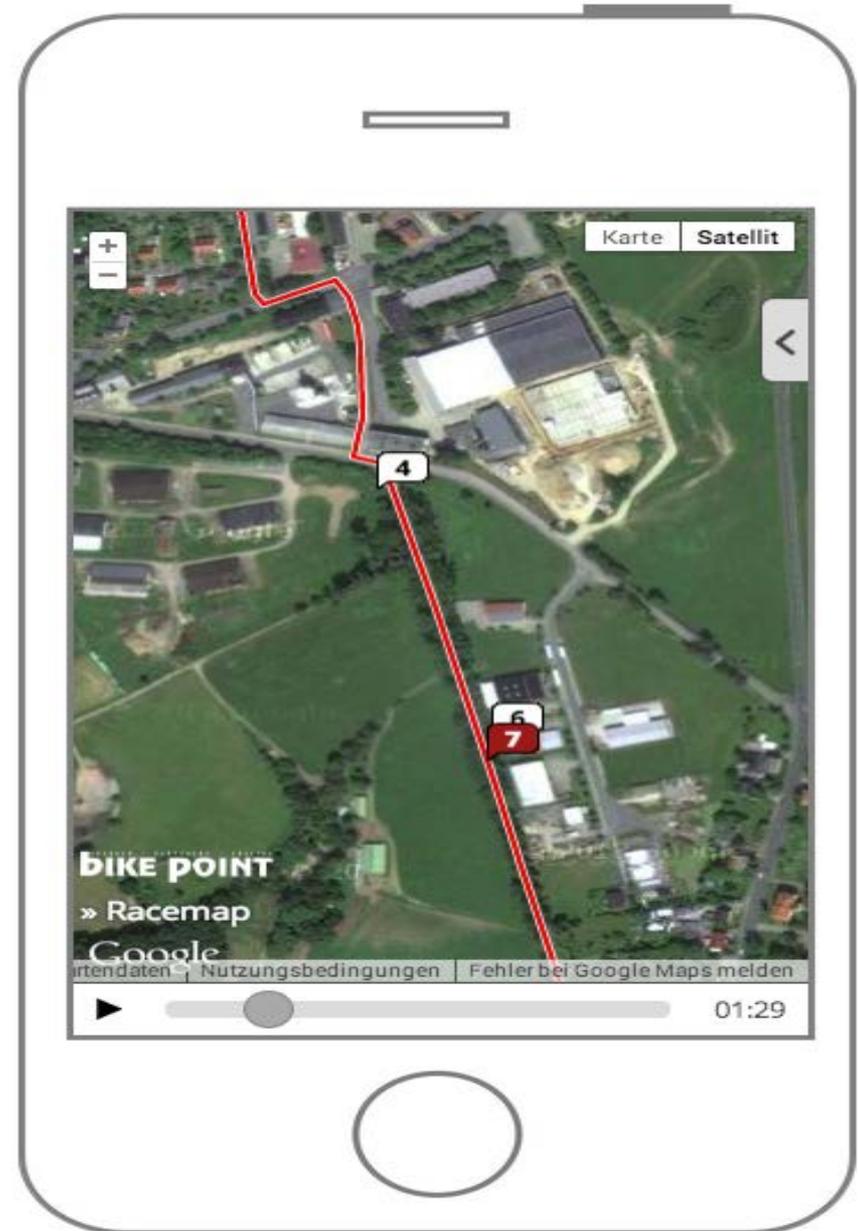
Simply with Racemap »
App. For spectators,
athletes and organizers.

With Racemap you do easy and
flexible live GPS-tracking for your
sports event. Racemap streams your
competition live on the Internet, on
smartphones and Facebook.



Do you want to broadcast your sports
event live on the Internet and on
smartphones?

Create Event now





Login • Register | English • Deutsch

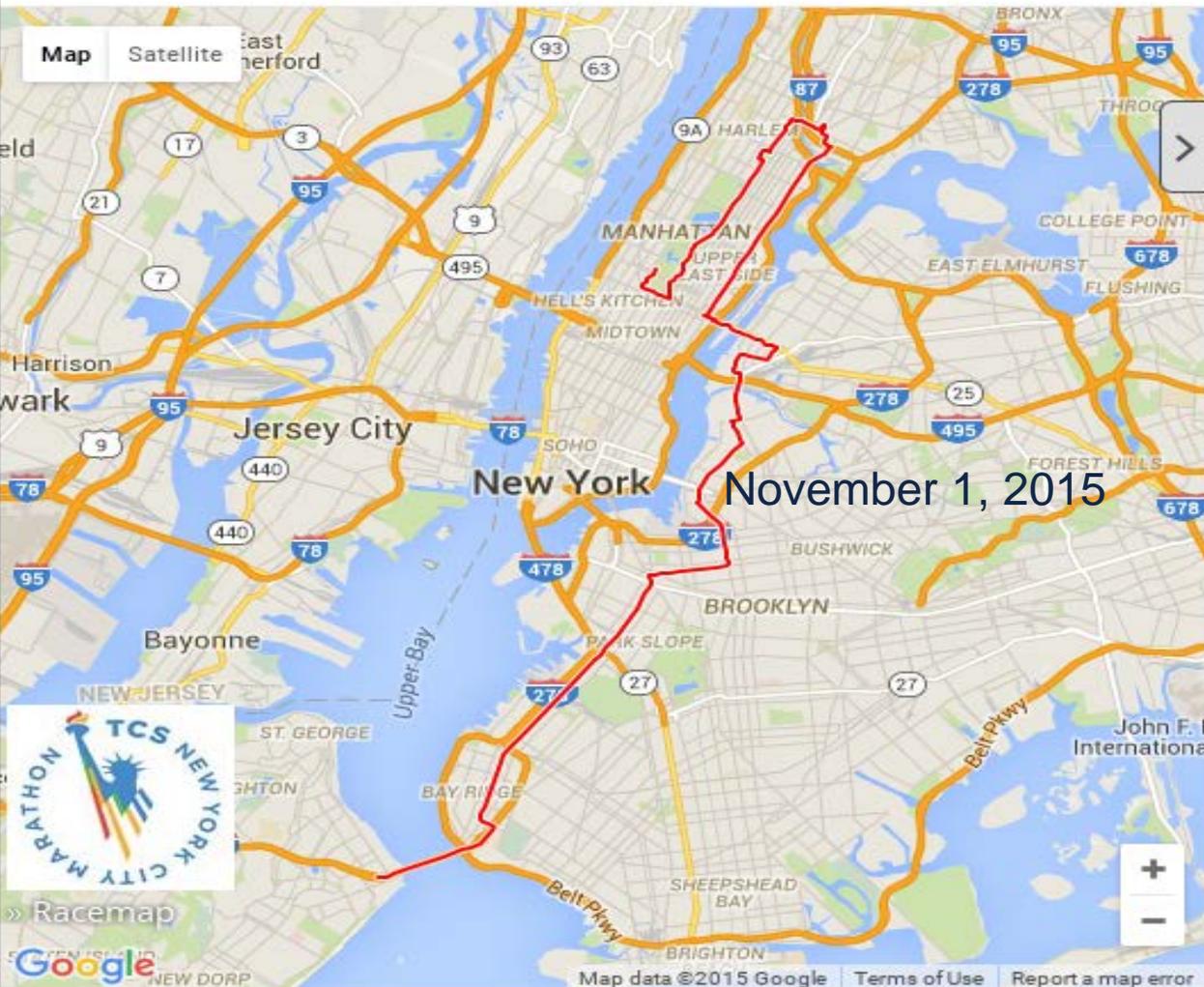
New York City Marathon



Map Satellite

Search... Selection

- 40923. Mittnacht
- 2782. Roesler Jens

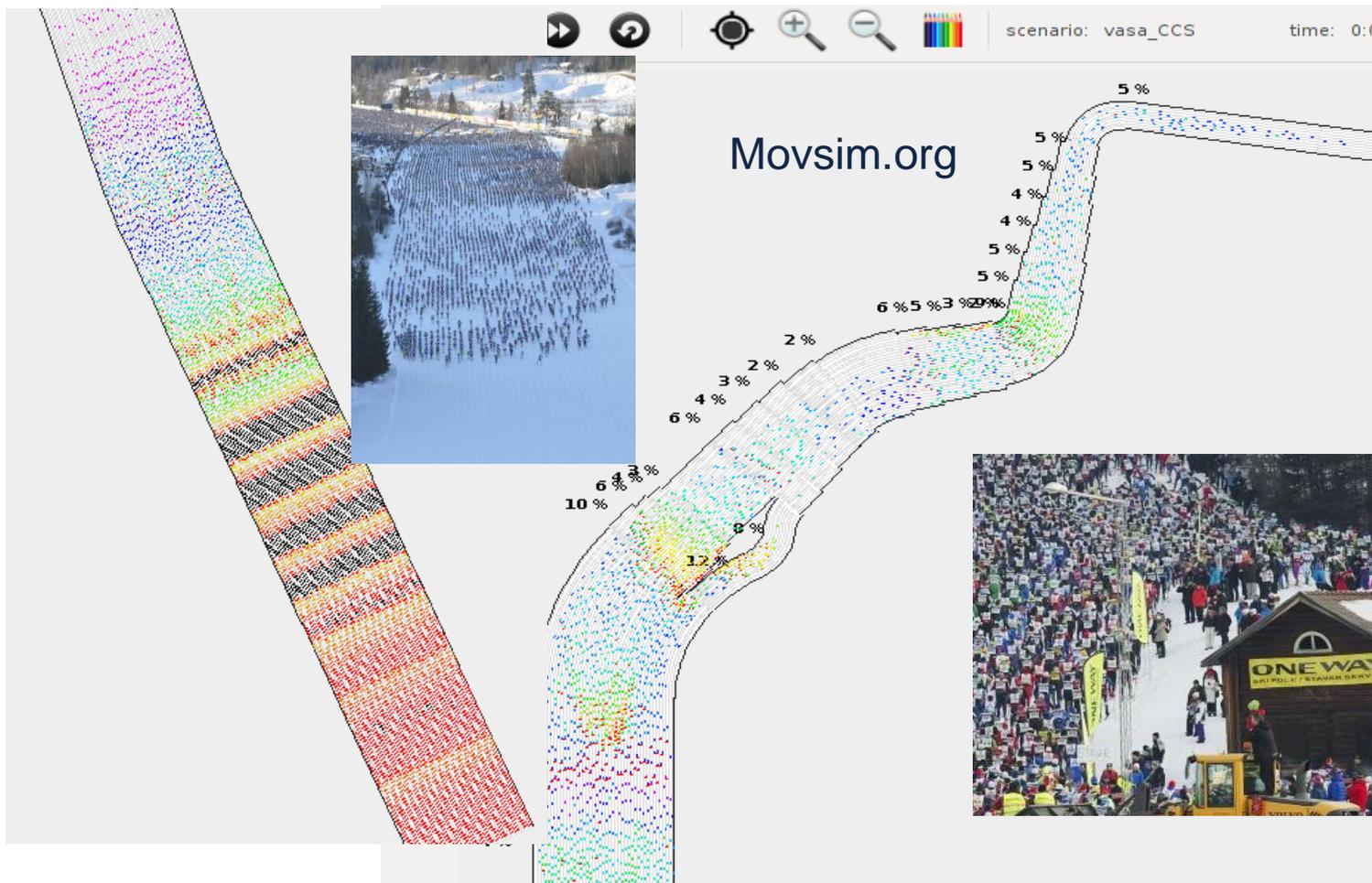


Racemap



Map data ©2015 Google Terms of Use Report a map error

<iframe src="https://racemap.de/player/new-york-cit



► Time: about 1 minute

► Time: about 10 minutes

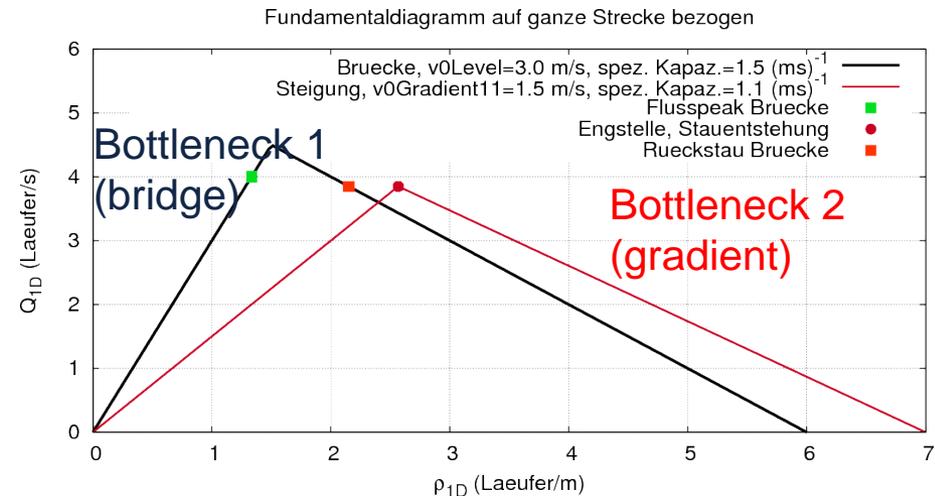
▶ Fast athletes remain fast, and slow remain slow:
 dispersion-transport equation instead of diffusion-
 transport equation

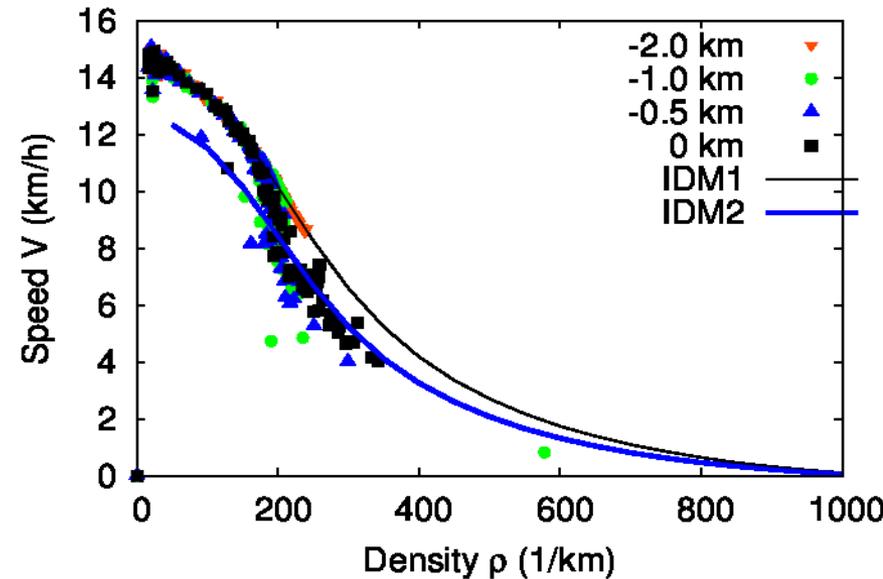
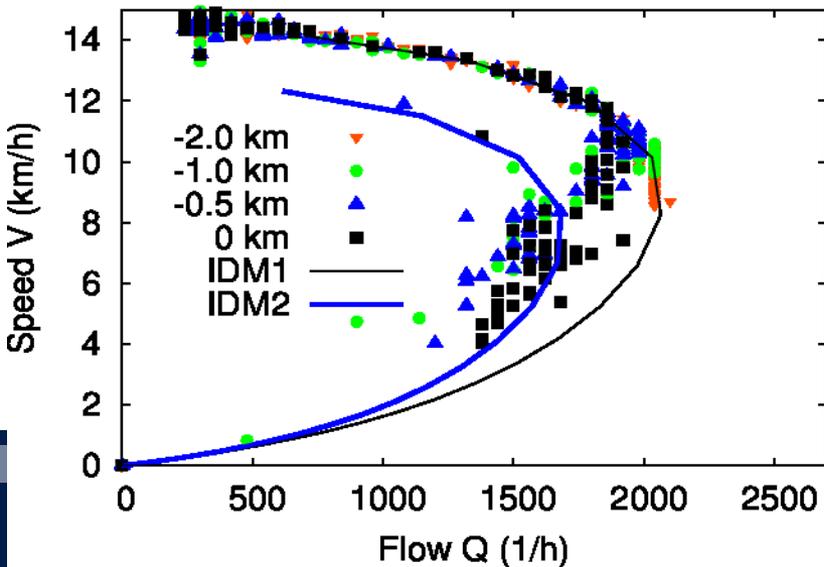
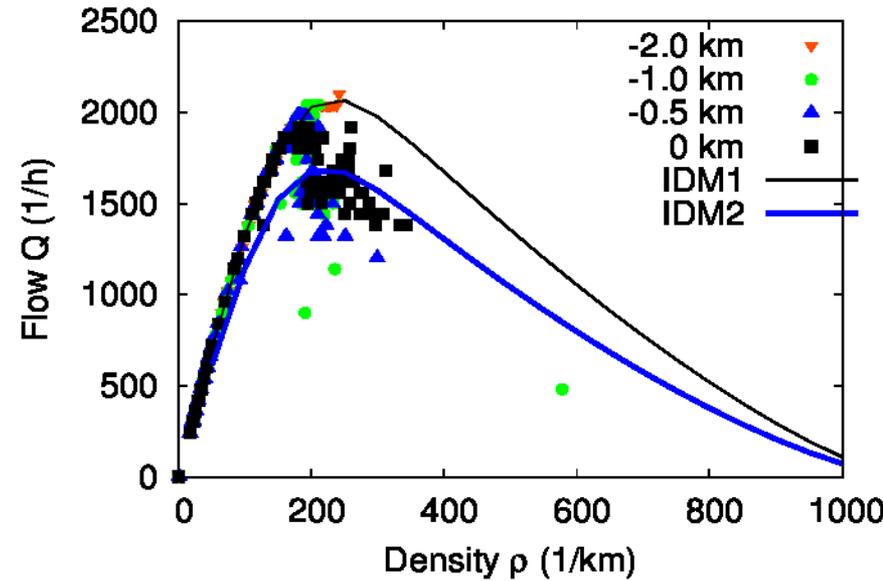
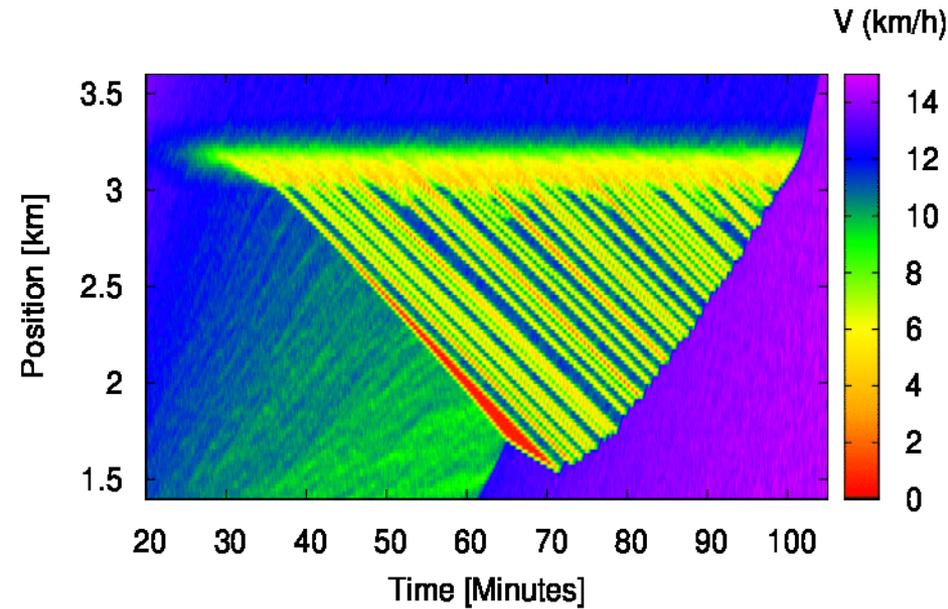
▶ Speed distribution of each block k is Gaussian:

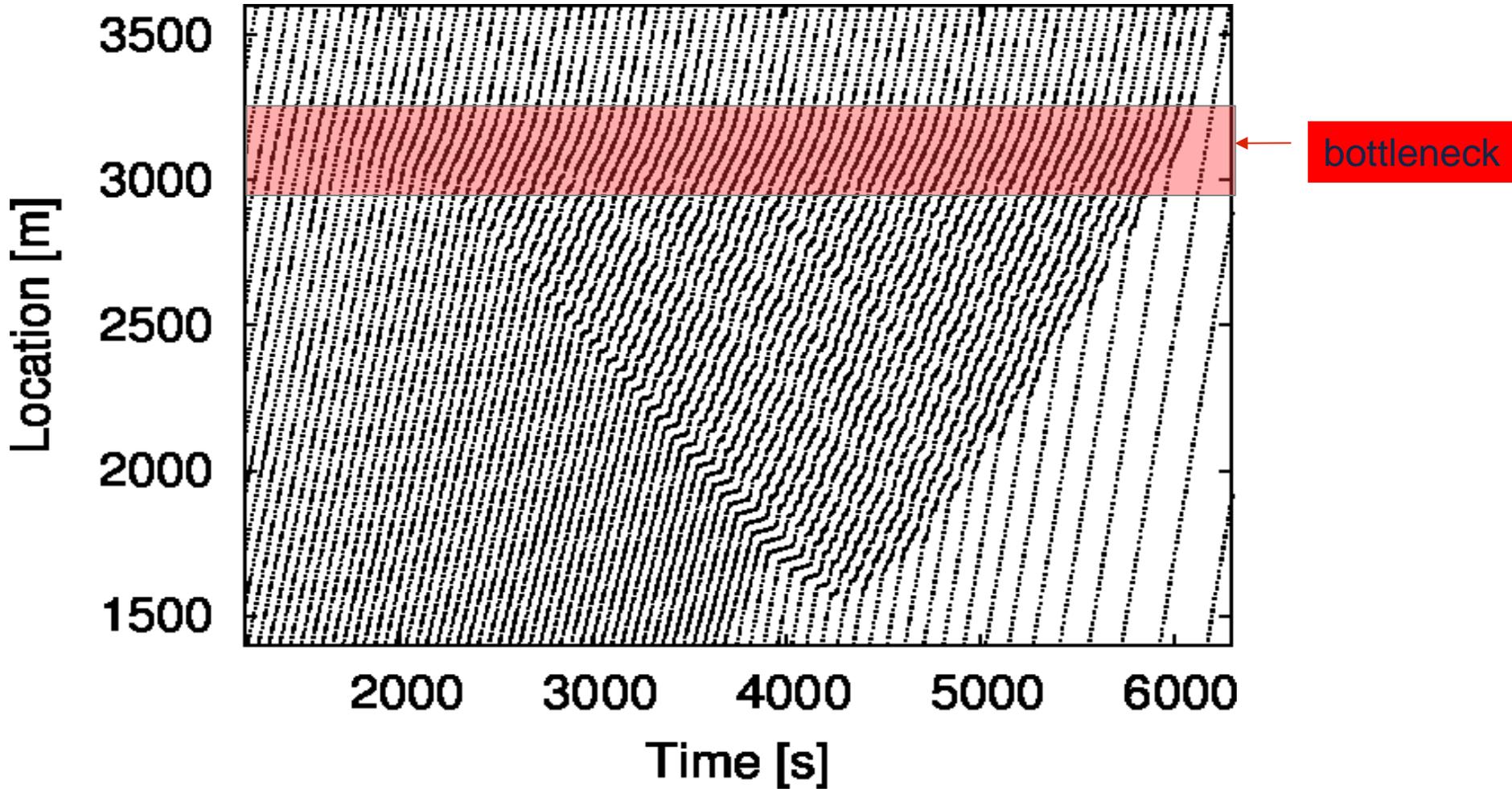
$$V_k \sim N(\hat{\mu}_k, \hat{\sigma}_k^2)$$

▶ If traffic demand (athletes per second) exceeds the local capacity, traffic breaks down and congested traffic is described by a LWR model with a triangular fundamental diagram

▶ In jams, everybody is equal – there are no longer block differences

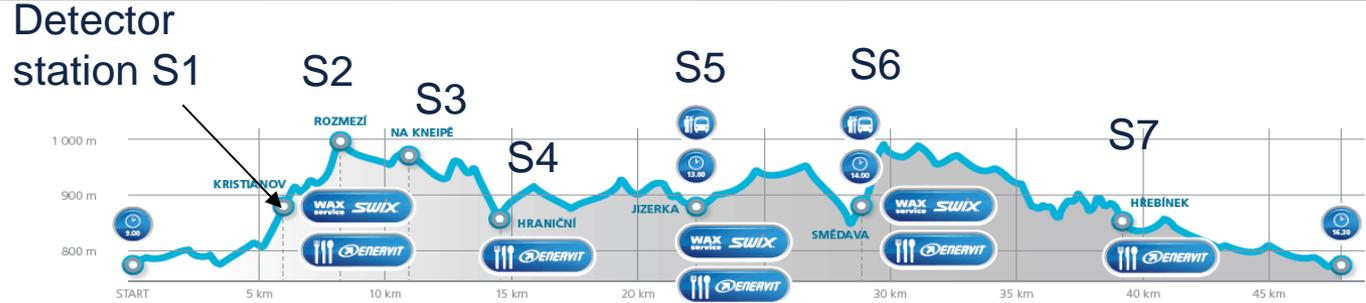




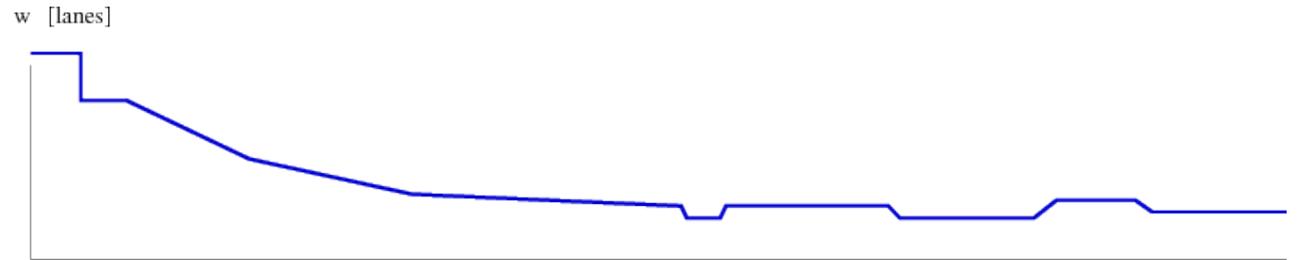




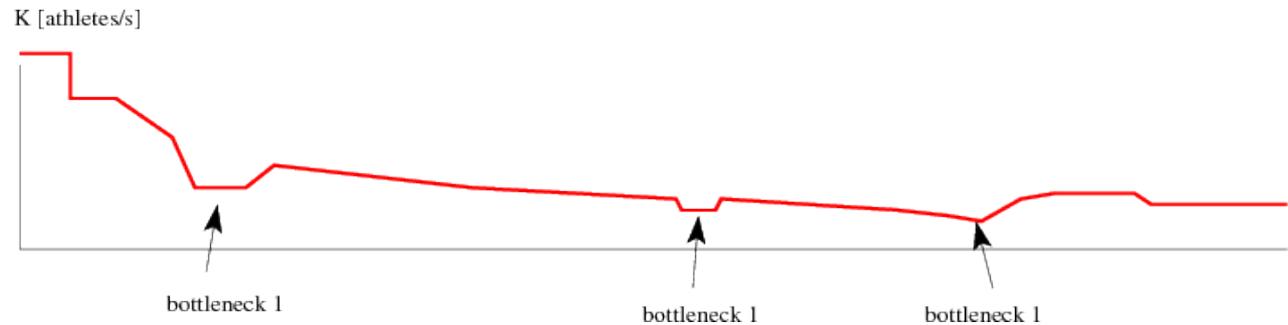
► Vertical profile

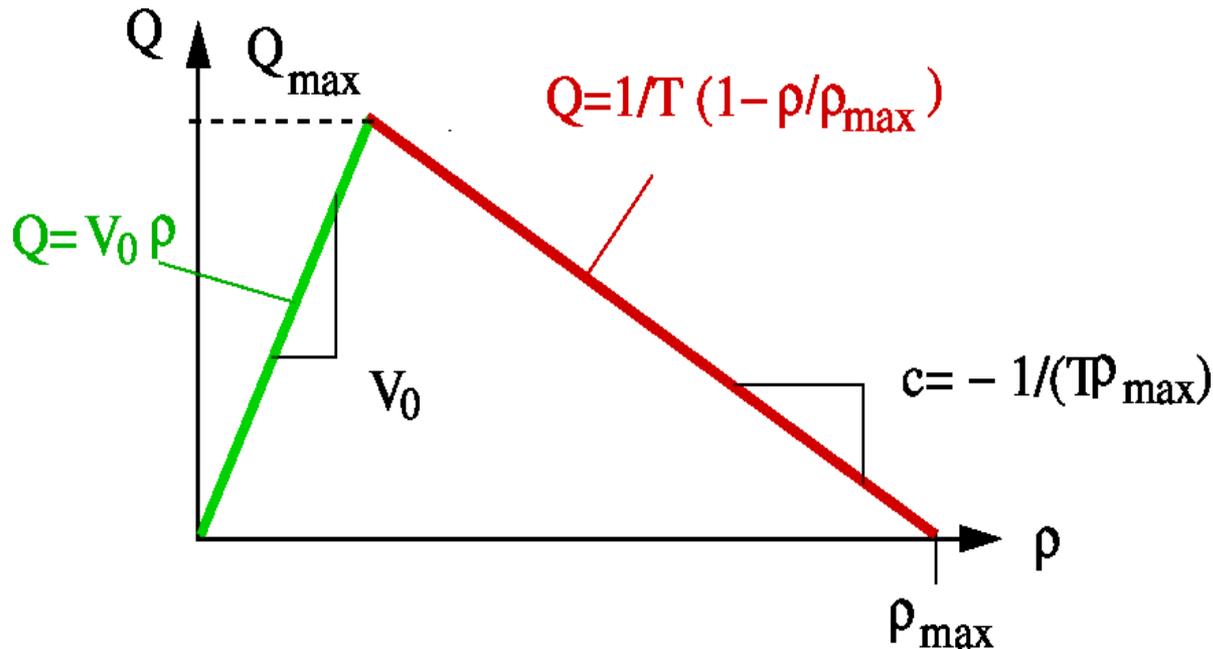


► Width profile



► Local capacity





► 3 parameters: select three from V_0 , c , T , ρ_{\max} , and Q_{\max}

► Usage I: Congested component of the macroscopic hybrid crowd-flow model

► Usage II: Real-time jam detection and short-term prediction

=> check on vehicular flow data: proof of robustness

=> apply to pedestrian/athlete SDD and FAD generated by the IDM: proof of concept for the application to crowd flow

► Flow (and density):

$$Q(x, t) = \begin{cases} Q_d(x, t) & \text{free traffic (demand)} \\ Q_s(x, t) & \text{jam due to a bottleneck (supply)} \end{cases}$$

► Front propagation:

$$\frac{dx_{\text{up}}}{dt} = \frac{Q_s(x_{\text{up}}, t) - Q_d(x_{\text{up}}, t)}{\rho_s(x_{\text{up}}, t) - \rho_d(x_{\text{up}}, t)}$$

► Congested flow and density:

$$Q_s(x, t) = K \left(x_B, \frac{t - (x - x_B)}{c} \right),$$

$$\rho_s(x, t) = \left(1 - \frac{Q_s(x, t)}{K(x)} \right) \rho_{\max}(x)$$

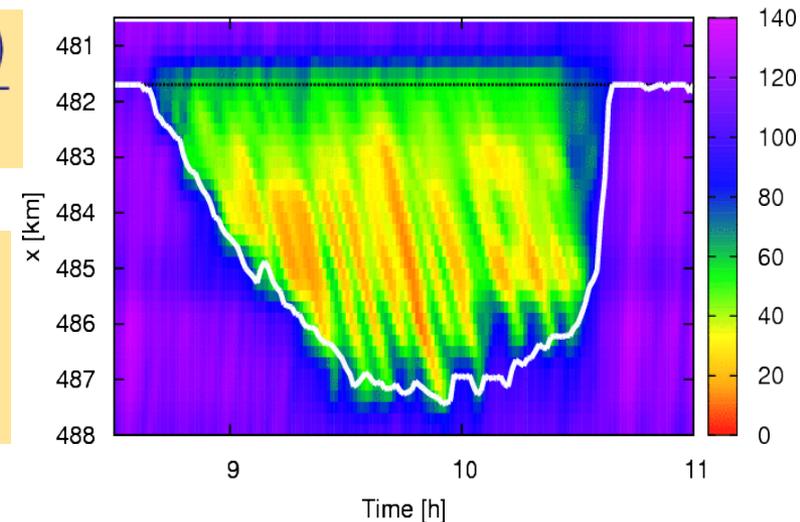
► Jam dissolution:

$$\frac{dx_{\text{up}}}{dt} > 0, \quad x_{\text{up}} = x_B$$

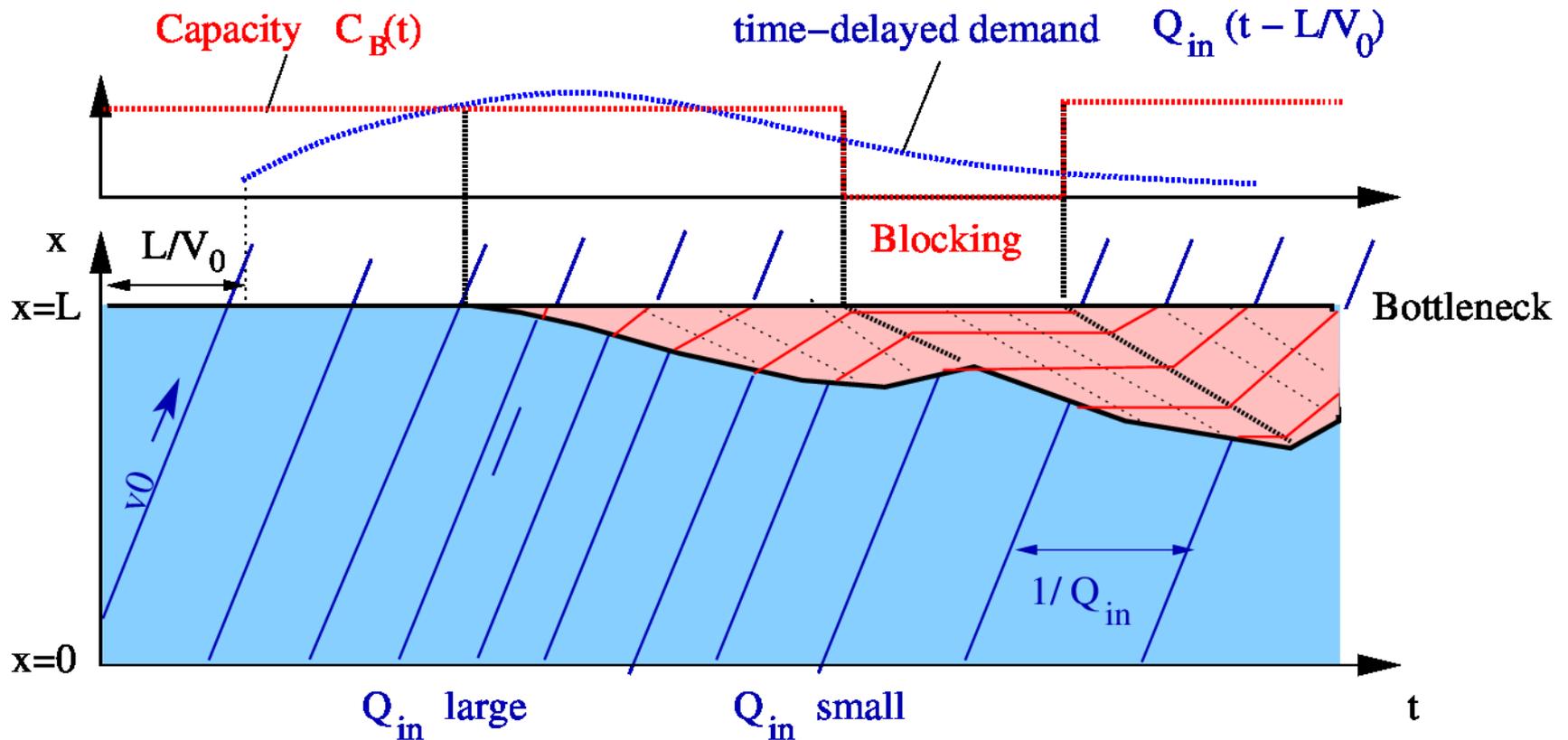
► Estimation method:

$$Q_s(x, t) = Q_{D2} \left(\frac{t - (x - x_{D2})}{c} \right), \quad Q_d(x, t) = Q_{D1} \left(\frac{t - (x - x_{D1})}{V_0} \right)$$

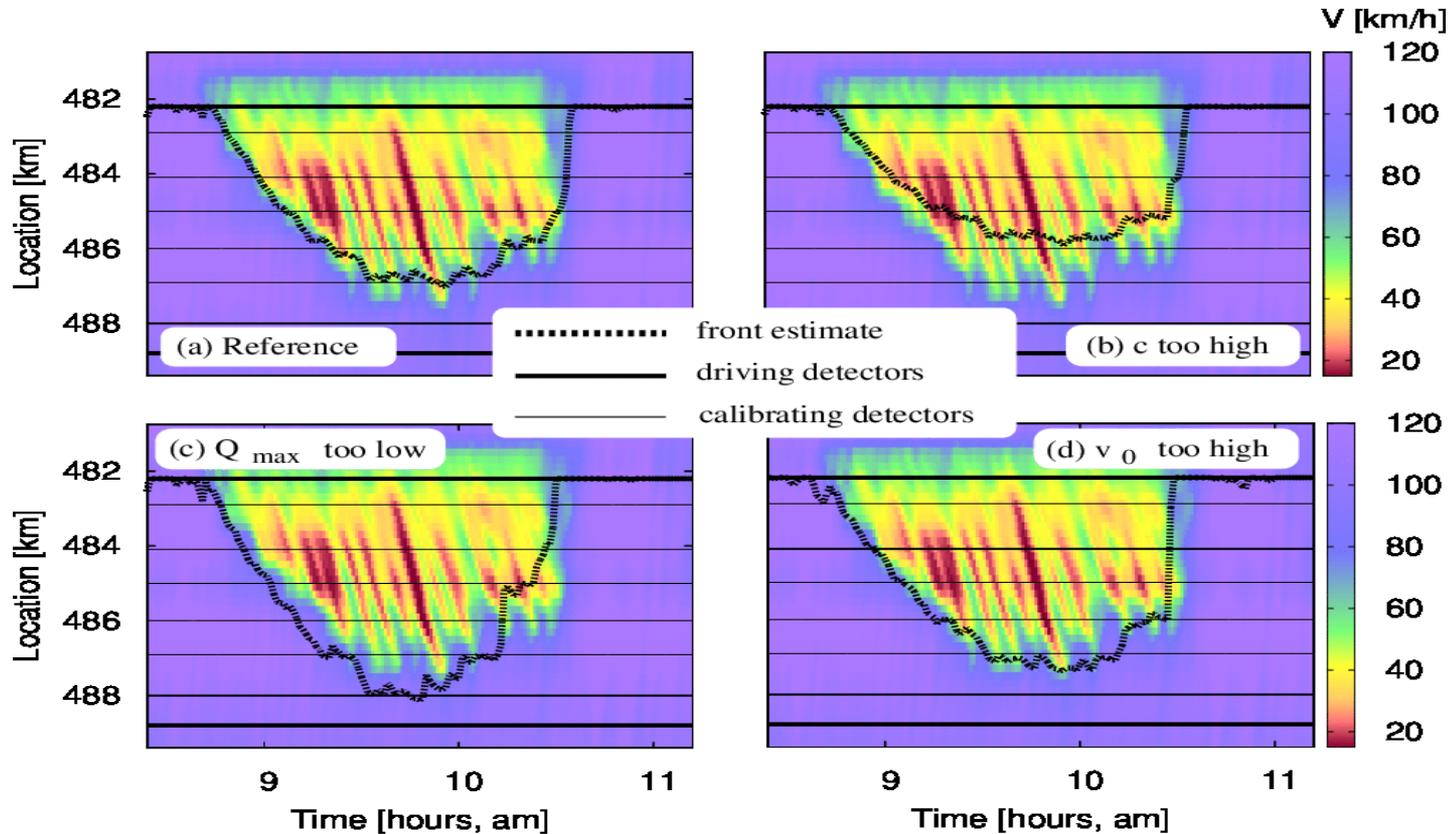
A5 North, April 11, 2001



Shockwave formula: $c_{12} = (Q_1 - Q_2) / (\rho_1 - \rho_2)$
plus propagation velocities V_0 and c



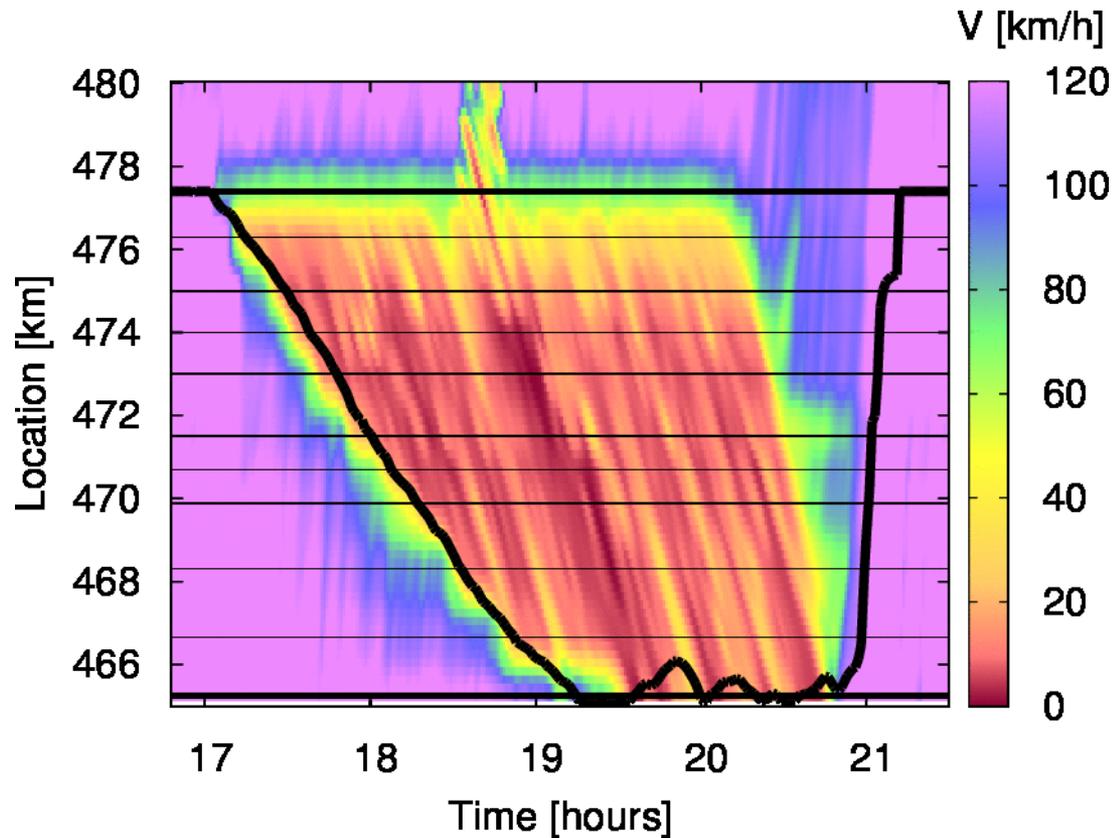
Data: only one-minute flows from stationary detectors

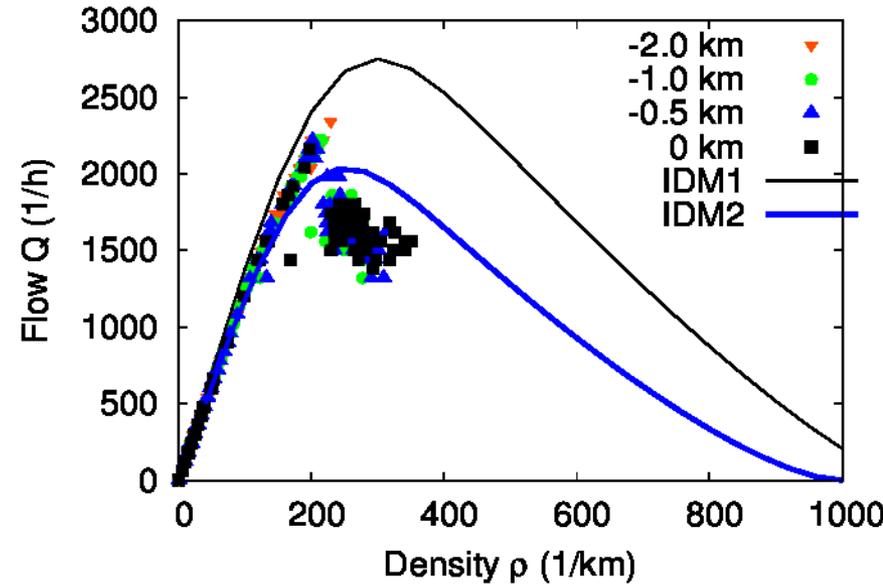
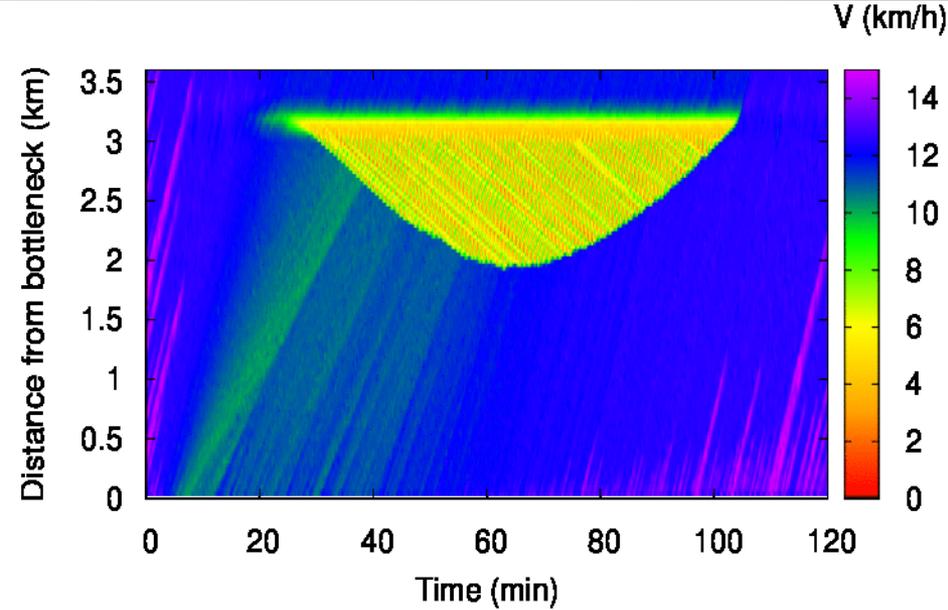


- parameters: Q_{\max} , V_0 , and c

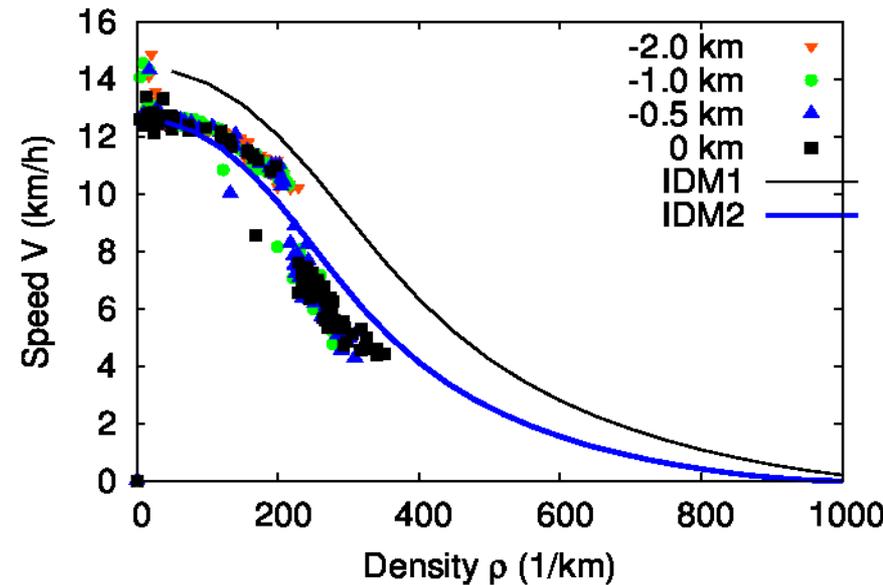
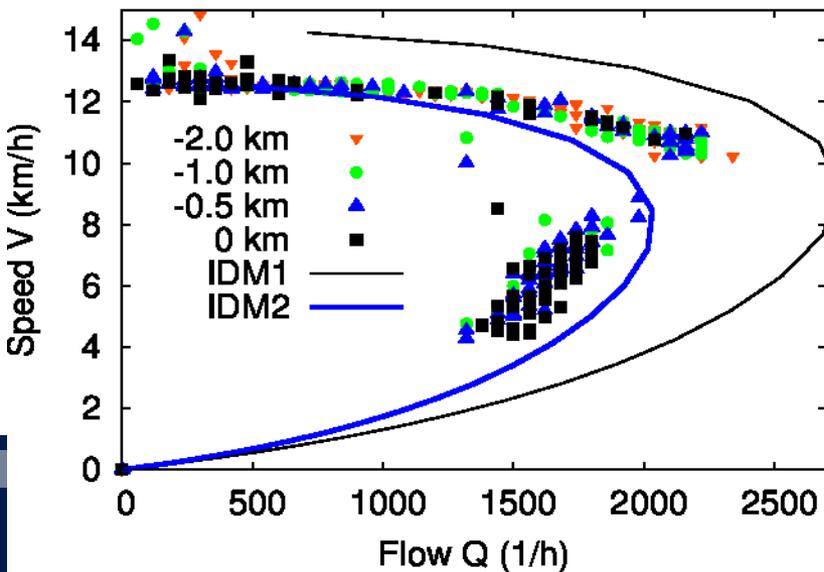
- objective function: 1-norm of positional errors of front

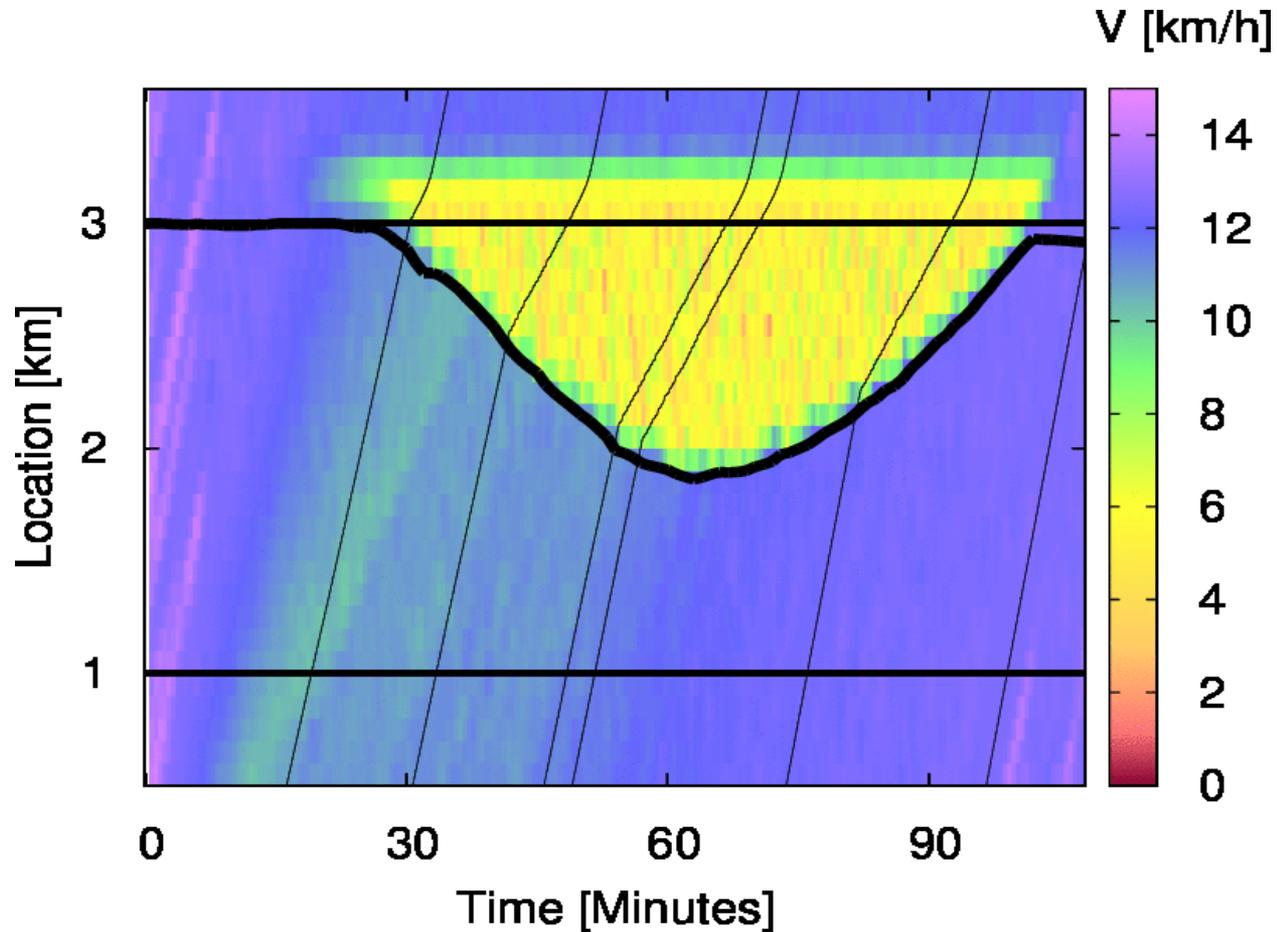
Congestion on the A5-South with LWR prediction as calibrated by the A5-North jam of the previous slides



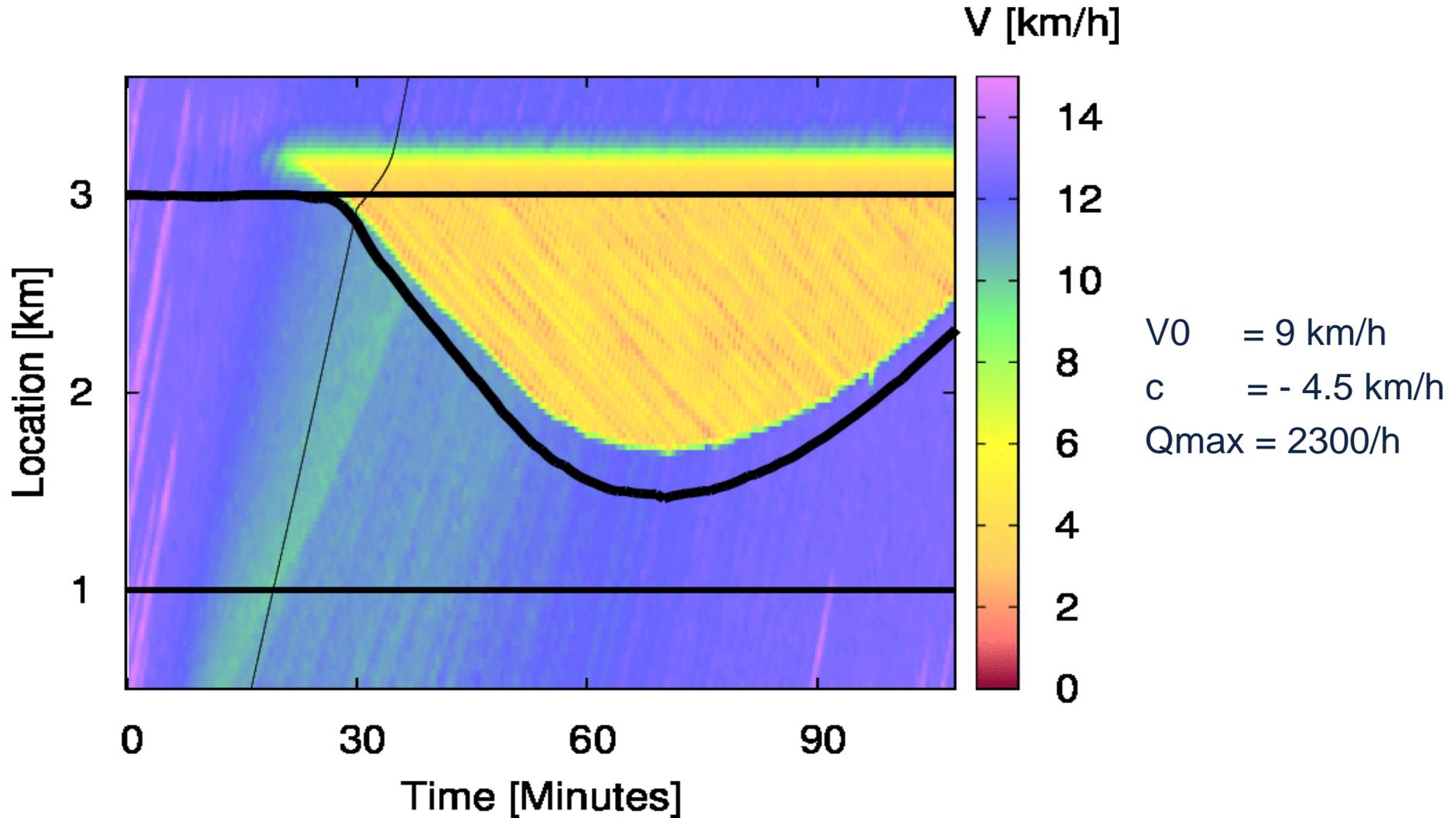


IDM



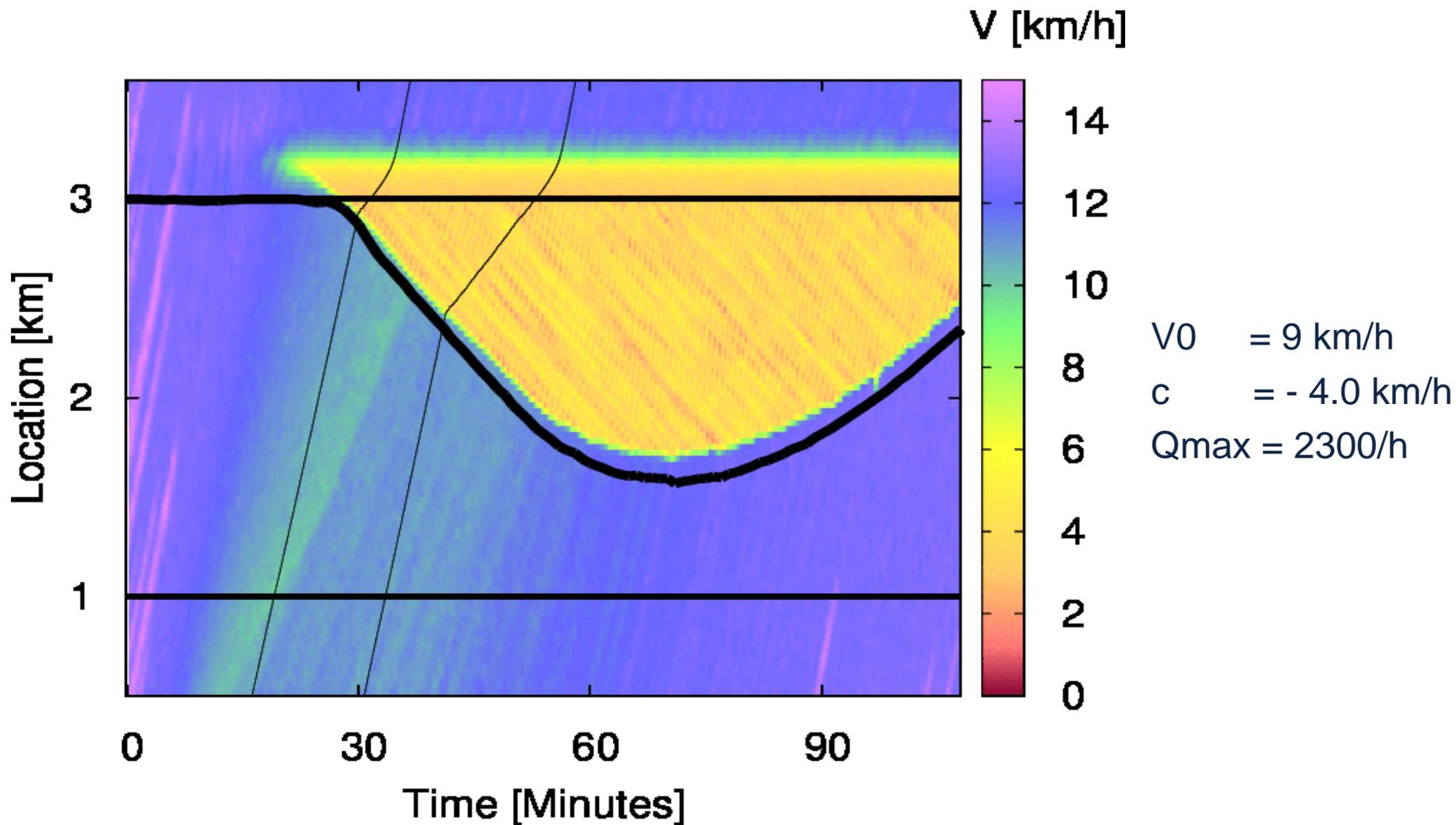


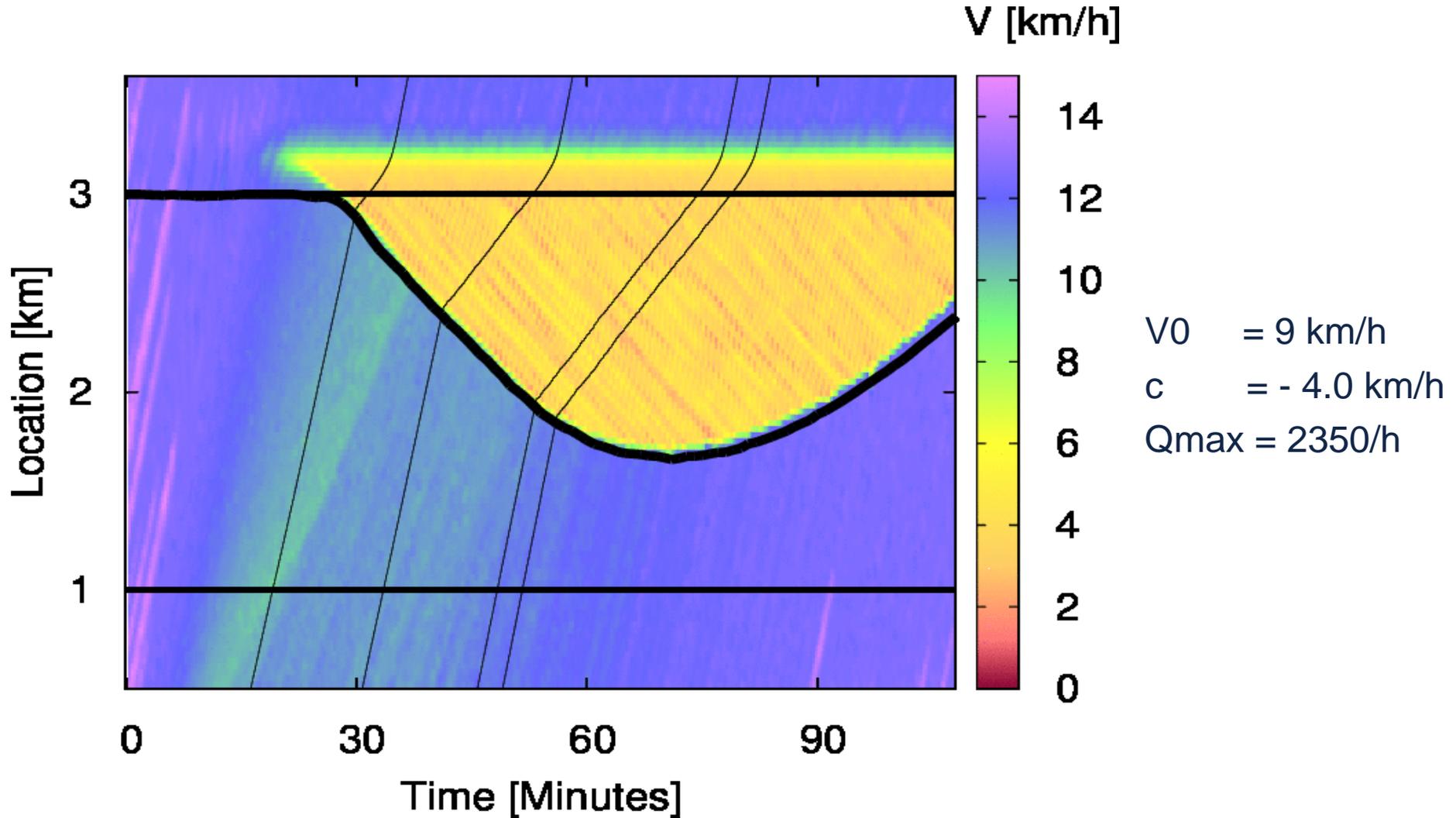
$V_0 = 9 \text{ km/h}$
 $c = -4.5 \text{ km/h}$
 $Q_{\max} = 2300/\text{h}$

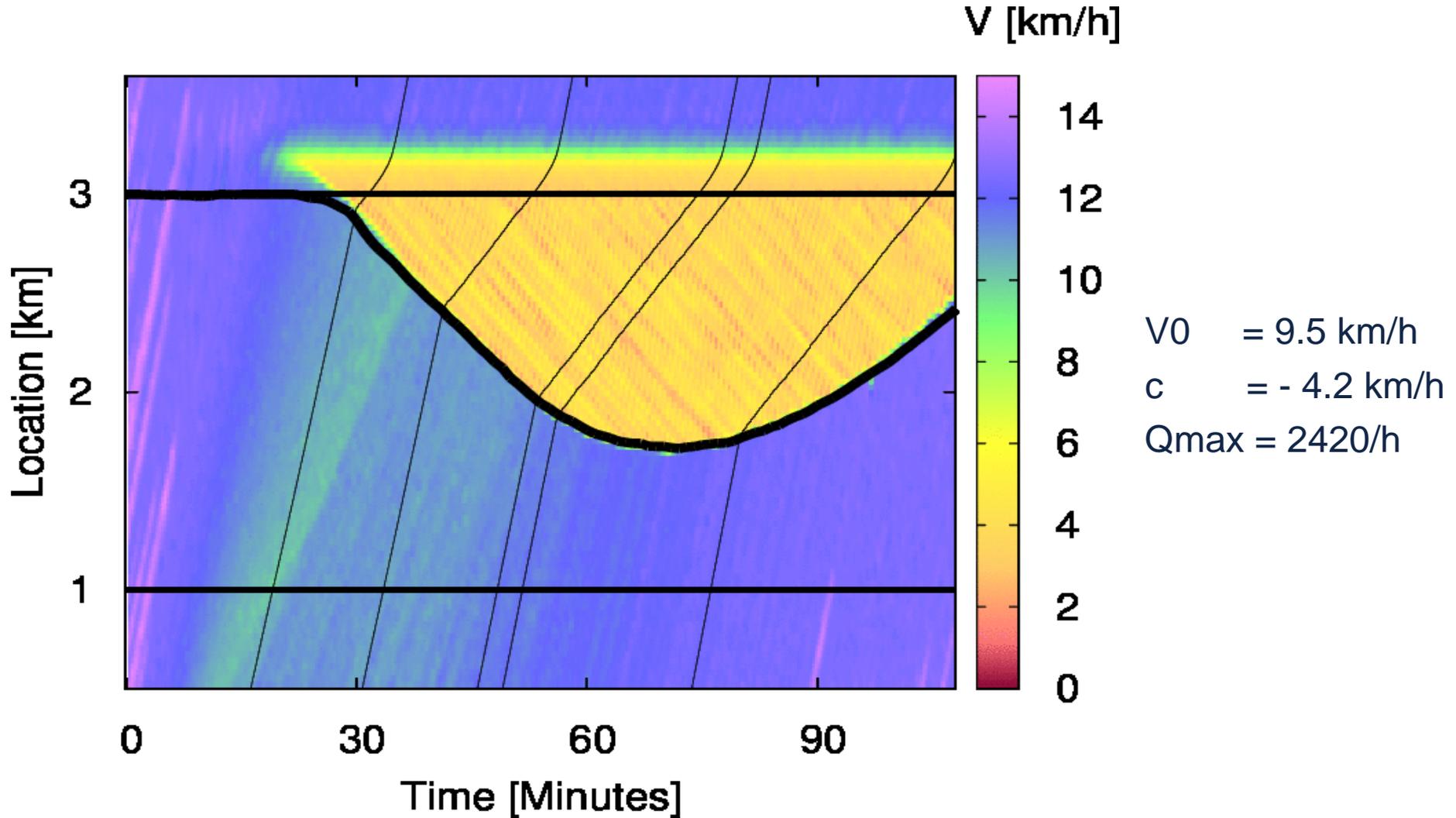


Dynamic calibration 1

using the second FA trajectory







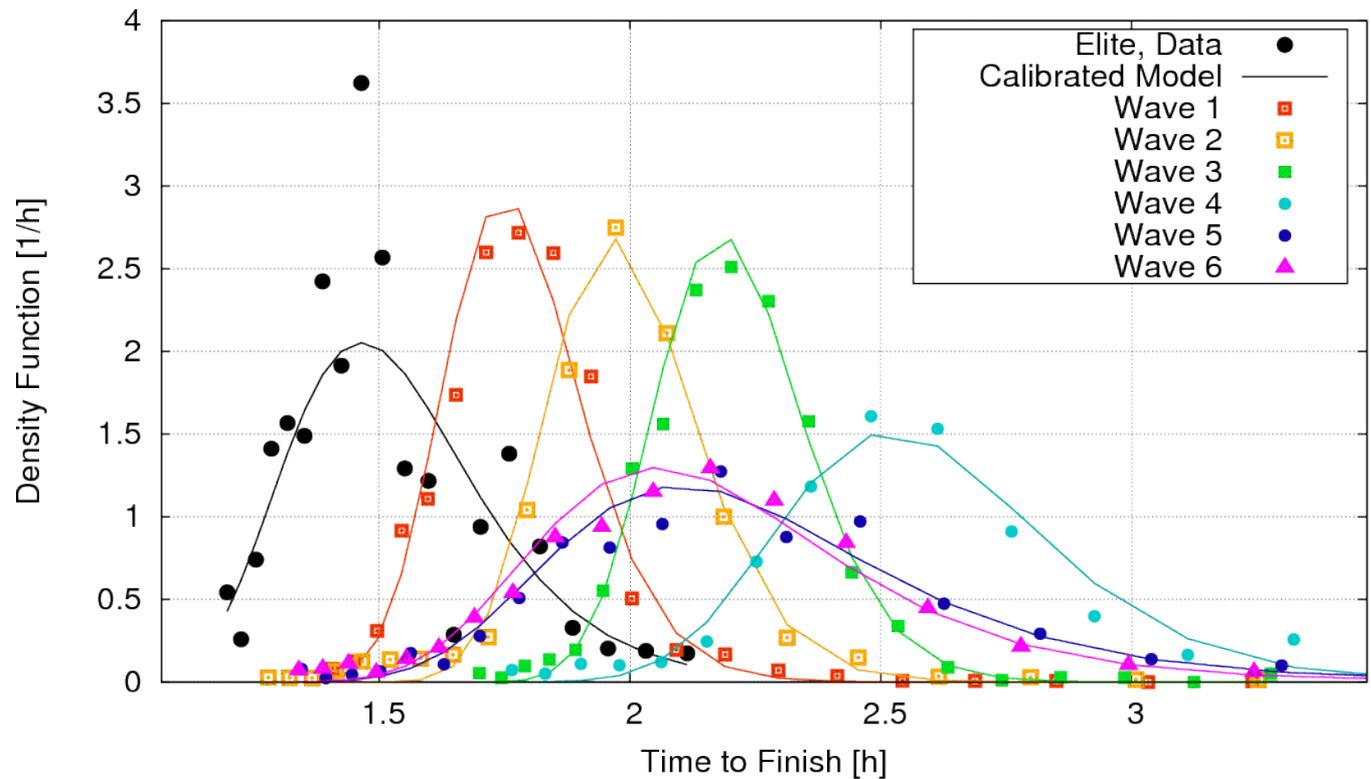


- Unidirectional crowd flow (running, cross-country skiing, and inline-skating) including jam formation can be simulated macroscopically by a **simple dispersion-transport-LWR model** and microscopically by the **reparameterized IDM with flow-conserving bottlenecks**
- The complete LWR model with tridiagonal FD and location-dependent local capacity can be applied to **detect and short-term predict** jam fronts of crowd and vehicular flow by using two stationary counting detectors
- The detection algorithm can be **calibrated in real-time** by **Floating-Athlete (FA) trajectories** e.g., taken by smartphones. A few athletes/vehicles per hour is sufficient

$$f_T^k(T|x) = \frac{x f_v^k\left(\frac{x}{T}\right)}{T^2},$$

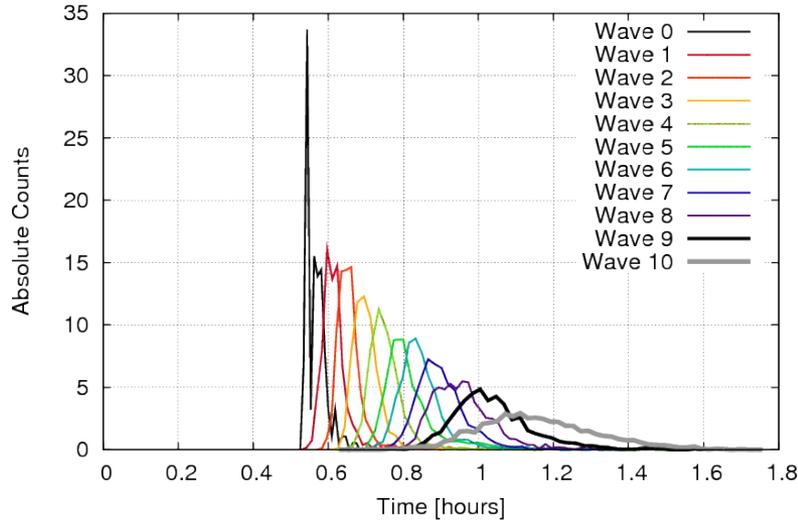
$$f_v^k(v) \propto \exp\left[\frac{(v - \hat{\mu}_k)^2}{2\hat{\sigma}_k^2}\right]$$

Rennsteig
Half
Marathon
2012 at
finish



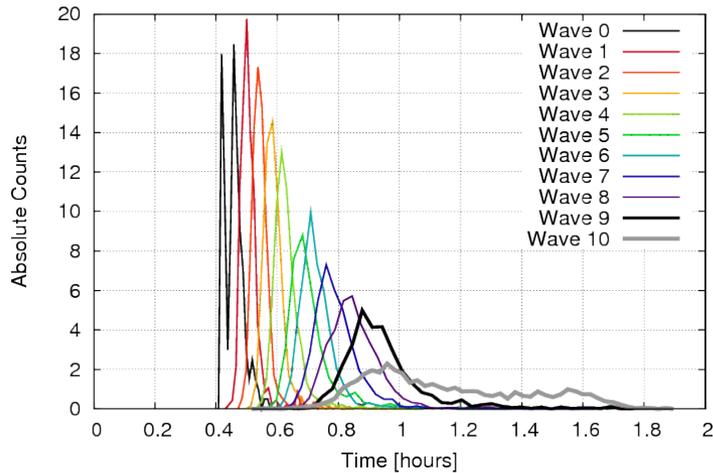


Time spent between Stations S12



► Between stations 1 and 2: skewness >0

Time spent between Stations S23



► Between stations 2 and 3: evidence for congestion!



► Partial flow and density of block k at distance x and time t after the start of this block:

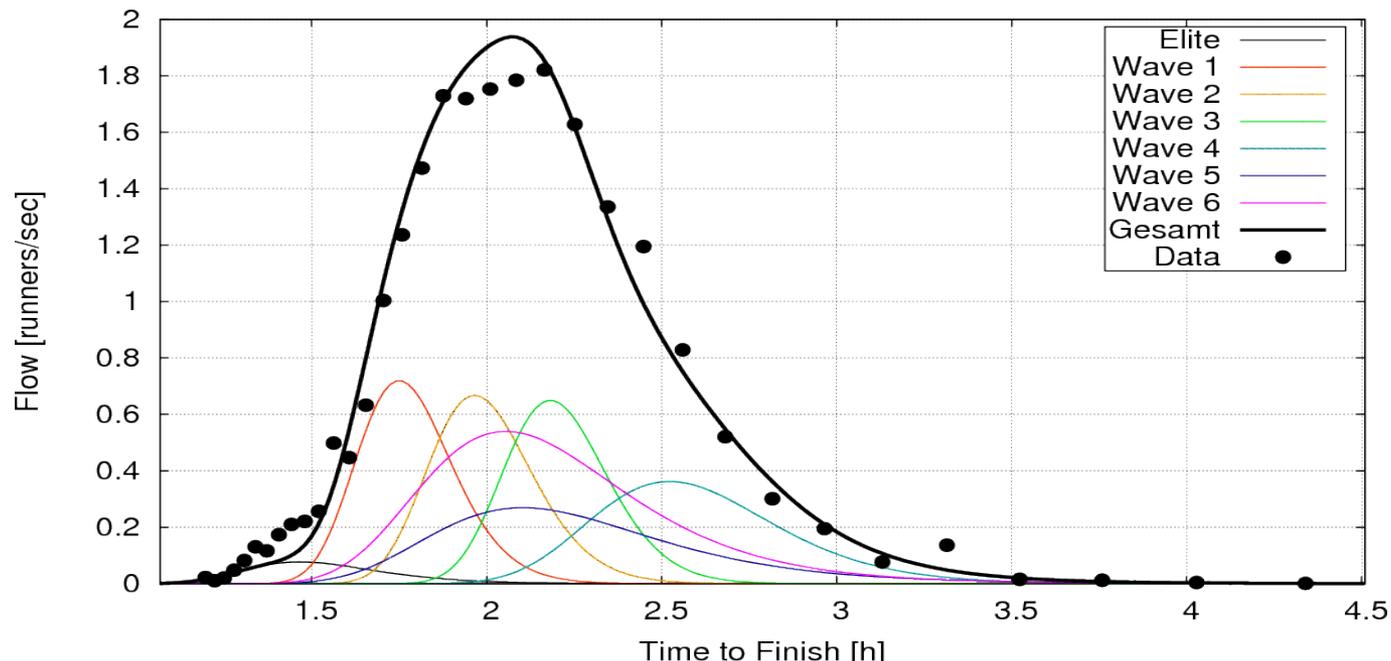
$$Q_d^k(x, t) = n_k f_T^k(t|x),$$

$$\rho_d^k(x, t) = \frac{Q_d^k(x, t)}{x/t}$$

► Total demand and density (free flow):

$$Q_d(x, t) = \sum_k Q_d^k(x, t - \Delta t_k)$$

$$\rho_d(x, t) = \sum_k \rho_d^k(x, t - \Delta t_k)$$



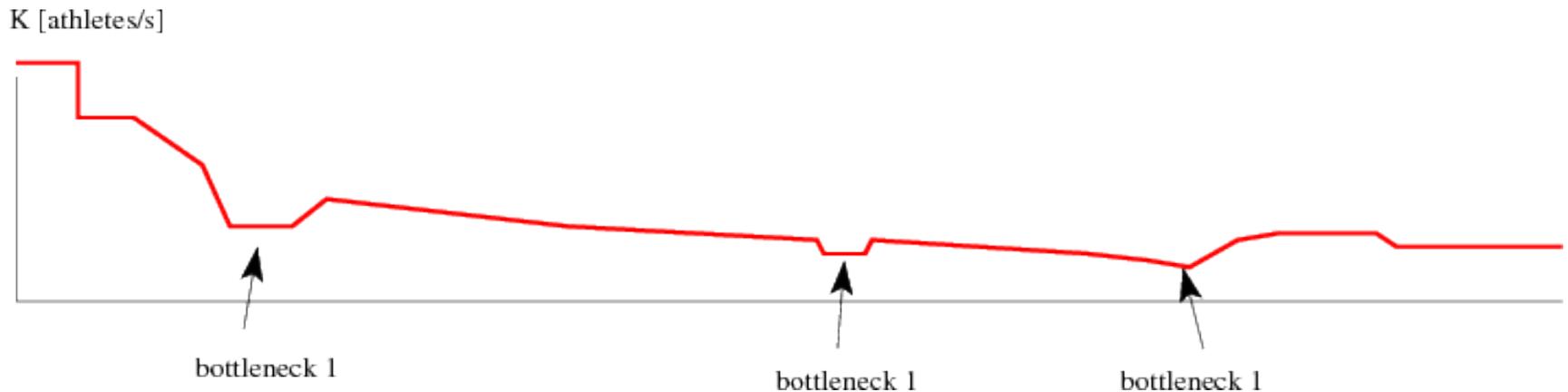
► Local capacity:

$$K(x) = K_{\text{spec}}(\alpha(x)) w(x)$$

► Breakdown condition:

$$Q(x, t) > K(x)$$

► The bottleneck location $x=x_B$ is the position where the breakdown condition is satisfied for the first time:



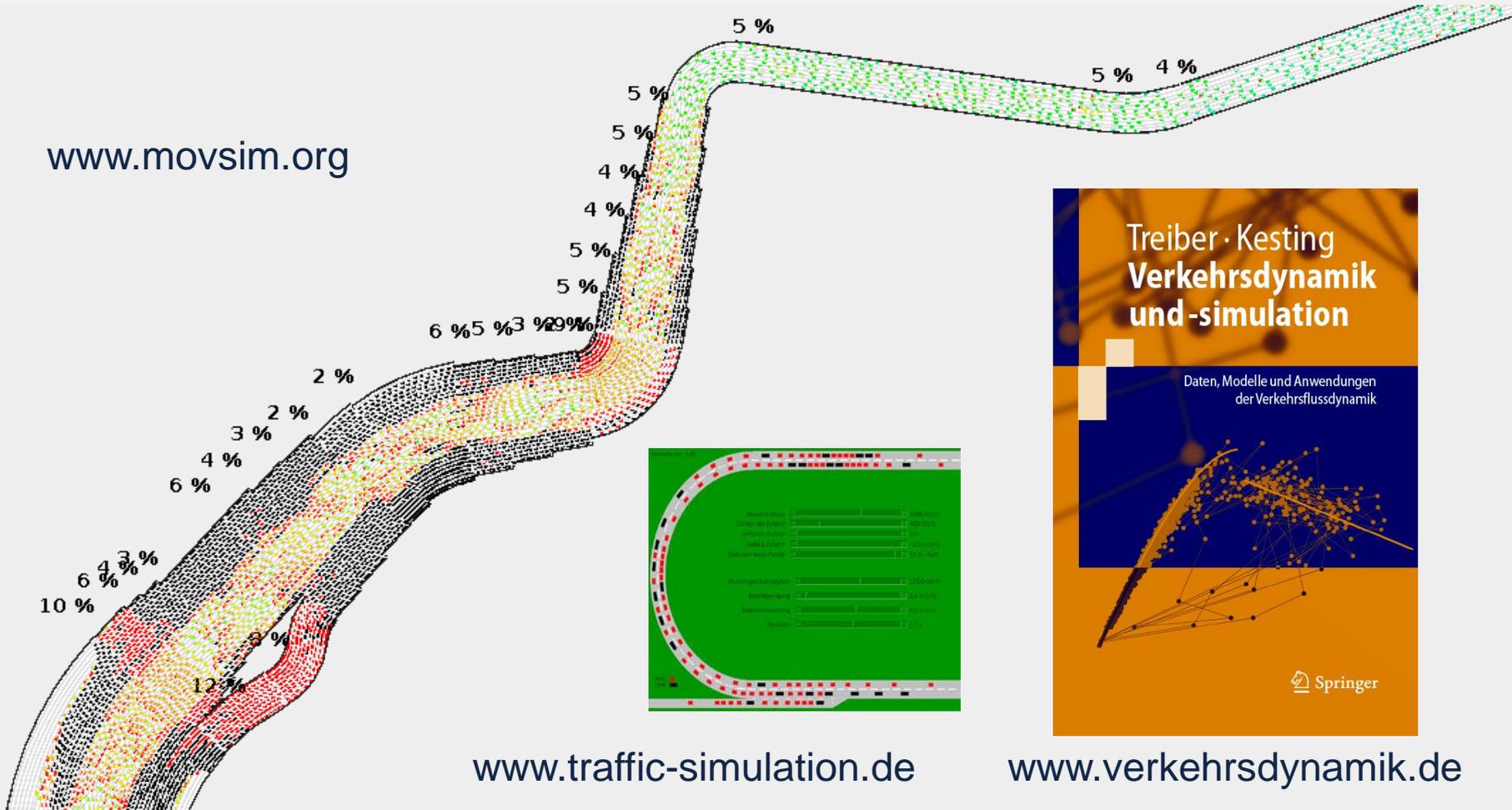
„b
cc



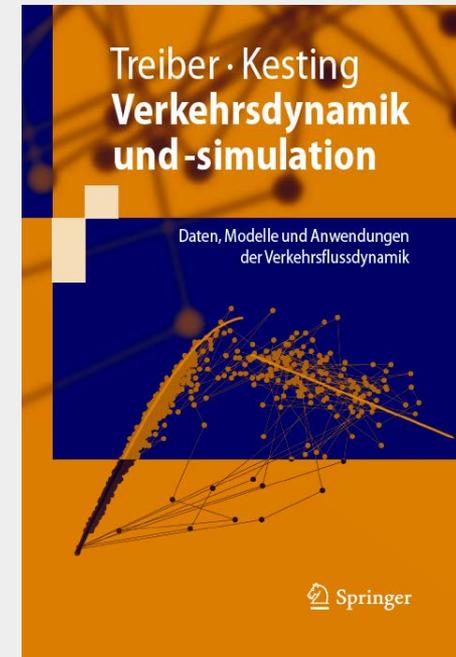


▶ ◀ ▶ ↻ 📍 🔍 🔍 🌈
scenario: vasa_CCS
time: 0:13:44
time warp: 4.0
update time: 0.2 s
vehicles: 11008

www.movsim.org



www.traffic-simulation.de



www.verkehrsdynamik.de



- **“Traffic Jams” in Mass Sports Events**
- **What Can a Traffic Flow Modeler Do?**
- **A Macroscopic Model**
- **Simulation of Three Events**
- **Discussion**

- ▶ 1. Optimize the spatial configuration of the starting field, partII

No blocks
(athletes can
take
positions by
self-
assessment)



Geometrical Class

► **Unidirectional and lane-based:**

Vehicular traffic, cross-country skiing
(classic style)



► **Unidirectional and non-lane-based:**

Vehicular traffic in developing countries
(mixed traffic), cross-country skiing
(skating style), running, inline skating,
pedestrian traffic with a definite target

► **Neither unidirectional nor lane-based:**

Pedestrian traffic in city centers

Model Class

micro, macro

micro, macro

only micro!



► simultaneous mass start

► Block/wave start

Wave 2: Delay 5
minutes

Wave 3: Delay 10
minutes

Wave 4: Delay 15
minutes

Wave 5: Delay 20
minutes

