Steady State of Pedestrian Flow in Bottleneck Experiments

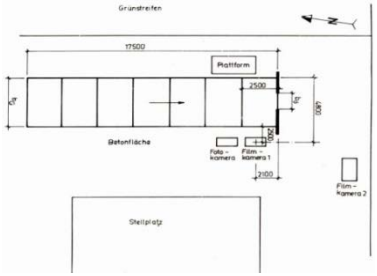
28. Oktober 2015 | Weichen Liao

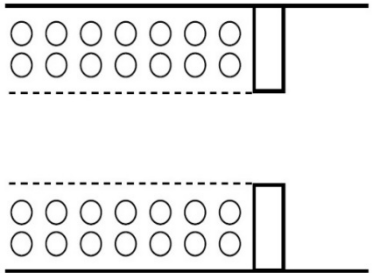
Jülich Supercomputing Centre

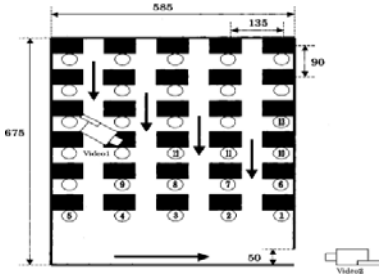
Overview

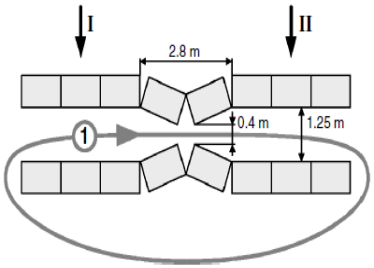
- Background
- Detection of steady state
- Pedestrian flow in bottleneck experiments
- Conclusions and outlook

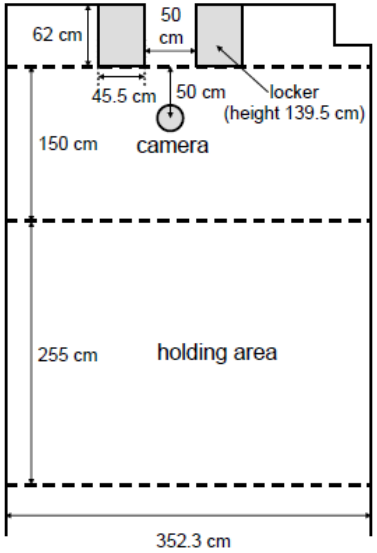
Background

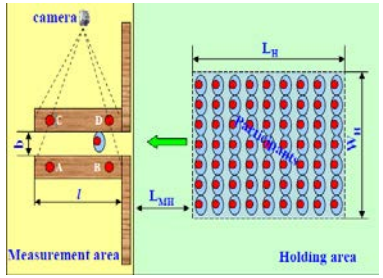

Grundrissen
17500
Plattform
2500
Betonfläche
Foto-Kamera
Film-Kamera 1
Film-Kamera 2
2100
Stellplatz

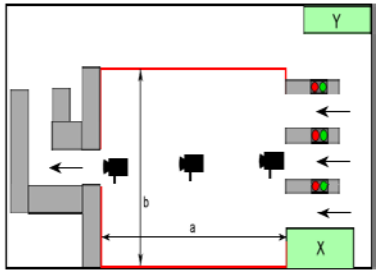



585
135
90
675
50
Videoset

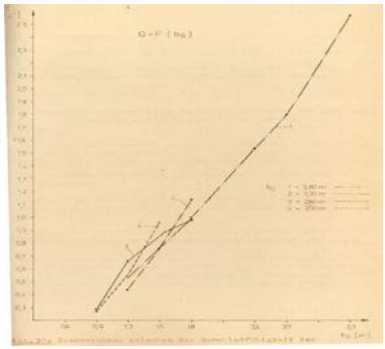

I
II
2.8 m
0.4 m
1.25 m
1

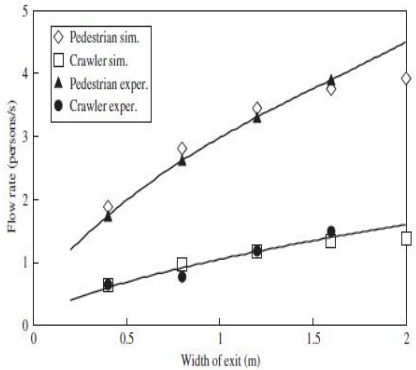

62 cm
50 cm
45.5 cm
50 cm
locker
(height 139.5 cm)
camera
150 cm
255 cm
holding area
352.3 cm

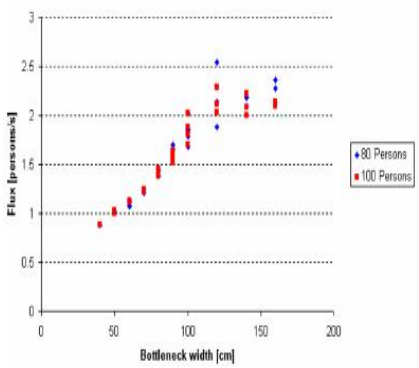

camera
C
D
A
B
l
L_H
L_{MH}
Measurement area
Holding area

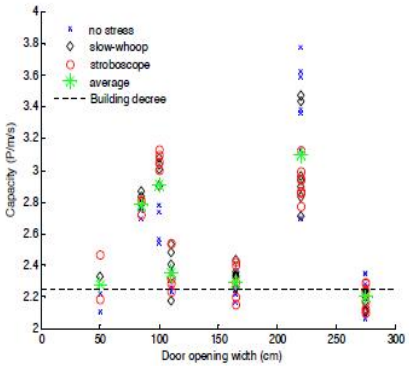

Y
b
a
X

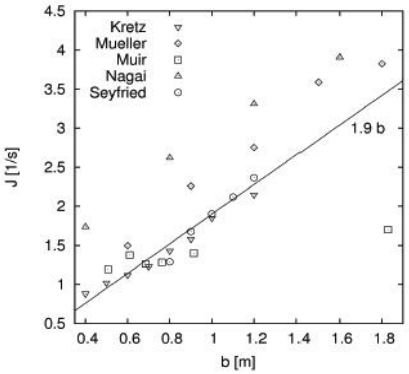
Background

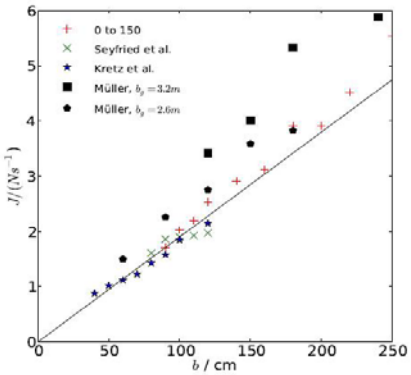


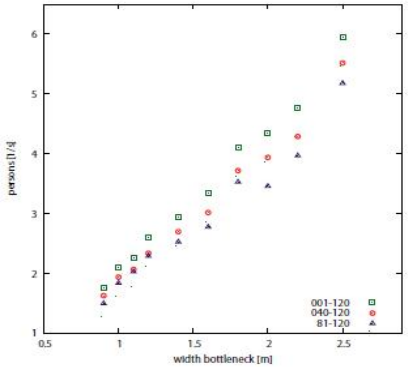

Pedestrian sim.
Crawler sim.
Pedestrian exper.
Crawler exper.
Flow rate (persons/s)
Width of exit (m)

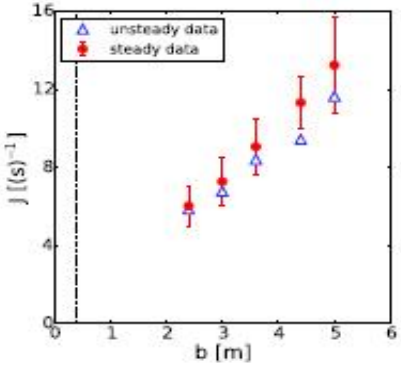

80 Persons
100 Persons
Flux [persons/s]
Bottleneck width [cm]

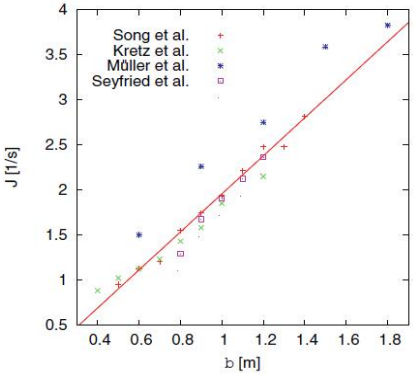

no stress
slow-whoop
stroboscope
average
Building decree
Capacity (P/m/s)
Door opening width (cm)

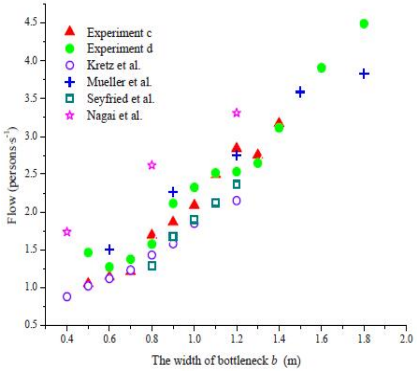

Kretz
Mueller
Muir
Nagai
Seyfried
1.9 b
J [1/s]
b [m]

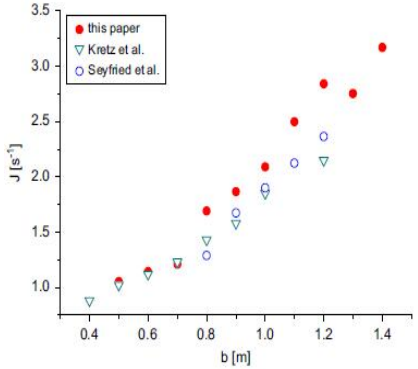

0 to 150
Seyfried et al.
Kretz et al.
Müller, $b_y = 3.2m$
Müller, $b_y = 2.6m$
$J/(Ns^{-1})$
b / cm

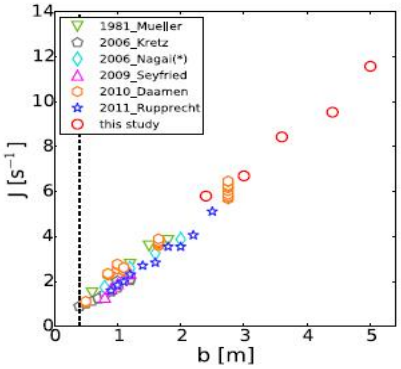

001-120
040-120
81-120
persons [1/s]
width bottleneck [m]


unsteady data
steady data
J [(s)$^{-1}$]
b [m]


Song et al.
Kretz et al.
Müller et al.
Seyfried et al.
J [1/s]
b [m]

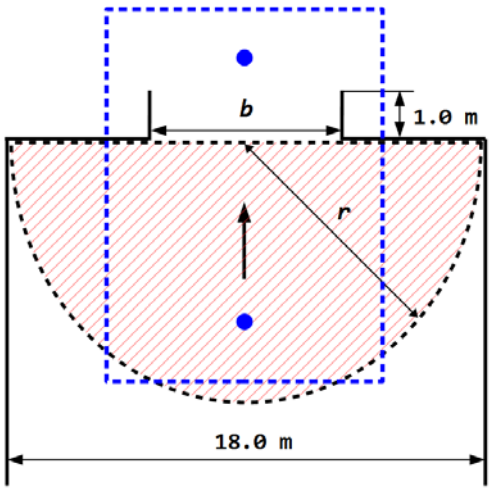

Experiment c
Experiment d
Kretz et al.
Mueller et al.
Seyfried et al.
Nagai et al.
Flow (persons s^{-1})
The width of bottleneck b (m)


this paper
Kretz et al.
Seyfried et al.
J [s^{-1}]
b [m]


1981_Mueller
2006_Kretz
2006_Nagai(*)
2009_Seyfried
2010_Daamen
2011_Rupprecht
this study
J [s^{-1}]
b [m]

Background

Experiment AO



l = 1.0 m

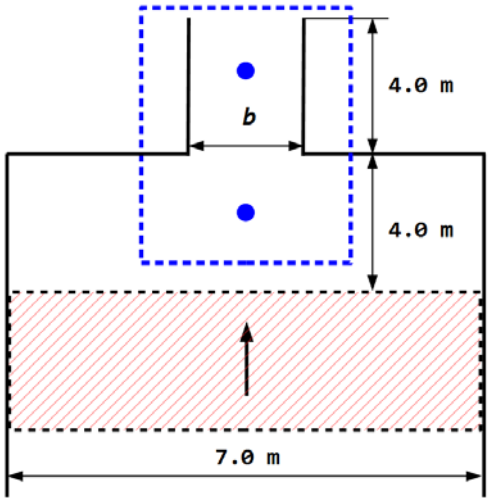
w = 18.0 m

d = 0 m

ρ_{ini} = 3.0 m^{-2}

N = 350 pers

Experiment EG



l = 4.0 m

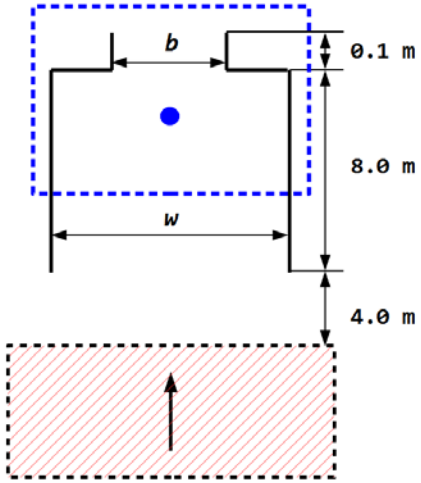
w = 7.0 m

d = 4.0 m

ρ_{ini} = 2.6 m^{-2}

N = 180 pers

Experiment UO



l = 0.1 m

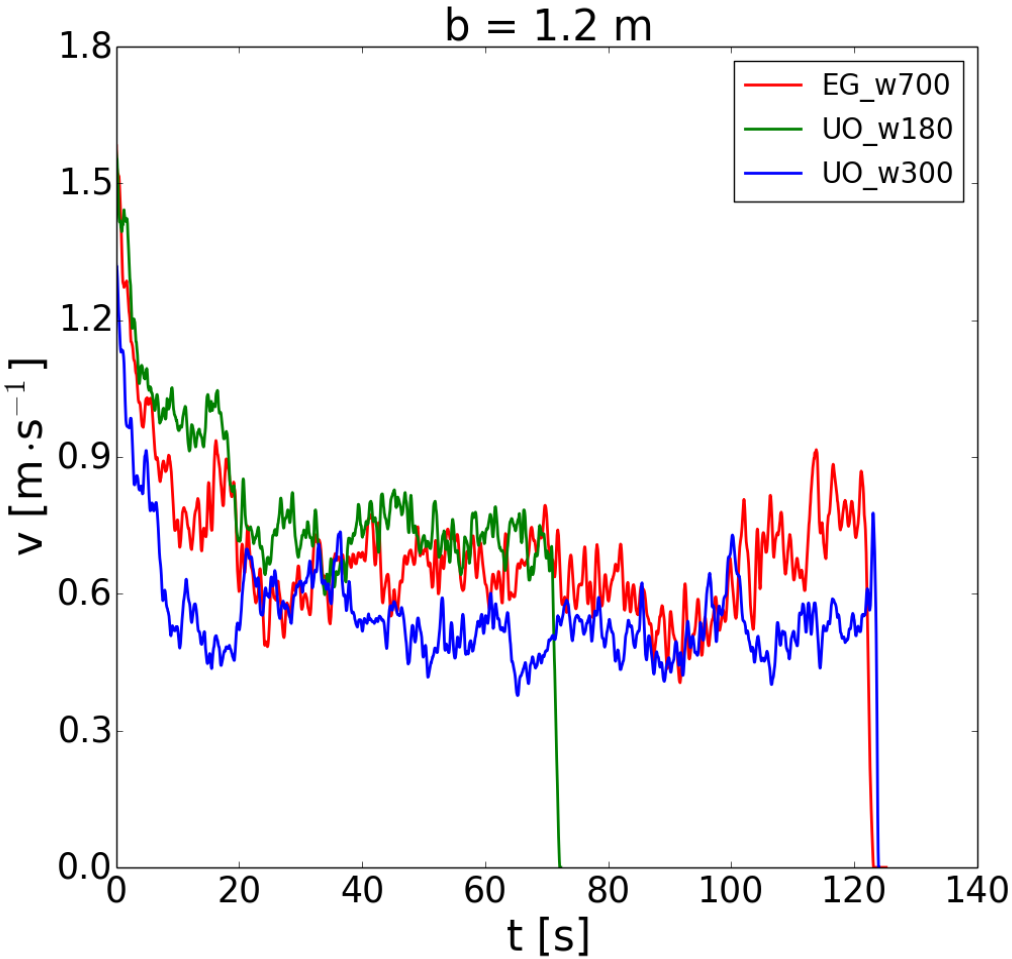
w = 1.8, 2.4, 3.0 m

d = 12.0 m

ρ_{ini} = 3.0 m^{-2}

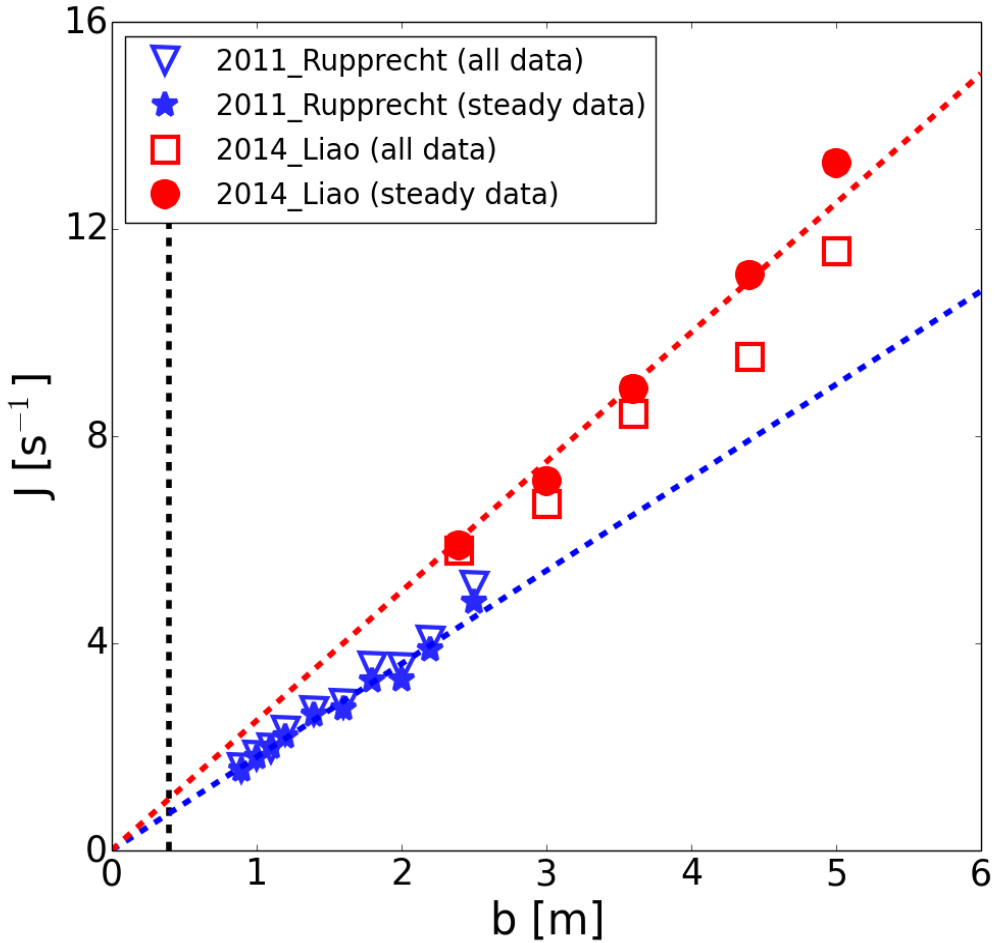
N = 150, 250, 400 pers

Background



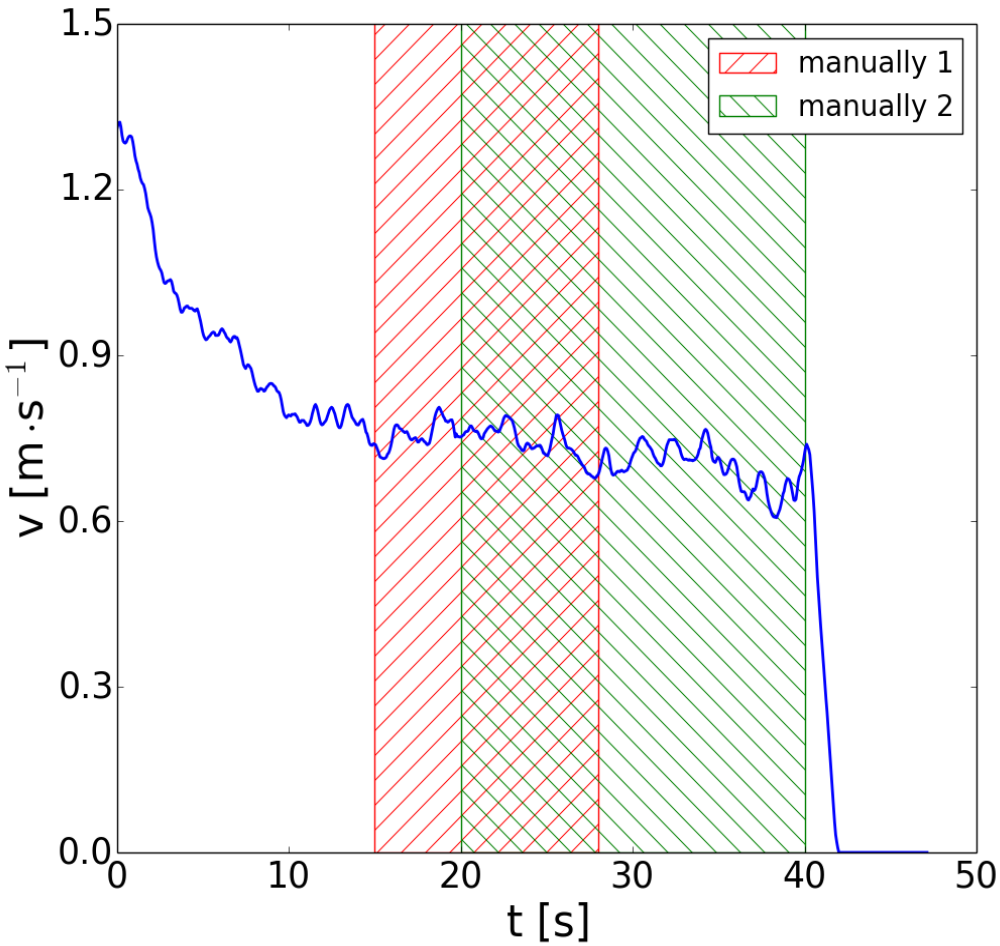
Steady state: mean, standard deviation and autocorrelation are constants

Background



W. Liao et al., PED 2014, 2: 26-33 (2014)

Background



How to detect steady state reproducibly?

Detection of Steady State - Variables

- **Classic definition of flow:** $J = N/T = 1/\overline{\Delta t_i}$ **(1)**

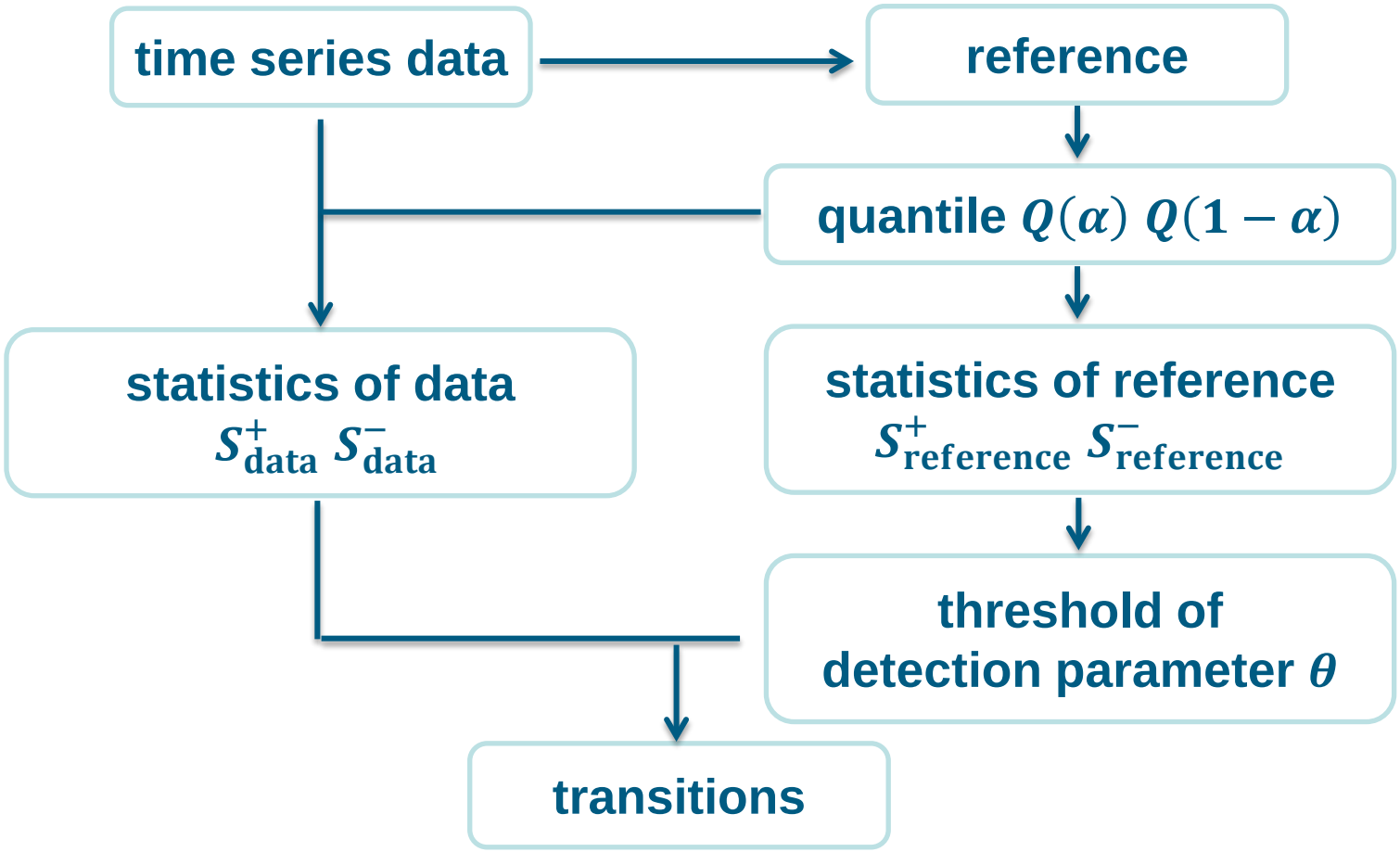
  Microscopic measurements of flow could lead to strong fluctuations.

- **Flow equation from fluid dynamics:** $J = \rho \cdot v \cdot W$ **(2)**

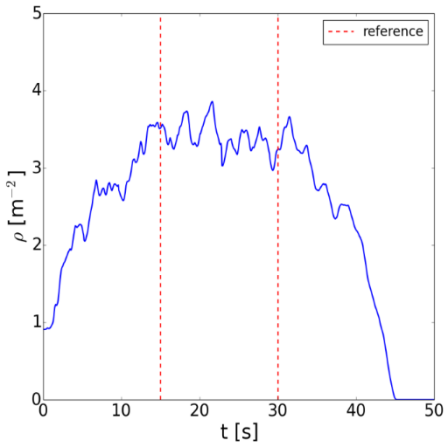
  The steady state of both density and speed is the steady state of flow.

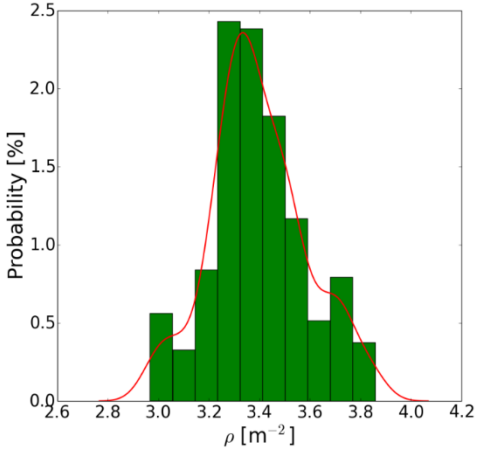
CUSUM (Cumulative Sum Control Chart)

E. S. Page, Biometrika, 41(1/2): 100-115 (1954)



Detection of Steady State - CUSUM



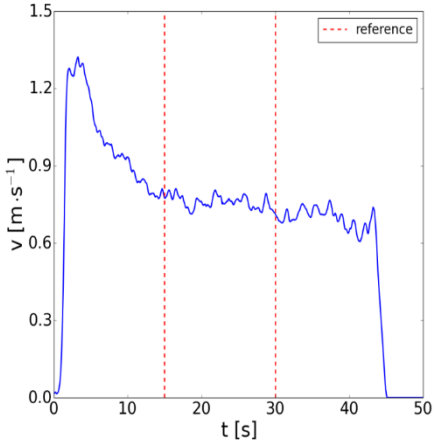


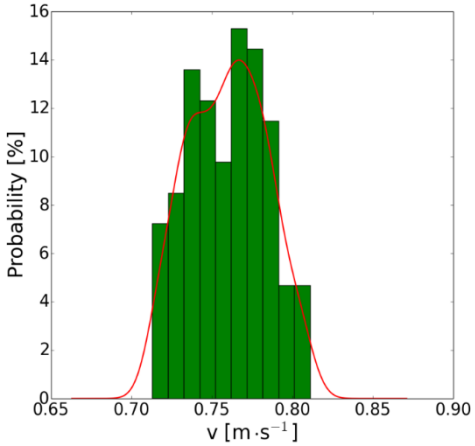
Reference:

- **Observations**

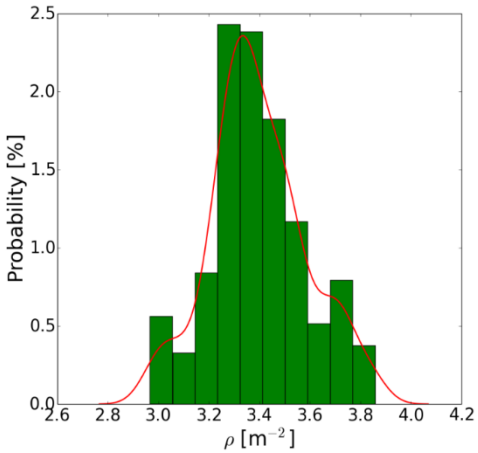
Quantile $Q(\alpha)$ and $Q(1-\alpha)$:

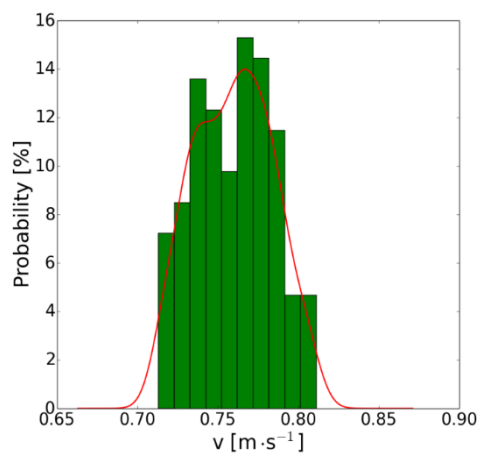
- **Histogram distribution**
- **Kernel estimation**





Detection of Steady State - CUSUM



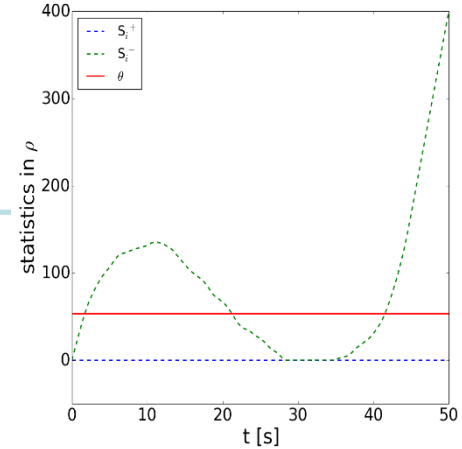


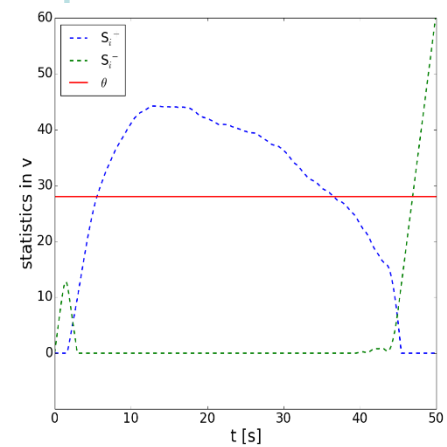
Statistics S_i^+ and S_i^-:

- $S_0^+ = S_0^- = 0$
- $S_i^+ = \max\{0, S_{i-1}^+ + x_i - Q(\alpha)\}$
- $S_i^- = \max\{0, S_{i-1}^- + Q(1-\alpha) - x_i\}$

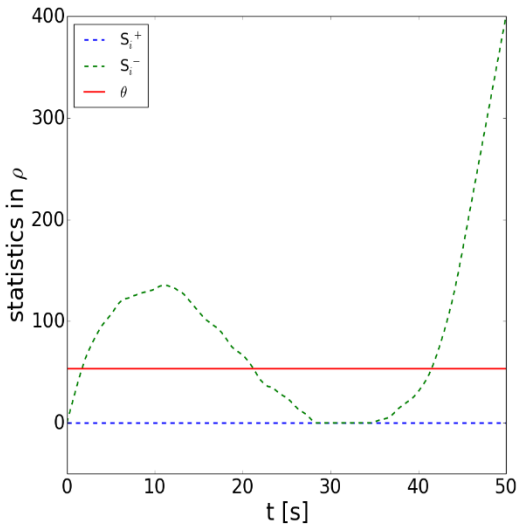
Criteria θ:

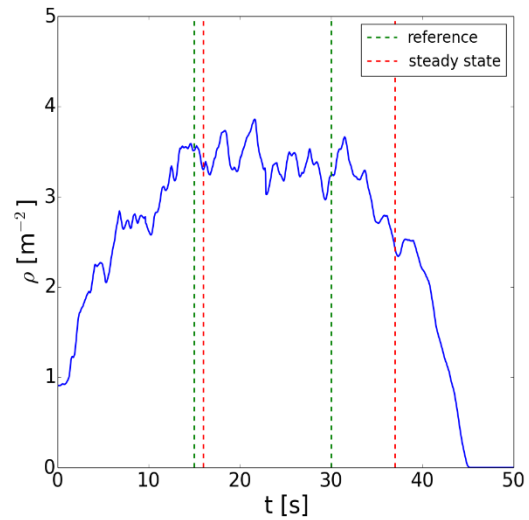
- Quantile of $S_{\text{reference}}$





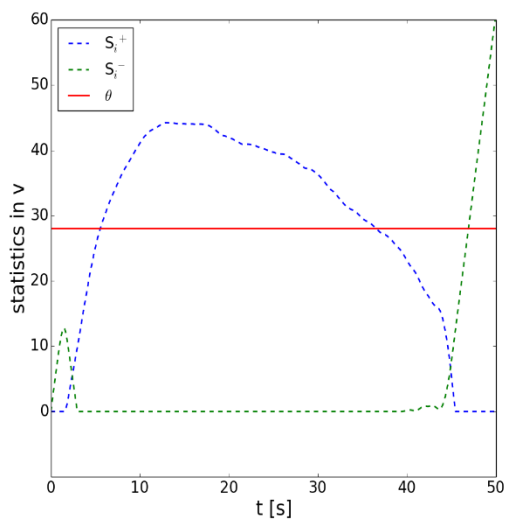
Detection of Steady State - CUSUM

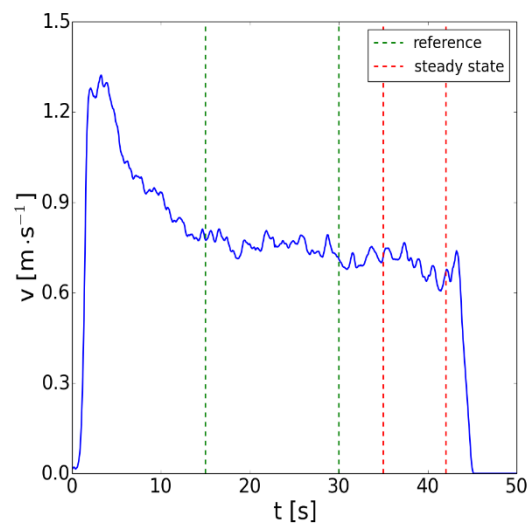




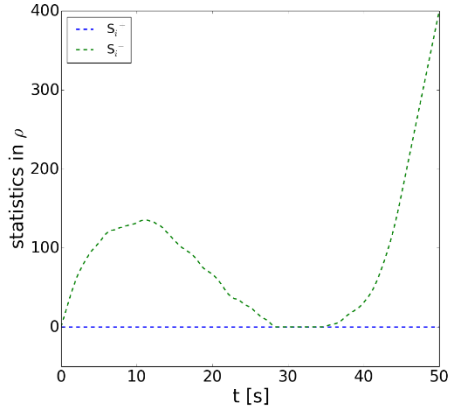
Reaction time:

- $t_{\text{reaching}} = \frac{S' - \theta}{f}$
- $t_{\text{leaving}} = \frac{\theta}{f}$



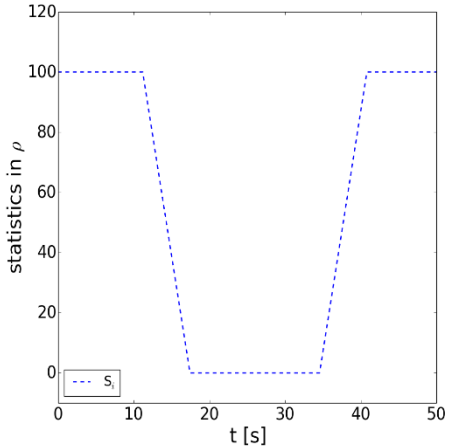


Detection of Steady State - CUSUM



Problems about statistics:

- **Not sensitive**
- **No boundary**
- **Redundant**

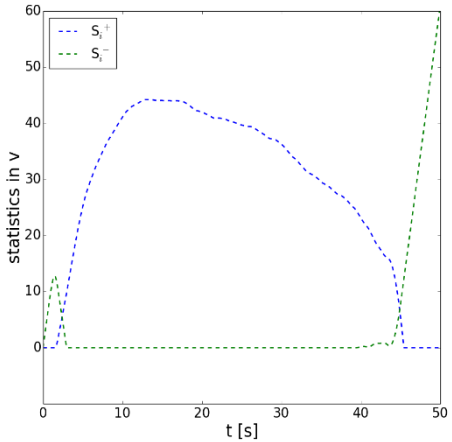


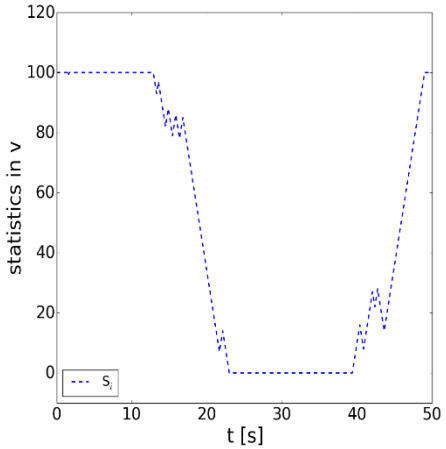
Improvement:

- $F(\tilde{x}_i) = \begin{cases} 1 & \text{if } |\tilde{x}_i| > q(\alpha) \\ -1 & if \ |\tilde{x}_i| \leq q(\alpha) \end{cases}$

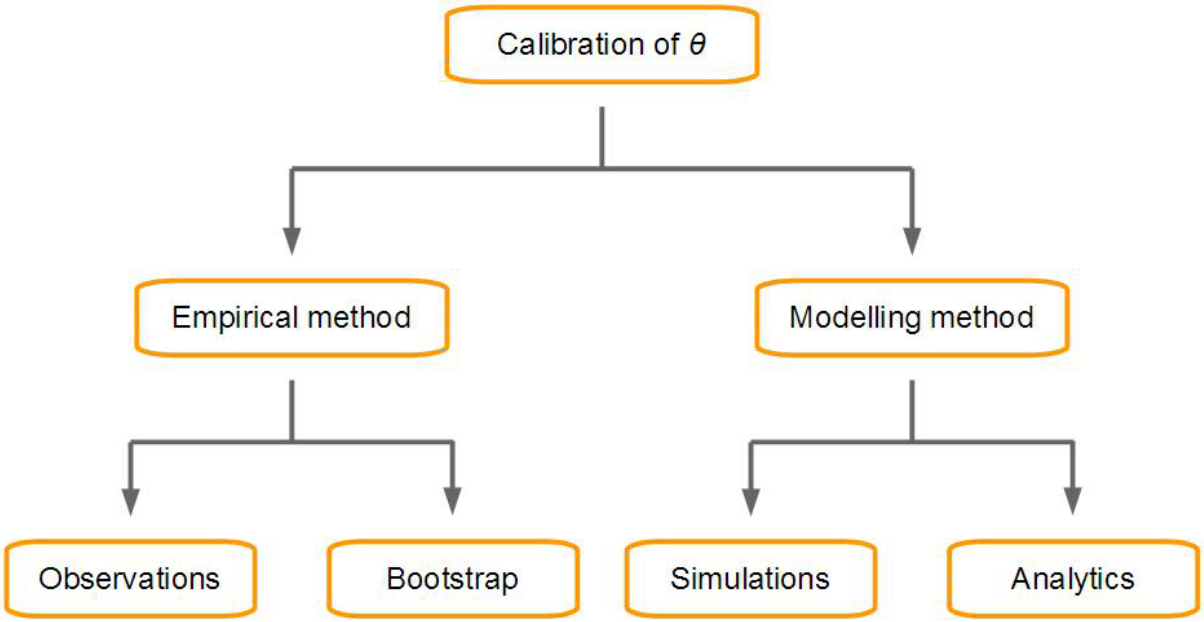
  where $\tilde{x}_i = (x_i - \mu)/\sigma$
- $S_{\max} = 100$
- $S_0 = S_{\max}$

  $S_i = \min\{\max\{0, S_{i-1} + F(\tilde{x}_i)\}, S_{\max}\}$





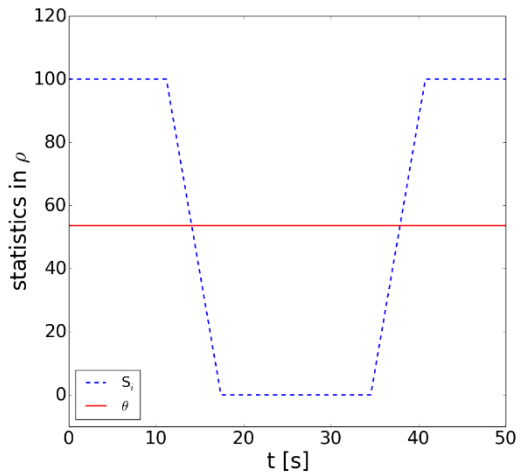
Calibrating the threshold of detection parameter θ

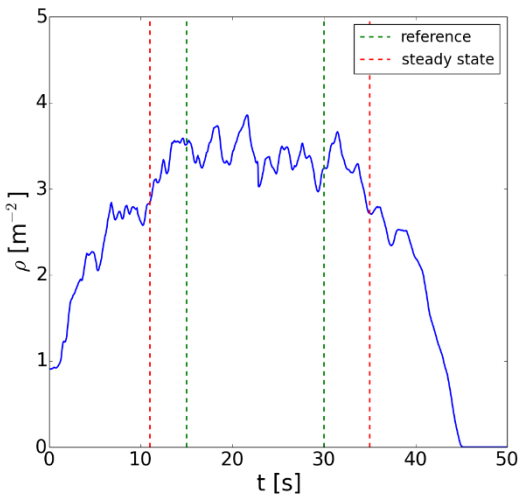


Autoregressive Model:

- $y_0 = 0$
- $y_i = c \cdot y_{i-1} + \sqrt{1 - c^2} \cdot \varepsilon_i$

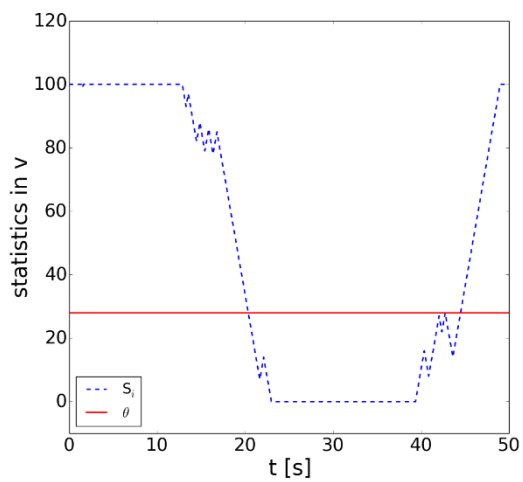
Detection of Steady State - CUSUM

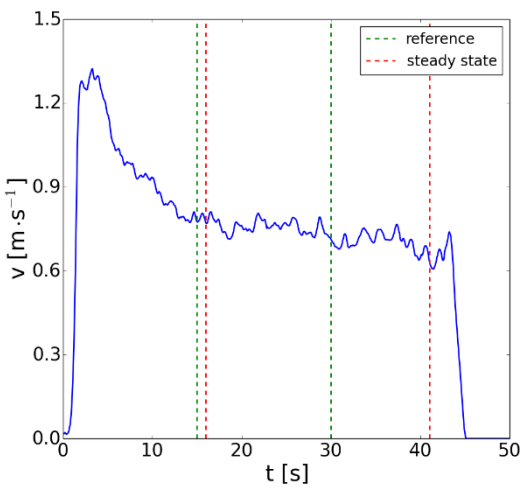




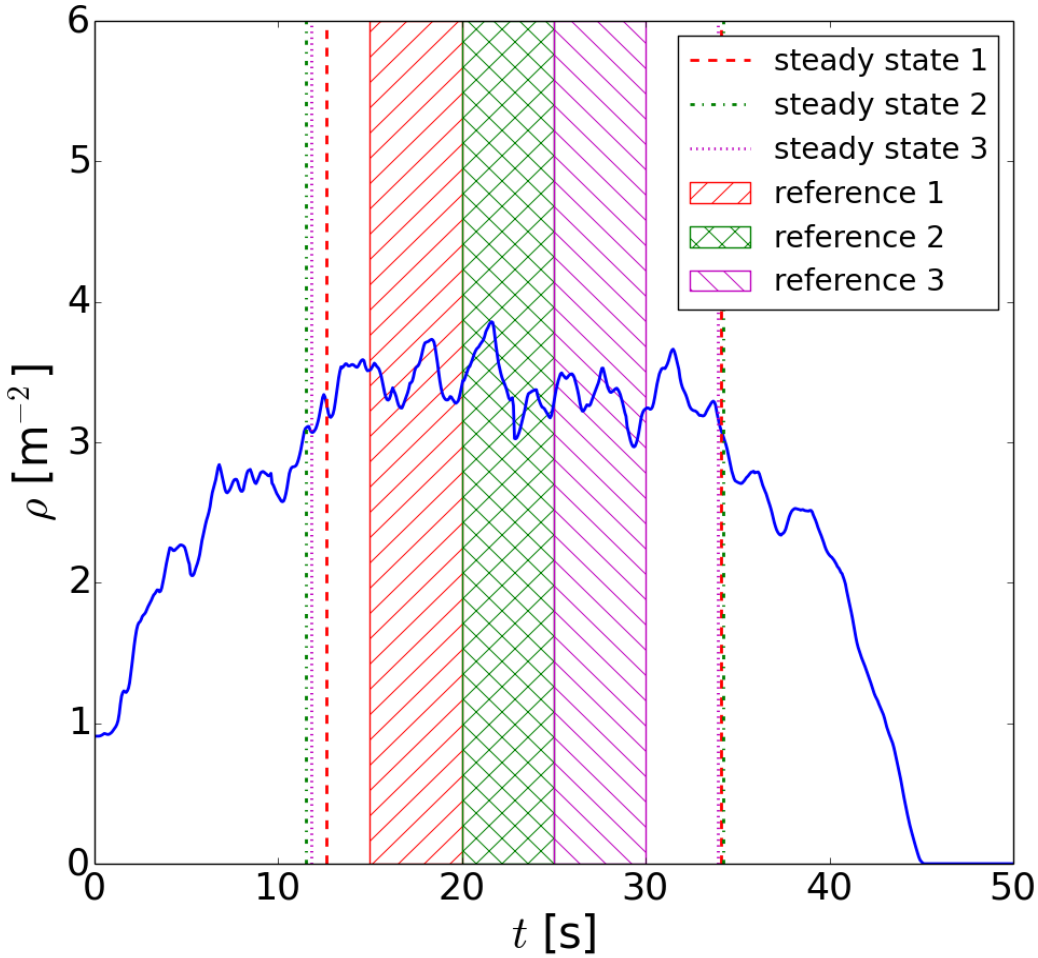
Reaction time:

- $t_{\text{reaching}} = \frac{S_{max} - \theta}{f}$
- $t_{\text{leaving}} = \frac{\theta}{f}$



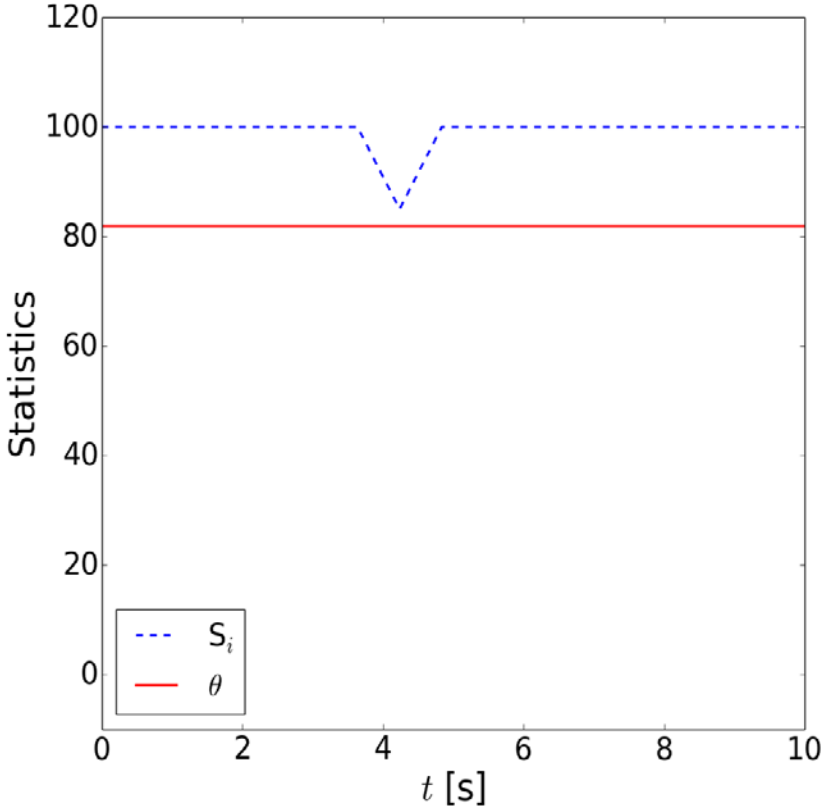


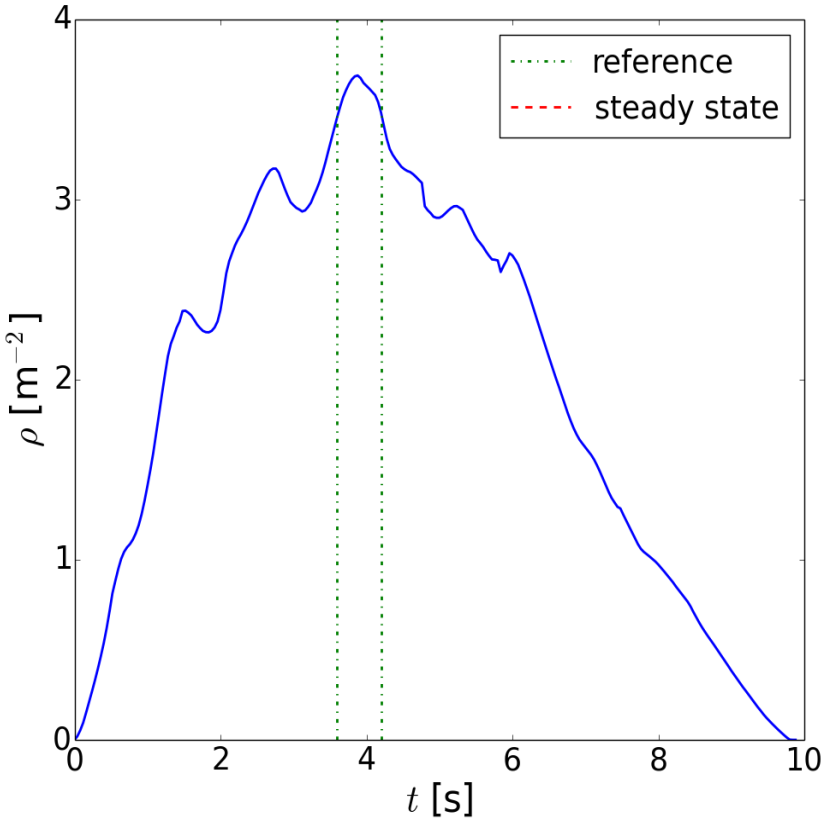
Detection of Steady State - Robustness



Reproducible steady state

Detection of Steady State - Robustness

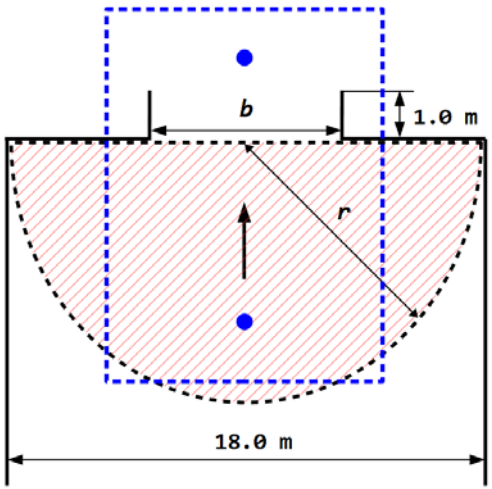




No steady state

Pedestrian Flow in Bottleneck Experiments

Experiment AO



l = 1.0 m

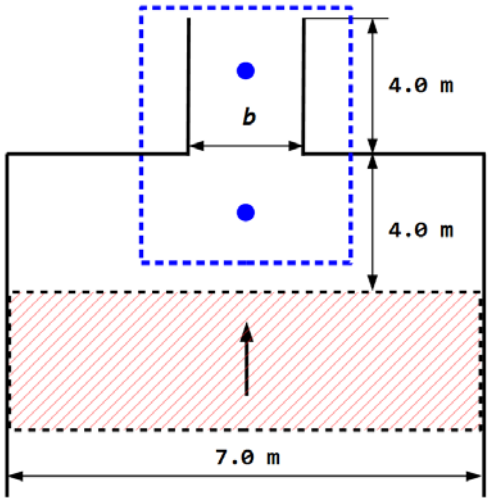
w = 18.0 m

d = 0 m

ρ_{ini} = 3.0 m^{-2}

N = 350 pers

Experiment EG



l = 4.0 m

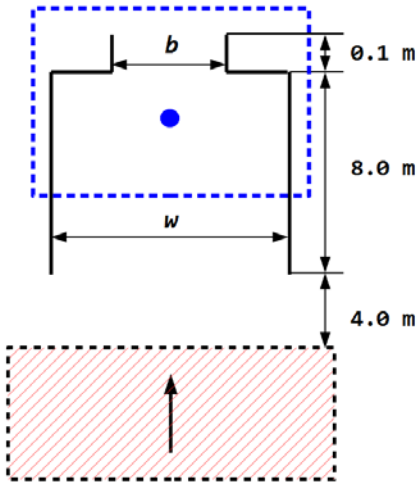
w = 7.0 m

d = 4.0 m

ρ_{ini} = 2.6 m^{-2}

N = 180 pers

Experiment UO



l = 0.1 m

w = 1.8, 2.4, 3.0 m

d = 12.0 m

ρ_{ini} = 3.0 m^{-2}

N = 150, 250, 400 pers

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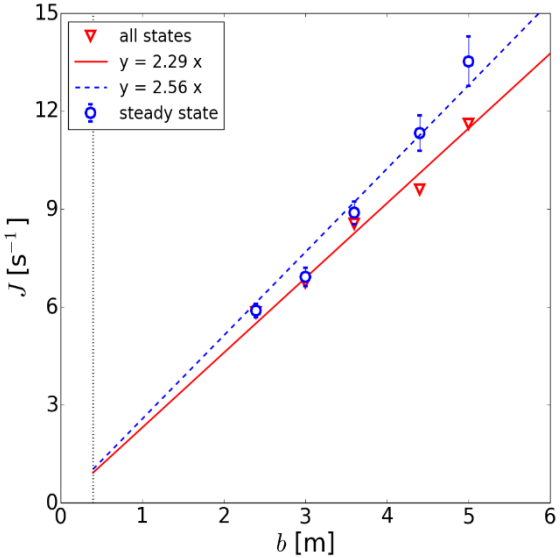
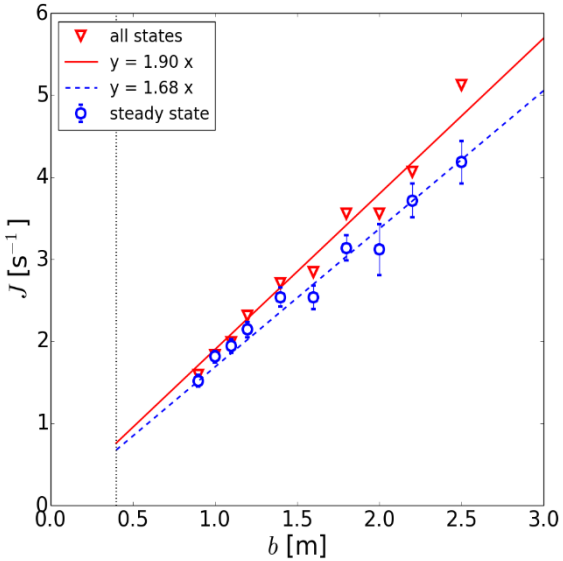
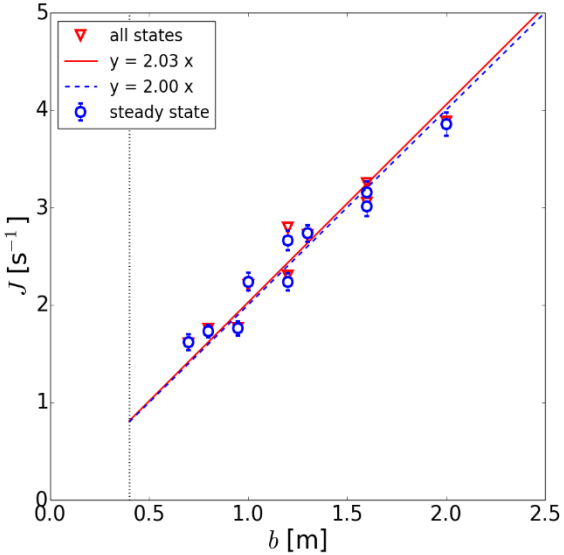
Experiment AO



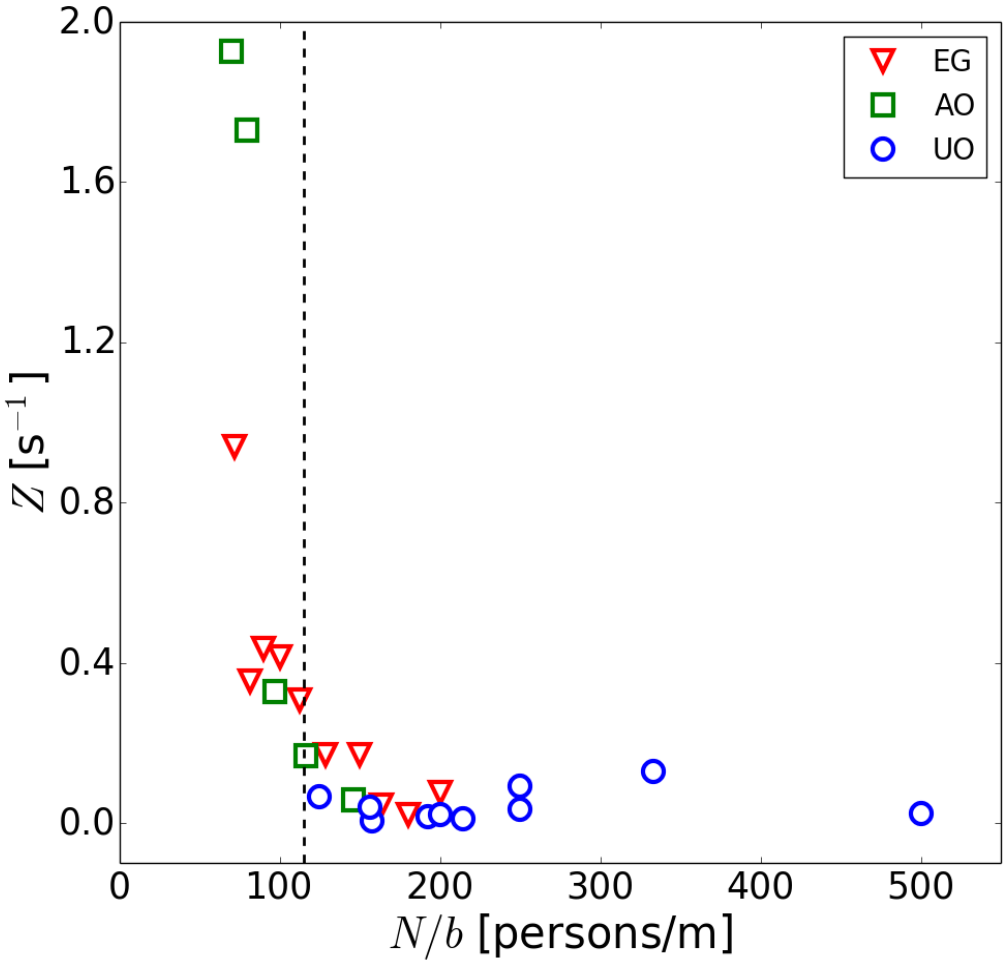
Experiment EG



Experiment UO



Detection of Steady State - Robustness



Critical value: *N/b* = 115 persons/m

Conclusions and outlook

- **Comparison of pedestrian experiments requires to distinguish carefully between transient state and steady state.**

- **For existing bottleneck experiments:**
  - ✓ **If $N/b \geq 115$ persons/m, the flow in all states can be used.**
  - ✓ **If $N/b < 115$ persons/m, first use the modified CUSUM algorithm to detect steady state, then use the flow in steady state.**

- **For the future design of bottleneck experiments:**
  - ✓ **Better to meet the requirement of $N/b \geq 115$ persons/m.**
  - ✓ **If not, pay attentation to the analysis.**

Thank you!