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JÜLICH FORSCHUNGSZENTRUM

Validation of cellular models of pedestrian dynamics using controlled large-scales experiments

25. March 2008

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Outline

Introduction

- Importance of the fundamental diagram (FD)
- Example: Evacuation simulation

Fundamental diagram – single file movement

- Experiment
- Modeling

Fundamental diagram – 2d

- Discrepancies in the literature
- Connection between bottleneck flow and the FD

Summary and Outlook

- Research-project (DFG-grant)

Importance of the fundamental diagram

Typical FAQ

- Travel or egress time

  How long does it take to reach a certain destination?

  Velocity v in dependence of density ρ

- Capacity analysis

  How many persons N can pass a facility in a given time interval Δt

  Flow: $N / \Delta t = J$ $J = J(\rho)$ Capacity: $C = J_{max}(\rho)$

The basic quantities v, ρ, J, C are related by

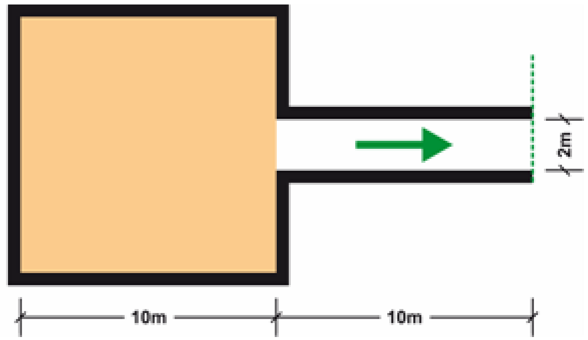
- the empirical relation $J(\rho)$ or $v(\rho)$ - fundamental diagram
- and the flow equation $J = \rho\, v\, b$.

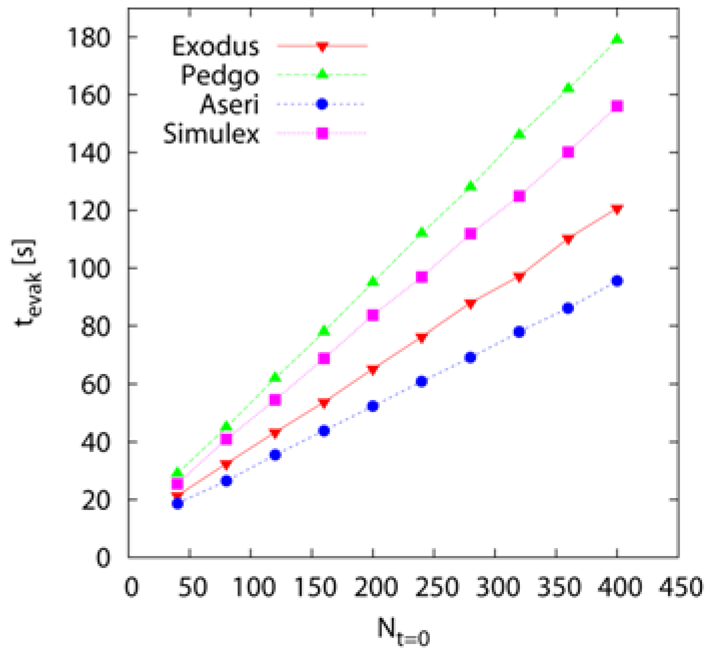
If a computer model does not reproduce the FD it is questionable whether the calculate capacities or egress times are usable!

Example: Simulation of building evacuation

Egress time calculation

- test of Aseri, PedGo, Simulex and BuildingExodus at very simple geometries
- calculated evacuation times differ significantly (factor 2-4)
- some models do not any velocity-density dependence





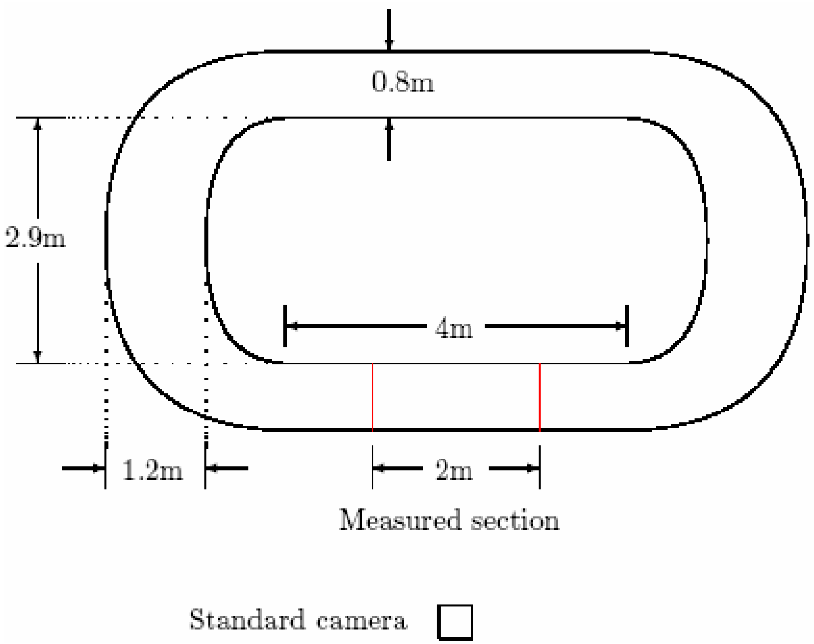
[1]Diploma thesis, C. Rogsch, University of Wuppertal

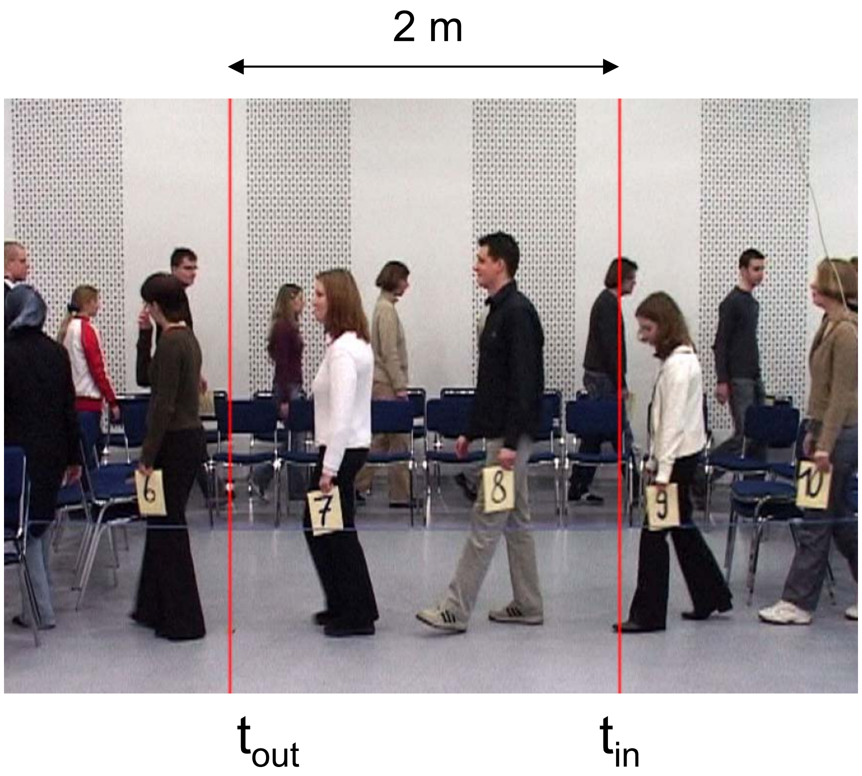
Fundamental diagram – single file movement
Experiment

Armin Seyfried, Jülich Supercomputing Centre (JSC)

Velocity-density relation – Single file movement

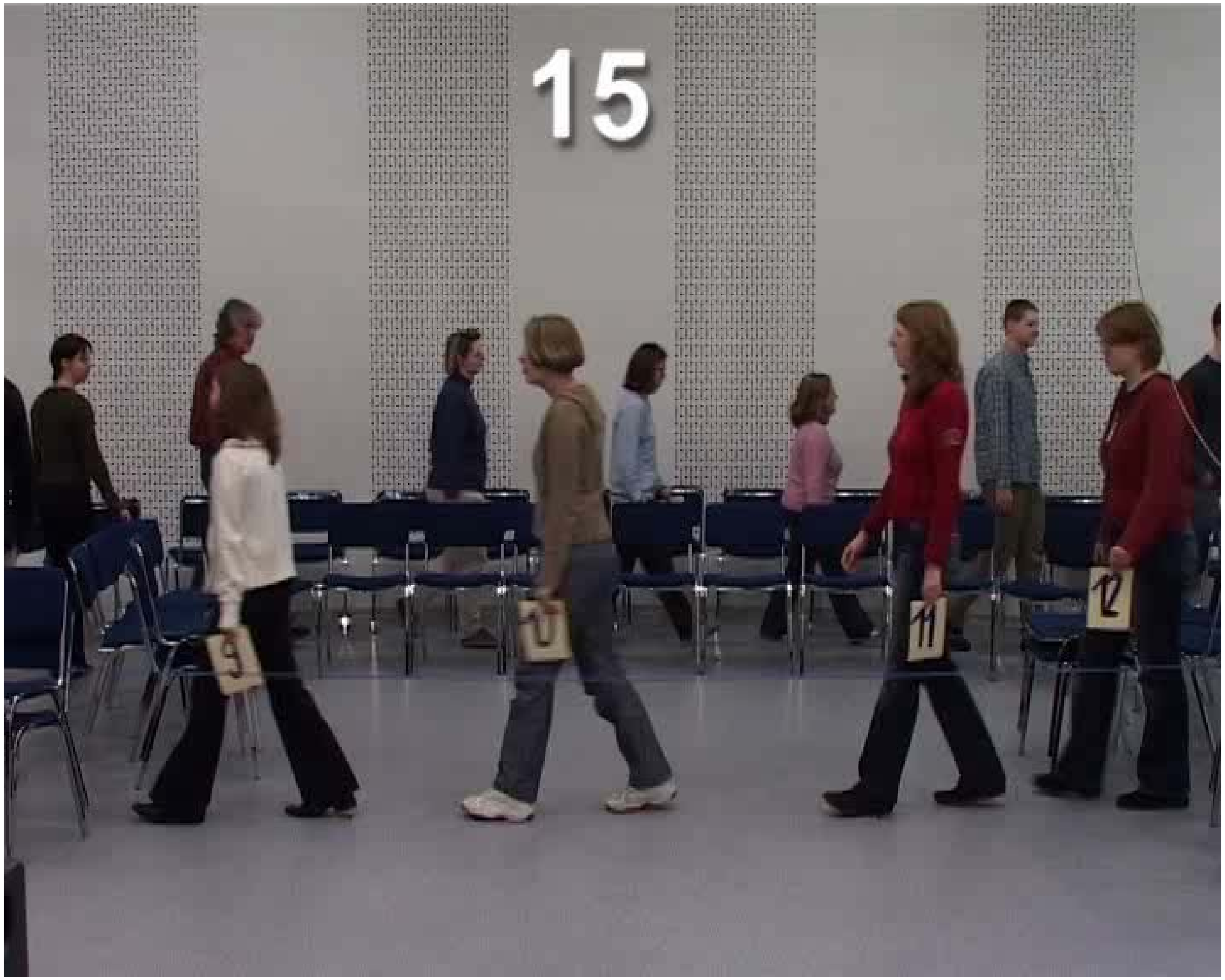
Reduction of the degree of freedom - Movement along a line





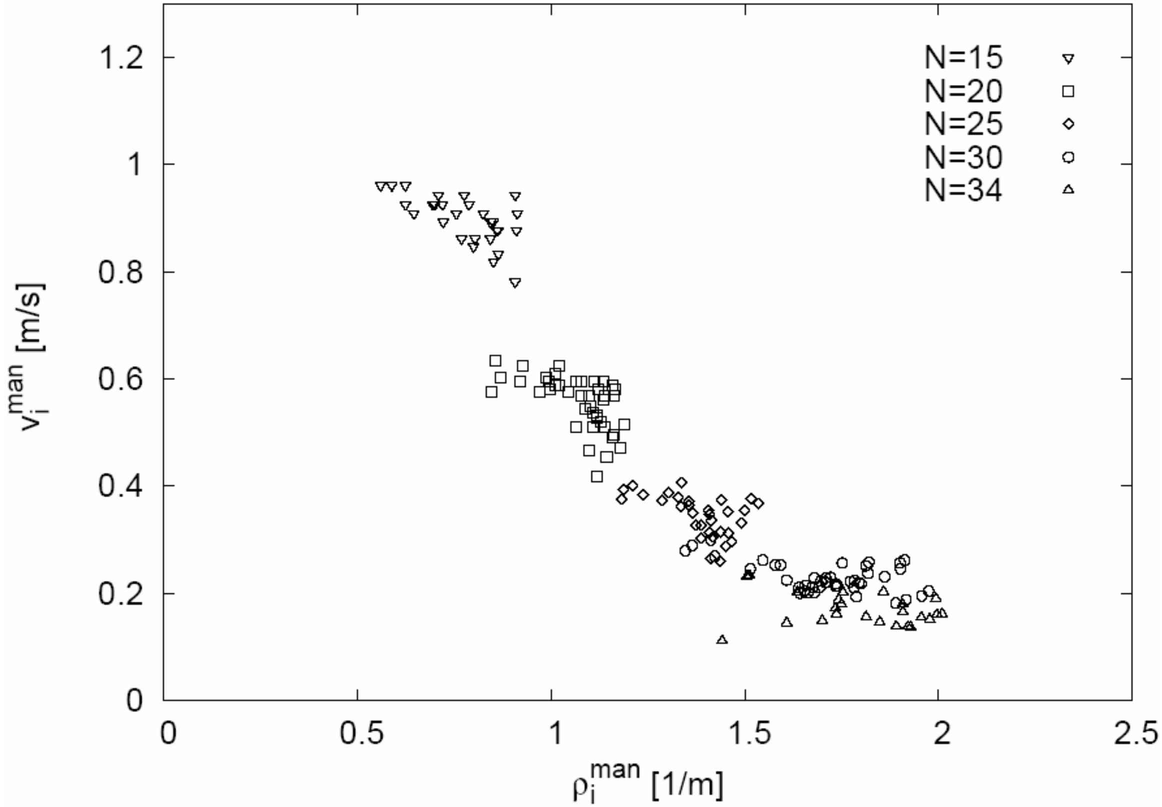
N = 1, 15, 20, 25, 30, 34

Velocity-density relation – Single file movement



Results – Single file movement

$t_{in}, t_{out} \rightarrow v_i, \rho_i$



Fundamental diagram – single file movement
Modeling

Social Force Model[1] in d = 1

Self-driven objects moving in a continuous space

$$\frac{dx_i}{dt} = \mathrm{v}_i \qquad m_i \frac{d\mathrm{v}_i}{dt} = F_i = \sum_{j \neq i} F_{ij}(x_j, x_i, \mathrm{v}_i)$$

$$F_i^{drv} = m_i \frac{\mathrm{v}_i^0 - \mathrm{v}_i}{\tau_i} \qquad F_i^{rep} = -\nabla \sum_{j \neq i} \frac{e_i}{\left(\left|x_j - x_i\right| - d_i/2\right)^{f_i}}$$

Modification $d_i(t) = a_i + b_i \mathrm{v}_i(t)$ **and influence of the remote force**

[1]D. Helbing and P. Molnar, Phys. Rev. E 51 (1995)

Hard bodies without remote force

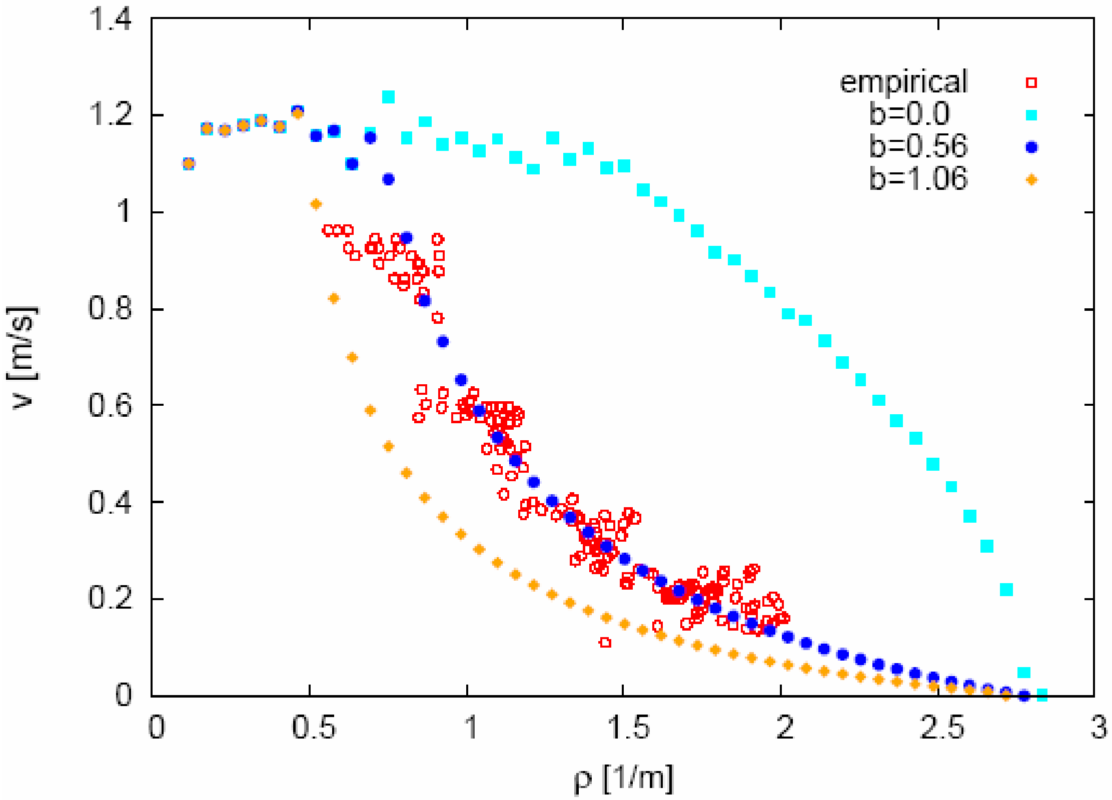
$$F_i(t) = \begin{cases} F_i^{drv} & x_{i+1}(t) - x_i(t) > d_i(t) \\ -\delta(t)\mathrm{v}_i(t) & x_{i+1}(t) - x_i(t) \le d_i(t) \end{cases} \qquad d_i(t) = a + b\ \mathrm{v_i}(t)$$

Parameter:

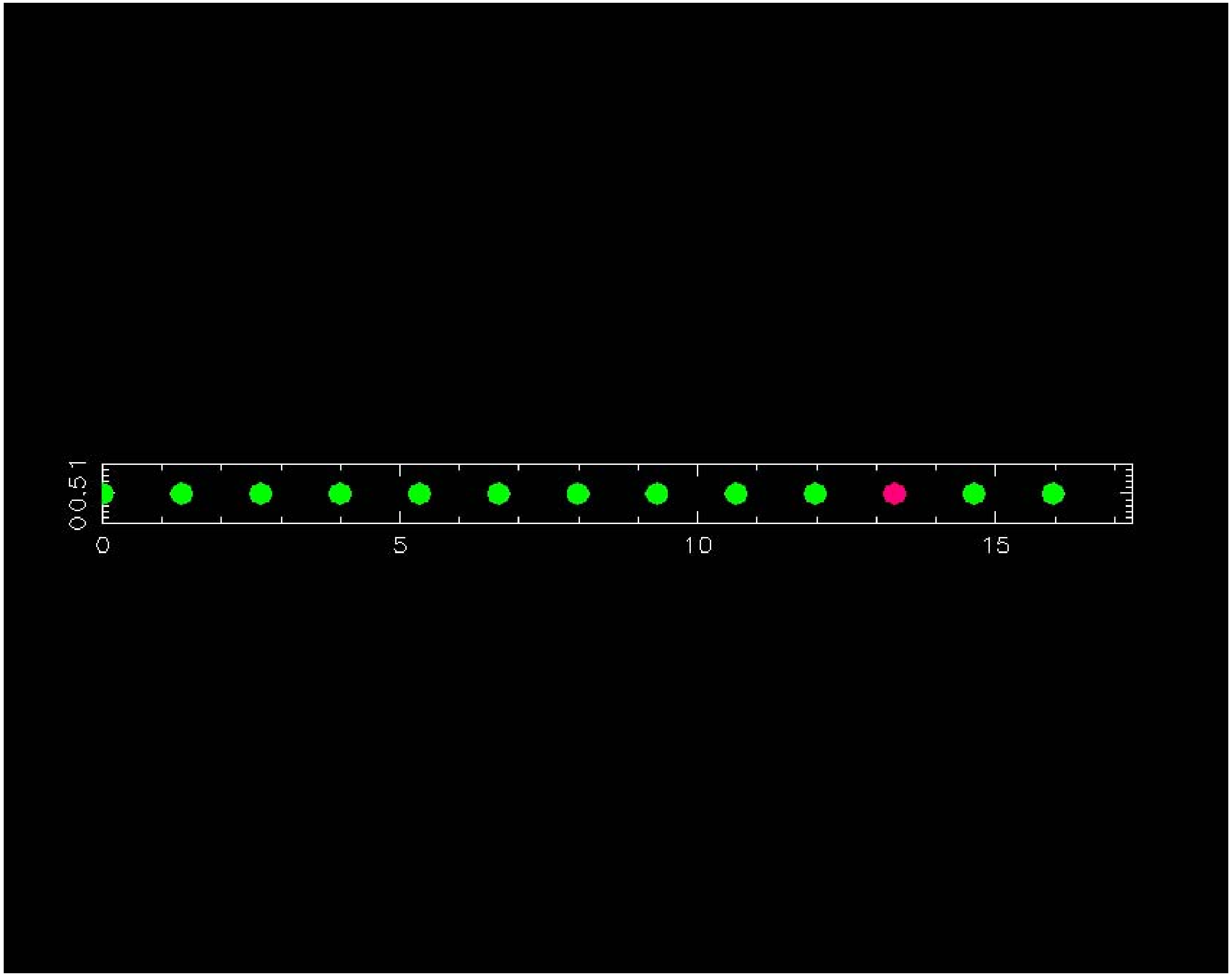
$a = 0.36\ \mathrm{m}$

$\mathrm{L} = 17.3\ \mathrm{m}$

$\Delta\mathrm{t} = 0.001\ \mathrm{s}$



Hard bodies without remote force

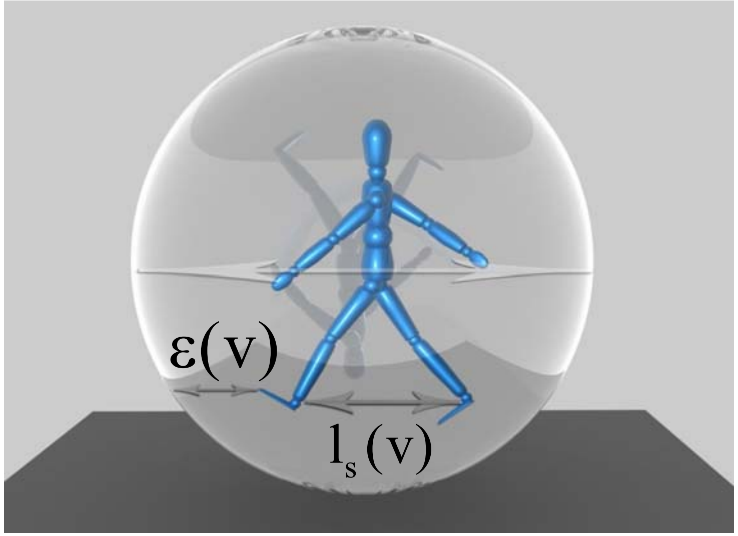


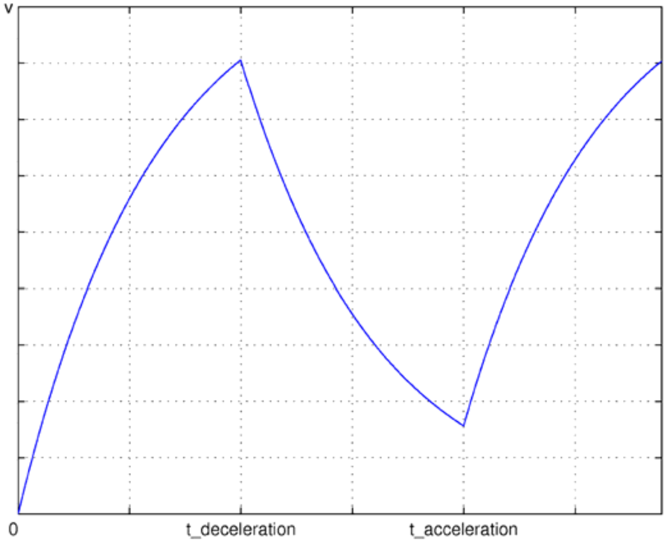
Hard bodies without remote force

New approach

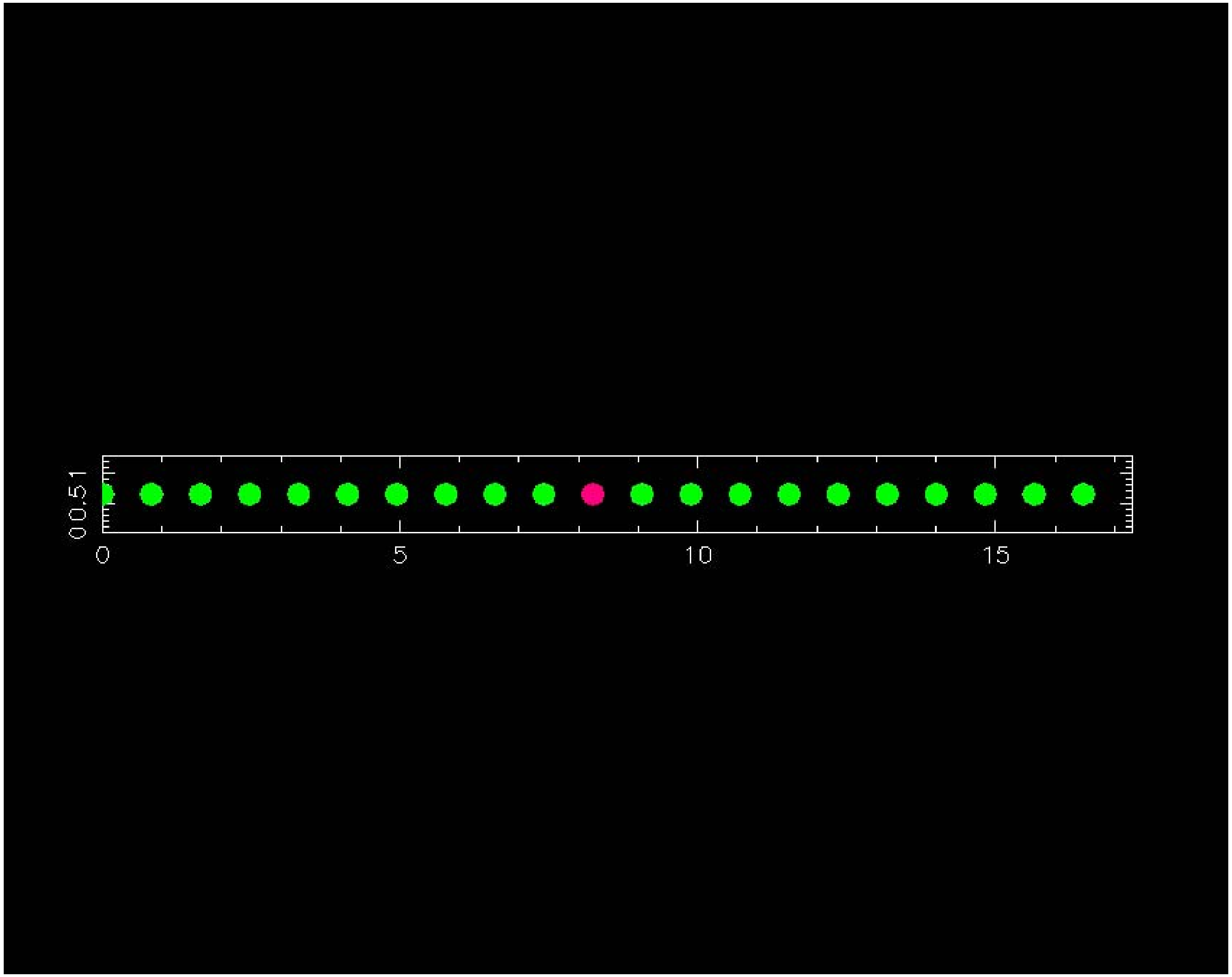
- Event driven dynamics
- Space requirement depends on current velocity
- Velocity adaptation

Step length: $l_s(v)$ Security distance: $\varepsilon(v)$





Velocity adaptation



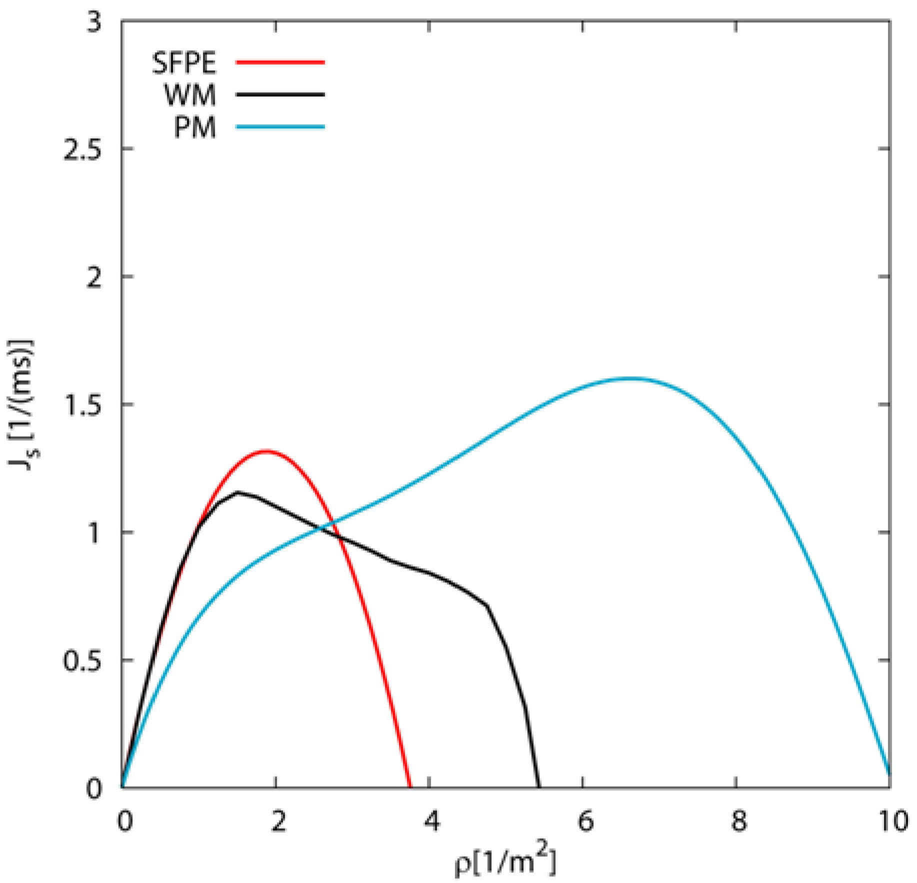
Fundamental diagram 2d

Fundamental diagram

Specifications in guidelines

- Different shapes
- Capacity values C_s
  - C_s: 1.2 – 1.6 $(ms)^{-1}$
- Location of the maximum
  - ρ_C: 1.8 – 7 m^{-2}
- Location of ρ_0
  - ρ_0: 3.8 – 10 m^{-2}

Non-negligible differences
In particular for ρ_0



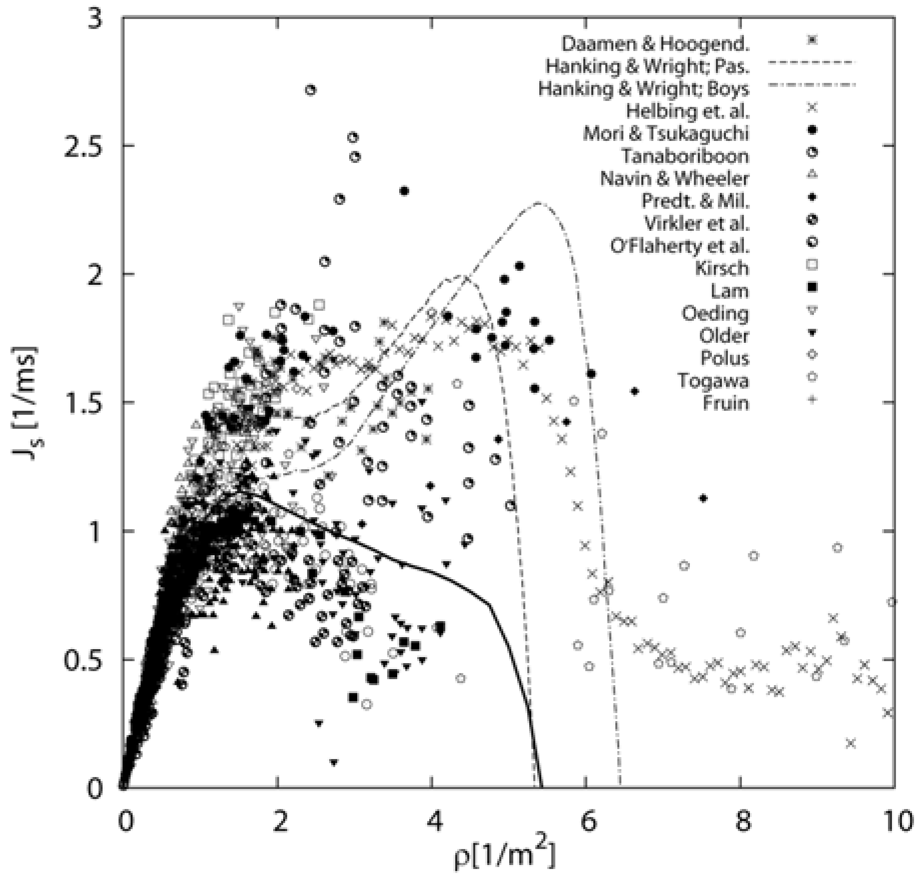
SFPE P. J. DiNenno (2002) *SFPE Handbook …*
PM V. M. Predtechenskii and Milinskii (1978)
WM U. Weidmann (1993) *Transporttechnik …*

Comparison of experimental data

Causes discussed in the literature

- Uni- and bidirectional
- Way of measurement
- Fluctuations
- Culture and population demographics
- Psychological factors

Unfortunately most authors give not all necessary information!



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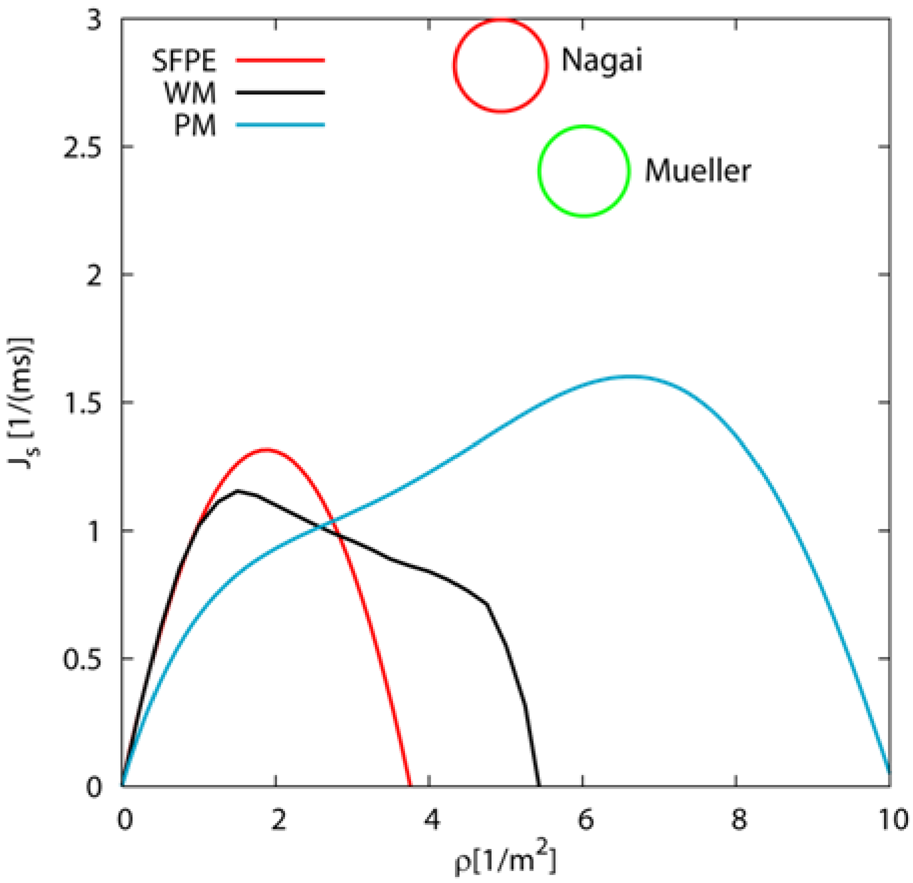
Connection between bottleneck flow and FD

Comparison of bottleneck flow and the fundamental diagram

- $C = J_{max}(\rho)$
- Nagai and Mueller

  $J_{s,max} = 2.3$ and $2.8 (ms)^{-1}$
- test persons are advised to move normally!
- High initial density ≈ 5 1/m²

Note:
Measured flow at bottlenecks are significantly higher than maxima of common FD!



Mueller K. Dissertation, Magdeburg (1981)
Nagai et al. Physica A 367, p449 (2006)

Summary and Outlook

Summary

The fundamental diagram connects ρ, v, J, C and is the most important relation in pedestrian dynamics

Our knowledge is insufficient and is founded on an contradictory data base

Major questions

- How does the “right” fundamental diagram look like?
- How is the flow through bottlenecks connected with the FD?

More detail discussion

A. Schadschneider, W. Klingsch, H. Klüpfel, T. Kretz, Ch. Rogsch and A. Seyfried, *Evacuation Dynamics, Empirical Results, Modeling and Applications*, Encyclopedia of Complexity and Systems Science, Springer, to appear 2008 (available from www.arxiv.org)

Research project

Research project

Boundary Effects and Non-Equilibrium States in Pedestrian Dynamics – Experiments and Modeling

DFG - Grant KL 1873/1-1 and SE 1789/1-1

Universität Wuppertal

Prof. W. Klingsch
C. Böhlefeld
J. Kähler
T. Rupprecht
A. Winkens
S. Zens

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Prof. A. Schadschneider

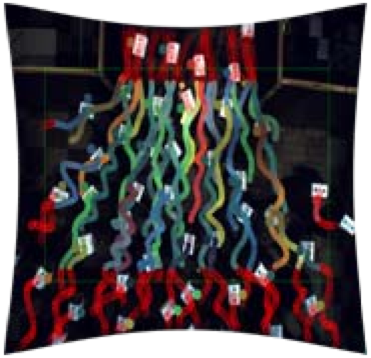
Forschungszentrum Jülich

M. Boltes
M. Chraibi
A. Portz
Dr. A. Seyfried
Dr. B. Steffen

Research project – Overview

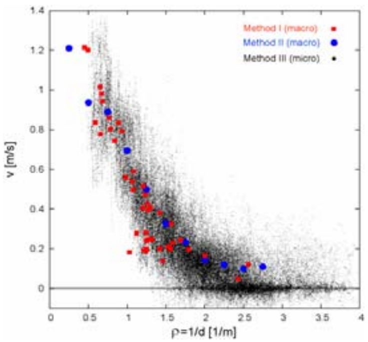
Experiments

- 99 different runs over five days with up to 250 people
- Well controlled laboratory conditions



Data collection

- Automated procedure
- Trajectories with high accuracy

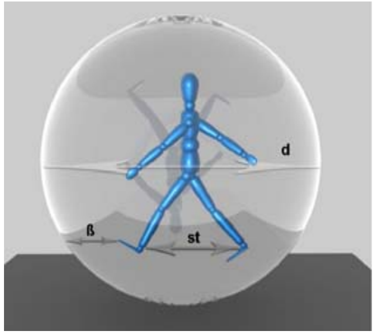


Data analysis

- Macroscopic and microscopic

Modeling

- Developments of ‘microscopic’ models for pedestrian dynamics



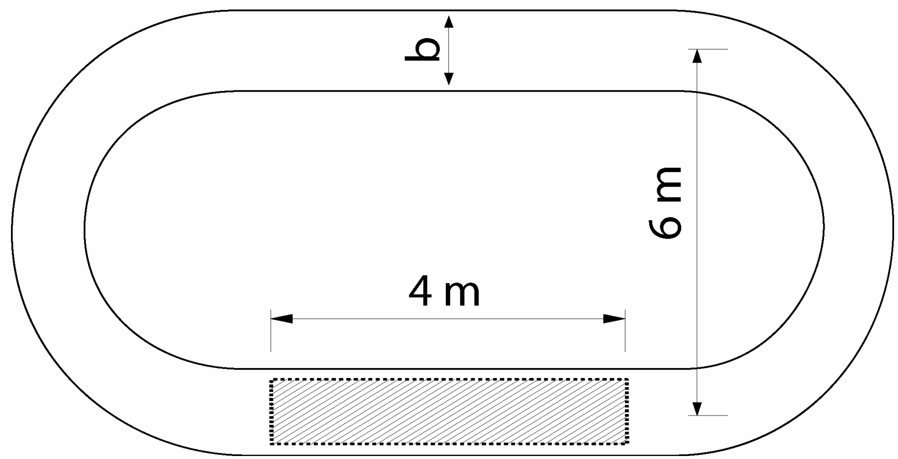
Sets of the experiments: Part 1

Fundamental diagram

- Number of pedestrians **N**

  17 - 110
- Corridor width **b**

  0.7, 0.85 and 1.0m
- Uni – bidirectional flow
- Closed and open boundaries
- Motivation



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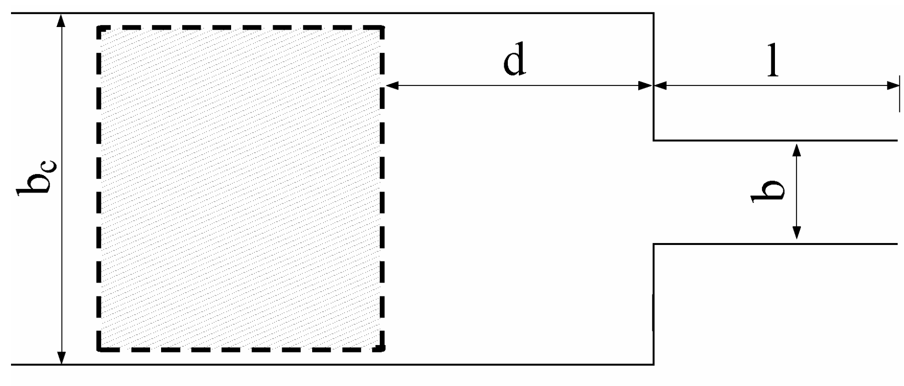
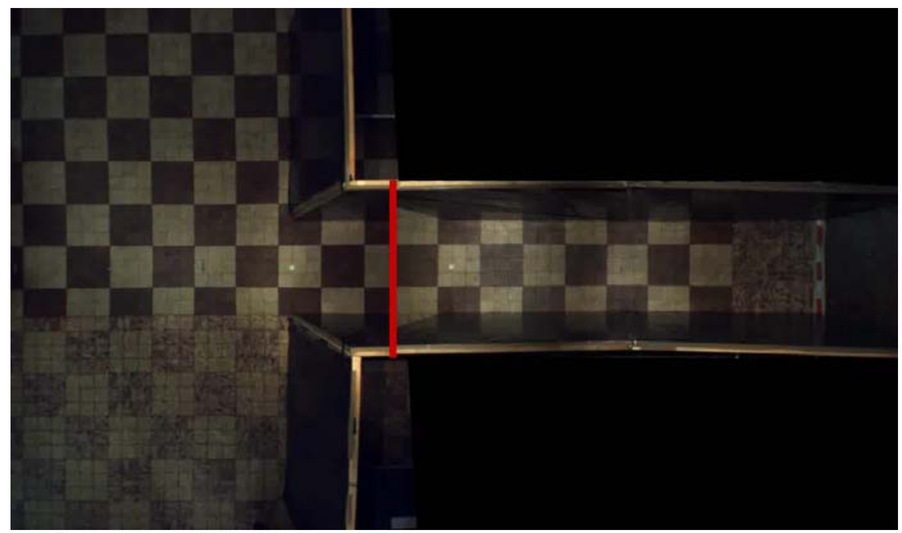
Sets of the experiments: Part 2

Bottleneck flow

- Bottleneck width **b**
  0.8, 0.9, …, 2.5m
- Bottleneck length **l**
  0.1, 2.0, 4.0m
- Corridor width $\mathbf{b_C}$
  4.0, 5.0, 6.0m
- Number of pedestrians **N**
  50, 100, …, 250
- Distance to the entrance **d**
  1.0, 2.0, 3.0, 4.0m





Thank you for your attention