# Modeling stride length and stepping frequency 

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## Motivation

Simulation of the movement and the behaviour of pedestrians and crowds becomes more and more important.

To have predictive power, simulations require realistic locomotion models. MUNCHEN

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A reliable pedestrian motion model must be

- calibrated to measured data and
- validated against observations.

Characteristics of pedestrian movement are for example

- flow through bottlenecks,
- fundamental diagrams,
- speed distributions,
- stride length, and
- stepping frequency.

The correlations between stride length, frequency, density, and speed have been measured in several experiments.

They can only be reproduced by a pedestrian locomotion model that captures stepping behaviour. One such locomotion model with stepping behaviour is the Optimal Steps Model (OSM).

Can we reproduce the dependencies as measured in the experiments?

## Outline

Background
Stride length
Stride duration

Optimal Steps Model
General Overview
Stepping forward
Navigation

Results

Conclusion and future work

## Background

## Stride length

Observations of free flow walking show that the velocity linearly corresponds to the stride length (Weidmann, 1992; Seitz and Köster, 2012; Seitz et al., 2014).

Correlations of Stride Length and Veloctiy
This linear correlation is also observed in walking-in-line experiments (Seyfried et al., 2005; Jezbera et al., 2010;
Chattaraj et al., 2009; Jelić et al., 2012b).


## Stride duration

Measurements of step duration (or stepping frequency) (Weidmann, 1992; Hoogendoorn and Daamen, 2005; Jelić et al., 2012b) show two main aspects.

1. Slow walking speeds:

Step duration decreases with increasing speed.
2. Medium/high walking speeds:

Step duration remains constant/decreases slowly.

These observations were made in different situations:

- free walking (Weidmann, 1992)
- bottleneck (Hoogendoorn and Daamen, 2005)
- walking-in-line (Jelić et al., 2012b)

Optimal Steps Model

- The Optimal Steps Model (OSM) is a pedestrian locomotion model.
- The model is inspired by the stepwise movement of pedestrians.
- First publication: Seitz and Köster (2012)
- Version used for this study: von Sivers and Köster (2015)



## Stepping forward

- A pedestrian in the OSM has a given free flow velocity $v_{f f}$.
- The maximum stride length $l_{f f}$ is calculated by $I_{f f}=\alpha+\beta \cdot v_{f f}$.
- The minimum stride length of a pedestrian in the OSM is the residual step length $\alpha$.
- Every $\frac{I_{f f}}{v_{f f}}$ seconds, a pedestrian can make a step.


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- In the OSM, pedestrians want to avoid other pedestrians and obstacles and to take the shortest way to the target.
- The superposition of the functions for these behaviours constitutes the utility function.
- Pedestrians optimise the utility of their next step, that is, they choose the position on their step disk with the best value.


Figure: Finding the new position.

Results

## Scenario

We focus on the experiment from Jelić et al. (2012a,b).
Different numbers of pedestrians (from 8 to 28) walk on two circles with radii 2.4 m and 4.1 m .


Figure: Simulation setup for the ring experiment from Jelić et al. (2012a).

## Calibration

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Calibration of the OSM's social distance parameters to the fundamental diagram from Jelić et al. (2012a).
$I_{f f}=0.065+0.724 \cdot v_{f f}$ and $\alpha=0.065$


Figure: Simulation output of the OSM.

## Stride lengths



Figure: The correlation of the stride lengths and the velocities in the OSM (reference function from the ring experiment (Jelić et al., 2012b)).

## Stride durations

Duration of Strides


Figure: The correlation of the stride durations and the velocities in the OSM (reference data from the ring experiment (Jelić et al., 2012b) and the function from (Hoogendoorn and Daamen, 2005)).

Conclusion and future work

## Conclusion:

With the OSM, one can reproduce

- the correlation of the stride length and the velocity and
- the correlation of the stride duration and the velocity.


## Future work:

- To further validate the OSM, reproduce measured correlations from other experiments that focus on stepping.
- Find out why the slopes of the stride length functions vary that much.

Chattaraj, U., Seyfried, A., and Chakroborty, P. (2009). Comparison of pedestrian fundamental diagram across cultures. Advances in Complex Systems, 12(3):393-405.

Hoogendoorn, S. P. and Daamen, W. (2005). Pedestrian behavior at bottlenecks. Transportation Science, 39(2):147-159.
Jelić, A., Appert-Rolland, C., Lemercier, S., and Pettré, J. (2012a). Properties of pedestrians walking in line: Fundamental diagrams. Physical Review E, 85(3):036111.
Jelić, A., Appert-Rolland, C., Lemercier, S., and Pettré, J. (2012b). Properties of pedestrians walking in line. ii. stepping behavior. Physical Review E, 86(4):046111.
Jezbera, D., Kordek, D., Křiž, J., Šeba, P., and Šroll, P. (2010). Walkers on the circle. Journal of Statistical Mechanics: Theory and Experiment, 2010(01):L01001.
Seitz, M. J., Dietrich, F., and Köster, G. (2014). A study of pedestrian stepping behaviour for crowd simulation. In The Conference in Pedestrian and Evacuation Dynamics 2014, Transportation Research Procedia, pages 282-290, Delft, The Netherlands.
Seitz, M. J. and Köster, G. (2012). Natural discretization of pedestrian movement in continuous space. Physical Review E, 86(4):046108.
Seyfried, A., Steffen, B., Klingsch, W., and Boltes, M. (2005). The fundamental diagram of pedestrian movement revisited. Journal of Statistical Mechanics: Theory and Experiment, 2005(10):P10002.
von Sivers, I. and Köster, G. (2015). Dynamic stride length adaptation according to utility and personal space. Transportation Research Part B: Methodological, 74:104-117.
Weidmann, U. (1992). Transporttechnik der Fussgänger, volume 90 of Schriftenreihe des IVT. Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau (IVT) ETH, Zürich, 2 edition.


VADERE soon to be open source!

## Settings and parameters

Parameters for the OSM:

| Param. | Description | Value |
| :--- | :--- | :--- |
| $\delta_{\text {int }}$ | intimate distance | 0.45 m |
| $\delta_{\text {pers }}$ | personal distance | 1.20 m |
| $\delta_{o}$ | distance kept from obstacles | 0.8 m |
| $\mu_{p}$ | strength of 'pedestrian avoidance' | 55.0 |
| $a_{p}$ | moderation between intimate and personal | 0.8 |
|  | space |  |
| $b_{p}$ | intensity of intimate space | 1 |
| $c_{p}$ | intensity of personal space | 3 |
| $\mu_{o}$ | strength of 'obstacle avoidance' | 6.0 |
| $v_{f f}$ | mean free-flow speed | $1.4 \frac{\mathrm{~m}}{\mathrm{~s}}$ |
| $\sigma_{f f}$ | variance of the free-flow speed | $0.2 \frac{\mathrm{~m}}{\mathrm{~s}}$ |

## Mathematical description

Mathematical description of the pedestrian avoidance in the OSM:

$$
\begin{align*}
& p_{1}^{j}(x):=\mu_{p} \cdot \exp \left(\frac{4}{\left(d_{j}(x) /\left(\delta_{\text {per }}+r_{p}\right)\right)^{2}-1}\right) \\
& p_{2}^{j}(x):=p_{1}+\frac{\mu_{p}}{a_{p}} \cdot \exp \left(\frac{4}{\left(d_{j}(x) /\left(\delta_{\text {int }}+r_{p}\right)\right)^{2 \cdot b_{p}}-1}\right)  \tag{1}\\
& p_{3}^{j}(x):=p_{2}+1000 \cdot \exp \left(\frac{1}{\left(d_{j}(x) / r_{p}\right)^{2 \cdot c_{p}}-1}\right) \\
& P_{p}^{j}(x):= \begin{cases}p_{3}^{j}(x) & d_{j}(x)<2 r_{p} \\
p_{2}^{j}(x) & 2 r_{p} \leq d_{j}(x)<\delta_{\text {int }}+r_{p} \\
p_{1}^{j}(x) & \delta_{\text {int }}+r_{p} \leq d_{j}(x)<\delta_{\text {per }}+r_{p} \\
0 & \text { else }\end{cases} \tag{2}
\end{align*}
$$

Mathematical description of the obstacle avoidance in the OSM:

$$
\begin{align*}
o_{1}^{k}(x) & :=\mu_{o} \cdot \exp \left(\frac{2}{\left(d_{k}(x) /\left(\delta_{o}\right)\right)^{2}-1}\right)  \tag{3}\\
o_{2}^{k}(x) & :=o_{1}+100000 \cdot \exp \left(\frac{1}{\left(d_{k}(x) / r_{p}\right)^{2}-1}\right) \\
P_{o}^{k}(x) & := \begin{cases}o_{2}^{k}(x) & d_{k}(x)<r_{p} \\
o_{1}^{k}(x) & r_{p} \leq d_{k}(x)<\delta \\
0 & \text { else }\end{cases} \tag{4}
\end{align*}
$$

## Mathematical description

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Mathematical description of the target orientation (solution of the eikonal equation) in the OSM:

$$
\begin{equation*}
F(x)\|\nabla \Phi(x)\|=1 \quad \text { for } x \in \Omega \tag{5}
\end{equation*}
$$

with boundary condition

$$
\begin{equation*}
\Phi(x)=0 \quad \text { for } x \in \Gamma \tag{6}
\end{equation*}
$$

## Mathematical description

Mathematical description of the utility optimisation in the OSM:
Navigation field $P_{i}(x)$ for any point $x \in \Omega$ :

$$
\begin{equation*}
P_{i}(x)=P_{t}(x)+\sum_{j=1, j \neq i}^{n} P_{p}^{j}(x)+\max _{k=1 \ldots m} P_{o}^{k}(x) \tag{7}
\end{equation*}
$$

Optimisation for the next step:

$$
\begin{array}{rr} 
& \min _{x \in \Omega} P_{i}(x) \\
\text { s.t. } & d_{i}(x)-l_{f f} \leq 0 \\
d_{i}(x)-\alpha \geq 0 \tag{8}
\end{array}
$$

