# A cell-based propagation model for pedestrian flows in railway stations

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**Summary:** Pedestrian flows occurring in train stations are by nature multi-directional and highly non-stationary. In this work, we present a cell-based pedestrian flow model capable of describing flow patterns arising when a multitude of trains arrive and depart in close succession. Based on first-order pedestrian flow theory and a cell-transmission model, characteristic flow patterns and local densities can be realistically reproduced. Furthermore, individual walking times can be predicted for groups of pedestrians depending on route, departure time and walking-specific attributes (e.g. 'in a hurry'). A detailed derivation of the mathematical framework and of the computational architecture as well a literature review is provided. A real case study is discussed, underlining the applicability of the proposed model.

## 1 Introduction

In peak hours, many railway stations are used at the limits of their capacity. While railway networks have been systematically extended in the past, pedestrian facilities in train stations have, at least in Switzerland, largely been neglected. Today, walkable areas are regularly congested during peak periods.

To better understand this phenomenon, we are currently developing a methodology for dynamically estimating pedestrian travel demand in train stations. Of importance in this framework is a pedestrian flow propagation model, predicting walking times of pedestrian routes depending on prevailing traffic conditions.

In this study, we aim at developing such a pedestrian propagation model. A mesoscopic first-order traffic flow model is envisaged. A mesoscopic ansatz allows to consider individual groups of pedestrians without the need of modeling the behavior of single agents. This is computationally cheap and desirable in the framework of dynamic demand estimation. Regarding the traffic model, a set of equations representing flow conservation, hydrodynamic theory and a characteristic fundamental diagram are combined with a cell-based space representation. Governing equations are solved numerically in discrete time using finite differences.

This approach is inspired by Daganzo's cell-transmission model (CTM), initially developed for single-lane car traffic on highways [1]. Unlike the original model, the scope of this work is on multidirectional pedestrian flows occurring in extended pedestrian facilities.

## 2 First-order pedestrian flow theory

First-order traffic theory is a continuum theory developed for general one- or two-dimensional flow problems. It combines the use of the principle of conservation and a statistical relation between characteristic flow parameters. Such a macroscopic relation is usually referred to as fundamental diagram.

In uni-directional flow, conservation is expressed by means of a one-dimensional continuity equation

$$\frac{\partial q(x,t)}{\partial x} = -\frac{\partial k(x,t)}{\partial t} \tag{1}$$

where $x$ denotes space, $t$ time, $q$ flow and $k$ density. From elementary hydrodynamic theory,

$$q(x,t) = kv(k) \tag{2}$$

where a density-velocity relation of the form $v(k)$ has been assumed. For instance, according to reference [2], average pedestrian speed depends on density as follows

$$v(k) = v_m \left\{ 1 - \exp\left[ -\gamma \left( \frac{1}{k} - \frac{1}{k_M} \right) \right] \right\}, 0 \le k \le k_M \tag{3}$$

where $v_m$ denotes free flow speed (typically 1.34 m/s), $\gamma$ is a shape parameter (1.913 $\#/\text{m}^2$), and $k_M$ represents jam density (5.4 $\#/\text{m}^2$). Density-speed relations represent the most prevalent type of fundamental diagrams, but others are possible and also explored in this study.

## 3 Cell-based pedestrian propagation model

First-order flow theory has proven useful for describing pedestrian flows in various contexts [2, 3] thanks to the wide availability of fundamental diagrams. Modeling of general flow patterns, in particular if non-stationary, typically requires numerical methods. A seminal contribution in this respect is due to reference [1], in which a finite difference-based approximation scheme for first-order car traffic theory is developed. This approach, widely known as 'cell-transmission model', describes traffic occurring on a single-lane highway.

Following a similar approach, this work considers space as a two-dimensional network of homogeneous cells with uniform pedestrian density. Pedestrians are distinguished with respect to their route, departure time, and any further characteristic attribute such as 'in a hurry' or 'handicapped'. Pedestrians having the same attributes form a logical group [4].

Between any two adjacent cells, flow propagation is calculated based on the outflow capacity of the emitting cell and the inflow capacity of the receiving cell. Using this concept, eq. (1) is solved in discrete time for each logical group. In presence of congestion, demand-proportional supply distribution is applied to allocate flows to cells.

The resulting flow propagation scheme allows for i) a particularly flexible space discretization, ii) cell- and even direction-specific flow speeds (important on e.g. inclined areas), and iii) separate 'lanes' for slow or fast walkers, depending on the aforementioned 'characteristic attribute' [4].

A detailed derivation and motivation of the model outlined above, as well as a description of the software architecture are provided. A review of similar models [4, 5, 6, 7] and other related work [8, 9, 10, 11] is included as well.

# 4 Case studies

To demonstrate the validity of our model, counter- and cross-wave scenarios are investigated in detail at the example of a longitudinal corridor and an orthogonal intersection, respectively. This allows to elucidate the different behavior under free-flow conditions and in presence of congestion. Subsequently, a real case study is considered. For a large Swiss railway station, we dispose of comprehensive pedestrian tracking data for main pedestrian walkways. Dynamic origin-destination demand extracted from this data is used as model input. Model prediction and actual data are compared in terms of travel time, density and macroscopic patterns.

# References

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