Modeling of position finding in waiting processes on platforms

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Abstract. The distribution of passengers waiting for a train is one of the limiting factors when improving the performance of a train station, as it heavily influences the boarding and alighting times of trains. We introduce a probability-based model for the pedestrians' choice of a waiting position. Different factors as the geometry and the positions of other waiting pedestrians are taken into account. To assess the model, simulations on a simplified representation of a platform were used. The results of this simulation show good agreement with observations of previously conducted field studies.

Keywords: pedestrian dynamics, waiting pedestrian, inflow, spatial distribution, train station

1 Introduction

Usually, pedestrian models describe the movement of pedestrians with varying levels of detail. Often complex processes like way-finding in buildings or navigation through a crowd are solved in a simplified way by collision avoidance algorithms or social forces [1, 5, 11]. Moving towards a specific goal is a substantial contribution determining the dynamics of a process, especially in evacuation scenarios. However, in more complex buildings, e.g., platforms or airport gates, the dynamics are heavily influenced by waiting people, who may restrict the space for the movement of others. After reaching their waiting position, pedestrians do not have any need to keep moving unless the event they are waiting for occurs, e.g., a train arrives or boarding of the plane starts. In this regard, as opposed to "moving dynamics" resulting from pedestrians evacuating a specific place, we focus on the modelling of "waiting" where pedestrians wait for a certain amount of time by standing or slowly moving without a explicit goal.

Recently, the investigations of inflow processes gained importance in the research of pedestrian dynamics. In [8], different hypotheses of the inflow process are compared with experimental data. Ezaki et al. [3] conducted experiments on the inflow to a confined space and derived a theoretical description of the process. When investigating inflow processes, usually, a confined space with a dedicated entrance/exit is considered. These works point out that the distribution is influenced by the geometry, i.e., the platform's shape and size, and the positioning of entrances/exits. Additionally, the positions of other pedestrians affect the choice of a waiting position.

Multiple studies focusing on the dwell times of trains also report findings on the longitudinal distribution of passengers on platforms of train and metro stations [4, 7, 10, 12]. One of the observation of these studies is the clustering of passengers around the entrances and further platform infrastructure as seats, rain shelters, and vending machines. For more experienced travelers, also the position at the departing station or less crowded coaches influence their position choices. However, no further notions of the distribution of the passengers between the tracks were reported.

Waiting pedestrians were investigated by simulations of train stations in [2] and [6], where the influence of standing pedestrians on the flow of passing pedestrians was discussed. In particular it was analyzed how standing pedestrians constrict the flow of passing pedestrians. As waiting positions, arbitrary positions within a designated waiting area were assigned to waiting pedestrians. An approach to model the passengers' distribution on a metro platform with a cost function approach is discussed in [13]. The introduced cost function takes different influences as the distance to a particular waiting area, density, length of the waiting area into account. Contrary to the investigated metro station in Beijing with guiding lines and specific waiting area, we intend to develop a model which is valid in a more general context.

In this paper, we develop a mathematical model to describe the position finding process for waiting pedestrians. We define waiting pedestrians, as pedestrians who enter a specific region, called waiting area (e.g., platform), until the awaited event is triggered, e.g., the arrival of the train. We focus on pedestrians who stand during the waiting process, hence they move towards their waiting position and come to a halt.

2 Model

The determination of the waiting position is an optimization problem in which every pedestrian tries to determine a position that is optimal for him or her, taking various factors into account. As the results highly depend on the individual's personal preferences and intentions, we propose a heuristic approach. In our model, space is discretized into small cells of $0.5 \times 0.5\,\mathrm{m}^2$, which can either be empty or occupied by exactly one person. Each of the pedestrians gets an unoccupied cell assigned as waiting position depending on three floor fields. The two fields S and D determine the probability of a cell to be assigned as waiting position. S takes geometrical influences, as the distance to exits, walls, and door areas into account. D considers the distance to a specific position, including detours forced by other pedestrians. R is used as a filter function, to reward a certain distance to other pedestrians. N is a normalization factor such that $\sum_{i,j} P_{i,j} = 1$. The resulting probability for a cell (i, j) to be assigned is given by

$$P_{i,j} = N \cdot \left[(S_{i,j} + D_{i,j}) \cdot R_{i,j}\right]. \quad (1)$$

The floor fields used will be described in detail in the following subsection together with the algorithm for choosing a waiting position.

2.1 Static floor field S

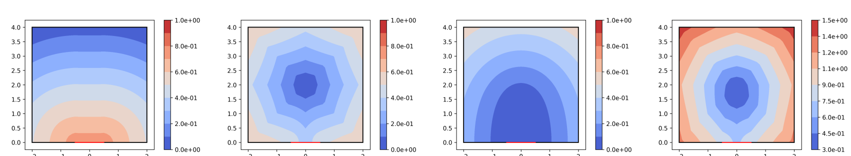
The static floor field S is defined as

$$S_{i,j} = w_e \cdot E_{i,j} + w_w \cdot W_{i,j} + w_f \cdot F_{i,j}, \tag{2}$$

and does not change over time as it is affected by fixed walls, doors and obstacles. It is a combination of multiple probability fields E, W, F, which are scaled by the diameter of the circumcircle of the room w, hence $E_{i,j}, W_{i,j}, F_{i,j} \in [0, 1]$. To model different behavior patterns, the fields are scaled by individual weights $w_e, w_w, w_f \in \mathbb{R}^+$. The influences considered in S are the distance to the designated exits/platform edges, the distance to boundaries, e.g., walls and corners, as well as the distance to an area close to doors where more pedestrians are expected to pass.

In the first two cases, distance to exits and boundaries, passengers will try to minimize their distance to these areas, resulting in a higher probability that pedestrians will choose these areas as their waiting position. The corresponding probabilities are given by $E_{i,j} = 1 - \frac{d_{e_{i,j}}}{w}$ and $W_{i,j} = 1 - \frac{d_{b_{i,j}}}{w}$. Where d_e denotes the distance to the closest point of an exit, and d_b is given $d_b = d_w + 0.5d_c$ where d_w and d_c denote the distance to the closest point of a wall or corner.

Contrary to the other factors, pedestrians will try to maximize their distance to the area in front of doors where they entered the room, as they will expect more passengers to follow. We modeled the area where more pedestrians are expected to pass and hence are uncomfortable to stand in as an ellipse. The ellipse's center is located in the middle of the door, the semi-minor axis is oriented along the door, whereas the semi-major axis points in the movement direction of the pedestrians. The probability of a cell to be assigned as waiting position is given by $F_{i,j} = \frac{d_{f_{i,j}}}{w}$ where d_f is the distance to the closest point of that ellipse. The resulting static floor field S as in Eq. 2 is shown in Fig. 1d.



(a) E. (b) W. (c) F. (d) S.

Fig. 1: Probability of the static influences. A higher numbers indicates a more preferable waiting position. The door is located in the center at the buttom.

2.2 Dynamic floor fields D and R

The dynamic floor fields D and R take the waiting positions of other pedestrians into account and are changed with every pedestrian entering the room. D is a probability field, and R is as a filter function, ensuring a certain distance between the waiting pedestrians.

Pedestrians tend to minimize the distance they have to walk to reach their waiting position. For the computation of the walking distance d_w, a fast marching approach [9] is used, where the pedestrians are interpreted as circular obstacles with a radius of 0.5 m. The probability for each cell is given by

$$D_{i,j} = w_d \cdot \left(1 - \frac{d_{w_{i,j}}}{w}\right), \tag{3}$$

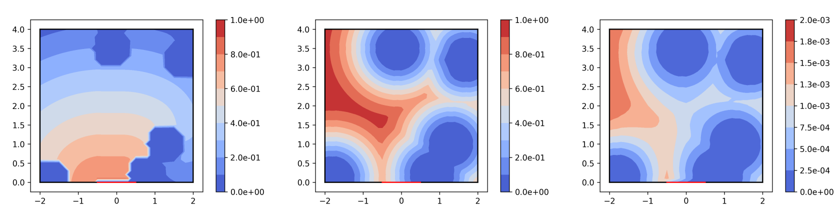
where $w_d \in \mathbb{R}^+$ is the corresponding weight. For unreachable areas the distance is set to $d_w = w$. The resulting floor field is shown in Fig. 2a.

Additionally, the pedestrians try to maximize the distance to the closest neighbor d_p to a certain extent. This repulsion gets modeled as

$$R_{i,j} = 1 - \exp\left(-\frac{2 \cdot d_{p_{i,j}}^2}{c}\right). \tag{4}$$

where $c \in \mathbb{R}^+$ corresponds to the desired personal space of a pedestrian.

Fig. 2b shows the resulting floor field. Combining all influence factors as in Eq. 1, yields a probability field as in Fig. 2c.



(a) D. (b) R. (c) P.

Fig. 2: Probability of the dynamic influences with 5 pedestrians inside the room. A higher numbers indicates a more preferable waiting position.

The algorithm for determining the waiting position of a pedestrian is given in Alg. 1. This position can be used as a goal for navigation through crowds in models like [1,5,11]. When the waiting position is reached, the pedestrian stands until the awaited event is triggered.

3 Results

We used the model from Sect. 2 to simulate the selection of waiting positions on a simplified platform, as depicted in Fig. 3. The platform is 40 m long and 10 m

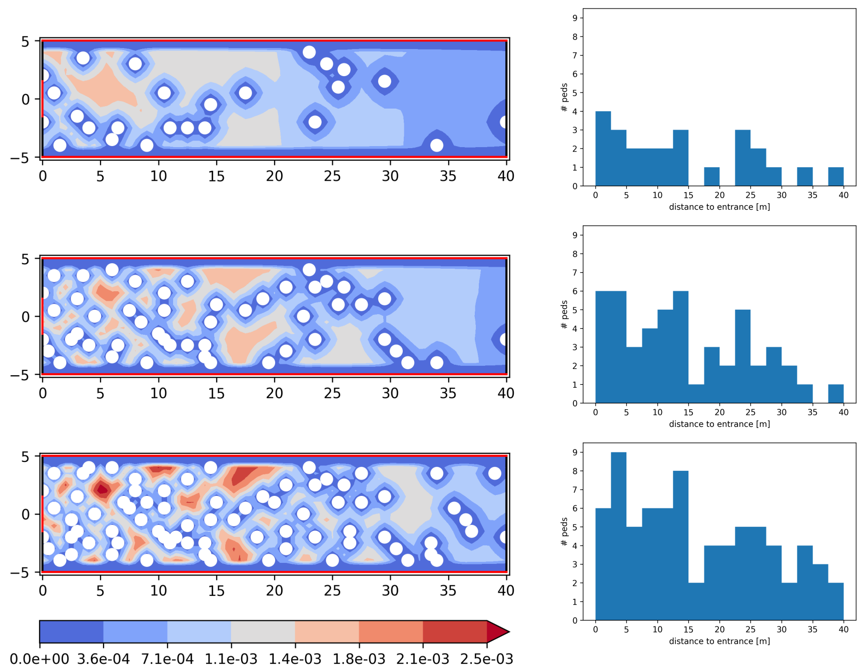
Algorithm 1 Choose a waiting position.

$\forall i, \forall j$: compute $S_{i,j}$ according to Eq. 2, set $D_{i,j} = 0$ and $R_{i,j} = 1$;
for all pedestrian entering the room/platform **do**
  Compute P according to Eq. 1;
  Assign a waiting position to the entering pedestrian based on P;
  Update D and R according to Eq. 3 and Eq. 4 respectively
end for

wide with an entrance of 3 m located at the center of the left hand side. Tracks run along the upper and lower edges of the platform. To avoid pedestrian choosing waiting position in dangerous areas close to the tracks, a 0.5m wide corridor along the top and bottom edges is not used for the computation of the waiting positions. As the distribution tends to be more uniform with higher densities, we restrict our simulation to a maximum of 75 passengers on the platform.

In field observations [4, 7, 10, 12] on different train stations, the positions of entrances were emphasized as the leading factor to the pedestrian longitudinal distributions on platforms. In most cases clustering of pedestrians occurs close to platform entries and exits, leading to a non-uniform distribution and in some cases, leaves parts of the platform empty, which are further away from entrances. This behavior can also be seen in the results from our simulations, as displayed in Fig. 4b. Of the first 25 passengers on the platform, 44 % will choose a location within 10 m of the entrance, and almost 70 % are located in the half closer to the platform entrance. The distribution stays almost the same after 50 pedestrians have entered the platform, 38 % are closer than 10 m to the entrance, and 68 % choose a waiting position in the left half of the platform. With 75 pedestrians the distribution starts to get more uniform, as only 62 % are assigned a waiting position in the half of the platform with the entrance. Only 35 % of the passengers stand within the first 10 m of the entrance. In our simulation, the distribution of the passengers tends to become more uniform with higher densities, which qualitatively agrees with field observations.

Fig. 3: Geometry of the simplified platform. Entrance is located on the left hand side. Tracks are located at the top and bottom. Red areas mark prohibited waiting areas like danger zones close to tracks.



(a) Passenger distribution.

(b) Longitudinal passenger distribution.

Fig. 4: Passenger distribution on the platform after 25, 50, and 75 have found a waiting position. Left side shows the distribution and the underlying probability, white circle indicate pedestrian positions. Right side shows the longitudinal distribution of the passengers.

4 Conclusion & Outlook

In this work, we developed an optimization and random based approach to qualitatively model the position finding of pedestrians in a waiting context. The model is based on probability fields derived from different influence factors that are found in experiments as well as field studies. Due to its modularity, extra factors that are needed in a more general context as attraction, repulsion, and danger zones can be easily added to the model.

Due to the strong influence of the entrance on the distribution of the waiting pedestrian, blockage may occur, which would prevent that further pedestrians enter the waiting area. In our simulations, we focused on the process of finding a waiting position, neglecting the interaction between moving pedestrians. In future work, it has to be investigated if the interaction between pedestrians may solve the problem of a blocked entry, as the blocking pedestrian retreat into the room to make space for passing persons. An essential factor that needs to be included in the future is group behavior, as pedestrians would usually stand close to each other during waiting.

Moreover, the model introduced in this paper assumes a global knowledge about layout and occupation of the platform. This has to be replaced by a view-field based knowledge allowing to model the behavior of pedestrians who are unfamiliar with the place and to consider the restricted field of view of passengers just entering the platform. Also, when incorporating the position finding in a movement context, an iterative position finding process is needed, as the pedestrians need to react to other pedestrians taking their preferred spot, and they need to find a new one.

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