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Waiting pedestrians in the social force model

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HIGHLIGHTS

- Extensions to the social force model to include waiting pedestrians are proposed.
- Simulations of interactions between waiting and passing pedestrians are performed.
- Predictions of the models are characterized and the differences are analyzed.
- Sufficient criteria for the stability of the models are given.
- The choice of waiting model is showed to significantly impact simulation results.

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ABSTRACT

Microscopic simulation of pedestrian traffic is an important and increasingly popular method to evaluate the performance of existing or proposed infrastructure. The social force model is a common model in simulations, describing the dynamics of pedestrian crowds given the goals of the simulated pedestrians encoded as their preferred velocities.

The main focus of the literature has so far been how to choose the preferred velocities to produce realistic dynamic route choices for pedestrians moving through congested infrastructure. However, limited attention has been given the problem of choosing the preferred velocity to produce other behaviors, such as waiting, commonly occurring at, e.g., public transport interchange stations.

We hypothesize that: (1) the inclusion of waiting pedestrians in a simulated scenario will significantly affect the level of service for passing pedestrians, and (2) the details of the waiting model affect the predicted level of service, that is, it is important to choose an appropriate model of waiting.

We show that the treatment of waiting pedestrians have a significant impact on simulations of pedestrian traffic. We do this by introducing a series of extensions to the social force model to produce waiting behavior, and provide predictions of the model extensions that highlight their differences. We also present a sensitivity analysis and provide sufficient criteria for stability.

1. Introduction

During the last couple of decades, the interest in simulation of pedestrian traffic has increased significantly. One reason for this is the recognition of walking as an important mode of transport, especially in connection to public transport, that

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should be prioritized to decrease the environmental impact of the transportation system. Another reason for the increased interest in pedestrian simulation is that development of accurate simulation tools have been made possible thanks to the increase in available computational power, and the advent of new models of pedestrian behavior. One of these models, the social force model (SFM) was introduced two decades ago by Helbing and Molnár [1], and has since then been frequently investigated in the literature, see e.g. Refs. [2–11], and is also implemented in commercial software [12]. It should be noted that the SFM is only one of a large class of force based models of pedestrian dynamics with a history ranging as far back as the work by Hirai and Tarui [13].

The first applications of the SFM were mainly focused on simulating emergency evacuation of buildings, see for example Helbing et al. [14]. In such applications the goal of the pedestrians is to reach an exit as quickly as possible. However, the model has since its conception been extended to include a number of nontrivial behaviors, e.g. dynamic route choice [12] and pedestrians preferring to walk in a group [15]. Also, many variations of it have been proposed. Some examples to illustrate the diversity of the variations are: A. Johansson [16] experimented with the shape of the social field by letting it depend on the relative velocity of the interacting pedestrians, and performed a thorough comparison between the proposed and the traditional specifications of the field. Parisi et al. [17] extended the model to avoid that simulated pedestrians with a high preferred speed push other pedestrians forward or to the side when trying to walk by them. This was accomplished by temporarily setting the preferred speed to zero if the space immediately in front of the pedestrian is occupied. Lakoba et al. [18] introduced a numerically stable and efficient method to impose a minimum physical radius of the pedestrians, and also proposed an extension to include memory effects.

One nontrivial behavior that has received little attention, is that of waiting. Waiting pedestrians is a common feature in almost any normal traffic situation, specially at public transport interchange stations where pedestrians wait in front of information signs, in waiting rooms and at platforms. Accurate modeling of waiting pedestrians is important when using simulation to determine the level of service at a pedestrian facility, since groups of waiting pedestrians may reduce the capacity and create bottlenecks for passing pedestrians as showed by Davidich et al. [19]. In their work a spatially discrete model in which a waiting pedestrian is fixed in one cell and do not react to other pedestrians in its neighborhood is applied. The modeling of waiting pedestrians therefore becomes restricted to the choice of waiting position. In contrast, we will in this paper investigate a number of possible ways to include, in a spatially continuous model, the reaction of the waiting pedestrians to their surroundings.

Helbing and Molnár [1,20] and Helbing et al. [21] mention, without further analysis, that group formation among pedestrians due to social bonds, and attraction to special places, such as street artists, can be modeled by attractive, often time dependent, forces similar to the repulsive forces used to model the aversion to walking close to walls, but with opposite sign. Such a model would, however, as noted by Helbing and Molnár [20], result in a behavior similar to that observed at rock concerts, with people struggling to get as close to the stage as possible; a behavior significantly differing from what is usually meant by waiting.

However, by modeling the operational behavior of the pedestrians using the SFM, it is possible to qualitatively reproduce a well known emergent phenomenon: the river-like streams of moving pedestrians through a standing crowd reported by Helbing et al. [21]. The ability of a model to correctly reproduce the formation of such streams may be important for the accuracy of predictions of macroscopic quantities, such as flow, since the formation of streams may facilitate the passage through a standing crowd in a similar way as dynamical lane formation facilitates bi-directional flow. Unfortunately dynamic lane formation and their correspondence in a standing crowd are hard to quantify.

In this article, we restrict the meaning of waiting to denote only the desire to stay at a certain place. This is the type of behavior typically displayed by people waiting at a railway platform, or in front of an information sign in a public transport interchange station. We do not include for example random strolling, or any such activity in the term waiting. Moreover, we assume that there exists a model determining if and where the simulated pedestrian prefers to stand, and investigate how this desire can be coupled to the SFM, thereby providing waiting agents with an operative behavior.

The purpose of this paper is to investigate the importance of accurate modeling of waiting pedestrians. More specifically, we hypothesize that: (1) the inclusion of waiting pedestrians in a simulated scenario will significantly affect the level of service for passing pedestrians, and (2) the details of the waiting model affect the predicted level of service, that is, it is important to choose an appropriate model of waiting.

The modeling of waiting pedestrians has two aspects, the reaction of passing pedestrians to the waiting, and the reaction of the waiting pedestrians to the passing. The main focus of the paper is on the first aspect at an aggregated level. However, the two aspects are closely connected and to understand the influence of the waiting pedestrians on the passing we also describe the reactions of the waiting pedestrians on an aggregated level. To investigate the effects of including waiting pedestrians and the sensitivity to the model used, a sequence of extensions to the SFM to include waiting pedestrians is presented, having simplicity as the guiding modeling principle.

We investigate the properties of the proposed model extensions and characterize the differences between the extensions by comparing their predictions. Furthermore we present a sensitivity analysis implying the sensitivity to the introduced model parameter and give sufficient criteria for the stability of the models. Finally, we conclude that the treatment of waiting pedestrians has significant impact on the predictions of pedestrian simulation models.

We start off in Section 2 by describing the general type of modeling framework for which the proposed model extensions are intended, followed in Section 3 by the presentation of the model extensions. In Section 4, the simulation scenario and