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Specification, estimation and validation of a pedestrian walking behavior model

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ABSTRACT

We propose and validate a model for pedestrian walking behavior, based on discrete choice modeling. Two main types of behavior are identified: *unconstrained* and *constrained*. By unconstrained, we refer to behavior patterns which are independent from other individuals. The constrained patterns are captured by a *leader–follower* model and by a *collision avoidance* model. The spatial correlation between the alternatives is captured by a cross nested logit model. The model is estimated by maximum likelihood estimation on a real data set of pedestrian trajectories, manually tracked from video sequences. The model is successfully validated using a bi-directional flow data set, collected in controlled experimental conditions at Delft university.

1. Introduction

Pedestrian behavior modeling is an important topic in different contexts. Architects are interested in understanding how individuals move into buildings to create optimal space designs. Transport engineers face the problem of integration of transportation facilities, with particular emphasis on safety issues for pedestrians. Recent tragic events have increased the interest for automatic video surveillance systems, able to monitor pedestrian flows in public spaces, throwing alarms when abnormal behavior occurs. Special emphasis has been given to more specific evacuation scenarios, for obvious reasons. In this spirit, it is important to define mathematical models based on behavioral assumptions, tested by means of proper statistical methods. Data collection for pedestrian dynamics is particularly difficult and only few models presented in the literature have been calibrated and validated on real data sets.

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Previous methods for pedestrian behavior modeling can be classified into two main categories: *microscopic* and *macroscopic* models. In the last years much more attention has focused on microscopic modeling, where each pedestrian is modeled as an agent. Examples of microscopic models are the *social forces* model in Helbing and Molnar (1995) and Helbing et al. (2002) where the authors use Newtonian mechanics with a continuous space representation to model long-range interactions, and the multi-layer utility maximization model by Hoogendoorn et al. (2002) and Daamen (2004). Blue and Adler (2001) and Schadschneider (2002) use cellular automata models, characterized by a static discretization of the space where each cell in the grid is represented by a state variable. Another microscopic approach is based on space syntax theory where people move through spaces following criteria of space visibility and accessibility (see Penn and Turner, 2002) and minimizing angular paths (see Turner et al., 2001). Finally, Borgers and Timmermans (1986), Whynes et al. (1996) and Dellaert et al. (1998) focus on destination and route choice problems on network topologies. For a general literature review on pedestrian behavior modeling we refer the interested reader to Bierlaire et al. (2003). For applications of pedestrian models in image analysis, we refer the reader to our previous work (Antonini et al., 2004; Venegas et al., 2005; Antonini, 2005; Antonini et al., 2006).

Leader–follower and collision avoidance behavior play a major role in explaining pedestrian movements. Existing literature has shown the occurrence of self-organizing processes in crowded environments. At certain levels of density, interactions between people give rise to lane formation (Helbing et al., 2005; Hoogendoorn and Daamen, 2005). Collision avoidance (e.g. Collett and Marsh, 1974) and leader–follower (e.g. Li et al., 2001) have been widely studied. In order to include these aspects in our model, we took inspiration from previous car following models in transport engineering (including Newell, 1961; Herman and Rothery, 1965; Lee, 1966; Ahmed, 1999). The main idea in these models is that two vehicles are involved in a car following situation when a subject vehicle follows a leader, normally represented by the vehicle in front, reacting to its actions. In general, a sensitivity-stimulus framework is adopted. According to this framework a driver reacts to stimuli from the environment, where the stimulus is usually the leader's relative speed. Different models differ in the specification of the sensitivity term. This modeling idea is extended here and adapted to the more complex case of pedestrian behavior. We want to stress the fact that in driver behavior modeling a distinction between acceleration and direction (or lane) is almost natural (see Toledo, 2003; Toledo et al., 2003), being suggested by the transport facility itself, organized into lanes. The pedestrian case is more complex, since movements are two-dimensional on the walking plane, where acceleration and direction changes are not easily separable. Constrained behavior in general, and collision avoidance in particular are also inspired by studies in human sciences and psychology, leading to the concept of *personal space* (see Horowitz et al., 1964; Dosey and Meisels, 1969; Sommer, 1969). Personal space is a protective mechanism founded on the ability of the individual to perceive signals from the physical and social environment. Its function is to create spacing patterns that regulate distances between individuals and on which individual behaviors are based (Webb and Weber, 2003). Helbing and Molnar (1995) in their social forces model use the term "territorial effect". Several studies in psychology and sociology show how individual characteristics influence the perception of space and interpersonal distance. Brady and Walker (1978) found for example that 'anxiety states' are positively correlated with interpersonal distance. Similarly, Dosey and Meisels (1969) found that individuals establish greater distances in high-stress conditions. Hartnett et al. (1974) found that male and female individuals approached short individuals more closely than tall individuals. Other studies (Phillips, 1979; Sanders, 1976) indicate that an other person's body size influences space.

The validation of pedestrian walking models is a difficult task, and has not been extensively reported in the literature. Berrou et al. (2007) and Kretz et al. (2008) validate their model by comparing real and simulated flows and densities at bottlenecks. Brogan and Johnson (2003) compare real walking paths with simulated paths using three different metrics: the distance error, that is the mean distance between the real and the simulated path for all simulation time steps, the area error, that is the area between the two paths, and the speed error, that is the mean difference in speed between the two paths for all simulation time steps.

2. Modeling framework

In this work we refer to the general framework for pedestrian behavior described by Daamen (2004). Individuals make different decisions, following a hierarchical scheme: *strategical*, *tactical* and *operational*. Destinations and activities are chosen at a strategical level; the order of the activity execution, the activity area choice and route choice are performed at the tactical level, while instantaneous decisions such as walking and stops are taken at the operational level. In this paper, we focus on pedestrian walking behavior, naturally identified by the operational level of the hierarchy just described. We consider that strategic and tactical decisions have been exogenously made, and are interested in modeling the short range behavior in *normal* conditions, as a reaction to the surrounding environment and to the presence of other individuals. By "normal" we mean non-evacuation and non-panic situations.

The motivations and the soundness of discrete choice methods have been addressed in our introductory work (Bierlaire et al., 2003; Antonini et al., 2006; Antonini and Bierlaire, 2007). The objective of this paper is twofold. First, we aim to provide an extended disaggregate, fully estimable behavioral model, calibrated on real pedestrian trajectories manually tracked from video sequences. Second, we want to test the coherence, interpretability and generalization power of the proposed specification through a detailed validation on external data. Compared with Antonini et al. (2006), we present three important