PEDESTRIAN BEHAVIOR: MODELS, DATA COLLECTION AND APPLICATIONS

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Introduction

Compared to the car and public transport, pedestrian movement has received considerably less attention in the transportation and urban planning literature. Yet, an understanding of pedestrian decision-making and movement is critical in a variety of application domains. The viability of stores in inner city areas largely depends on pedestrian flows. Especially those stores that cannot attract customers in their own right depend on pedestrian movement patterns. In addition to such feasibility and impact assessments, an understanding of pedestrian movement is important for planning and designing public spaces. The dimensions of public space influence pedestrian movement and in turn have an important impact on the general atmosphere in pedestrianized areas. In addition to public space, pedestrian movement patterns are critical in large buildings such as train stations, airports, stadiums and theatres not only in terms of the capacity of such buildings, but also with respect to such issues as safety, evacuation and navigation.

Although some attempts of modeling and simulating pedestrian movement have been around for decades, this field of research recently received a clear boost in attention in a variety of disciplines, not only in the disciplines, traditionally concerned with pedestrians such as urban planning, transportation and urban design, but also in computer science and applied physics. In the latter case, pedestrian movement is often viewed as an interesting case to show properties of complexity theory and multi-agent models such as aggregate patterns emerging from simple principles applied to microscopic agents.

The aim of this book is to document these new developments in research and modeling approaches. To that effect, leading scholars representing different new modeling approaches and fields of application were invited to write a chapter about the analysis and modeling of pedestrian movement patterns. Most of these chapters relate to contributions in modeling pedestrian choice behavior and movement. Innovative work related to different modeling approaches is included in this book. Other chapters are more focused on applications. They serve to illustrate how models of pedestrian behavior and movement patterns can be applied to a variety of important policy and design issues. Any empirical model of pedestrian behavior requires data. Over the years, different data collection methods have been used. Originally, data on pedestrian and movement depended largely on counts and survey. More recently, modern technology such as video, experiments and GPS tracking has supplemented the portfolio of different data collection methods. The various chapters illustrate the different data collection methods that are applied in this field of research.

Normally, an introductory chapter like this starts with a brief summary of lines of development in the topic area of interest. In this case, however, this is not done because the contribution by *Bierlaire and Robin* is doing an excellent job in this regard. This chapter illustrates that cellular automata (CA) models constitute an important and viable approach to modeling pedestrian movement. *Schadschneider and Seyfried* discusses the principles underlying this approach and provides a framework for extremely efficient simulations even of very large systems. Various CA models and results derived from this framework are presented. The main focus is on the so-called floor-field CA model, in which the interactions are based on a kind of virtual chemotaxis, similar to the communication used by ants. This is especially useful for modeling pedestrian crowding.

CA models have found a strong competitor in multi-agent systems. *Bandini, Manzoni, and Vizzari* presents several computer simulations of multi-agent technology in simulating crowding. In particular, their chapter presents modeling and software tools provided by the so-called Situated Cellular Agent (SCA), an approach based on Multi-Agent Systems principles whose roots are on CA. Examples in which SCA formal tools have been exploited to represent relevant crowds' features and dynamics are presented.

The next chapter, by *Dijkstra, Timmermans, and de Vries*, is also about a multi-agent system, but in this case the focus is on impulse and non-impulse shopping. Their AMANDA model is quite general in scope, but still some parts need elaboration. In addition to outlining the general model system, the chapter focuses on some estimation results of the submodels on impulse and non-impulse buying behavior.

Compared to the CA models and some other multi-agent models, the richness of the behavioral underpinnings of their model is a distinctive feature. In that sense, different concepts of behavior have been used in the literature. Beyond pedestrian movement, random utility theory has been a dominant approach in transportation research and spatial choice behavior. This theory assumes that when choosing between discrete choice alternatives (destinations, routes, etc.) individuals choose the alternative that maximizes their utility. *Borgers, Kemperman, and Timmermans* demonstrate how this approach can be used in modeling pedestrian movement in shopping street segments, including entering shops. The model assumes a detailed network of links to represent the structure of street segments and entrances to the shops. The choice of a destination is modeled by means of a discrete choice model, including variables such as type-specific supply of shops, distances and tendency to visit a shop. After choosing a destination, the route to that destination is modeled using a similar type of model.

Zachariadis, Amos, and Kohn also report new developments, based on utility-maximizing behavior. They propose a dynamic pedestrian routing and traffic assignment approach that is based on route choices that are neither constrained by grid-based discretizations of space nor follow a user-defined network. Pedestrian movement choices are defined heuristically and utility feedback is used to evaluate alternative options. Route choices are based on the experienced utility of preceding pedestrians as realized by Legion Studio's micro-navigation module.

Behaviorally, the principle of utility-maximization implies that pedestrians take into account all attributes that are relevant to their decision, use these attributes in a continuous manner and discriminate between choice options also with much precision. Because these assumptions may not be very realistic for pedestrian behavior, *Zhu and Timmermans* explore modeling pedestrian choice behavior using principles of bounded rationality. Their model acknowledges that pedestrian may only use a subset of attributes and use thresholds to identify satisfactory outcomes. An interesting unique feature of their model is that heterogeneous decision styles and rule are part of a single model.

The temporal dimension is most of this work does not play a role at all or an implied role. *Zhang* develops a model of time use and expenditures of pedestrians in city centers. A new resource allocation model is developed to describe how pedestrians allocate their available time and expenditure budgets to various activities using a utility-maximizing framework. Pedestrian's utility is defined as a multi-linear function, composed of time- and expenditure-specific utilities and inter-activity interactions. By maximizing the pedestrian's utility, conditional on available time and expenditure budgets, time use and expenditure functions for all the activities are derived as a nonlinear simultaneous-equation model system.

Data collection and parameters estimated of many models of pedestrian movement represent challenges in their own right. *Hoogendoorn and Daamen* provide a valuable generic approach to the calibration of especially microscopic pedestrian models using pedestrian trajectory data as the prime data source. The method allows for statistical analysis of the parameter estimates, including their cross-correlations. Moreover, as a further extension of the method, the inclusion of prior information on the parameters of the model, their distribution, and their cross-relations is proposed.

The remaining chapters, although some are also interesting from a modeling or data collection perspective, offer a good overview of the kind of applications for these models. The chapter by *Klüpfel* offers examples of evacuation and emergencies studies that benefit from models of crowd dynamics. His chapter also discusses the BDI framework (Beliefs, Desires, Intentions) that is often used in multi-agent modeling and discusses various issues including panic that should be incorporated into models of crowd dynamics for application to evacuation and emergency.

The next chapter, written by *Lämmel, Klüpfel, and Nagel* is also about emergency. In this case however, the MATSim multi-agent simulation system is applied to simulate the possible effects of a tsunami wave for the city of Padang, with approximately 1,000,000 inhabitants. The MATSim framework was originally developed for large-scale transport simulations, but this chapter shows the rich potential of this system. The paper also shows that large-scale applications of multi-agent models are now within reach.

The relevance of these approaches to shopping behavior is also illustrated in the next chapters. *Kurose, Deguchi, and Zhao* examines several temporal and spatial heuristics to simulate pedestrian shopping behavior. They compare pedestrian behavior in the central shopping areas of Fukuoka (Japan), Busan (Korea), and Tianjin (China). Findings indicate that pedestrian behavior dependsnot only on pedestrian characteristics such as age and occupation, but also on street characteristics. Pedestrians in the central shopping areas of Busan and Fukuoka, where many shops are distributed in a rectangular shape make more trips than those in Tianjin, where shops are concentrated along a line. Compared with Fukuoka, pedestrians in the central shopping area of Busan, which has shorter links and a more densely distributed pattern of shops and vendors, make more return trips.

The influence of the environment at different environmental scales on pedestrian itineraries is nicely articulated in the next chapter by *Zacharias*, based on both theoretical considerations and empirical results from various studies. He assumes that decision points are decided *a priori* or are inserted into the itinerary as new information or events modify the set of opportunities available. The transport and land use structure of the larger environment plays a role at the urban scale. At the finer scale of blocks and streets, different physicalist descriptions of the walking network layout relate significantly to local choices, as do sensory inputs and the social meanings.

The application of models of pedestrian movement to support design (layout and capacity) decision is nicely illustrated by *Wang, Ma, and Zhu*, who applied a multinomial logit model to simulate pedestrian behavior of visitors in the Expo 2010, Shanghai. Influential factors, such as the distance and neighborhood between the visitor and the exhibition hall, features and the size of the hall, whether it is along the river and at the same bank as the visitor, and the number of visits the visitor accumulated, are used to explain the visitor choice behavior. The potential problem of an unbalanced distribution of visits and pedestrian flows is identified.

The final chapter by *Bauer* et al. is not only of interest for the case studies but also especially because they discuss the latest technology in collecting data on pedestrians' spatial movement at the very local level as an alternative to survey methods. The chapter reviews existing technologies for collecting such disaggregated information of pedestrian movement, with examples of infrared laser scanners and image analyses.

Together these chapters convincingly report the rapid recent progress in the analysis and modeling of pedestrian behavior and the wide range of problems to which these models can be applied. Hopefully, this book will stimulate innovative future work in this field.

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Chapter 1

Pedestrians Choices

Michel Bierlaire and Thomas Robin

Abstract

We approach pedestrian modeling from a choice perspective. We first identify the list of choices that pedestrians are facing, and identify how each of them has been addressed in the literature. Then, we consider how the framework of discrete choice models may be considered in each case. Our objective is to trigger new ideas and new tracks of research in this particularly challenging field.

1.1. Introduction

Among the various modes of transportation, walking is probably the most natural but also the most complicated to apprehend from an analyst viewpoint. Contrary to most other travel modes, it is not associated with a vehicle and the underlying infrastructure is highly heterogeneous (sidewalks, crossings, buildings, shopping malls, squares, etc.). Understanding and predicting the evolution of pedestrians in these various environments is important in many aspects. The first application that comes to mind is the planning of building evacuation in case of emergency, or city evacuation in case of a disaster. Another important application is the description of congestion caused by heavy flows of pedestrians and their conflicting movements. Indeed, it must be accounted for the efficient design of new facilities (such as public buildings, train stations, airports, or intersections of urban streets) and the daily operations of these facilities. Focusing on individual behavior in sparse conditions is also important. Among others, travel guidance and information systems aim at helping the pedestrian in implementing her journey, surveillance systems are interested in detecting abnormal behavior, advertisers are interested in evaluating

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the global exposure of their announcements, movie and video games makers are interested in generating realistic synthetic behavior.

The flourishing scientific literature, as well as the increasing availability of commercial tools, are evidences of the growing importance of this field, but also of its multidisciplinary nature. Indeed, models inspired by physics, artificial intelligence, computer vision, econometrics, biology, and traffic flow theory have been proposed.

In this chapter, we consider the models capturing the behavior of individual pedestrians, described in terms of choices. Choice models have been successfully applied to forecast behavior in many instances of travel demand analysis for the past 40 years. Therefore, they immediately come to mind for pedestrian behavior. In Section 1.2, we identify the types of choices that a pedestrian is confronted to, and describe how each of them has been addressed in the literature. Section 1.3 summarizes the discrete choice framework and its underlying assumptions, and emphasizes how discrete choice models could be or have been used in this context.

1.2. Choices of Pedestrians

The concept of choice is present in many dimensions of the pedestrian behavior. Although most of these choice dimensions are highly interrelated in reality, and usually considered jointly in the literature, it is more convenient to analyze each of them separately. Let us consider a single individual at a given location at a given point in time.

1.2.1. Activity Choice

The first decision to be made is about what to do next. The choice of the next activity will indeed trigger the travel. This type of choice is not necessarily related to pedestrians, as it is relevant to any travel mode. Among the vast literature, we refer the reader to Jones, Koppelman, and Orfueil (1990), Morey, Shaw, and Rowe (1991), Axhausen and Gärling (1992), Ettema and Timmermans (1997), Kitamura and Fujii (1998), Bhat and Singh (2000), Bowman and Ben-Akiva (2001), Bhat and Koppelman (2004) and Abdelghany, Mahmassani, and Chiu (2001).

Few authors analyze the activity choice in the specific case of pedestrians. Hoogendoorn and Bovy (2004) distinguish between the choice of an *activity pattern*, performed at a so-called "strategic" level, from *activity scheduling*, performed at a "tactical" level, and assume that pedestrians make a simultaneous path-choice and activity area choice decision. Handy (1996) analyzes the impact of the urban form on the choices of the pedestrians in Austin to test if appropriate urban design can discourage automobile dependence. Borgers and Timmermans (1986) consider impulse stops, where the choice of the activity is not planned, but triggered by stimuli in the pedestrian's environment.

1.2.2. Destination Choice

The choice of the destination is related to the choice of the location of the chosen activity. Again, such a choice is not specific to pedestrians, and has been widely analyzed in the literature (Fotheringham, 1986; Fesenmaier, 1988; Woodside & Lysonki, 1989; Furuichi & Koppelman, 1994; Timmermans, 1996; Dellaert, Arentze, Bierlaire, Borgers, & Timmermans, 1998; Oppermann, 1999; Scarpa & Thiene, 2005; Bigano, Hamilton, & Tol, 2006 and many others).

With respect to pedestrians, Borgers and Timmermans (1986) develop a destination choice model as part of a system of models to predict the total demand for retail facilities within inner-city shopping areas. Timmermans, der Hagen, and Borgers (1992) provide a review of models existing in 1992 and of a few applications to urban and transportation planning in The Netherlands. Zhu and Timmermans (2005) focus on shopping decision processes, using bio-inspired heuristics to mimic the decision process. Eash (1999) has developed models for nonmotorized destination choice and vehicle versus nonmotorized mode choice, with application to the Chicago Area.

1.2.3. Mode Choice

Two types of mode choice are considered in the literature on pedestrian travel. First, the usual transportation mode choice analysis, where walking is one of the alternatives. For instance, Bhat (2000) presents a mode choice model in the Bay Area for work travel. Ewing, Schroeer, and Greene (2007) analyze travel decision of students going to school. Cervero and Radisch (1996) investigate the effects of New Urbanism design principles on both nonwork and commuting travel by comparing modal splits between two distinctly different neighborhoods in the San Francisco Bay Area. Rodriguez and Joo (2004) illustrate the link between mode choice and environmental attributes for commuters to the University of North Carolina in Chapel Hill.

The second type of mode choice focuses on the choice among stairways, escalators, or elevators while walking. Several models have been proposed in order to quantify the impact of such elements on the pedestrian behavior. Hamada et al. (2008) are interested in the configuration of a high building, in terms of optimization of floor plan, and elevator configuration. Cheung and Lam (1998) report on the behavior of pedestrians in choosing between escalators and stairways in Hong Kong Mass Transit Railway (MTR) stations during peak hours. Kinsey et al. (2008) propose an escalator model designed for circulation and evacuation analysis, involving microscopic person–person interactions. Toshiaki, Naoki, Masaru, and Minoru (2000) compare the choice between the stairs and the escalator for healthy and disabled people. Note that the analysis of this type of choice is of increasing interest for health applications in general, and overweight and obesity issues in particular (Eves, Webb, & Mutrie, 2006).