Transportation Research Part C 59 (2015) 183–197

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

21st International Symposium on Transportation and Traffic Theory

Continuum theory for pedestrian traffic flow: Local route choice modelling and its implications

Serge P. Hoogendoorn [a,*], Femke van Wageningen-Kessels [a], Winnie Daamen [a], Dorine C. Duives [a], Majid Sarvi [b]

[a] Transport & Planning, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands
[b] Institute of Transport Studies, Department of Civil Engineering, Monash University, Australia

ARTICLE INFO

Article history:
Received 29 April 2015
Accepted 1 May 2015
Available online 2 June 2015

Keywords:
Continuum flow modelling
Local route choice
Hybrid modelling

ABSTRACT

This contribution puts forward a novel multi-class continuum model that captures some of the key dynamic features of pedestrian flows. It considers route choice behaviour on both the strategic (pre-trip) and tactical (en-route) level. To achieve this, we put forward a class-specific equilibrium direction relation of the pedestrians, which is governed by two parts: one part describing the global route choice, which is pre-determined based on the expectations of the pedestrians, and one part describing the local route choice, which is a density-gradient dependent term that reflects local adaptations based on prevailing flow conditions.

Including the local route choice term in the multi-class model causes first of all dispersion of the flow: pedestrians will move away from high density areas in order to reduce their overall walking costs. Second of all, for the crossing flow and bi-directional flow cases, local route choice causes well known self-organised patterns to emerge (i.e. diagonal stripes and bi-directional lanes). We study under which demand conditions self-organisation occurs and fails, as well as what the impact is of the choices of the different model parameters. In particular, the differences in the weights reflecting the impact of the own and the other classes appear to have a very strong impact on the self-organisation process.

1. Introduction

Although microscopic pedestrian flow modelling has received quite some attention in the past decade, a comprehensive macroscopic theory for pedestrian traffic operations has not been put forward. Amongst the limited contributions are the papers of Hughes (2002) and Hoogendoorn and Bovy (2004a), both using a combination of a conservation of pedestrians equation and a global route choice model. Both papers propose iterative frameworks to achieve consistency between assigning pedestrians to the available space and the delays caused by overcrowding of some of the routes. However, for simulation purposes, these frameworks are impractical due to the lengthy computation times, the poor convergence behaviour, and the unrealistic behavioural assumptions. Furthermore, to the best of our knowledge, none of the macroscopic models presented

* Corresponding author. Tel.: +31 15 2785475.
E-mail address: s.p.hoogendoorn@tudelft.nl (S.P. Hoogendoorn).

http://dx.doi.org/10.1016/j.trc.2015.05.003

in literature captures the key features of pedestrian flows, such as the different types of self-organisation (e.g. dynamic lane formation); see Helbing et al. (2005).

This paper presents a new continuum pedestrian flow model that remedies some of the key issues observed in previous macroscopic flow models. This is achieved by including a local route choice next to global route choice. In the proposed model, local route choice in achieved by including a *local value or potential function*. This term causes an increase in flux into areas with a relatively low density, yielding a natural spatial distribution of the density. The local route choice model also provides a unique mechanism that enables reproduction of dynamic lane formation and other types flow separation (e.g. formation of diagonal stripes; see Helbing et al. (2005)).

The main contribution of the presented work is the new mathematical modelling framework for two-dimensional continuum pedestrian flow, which reproduces realistic (self-organised) pedestrian traffic operation features. Using efficient solves, the macroscopic model can be used to simulate large-scale areas, which is more difficult using microscopic models. Furthermore, macroscopic models such as the model presented here, can be used in optimisation frameworks, such as described in Hoogendoorn et al. (2013).

After the introduction and literature review in Section 2, we present a generic first order pedestrian flow model in Section 3. In Section 4 we introduce the local route choice model and show how it generalises the model presented in Hoogendoorn et al. (2014). In Section 5 we apply simulations to show that the model reproduces some important phenomena, such as lane and stripe formation, and we illustrate the influence of the model parameters on the simulation results. We conclude this contribution with conclusions in Section 6.

2. State-of-the-art

In this section, we review some of the key studies that form the foundation of the model presented in this manuscript. While not trying to be complete, we briefly present relevant empirical studies, as well as the main modelling approaches that have been put forward, with an emphasis on continuum models. In particular the latter type of models will be discussed in more detail, focussing on their ability to reproduce the aforementioned pedestrian flow phenomena.

2.1. Empirical features

Previous empirical and experimental studies of pedestrian flow characteristics showed many interesting features, including the existence of a fundamental relation between density and flow and self-organised structures (Schadschneider et al., 2009). As the combination of the fundamental diagram and different phenomena of self-organisation characterise pedestrian dynamics, begin fundamental for a macroscopic model, these are briefly discussed in this section.

The fundamental relation reflects the statistical relation between density ρ and (absolute) flow Q or speed V, i.e. $V = V(\rho)$ or $Q = \rho \cdot V = Q(\rho)$; see Weidmann (1993). Many factors influence the shape of this fundamental relation. Chattaraj et al. (2009) show the effect of cultural differences on the shape of the fundamental relation. The characteristic values of the fundamental diagram, such as the capacity and the jam density, are also influenced by factors such as trip purpose (Oeding, 1963) and the heterogeneity of the pedestrians (Helbing et al., 2007). Its shape also varies for various types of facilities (such as stairs, ramps and bottlenecks) and the direction of the pedestrian flows (unidirectional or bi-directional) (Weidmann, 1993; Navin and Wheeler, 1969).

Self-organisation is defined as the spontaneous occurrence of qualitatively new behaviour through the non-linear interaction of many objects or subjects (Helbing and Johansson, 2010) without the intervention of external influences (Camazine et al., 2010).

The most common self-organisation phenomenon is lane formation (Hoogendoorn and Daamen, 2004). During this process a number of lanes of varying width form dynamically in a corridor. Next to lane formation in bi-directional flows, diagonal stripe formation in crossing flows has been observed; e.g. see Hoogendoorn and Daamen (2004).

During their research at the Jamarat bridge, Helbing et al. (2007) found stop and go waves. These are temporarily interrupted longitudinal flows that appear at higher densities in uni-directional crowds. In an even denser flow regime, turbulent flows were found. In this regime a pedestrian has no control over its own movements anymore. Local force based interactions between pedestrian bodies are seen.

Three other effects have been described at an operational level, namely herding, the zipper effect and the faster-is-slower effect. Herding occurs when unclarity of the situation causes individuals to follow each other instead of taking the optimal route (Helbing et al., 2005). This behaviour is predominantly seen during stressful evacuation situations. The zipper effect describes the situation in which individuals allow others within the territorial space diagonally in front of them, as long as the direct space in front of their feet is still empty (Hoogendoorn and Daamen, 2005). It allows for narrower lanes in a bottleneck than expected based on the width of a pedestrians territorial zone. The faster-is-slower effect describes a situation where the density in a queue upstream of a bottleneck is increasing, due to the fact that people keep heading forward while the bottleneck is clogged (Helbing and Johansson, 2010). The higher densities cause coordination problems since a large number of individuals is competing for a few small gaps. Bodily interaction and friction slow down the total crowd motion.