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Pedestrian-oriented flow characterization

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Abstract

Definitions of flow indicators are derived by adapting Edie's definitions through a stream-based approach and a data-driven spatio-temporal discretization framework. The stream-based approach accounts for the multidirectional nature of pedestrian flows. The data-driven discretization framework, based on three-dimensional Voronoi tessellations, accounts for the pedestrian heterogeneity in the case when only samples of points are available, instead of the analytical description of trajectories. The proposed approach enables the pedestrian flow characterization to be applicable to any space-time domain of interest.

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Keywords: pedestrian flow indicators; multidirectinal flow; heterogeneity; discretization framework; Voronoi diagram

1. Introduction

Pedestrian flow characterization which is in accordance with reality is essential so as to provide a better understanding of pedestrian flow. This is important to many areas, ranging from urban planning, traffic forecasting, designing public spaces (airports, stadiums, train stations, etc.), the optimization of the processes within public facilities to the evacuation studies. The outcomes of the empirical studies reported in the literature however reveal large differences with respect to pedestrian flow characterization. In particular, the reported maximal value of flow goes from 1.2 ped/ms to 1.8 ped/ms, jam-density goes from 3.8 ped/m^2 to 10 ped/m^2 and the reported maximum flow density range is from 1.7ped/m^2 to 7 ped/m^2 (Seyfried et al., 2010). The researchers have suggested several explanations for these deviations some of which can be attributed to the complex nature of pedestrian interactions (Helbing et al., 2007a), the differences between pedestrian facilities and the effects of the environment (Rastogi et al., 2013), the cultural differences and personal characteristics (Schadschneider et al., 2009). Additionally, the differences in terms of the specification and measurement of the indicators play a cructial role as well (Seyfried et al., 2010). In this respect the methods used for pedestrian flow characterization are usually developed on the grounds of drawing parallels between pedestrian and vehicular flow. Although the field of vehicular flow modeling is quite well-established (Hoogendoorn

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and Bovy, 2001) this comparison is considered useful to some extent given the large differences that exist between the two types of traffic flow. In comparison to roadways where vehicular flow is separated by directions, pedestrian flow is such that pedestrian facilities permit them to move in a multidirectional fashion. Therefore the measurement methods developed in the field of vehicular traffic can be employed only in the case of unidirectional pedestrian flow (e.g. flow through doors, gates).

Zhang (2012) has provided a comprehensive analysis of several measurement methods and their influence on the fundamental relationships. In the first analyzed method (denoted by method A in Zhang (2012)) a reference location in space is considered and the mean values of flow and speed are calculated over time. This set of definitions is therefore not useful for the analysis of the flow behavior over longer sections. Furthermore, given that the fundamental relationship holds only in the case where speed refers to the space-mean speed, this method cannot be employed to calculate density. The second method (denoted by method C in Zhang (2012)) refers to the classical one where the speed and density are specified per areal unit which makes it impossible to employ this method in order to analyze the flow behavior over longer time intervals. There is a need for a different way of looking at flow indicators that would provide definitions that are applicable to pedestrian trajectories given a space-time domain of interest (Edie, 1963). This is provided by the third set of definitions (denoted by method B in Zhang (2012)), in which the measures of speed and density are averaged over time and space. The drawback of this method is however the assumption that pedestrians perform their movement in the form of a straight line, which is empirically shown to be not correct (Saberi and Mahmassani, 2014). This assumption becomes especially critical when the considered time and space intervals are arbitrary selected, given that it may lead to the loss of heterogeneity. The last method evaluated in the study of Zhang (2012) (denoted by method D) specifies the indicators via Voronoi diagrams providing the minimal scatter in the corresponding results. In addition to the described methods Helbing et al. (2007b) proposed the specification of local density and speed using Gaussian, distance-dependent function. Fruin (1971) specified a "pedestrian area module", the reciprocal of the density, in order to quantify the level of service of pedestrian facilities. Common to all described specifications of flow indicators is the neglecting of the multidirectional nature of pedestrian flows. In the case of an open space where multidirectional flow is present the existing approaches would constrain the pedestrian flow pattern to the unidirectional case, thus leading to unrealistic characterization. Saberi and Mahmassani (2014), on the other hand, have proposed a three-dimensional approach to pedestrian flow characterization thereby extending Edie′s definitions, similar to Hoogendoorn et al. (2011). Density and flow are defined as the flux of pedestrian trajectories through a plane specified for the considered volume in the three-dimensional space-time diagram. The distinction is made between the backward and forward flow, thus accounting to some extent for the directional composition of pedestrian flow. However, the improved methods that would provide generalized flow characterization in the case of pedestrians need to be developed.

Providing a comprehensive and realistic characterization of pedestrian flow is also important for the specification and estimation of fundamental relationships between the characteristics. These relationships are used for evaluating the performance of pedestrian facilities, but they can also act as an input or a calibration criterion for the mathematical models of pedestrian dynamics. Given that it has been empirically shown that speed of pedestrians is not only affected by density but also by the multidirectional flow composition, it is important that the interaction between the flow indicators from different directions is captured and explained by these relationships. For instance, in a bidirectional flow case Lam et al. (2003) reported the reduction in the walkway capacity and speed of minor streams observed based on empirical studies. Wong et al. (2010) have analyzed the effect of the intersecting angle between two pedestrian streams on the indicators and reported that the speed of a stream is more negatively affected by the intersection angle under greater total densities with the head-on conflict being the worst case. The presented studies have provided a better understanding of the effect of these different types of pedestrian flows on the fundamental relationship. However, the general formulation of the fundamental diagram which would model the interaction between streams in multidirectional flows and that would take into account the heterogeneity of the population of pedestrians is still missing. This may question the use of the existing approaches in practice.

The methodologies for the pedestrian flow characterization that would account for specificities related to this transportation mode still have not been defined. The existing approaches do not provide support for generalized multidirectional specifications of the flow indicators applicable to any space-time domain of interest. Accordingly, we propose a mathematical framework by adapting Edie′s definitions (Edie, 1963) through: (i) a stream-based approach and (ii) data-driven spatio-temporal discretization framework. The stream-based approach is proposed so as to account