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Comparison of intersecting pedestrian flows based on experiments

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HIGHLIGHTS

- Results from intersecting pedestrian flow experiments are analyzed.
- The fundamental diagrams show no difference regarding to intersecting angle.
- Head-on conflicts have the same effect on transport properties of various systems.

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ABSTRACT

Intersections of pedestrian flows feature multiple types, varying in the numbers of flow directions as well as intersecting angles. In this article results from intersecting flow experiments with two different intersecting angles are compared. To analyze the transport capabilities the Voronoi method is used to resolve the fine structure of the resulting velocity–density relations and spatial dependence of the measurements. The fundamental diagrams of various flow types are compared and show no apparent difference with respect to the intersecting angle 90° and 180°. This result indicates that head-on conflicts of different types of flow have the same influence on the transport properties of the system, which demonstrates the high self-organization capabilities of pedestrians.

1. Introduction

Diverse intersecting pedestrian flows can be observed in places like crosswalks, sidewalks as well as stairways etc. In contrary to vehicular traffic, these streams are usually not regulated by traffic lanes, rules or lights. Thus conflicts among pedestrians in intersecting flow can be more intense. In certain circumstance it could lead to serious consequences like Love Parade disaster in Duisburg 2010 [1], where multidirectional pedestrian streams led to a congestion at the entrance to a music event.

Intersecting flows could be influenced by series of factors including the intersecting angles (φ), the directional flow ratio (r), the boundary conditions, the width of the stream or the facility (b) as well as human factors amongst others. In this paper we define the intersecting angle $\varphi = 0°$ if both streams flow in the same direction and $\varphi = 180°$ if the stream directions are exactly opposite. In Ref. [2] we collect fundamental diagrams of bidirectional flow from different empirical studies. Most of the data were measured at low density situation for $\rho < 2.0$ m^{-2} and show large discrepancies. Since these data are obtained under different experimental situations and different measurement methods, it is difficult to identify the origin of these differences. In the following we discuss this in more detail.

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Firstly we focus on the question whether the directional flow ratio has influence on the capacity. In Highway Capacity Manual [3] it is mentioned that for bi-directional pedestrian streams of roughly equal flow in each direction, only a slight reduction of the capacity occurs. The manual suggests that the maximal reduction in the capacity sets in at a directional split ratio of 0.9 versus 0.1 [3]. Lam et al. also found that the maximum reduction in capacity is around 19% and it happens when directional split ratio is 0.9 versus 0.1 [4,5]. On the contrary, Wael et al. found that maximal reduction in the capacity occurs when the directional split ratio is 0.5 at signalized crosswalks [6]. They assume that this variation could be traced back to different behavior at long walkways and short signalized crosswalks. However, different definitions and measurements of the flow ratio are used in these studies and make a comparison impossible. In contrary to these studies, we do not find a reduction of the flow for different ratios when the density is smaller than 2 m^{-2} [2].

Secondly we discuss the influence of the intersecting angle. Existing empirical studies mainly focus on bidirectional pedestrian flow at crosswalks [4,7–11] and shopping streets [12] where the opposing flows have an intersecting angle close to 180°. In Refs. [13–15] crossing pedestrian flows are studied numerically and formation of pattern are discussed only qualitatively without considering the influence of intersection angle. Wong et al. conducted controlled experiments in which two groups of students were asked to walk on designated walkways with different levels of pedestrian flow and different intersecting angles [16,17]. The experiment was mainly used to obtain data for the development of bidirectional pedestrian stream model but was unfortunately not analyzed in detail due to technical restriction on the extraction of trajectories. In Ref. [2] we observed differences regarding stability of the lanes formed in bidirectional flows between different intersecting angles. For the former a clear separation of lanes occurs which is stable, while for the latter dynamical formation and extension of lanes are observable. However the fundamental diagrams show no difference in the observed density ranges.

Next, we discuss the impact of conflicts in intersecting streams. The fundamental diagrams of uni- and bi-directional flow [2] show obvious differences. We identified that conflicts of persons moving in the opposite direction reduce the speed of pedestrians leading the lane and reducing the speed of persons following in this lane. In intersecting flow with nonzero intersecting angle, the area where the streams meet and conflicts occur is minimal when the intersecting angle is 90°. If the intersection angle rises from 90° to 180°, the area where potential conflicts occur increases. This leads to the question whether reduction of flow in intersecting streams depend from the angle of intersection.

The above discussion shows that up to now there is no consensus about the origin of the discrepancies between different types of intersecting flow.

The influences of boundary conditions, intersecting angle as well as the influence of conflicts on the fundamental diagrams are still not analyzed in detail. The aim of our study is to compare the fundamental diagrams of different bidirectional flows and analyze the influence of head-on conflicts on the transport properties. We will also study the effects of boundary conditions and geometries on the fundamental diagrams of bidirectional streams.

The remainder of the paper is organized as follows. In Section 2 we describe the setup of the experiments. Section 3 describes the methods for data extraction and compares the fundamental diagrams for different types of streams. In the last part we reveal the main conclusions in Section 4.

2. Experiments

In this paper, four different scenarios are considered to investigate the transport properties of various intersecting flows. All of them were performed under laboratory conditions and realized different intersecting angles and boundary conditions. Scenario 1 was a part of the Hermes project and performed in the fairground Düsseldorf in 2009 [18,19]. While the Scenario 2 to 4 were conducted by Plaue et al. in the entrance area of the Department of Mathematics building of Technische Universität Berlin during the Long Night of the Science 2010 [20].

2.1. Scenario 1

Fig. 1 shows snapshots and pedestrian trajectories of bidirectional pedestrian flow with separated single lanes (SSL) and dynamical multi-lanes (DML). 22 runs were carried out in a 3.6 m wide corridor which was built on plane ground by boards. In each run, the inflow rate into the corridor was changed by varying the entrance widths to control the density in the corridor. The participants were given different instructions on exit selection to get different kinds of lanes. Without any instruction, pedestrians tried to move straight ahead and SSL flow was obtained. The intersecting angle of SSL flow here is about 180°. When the participants were asked to choose the exit at the end of the corridor according to their number (odd to the right, even to the left), DML flow were observed and the intersecting angle is correspondingly smaller than 180° due to the specific destination. The details of this experiment have been described in Ref. [2].

Intuitively, there should be more head-on conflicts in DML flow than in SSL flow, which maybe influence the fundamental diagram of them. However, no apparent difference is observed in our study at least for density $\rho < 2.5$ m^{-2}, which is the highest density obtained from our SSL flow experiment. Further, the so-called specific flow concept, which means that the flow depends linearly from the width of the facility (corridor here), is also applicable at the observed density ranges in our experiment [2]. Based on these considerations, we focus on the DML flow experiments in 3.6 m wide corridor for a wider range of density. It is worth noticing that the higher densities in DML flow here mainly thank to more runs, which can be seen in Fig. 2.