Steps Toward the Fundamental Diagram – Empirical Results and Modelling

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The empirical relation between density and velocity (fundamental diagram) of pedestrian movement is not completely analyzed, particularly with regard to the ‘microscopic’ causes which determine the relation at medium and high densities. The simplest system for the investigation of this dependency is the single-file movement. We present experimental results for this system and discuss the following observations. The data show a linear relation between the velocity and the inverse of the density, which can be regarded as the required length of one pedestrian to move. Furthermore we compare the results for the single-lane movement with literature data for the movement in a plane. This comparison shows an unexpected conformance between the fundamental diagrams, indicating that lateral interference has negligible influence on the velocity-density relation.

For the modelling we treat pedestrians as self-driven objects moving in a continuous space. On the basis of a modified social force model we analyze qualitatively the influence of various approaches for the interactions of pedestrians on the resulting velocity-density relation. The one-dimensional system allows focusing on the role of the required length and remote force. We found that the reproduction of the typical form of the fundamental diagram is possible if the model increases the required length of a person with increasing current velocity. Furthermore we demonstrate the influence of a remote force on the velocity-density relation.

1. Introduction

Pedestrian dynamics has a multitude of practical applications, like the evaluation of escape routes or the design of pedestrian facilities, along with some more theoretical questions [1, 2, 3, 4, 5]. Empirical studies of pedestrian streams can be traced back to the year 1937 [5]. To this day a central problem is the relation between density and flow or velocity. This dependency is termed the fundamental diagram and has been the subject of many investigations from the very beginning, see references in [6, 7]. It quantifies the capacity of pedestrian facilities and thus allows e.g. the rating of escape routes. One simple system is the uni-directional movement of pedestrians in a plane without bottlenecks. In this context the fundamental diagram of Weidmann [6] is frequently cited. It is a part of a review work and the author summarized 25 different investigations for the determination of the fundamental diagram. Apart from the fact, that with growing density the velocity decreases, the relation shows a non-trivial form. Weidmann notes that different authors choose different approaches to fit their data, indicating that the dependency is not completely analyzed. A multitude of possible effects can be considered which may influence the dependency. For instance we refer to passing maneuvers, internal friction, self-organization phenomena like marching in steps [8] or ordering phenomena like the ‘zipper’ effect [9]. A reduction of the degrees of freedom helps to

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restrict possible effects and allows an improved insight to the problem. Thus we choose a one-dimensional system for this investigation. Furthermore, the fundamental diagram is used for the evaluation of microscopic models for pedestrian movement [10, 11, 12, 13]. The models can be classified in two categories: the cellular automata models [14, 15, 16, 17, 18] and models in a continuous space [19, 20, 21, 22]. We focus on models continuous in space, which differ substantially with respect to the ‘interaction’ between the pedestrians and thus to the update algorithms as well. The social force model for example assumes, among other things, a repulsive force with remote action between the pedestrians [19, 23, 24, 25, 26]. Other models treat pedestrians by implementing a minimum inter-person distance, which can be interpreted as the radius of a hard body [21, 22]. For a one-dimensional system we introduce different approaches for the interaction between the pedestrians to investigate the influence of the required space and the remote action on the velocity-density relation. This contribution summarizes parts of two articles. The reader may consult [7, 27] for more detailed discussions and additional results.

2. Experiment

2.1. Description

Our target is the measurement of the relation between density and velocity for the single-file movement of pedestrians. To facilitate this with a limited amount of test persons also for high densities and without boundary effects, we choose an experimental set-up similar to the set-up in [28]. The corridor, see Figure 1, is build up with chairs and ropes. The width of the passageway in the measurement section is 0.8 m. Thus passing is prevented and the single-file movement is ensured.

![Figure 1](image.png)

Figure 1: Left: Experimental set-up for the measurement of the velocity-density relation for the single-file movement. Right: One frame of the cycle with $N = 30$. The two vertical lines mark the measured section.