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Why Pedestrians Deviate from the Shortest Route: A Deadline Effect in Navigation and Behaviors

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Abstract The shortest-route rule, explicitly or implicitly, is widely used in pedestrian modeling, yet the outcomes often show discrepancies with empirical evidence. In this work, the pedestrian behavioral law in route choice and navigation are explored based on optimal control modeling, to explain pedestrian deviation from the shortest-route. It is found that there is an increasing urgency imposed by proximity to the goal in pedestrian behavioral pattern and decisions, which is termed the deadline effect. An eye-tracking experiment is conducted to provide and validate this pattern. These findings could provide insights and theoretical basis for pedestrian behavior and crowd dynamics.

Keywords behavioral rule, route choice, pedestrian navigation, goal deviation

Introduction

Understanding and modeling pedestrian route choice and navigation are fundamental to the study of collective motion and human mobility. Accordingly, numerous behavioral rules have been developed to describe and model such behaviors, among which the shortest-route rule and its variants are the most widely adopted. But empirical evidence shows that pedestrians often deviate from the shortest-route. To this end, researchers have shifted the focus to factors such as vision, congestion and personal space, but fail to explain why such deviations still persist even in the absence of these factors.

Prevailing views, such as the shortest-route rule, typically assume that the guidance and constraint of goal on navigation and route choice remain constant as pedestrian moves. We suggest that, however, such constraint is dynamic and have a regular pattern. Therefore, it is necessary to develop a quantitative and behaviorally grounded framework to capture the behavioral pattern and explain the pedestrian deviation phenomenon.

Methods

Pedestrian route choice and decision-making process in navigation are modeled based on the optimal control equation. The behavioral assumption is that all actions of the pedestrian will provide utility (or cost). The pedestrian will predict and optimize this utility to choose the optimal route from an open area. The process can be described by Eq. (1). Applying the dynamic programming principle to Eq. (1) yields the HJB (Hamilton–Jacobi–Bellman) equation, shown as Eq. (2). It reveals the pedestrian decision-making process, where pedestrian considers the goal (proximity) and running cost. In this work, cost includes the length of route, and the variation of velocity.

$$J\big(v(\cdot)\big) = \int_{t_0}^{t_T} l\big(t, x(t), v(t)\big)\,\mathrm{d}t + \phi\big(t_T, x(t_T)\big) \tag{1}$$

$$-\frac{\partial V(t,x)}{\partial t} = \min_{v \in V_a} \left\{ \nabla V(t,x) \cdot f(x,v) + l(t,x,v) \right\} \tag{2}$$

where J denotes total utility, l utility of a decision (running cost), x and v the coordinates and decision (velocity), t the time, t_T the end of planning period, Φ the constraint of goal, $V(t,x)$ the value function, and $\nabla V(t,x) \cdot f(x,v)$ characterizes the proximity between pedestrian and the goal under decision v.

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The quantitative description of deviation, defined as goal deviation γ, is derived from the decision-making process, which is calculated as the opportunity cost in proximity to the goal by a decision deviating from the goal.

Further, experiments on pedestrian route choice and crossing flows are conducted to provide empirical evidence, support model calibration, and validate the behavioral rule. Tobii Pro 2 glasses are used to collect eye-tracking data in the crossing flow experiments for analyzing pedestrians' attention and eye-movement characteristics when making decisions. Experimental snapshots are shown in figure 1.

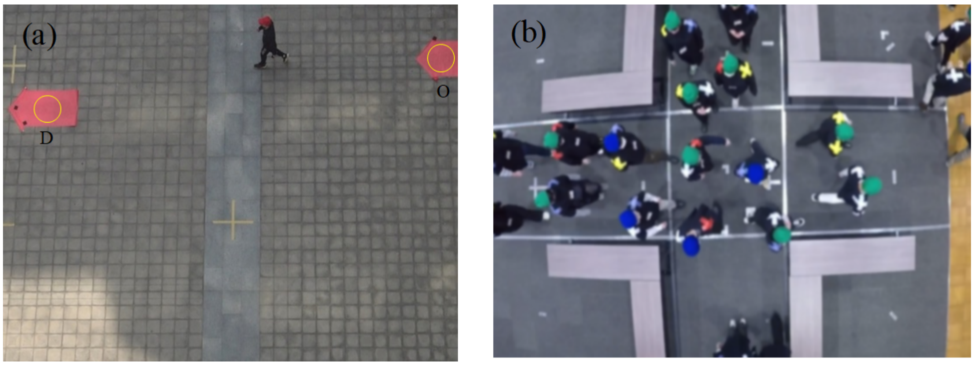

Figure 1: Experimental snapshots. (a) Route choice (b) Crossing flow. In the route choice experiment, pedestrians were required to start with a given initial velocity at point O and freely chose their route to reach goal D.

Results

The optimal routes predicted by the model exhibit the deviation phenomenon, consistent with experimental results, which is shown in Figure 2. It can be seen that pedestrians tend to maintain their initial velocity instead of following the shortest-route immediately, and gradually correct the deviation as they approach the goal. Besides, the magnitude of deviation (goal deviation γ) is also reported. It suggests that deviation increases significantly (which indicates higher cost in decision-making) with proximity to the goal when pedestrians do not follow the shortest-route. On the other hand, adjusting the deviating velocity incurs a velocity variation cost, which is constant (see Eq. (1)).

From the principles of utility and optimization, pedestrians will adopt corresponding strategies, so the behavioral pattern of route choice and navigation is shaped accordingly. Specifically, when pedestrians are far from the goal, the deviation cost is low, so they will tolerate the deviation to avoid higher velocity adjustment cost. As they approach the goal, the deviation cost increases sharply; in the trade-off, they will overcome the velocity adjustment cost and move toward the goal. This can be derived as an increasing urgency imposed by proximity to the goal, under which deviation from the shortest-route evolves from acceptable to binding. We term this pattern the deadline effect, which explains why and how pedestrians deviate.

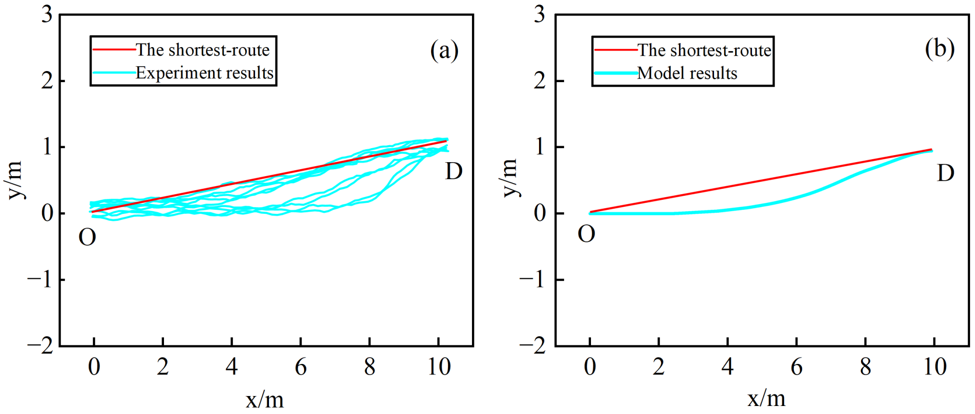

Figure 2: Comparison of experiment and model results. (a) Experiment trajectories. (b) Model trajectory.