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Modeling pedestrian switching behavior for attractions

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Abstract

While walking on the streets, pedestrians can aware attractions like shopping windows. Some of them might shift their attention towards the attractions, namely switching behavior. As a first step, this study investigates collective effects of the switching behavior for an attraction by means of numerical simulations. Such switching behavior leads some pedestrians head for the attraction, or even all the pedestrians have visited the attraction if the social influence is getting stronger. These collective patterns of pedestrian behavior are summarized in a phase diagram. The findings from this study can be interpreted into pedestrian facility management particularly for retail stores.

Keywords: attraction; switching behavior; social influence; average length of stay; saturated phase; unsaturated phase

1. Introduction

For the viability of pedestrian facilities including shopping centers and museums, it is important to understand the nature of pedestrians enticed by attractions such as window displays and street performances. When such attractions come into sight, individuals can make decisions between moving in their initially planned directions and stopping by the attractions. This behavior can be called switching behavior from the way that the individuals can shift their attention towards the attractions (Kwak et al. (2013)).

In reality, such switching behavior is likely to be influenced by what others select. In the marketing area, it is widely believed that others selection can affect one’s information processing by raising awareness of merchandise displays in stores, and consequently the individual is prone to make more purchases (Bearden et al. (1989); Childers and Rao (1992)). Therefore, marketing strategies have focused on identifying influential individuals and targeting at them (Aral (2011); Yim et al. (in press)).

In order to incorporate the switching behavior, this study develops a simple probability model assuming that the preference for the attraction depends on the number of people who have already joined. The proposed model predicts

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different pedestrian movement patterns with various values of the social influence and the average length of stay at the attraction. The predictions are illustrated with a phase diagram.

The remainder of this paper is organized as follows. The proposed switching behavior model is described in Section 2, and its numerical simulation results are presented with a phase diagram in Section 3. Finally, Section 4 discusses the findings of this study.

2. Model

2.1. Switching behavior

By the analogy with sigmoidal choice rule (Milgram et al. (1969); Gallup et al. (2012); Nicolis et al. (2013)), the probability of joining an attraction point $P_a$ is formulated with the number of pedestrians who have already joined $N_a$ and the number of pedestrians not stopping by the attraction $N_0$.

$$P_a = \frac{s(N_a + K_a)}{(N_0 + K_0) + s(N_a + K_a)}$$  \hspace{1cm} (1)

where $s > 0$ is the strength of the social influence reflecting the sensitivity to the number of attendees. When $s$ is small, individuals pay little attention to others choices. For large $s$, the joining probability is more likely to be influence by the number of people who have already joined to the attraction rather than the number of people not joining to the attraction. $K_a$ represents the intrinsic attractiveness of the attraction, and $K_0$ for not stopping by the attraction. After joining to the attraction, the individual will then stay near the attraction for an exponentially distributed time with an average of $\tau$, similar to previous studies (Helbing and Molnár (1995); Wu and Huberman (2007); Gallup et al. (2012)).

2.2. Pedestrian movement

According to the social force model (Helbing and Molnár (1995)), the velocity $\vec{v}_i(t)$ of pedestrian $i$ at time $t$ is given by the following equation:

$$\frac{d\vec{v}_i(t)}{dt} = \frac{v_d\vec{e}_i - \vec{v}_i(t)}{\tau} + \sum_{j\neq i} \vec{f}_{ij}^r + \sum_B \vec{f}_{iB}^r$$  \hspace{1cm} (2)

Here the first term on the right-hand side indicates the driving force describing the tendency of pedestrian $i$ moving toward his destination with the desired speed $v_d$ and an unit vector $\vec{e}_i$ pointing to the desired direction. The relaxation time $\tau$ controls how fast pedestrian $i$ adapts its velocity to the desired velocity. The repulsive force terms $\vec{f}_{ij}^r$ and $\vec{f}_{iB}^r$ reflect his tendency to keep certain distance from pedestrian $j$ and the boundary $B$ (e.g., wall and obstacles). A more detailed description of the pedestrian movement model can be found in previous studies (Helbing and Molnár (1995); Johansson et al. (2008); Kwak et al. (2013)).

2.3. Numerical simulation setup

Each pedestrian is modeled by a circle with radius $r_i = 0.25m$. $N = 100$ pedestrians move in a corridor of length 30 m and width 6 m with periodic boundary condition in the horizontal direction. They move with desired speed $v_d = 1.2m/s$ and with relaxation time $\tau = 0.5s$, and their speed cannot exceed $v_{max} = 2.0$ m/s. The desired direction points from the left to the right boundary of the corridor for one half of population and the opposite direction for the other half. The joining probability (Eq. 1) is updated with the social force model (Eq. 2) for each simulation step $\Delta t = 0.05s$ and the individual can decide whether he will join the attraction when the attraction come into his perception range $R_i = 10m$. Once the individual decided to join the attraction, then he shifts his desired direction vector $\vec{e}_i$ toward the attraction. The attraction is placed at the center of lower wall, i.e., at the distance of 15 m from the left boundary of the corridor.
3. Results and discussion

3.1. Phase diagram

The simulation results show different patterns of pedestrian movements depending on the social influence $s$ and the average length of stay $\bar{t}_d$. If the social influence is weak, one can define an unsaturated phase where some pedestrians move towards the attraction while others walk in their desired directions (see Fig. 1a). For large values of $s$, a saturated phase can be defined. Every pedestrian near the attraction heads for the attraction, thus no more pedestrians can be enticed anymore into the attraction (see Fig. 1b).

In order to quantitatively distinguish different collective patterns, this study evaluates the proportion of visitors, $n_v = N_v/N_p$, reflecting the attraction influence on pedestrians. Here $N_v$ indicates the number of pedestrians who have already visited the attraction and $N_p$ is the number of passersby within a range of $R_a = 10m$ from the center of the attraction. If all pedestrians have already visited the attraction, $n_v$ becomes 1. On the other hand, $n_v = 0$ is observed if no pedestrians have visited the attraction. Fig. 2 shows how $n_v$ depends on the social influence $s$ and the average length of stay $\bar{t}_d$. For a given $\bar{t}_d$, $n_v$ increases according to $s$, indicating that more pedestrians are distracted from their initial desired velocity due to others choice on the attraction. Furthermore, $n_v$ curves rapidly increases as $\bar{t}_d$ increases, meaning that the larger $\bar{t}_d$, the smaller $s$ is needed to attract the majority of pedestrians. According to the value of $n_v$, the parameter space of the social influence $s$ and the average length of stay $\bar{t}_d$ is divided into two regions. $n_v$ becomes 1 above a certain value of the social influence $s$, indicating the transition from the unsaturated phase to the saturated phase (see Fig. 3).

3.2. Marginal benefit

Although the proportion of visitors $n_v$ enables us to evaluate the attraction influence on pedestrians, quantifying marginal benefits of facility improvements can also provide useful information. Here the marginal benefit represents the increase in $n_v$ with respect to the change of $s$, $\partial n_v/\partial s$, which can be calculated as the first derivative of $n_v$ curves in Fig. 2. As indicated in Fig. 4a, each marginal benefit curve increases up to a certain level then decrease. For higher $\bar{t}_d$, the values of the marginal benefit are sensitive to a small increase of $s$ when the social influence $s$ is weak, meaning
Fig. 2. Numerical results of the proportion of visitors $n_v = N_v/N_p$. Different symbols represent the different values of $\overline{t}_d$. For each given $\overline{t}_d$, $n_v$ increases according to $s$. Different phenomena can be characterized in terms of the behaviors of $n_v$.

Fig. 3. A phase diagram summarize the numerical simulation results. The parameter space of the social influence $s$ and the average length of stay $\overline{t}_d$ is divided into two regions. The saturated phase indicates that all the pedestrians have visited the attraction, while the unsaturated phase represents that not all pedestrians are enticed by the attraction.

that a great improvement in $n_v$ can be observed. It is also apparent that the maximum values of marginal benefit increase as $\overline{t}_d$ grows, indicating that increasing $\overline{t}_d$ can amplify the impact of enhancing $s$ (see Fig. 4b).

4. Conclusion

In order to examine the collective effects of the switching behavior, this study has developed a simple behavioral model of joining an attraction. A phase diagram with different collective patterns of pedestrian behavior is presented. The phases are identified by means of the proportion of visitors $n_v$ as a function of the strength of the social influence $s$ and the average length of stay $\overline{t}_d$. For strong social influence, the saturated phase appears where all pedestrians were
enticed by the attraction, so all of them have visited the attraction. When the social influence is weak, the unsaturated phase is observed where the attraction is not captivating enough to entice all the pedestrians. The study results also indicate that the marginal benefit increases and then decreases as $\overline{t_d}$ increases.

The findings from this study might provide useful insight into pedestrian facility management. The proportion of the visitors $n_v$ can be interpreted as a store entry ratio which enables retailers to assess the attractiveness of the store and predict the number of buyers (Lam et al. (2001)). For pedestrian facilities such as stores and museums, there are likely to exist costs associated with increasing the strength of social influence $s$ and the average length of stay $\overline{t_d}$. Based on the marginal benefit and its maximum values, one can identify under what conditions facility improvements would be very effective.

A very simple scenario has been considered in order to study the collective effects of switching behavior. The presented model can be extended for more realistic considerations like a shopping street having several stores. In addition, one can take into account heterogeneous properties of attractions and pedestrians such as the strength of social influence and the average length of stay.

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