Understanding Social-Force Model in Psychological Principles of Collective Behaviors

Peng Wang

To well understand crowd behavior, microscopic models have been developed in recent decades, in which an individual's behavioral/psychological status can be modeled and simulated. A well-known model is the social-force model innovated by physical scientists. (Helbing and Molnar, 1995; Helbing, Farkas and Vicsek, 2000; Johansson and Helbing, 2014). A problem, however, is that the testing results of the model were not explained in consistency with the social-psychological findings, resulting in misunderstanding of the model by most social-psychologists. This paper will bridge the gap between psychological studies and physical explanation about this model. We interpret this physics-based model from a psychological perspective, clarifying that the model is consistent with psychological studies on stress and time-pressure. The simulation result of this model actually explicates how stress could improve or impair collective performance of crowd behaviors.

I. About the Social-Force Model

First, let us briefly review the mathematical description of the social force model. In this model an individual's motion is motivated by a self-driven force $\boldsymbol{f}_i^{self}$ and the resistances may come from surrounding individuals and facilities. Especially, the model characterizes the social-psychological tendency of two pedestrians to keep proper interpersonal distance (as called the social-force) in collective motion and if people have physical contact with others or facilitates, the physical forces are also taken into account. Let $\boldsymbol{f}_{ij}$ denote the interaction from individual *j* to individual *i*, and $\boldsymbol{f}_{iw}$ denote the force from walls or other facilities to individual *i*. Given the instantaneous velocity $\boldsymbol{v}_i(t)$ of individual *i*, the moving dynamics is given by the Newton Second Law:

$$m_i \frac{d\boldsymbol{v}_i(t)}{dt} = \boldsymbol{f}_i^{self} + \sum_{j(\neq i)} \boldsymbol{f}_{ij} + \sum_{w} \boldsymbol{f}_{iw} \tag{1}$$

where m_i is the mass of individual *i* and $\boldsymbol{v}_i(t)$ is its moving velocity at time *t*. Furthermore, the self-driven force is specified by

$$\boldsymbol{f}_i^{self} = m_i \frac{\boldsymbol{v}_i^0(t) - \boldsymbol{v}_i(t)}{\tau_i} , \tag{2}$$

This force describes an individual tends to move with a certain desired velocity $\boldsymbol{v}_i^0(t)$ and expects to adapt the instantaneous velocity $\boldsymbol{v}_i(t)$ within a certain time period τ_i. In particular, the desired velocity $\boldsymbol{v}_i^0(t)$ is the target velocity in one's mind, specifying the speed and direction one desires to realize. The physical velocity $\boldsymbol{v}_i(t)$ is the physical speed and direction achieved in the reality. The gap of $\boldsymbol{v}_i^0(t)$ and $\boldsymbol{v}_i(t)$ implies the difference between the human subjective wish and realistic situation, and it is scaled by a time parameter τ_i to form the self-driven force. This force motivates one to either accelerate or decelerate, making the realistic velocity $\boldsymbol{v}_i(t)$ approaching towards the desired velocity $\boldsymbol{v}_i^0(t)$.

By simulating many such individuals in collective motion, blocking was observed as they pass a bottleneck doorway, and this phenomenon is named by the "faster-is-slower" effect in Helbing, Farkas and Vicsek, 2000. Especially, it shows that increasing desired velocity $\boldsymbol{v}_i^0$ can inversely decrease the collective speed of crowd leaving through the doorway.

In the past decade, the social-force model has generated considerable recent research on evacuation modeling (Johansson and Helbing, 2014), and it has been incorporated into several egress simulators, such as Fire Dynamics Simulator with Evacuation (Korhonen and Hostikka, 2010) and Maces (Pelechano and Badler, 2006). The model has been partly validated based on data sets from real-world experiments. The method of validation involves comparing the simulation of the model

Peng Wang previously studied in the Department of Electrical and Computer Engineering, University of Connecticut, Storrs, USA, Email: wp2204@gmail.com

with associated observations drawn from video-based analysis (Helbing et. al., 2005; Johansson, et. al., 2008).

II. Psychological Explanation of the Social-Force Model

One problem about the social-force model is that the faster-is-slower effect was vaguely explained by "panic" behavior of people (Helbing, Farkas and Vicsek, 2000; Johansson and Helbing, 2014). However, existing research shows that the psychological state of panic occurs relatively rarely in real-world evacuation events (Sime, 1980; Proulx, 1993; Ozel, 2001; Rogsch et al., 2010), and this causes misunderstanding of the model by most social psychologists. Defined psychologically, "panic" means a sudden over-whelming terror so that people lose their ability of reasoning and judgment and thus behave irrationally. However, Equation (1) and (2) do not characterize any irrational behaviors of people, but only assume people have desire to move in certain directions. Thus, we see that the general use of the term panic is not essential to the social-force model.

By searching in literature of social psychological studies in emergency egress, we think that "stress" and "time-pressure" are more accurate conceptualizations of the social-force model than "panic." (Sime, 1980; Ozel, 2001). Stress can be caused by the mismatch of psychological demand and physical reality (Stokes and K. Kite, 2001). In Equation (2), the psychological demand is described by desired velocity $\boldsymbol{v}_i^0$ while the physical reality is described by the physical velocity $\boldsymbol{v}$. The gap of these two variables characterizes how an individual feels stressed during movement. Also, time-pressure is a kind of stress that is caused by insufficient time when people are involved in a time-related task. In Equation (2) the time-pressure is reflected by the time span τ_i within which one expects to attain the desired speed in his or her mind. The higher is the time-pressure, the smaller is time span τ_i such that one expects to reach the desired speed faster. In sum, although the social-force model is labeled with the term "panic," its mathematical description is not related to the true "panic" in a psychological sense and it actually agrees with the psychological concept of stress and time-pressure. This also explains why the model can be well used in simulation of emergency egress because "emergency" implies shortage of time in a process, and the faster-is-slower effect can be viewed as a group-level phenomenon of individual-level stress.

Next, we will explain the simulation results of the social-force model from the psychological perspective. In particular, the simulation of the model reiterates a common psychological knowledge: moderate stress improves performance in collective behavior (i.e., speeding up crowd motion); while excessive stress impairs their performance (i.e., disorders and jamming).

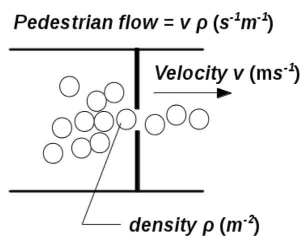

Figure 1. About crowd movement in a passageway

As crowd move in a passageway the realistic factor that confines their behaviors is the passage capacity. Commonly, the pedestrian flow ρv characterizes how many individuals pass through a doorway of unit width per time unit, and the passage capacity is the maximal pedestrian flow that people are able to realize in collective motion (Wang et al., 2008; Daamen and Hoogendoorn, 2012). When the passage capacity is sufficient, v increases along with v^o while ρ can be freely adjusted. As a result, people can move as fast as desired while still keep proper interpersonal distance. This effect can be deemed as the "faster-is-faster effect" in contrast of the faster-is-slower effect in Helbing, Farkas and Vicsek, 2000, and it was verified in the experiments in Daamen and Hoogendoorn, 2012. Although this phenomenon was not emphasized in Helbing, Farkas, and Vicsek, 2000, the testing results in that paper also testify this effect actually[1]. If the physical speed v and density ρ reach the maximum, the passage is saturate and the pedestrian flow ρv reaches the maximal. In this case, further increasing v^o could

[1] If the passage capacity is sufficient while v^o is controlled within a reasonable range, increasing v^o can actually speed up the crowd, and thus faster-is-faster effect also exists. As shown in See Figure 1(c) and Figure 1(d) in Helbing, Farkas, and Vicsek, 2000, the initial increase of desired velocity speeds up the crowd leaving: there is a descending portion in the curve of Figure 1(c) and an ascending portion also exists in the curve of Figure 1(d), and these plots implicate the faster-is-faster effect also exists. Especially, Figure 1(d) shows how the desired velocity v^d affects the "pedestrian flow ρv divided by the desired velocity" in order to emphasize the faster-is-slower effect. We infer that the ascending of the curve will be more significant if the pedestrian flow ρv ($s^{-1}m^{-1}$) is directly plotted.)

only intensify interactions among people, and increase the risk of disorder or disaster events at the bottleneck (e.g., jamming, stampeding). If such disastrous events occur, the moving crowd will be significantly slowed down and the faster-is-slower effect is exhibited.

From the perspective of psychological research, mismatch of psychological demand and physical reality results in stress on people. Stress at a moderate level speeds up crowd movement (faster-is-faster effect) while excessive stress impairs such performance (faster-is-slower effect). In brief, increasing the psychological demand v^d can either result in acceleration or disorder in the crowd movement, and this testing result testifies how stress could improve or impair human performance in collective behaviors. In sum, the testing results of the social-force model reiterate our previous thoughts: a better grounding of the social-force model in known psychological studies is the concept of "stress" and "time-pressure" and the general use of term panic is not essential to the model.

III. Conclusion

A group-level consequence of individual-level stress is the potential disorder and jamming when crowd move through a narrow passage. Such a blocking effect has previously been demonstrated by simulating the social force model of Helbing, Farkas, and Vicsek, 2000. However, the term "panic" was vaguely used to explain the simulation result even though the social science literature on egress calls this into question. Thus, it was clear that better grounding of the social force model in known psychological processes is essential to bridge the gap between physical innovation and psychological understanding about this model. This paper first clarifies that the social-force model describes people who have a desire to move fast, not necessarily "panicked" people. The model's mathematical description is well consistent with the psychological concept of stress and time-pressure. The simulation results agree with a common psychological finding: moderate stress improves performance of crowd behaviors (i.e., speeding up crowd movement); while excessive stress impairs their performance (i.e., disorders and jamming). In sum, our analysis gives a new insight to understand the model and simulation of Helbing, Farkas, and Vicsek, 2000, especially from the psychological perspective.

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