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Convection–diffusion effects in marathon race dynamics

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HIGHLIGHTS

- Data from the Chicago Marathon (35,000 participants) is considered.
- The overall dynamics are modeled as a convection–diffusion process.
- The effective diffusivity increases and the mean velocity decreases along the race course.
- Some implications for understanding pedestrian dynamics are discussed.

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ABSTRACT

In the face of the recent terrorist attack event on the 2013 Boston Marathon, the increasing participation of recreational runners in large marathon races has imposed important logistical and safety issues for organizers and city authorities. An accurate understanding of the dynamics of the marathon pack along the race course can provide important insights for improving safety and performance of these events. On the other hand, marathon races can be seen as a model of pedestrian movement under confined conditions. This work used data of the 2011 Chicago Marathon event for modeling the dynamics of the marathon pack from the corral zone to the finish line. By considering the marathon pack as a set of particles moving along the race course, the dynamics are modeled as a convection–diffusion partial differential equation with position-dependent mean velocity and diffusion coefficient. A least-squares problem is posed and solved with optimization techniques for fitting field data from the 2011 Chicago Marathon. It was obtained that the mean pack velocity decreases while the diffusion coefficient increases with distance. This means that the dispersion rate of the initially compact marathon pack increases as the marathon race evolves along the race course.

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1. Introduction

The recent three decades have witnessed a growth in number and participation of popular marathon races. The number of participants varies from about 35,000 runners for large marathons (e.g., Chicago and New York City) to about 5000 for middle-size marathon events. The realization of large marathon events is a complex process involving careful logistical steps for city authorities and organizers. The distribution of the basic kit including course instructions, T-shirt and number tags are carried out in the day previous to the event. The event day incorporates the actions of city authorities for ensuring the safety of runners along the marathon course. On the other hand, the accommodation of runners in the starting zone (commonly called corrals) follows well-established rules oriented to reduce the risk of catastrophic jams. Distributing supplies (e.g., hydrating beverages) as well as providing medical assistance to fatigued runners are major tasks that should be fulfilled under crowding environments. After the finish line, the distribution of event souvenirs (e.g., commemorative

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medals) and recovery kits involves commonly the evacuation of hundreds of persons arriving every minute. On the other hand, the recent terrorist attack in the 2013 Boston Marathon turned on alarms on the safety fragility of large crowds (runners and public) concentrated around certain zones of the marathon course. In this way, a close understanding of the dynamics of the marathon pack should provide important insights for the organization and safety monitoring of popular athletic events with a high number of participants.

A recreational athletic event can be seen as a scenario for gaining insights in the movement of a large number of pedestrians within urban streets. Also, studies in this line can provide important insights for understanding the movement of dense crowds during mass events [1,2]. The controlled conditions of marathon races can provide some important evidences on the dynamics of massive groups tracking urban roads [3,4]. Social and political parades, stadium evacuation and people displacement in subway corridors are examples of real environments for which marathon races are simple models of their dynamical behavior.

The incorporation of modern wireless technologies for popular athletic races has allowed the tracking of the position of every runner along the race course [5]. An electronic chip attached to the running shoe provides the crossing times at important course points, commonly every five kilometers. In the future, GPS technology micronization [6] and the development of e-textiles [7] can provide continuous monitoring of all participants along the whole race course. Actually, large marathon events provide every participant with an electronic chip for monitoring the race evolution at some points. Typically, the crossing times at half- and full-marathon as well as at every five kilometers are recorded. In principle, the data can be used as field data for developing mathematical models for the dynamics of massive athletic races. Despite the availability of data for large marathon events with as many as 35,000 participants (e.g., New York, Chicago, etc.), mathematical models for describing the marathon race dynamics are lacking. In fact, mathematical modeling has focused on the design of energy-based strategies for optimal performance (e.g., minimum time) of elite runners [8–12]. A suitable mathematical modeling framework based on available field data can provide important guidelines for understanding the dynamics of massive groups on urban tracks, as well as for improving the logistics and organization of marathon races with an increasing number of participants. Of particular interest is the understanding of how marathon participants are distributed on the race course for providing adequate support (e.g., electrolytes and medical assistance) and designing evacuation strategies in the face of risky events.

The aim of this work is to explore the use of convection–diffusion processes for modeling marathon race dynamics. Runners are seen as particles moving in a one-dimensional domain while dispersing by the effects of different physiological and athletic capacities. The crossing times recorded at every five kilometers for the 2011 Chicago Marathon are used as a case-study for estimating the model parameters; namely, the mean pack velocity and the diffusion coefficient. The results show that the mean pack velocity decreases while the diffusion coefficient increases with distance. This means that the dispersion rate of the initially compact marathon pack increases as the marathon race evolves along the race course.

2. Data

The 2011 Chicago Marathon (October 9, 2011) was considered in this work because of the large number of participants (about 35,000) for which the race results are publicly available on the website www.chicagomarathon.com. The marathon takes place on the main avenues of the City of Chicago along a flat course. Each participant is equipped with a chip for monitor the race progress along the marathon course. The official time starts with the gunshot when participants accommodated in corrals are gradually moved into the marathon course at the starting line. When a participant crosses the starting line, the chip is activated and his/her effective race time (i.e., chip time) is recorded every 5 km and at half- and full-marathon distances. The chip time every 5 km for all participants provides valuable data for studying the dynamics of massive races.

In this work, we are interested in studying the movement of the whole runners pack along the marathon course. The dynamics of runners in marathon races share some similarities with pedestrian dynamics [13,14]. The modeling approach for the runners pack is based on considering the official times for all participants at each distance. Official times are obtained from chip times by adding the "corral times", which is the time that a participant spends in corrals waiting for reaching the starting line. Corral times vary from zero minutes for elite runners to about thirteen minutes for runners in the last section of the starting pack. Corral times are obtained as the difference between the official time and the chip time. For each distance, the official time is obtained by adding the corral time to the chip time. Fig. 1(a) and (b) show respectively the corral and the official times ordered increasingly. The tails in the official times can be considered as outliers with respect to the main pack. In fact, the left and the right tails correspond to the fastest and the slowest runners. On the other hand, it is noted that the corral time is approximately a straight line, indicating that runners approach the starting line at an almost constant rate.

3. Convection–diffusion modeling of marathon dynamics

Before developing a mathematical model for the description of the marathon race dynamics, the following practical features should be considered:

- The marathon course is, in general, a flat route within sub-urban and urban regions. To obtain better runner performance, potential bottlenecks are avoided, so typical courses like that for the Chicago Marathon are designed over wide and long avenues with a reduced number of corners and turns. In this way, the marathon course can be considered as a one-dimensional domain for modeling purposes.

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