Fractal Analysis of Pedestrian Egress Behavior and Efficiency

Atsushi Nara, Paul M. Torrens

School of Geographical Science, Arizona State University,
Tempe, AZ 85287-0104 USA
Tel: +1 480-965-7533
Fax: +1 480-965-8313
Email: Atsushi.Nara@asu.edu

1. Introduction

Designing pedestrian facilities is not only an art but also requires the efficiency of pedestrian flows, in particular when many people meet at one place, for instance, airport terminals, stadia, or theaters (Helbing et al. 2005). In addition to the efficiency, safety issues including designing safe egress routes are another important concern for pedestrian crowds. During the emergency evacuation, an extreme case of egression, pedestrian crowds have a chance to encounter secondary disasters, the impact of which causes incidents of serious injuries and fatalities. Potential factors are overcrowding and crushing caused by human stampede behaviors and structural problems of pedestrian facilities. In fact, such incidents have been reported numerous times (Crowd Dynamics Ltd. 2004). In order to design effective and safe pedestrian facilities and egress routes, it is required to examine and understand pedestrian egressions, specifically how pedestrians move and how efficient their movements are in a certain environment.

This research reports on a spatial analysis of pedestrian egress behaviors and efficiency in different crowd environments. The objective of this research is to explore a spatial analytical methodology for pedestrian egress dynamics. To examine and quantify pedestrian egress behaviors and efficiency, pedestrian movement data on six different egress scenarios were collected with the use of Global Positioning Systems (GPS) and they were analyzed with the measurement of tortuosity, which is a property of a movement path being tortuous or crooked. Specifically, fractal analysis was employed for quantifying tortuosity of movement paths and answering three specific research questions; 1) how does the pedestrian crowd density influence the egress efficiency; 2) how does the structure of egress route affect the egress efficiency; and 3) how does the pedestrian mode impact the egress efficiency?

2. Methods

2.1 Data Collection

To acquire data of pedestrian movements in egression, a GPS receiver of GARMIN GPSMAP 60CS was used. It is a 12-parallel-channel receiver that continuously tracks and uses up to 12 satellites to compute and update information. The update rate was set to 1/second. To increase the accuracy of measurements, Wide Area Augmentation System (WAAS) was enabled. WAAS is a Federal Aviation Administration (FAA) funded program for use in precision flight approaches. With WAAS, the GPS accuracy on position errors increased from < 15 meters (95% typical) to < 3 meters (95% typical). In order to answer three research questions, six qualitatively different pedestrian egress movements were collected with GPS in Phoenix, AZ.

2.2 Fractal Analysis

To quantify and analyze pedestrian egress behaviors and efficiency, a measurement of tortuosity was considered in this research. Tortuosity for movement paths has been studied in last two decades largely in the field of biology and ecology to investigate the animal's movement path in relation to its habitats. This research specifically employed the analysis of fractal dimension to quantify and examine tortuosity of pedestrian movement paths. Fractal dimension (*D*) is the continuous analogue of discrete geometric dimensions (Mandelbrot 1967, Milne 1991); for example, a linear feature has the fractal dimension between 1 and 2, where 1.0 represents a straight path and 2.0 indicates that a path is so tortuous as to completely fill a plane.

Fractal analysis has been used in various types of studies of animal movements and habitats, for example, the landscape perceptions of grasshoppers (With 1994), habitat selection at different spatial scales of marten (Nams and Bourgeois 2004), and scale-dependent movements of seabirds (Fritz et al. 2003). Since *D* is a spatial-scale depended measurement, fractal analysis is significantly useful for studying how animals change in their response to their environment with changes in spatial scale (Nams 2005).

In past studies, however, fractal analysis has not much applied to examine pedestrian dynamics; therefore, this study contributes to explore the capability of using fractal analysis for examining pedestrian movements, especially different features of pedestrian egress movements in relation to various spatial scales.

3. References

Crowd Dynamics Ltd, 2004, *Crowd Disasters*, Retrieved December 19, 2006, from http://www.crowddynamics.com\main\Crowddisasters.html.

Fritz H, Said S and Weimerskirch H, 2003, Scale-dependent hierarchical adjustments of movement patterns in a long-range foraging seabird. *Proceedings of the Royal Society of London Series B*, 270: 1143-1148.

Helbing D, Buzna L, Johansson A and Werner T, 2005, Self-organized pedestrian crowd dynamics: Experiments, simulations, and design solutions. *Transportation Science* 39 (1): 1-24.

Mandelbrot B, 1967, How long is the coast of Britain? Statistical self-similarity and fractional dimension. *Science*, 156: 636-638.

Milne BT, 1991, Lessons from applying fractal models to landscape patterns. Pages 199-235 in M. G. Turner and R. H. Gardner, editors. *Quantitative methods in landscape ecology*. Springer-Verlag, New York, New York, USA.

Nams VO, 2005, Using animal movement paths to measure response to spatial scale. *Oecologia*, 143: 179-188.

Nams VO and Bourgeois M, 2004, Fractal dimension measures habitat use at different spatial scales: an example with marten. *Canadian Journal of Zoology*, 82: 1738-1747.

With KA, 1994, Ontogenetic shift in how grasshoppers interact with landscape structure: An analysis of movement patterns. Functional *Ecology*, 8: 477-485.