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A proposed pedestrian waiting-time model for improving space–time use efficiency in stadium evacuation scenarios

Zhixiang Fang [a,b,*], Qingquan Li [a,b,*], Qiuping Li [a,*], Lee D. Han [c], Dan Wang [a]

[a] State Key Laboratory for Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, 129 Luoyu Road, Wuhan 430079, China
[b] Engineering Research Center for Spatio-Temporal Data Smart Acquisition and Application, Ministry of Education of China, 129 Luoyu Road, Wuhan 430079, China
[c] Department of Civil & Environmental Engineering, The University of Tennessee, 112 Perkins Hall, Knoxville, TN 37996-2010, USA

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ABSTRACT

Efficiency is a fundamental requirement in evacuation planning and operations. The "faster-is-slower" phenomenon in pedestrian evacuation has been observed and deemed a significant obstacle to evacuation efficiency. This paper thus focuses on two aspects of evacuation planning in the case of stadium evacuation. The first is to define a space–time use efficiency measure for evaluating the utility of both space and time resources. The second is to propose a pedestrian waiting-time model for directing evacuees to alleviate evacuation bottlenecks. An agent-based simulation approach was employed to test the proposed model in stadium evacuation scenarios. The results demonstrate that compelled, or mandatory, waiting time strategy generated by this model is helpful in improving the space–time use efficiency of network links in the evacuation process by virtue of the strategically timed moving–waiting –restarting movement pattern of evacuees. The analysis of space–time evacuation paths in this study provides a practical and insightful alternative for measuring evacuation effectiveness. Results of this study compared reasonably against an existing cellular automaton based simulation both in microscopic and macroscopic perspectives. A number of future research directions were presented.

1. Introduction

The evacuation performance of large building complexes received increased interest by researchers in recent years [28,39,45]. Studies on this subject led to the development of several simulation-based models designed to investigate bottlenecks induced by panic behaviour [22], pedestrian movements [7,41], and waiting time in crowded areas [9,10]. These studies employed techniques including cellular automata models, lattice gas models, social force models, fluid-dynamic models, agent-based models, game theory models, as well as models based on animal experiments (reviewed by Zheng et al., 2009 [58]) as the basis for evacuation scenario simulations [55]. Results of a significant number of these evacuation simulations demonstrated a "faster-is-slower" effect [22,36], which is described as "… *trying to move faster can cause a smaller average speed of leaving…*" by Helbing et al. about the bottleneck mechanism. This effect implies that the utilization, in terms of both space and time, of evacuation routes has room for improvement.

Efficient use of evacuation routes (space) and evacuation duration (time) is a major challenge in evacuation planning and management. To this end, one of the objectives of this paper is to introduce a space–time utilization efficiency index for evaluating the resource usage, in terms of space and time, of alternative evacuation routes and plans. The other objective of this paper is to establish a pedestrian waiting-time model, which is essential if one wants to improve evacuation efficiency by minimizing pedestrian waiting time.

This paper is organized as follows. Section 2 discusses earlier work related to evacuation measures as well as space and time resources in evacuation. Section 3 presents a space–time use efficiency index to model the usage of space and time resources in an evacuation process. Section 4 introduces a pedestrian waiting-time model to avoid the faster-is-slower effect in evacuation operations. Section 5 introduces an agent-based simulation methodology that includes the route choices and waiting behaviours of evacuees. Section 6 analyses the results of computational experiments. Finally, Section 7 draws conclusions and discusses directions for future research.

Abbreviations: MOEs, Measures of effectiveness; FIFO, First-in-first-out.

* Corresponding authors. Permanent address: Transportation Research Center, Wuhan University, P.O. Box C307, Road Luoyu #129, Wuhan 430079, PR China. Tel.: +86 27 68778222 8110; fax: +86 27 68778043.
E-mail addresses: zxfang@whu.edu.cn (Z. Fang), qqli@whu.edu.cn (Q.Q. Li), liqiuping@gmail.com (Q.P. Li).

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