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Transportation Research Procedia 9 (2015) 36 – 55

Transportation Research Procedia

www.elsevier.com/locate/procedia

21st International Symposium on Transportation and Traffic Theory

Proposition and testing of a conceptual model describing the movement of individual pedestrians within a crowd

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Abstract

Our understanding of crowd movements has rapidly improved over the course of the last decades. This study shows that the empirical research has not kept up with the pace of the simulation studies. Based on an extensive literature review, this study proposes a conceptual model describing the movements of individuals within a crowd. The model features the relationships between the macroscopic flow variables and characteristics of the pedestrians, their physiologic environment and the surrounding infrastructure in which they reside. Using trajectory data sets gathered during large-scale pedestrian events in the Netherlands, the conceptual model has been statistically tested. The results show that the proposed framework is capable of explaining trends featured by the macroscopic flow variables based on the before mentioned characteristics.

Peer-review under responsibility of the Scientific Committee of ISTTT21

Keywords: framework; operational pedestrian movement dynamics; large scale events; empirical research;

1. Introduction

Large-scale events take place frequently. During many of these events, the safety of pedestrians poses no problems. Nevertheless, every year several events turn into a disaster. The stampedes and crowd crushes that occur during such a calamity leave many (fatally) wounded individuals behind. Although catastrophic crowd events are rare, temporary overcrowding occurs much more frequently during large-scale events. Consequently, during most events there is a

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Peer-review under responsibility of the Scientific Committee of ISTTT21
doi:10.1016/j.trpro.2015.07.003

considerable probability that highly dangerous situations arise. In order to predict and prevent these potentially dangerous situations a good understanding of how pedestrians move during large-scale events is necessary. A correct assessment of current crowd movements and prediction of future crowd movements at large-scale pedestrian events is an essential first step in the prevention of precarious situations.

Our understanding of crowd movements has rapidly improved over the course of the last decades. The work of among others Henderson (1971), Fruin (1971) and Predtechenskii et al. (1978) provided methods to quantify the dynamics of pedestrian movements. In recent years, among others Seyfried et al. (2005), Daamen et al. (2003b) and Moussaid et al. (2009), has improved our understanding of the exact relations between the pedestrian movement dynamics and the macroscopic and microscopic flow characteristics proposed by these earlier research attempts.

An extensive review of the research literature shows that even though numerous studies have been performed, the research has been disjointed. As a consequence, our understanding of the interrelations between the flow variables and other characteristics concerning the pedestrian, the crowd and the infrastructure is still limited. Besides that, the research has been focused on very specific relations between one of the macroscopic variables (generally walking velocity) and one of demographic, environmental and infrastructure characteristics.

As a result, the interplay and correlations between these characteristics under study has been left underexposed. For example, even if the influence culture on the walking velocity is understood, it is unclear how a third factor (e.g. an intersecting flow system) presents itself within the same flow system, due to the interplay between all three characteristics of the situation.

The objective of this study is to determine a conceptual model of constituent behavioral hypotheses that connects the relationships mentioned in literature. For the first time, this paper puts forward a comprehensive theory and conceptual model of related behavioral hypotheses which explains how the characteristics of the pedestrians, the physiological environment and the infrastructure influence the resulting operational movement dynamics of the crowd. The behavioral hypotheses incorporated within the conceptual model generate insights into the interrelations between velocity, density, flow, distance headway, the angle of interaction, the variability of interactions, age, temperature and the number of pedestrians within the infrastructure.

The paper describes the development and the subsequent statistical testing of the proposed conceptual model. Since only part of the behavioral hypothesis in the conceptual model could be derived directly from previous empirical research, preliminary tests have been performed to establish the validity and sign of the behavioral hypothesis that are part of the conceptual model using data sets featuring the movement of pedestrian crowds at various large-scale pedestrian events in the Netherlands.

This study shows that it is possible to predict general trends in the movement dynamics of crowd using the proposed conceptual model. The finalized conceptual model also shows that a complex interplay between the incorporated factors exist, which is more than just the simple addition of factors.

The remainder of this paper elaborates on the development and testing of the conceptual model. Section 2 details the results of a comprehensive literature review. In the review the factors which influence pedestrian movement dynamics, according to the contemporary research literature, are determined. Subsequently, a conceptual model is proposed in section 3. In section 4 the data gathering methodology, the general characteristics of the data and a mathematical definition of the variables used in the conceptual framework process are mentioned. The conceptual model is put to the test in section 5. Preliminary statistical tests are performed on behavioral hypothesis mentioned in the conceptual model. Subsequently, a final version of the conceptual model is presented. Section 6 concludes this paper with some conclusions and a discussion of the possibilities for future research.

2. Review of literature featuring empirical research into crowd dynamics

Many research papers indicate factors which influence the actual physical movement dynamics of pedestrians during large-scale events. Some of the descriptive factors mentioned in the research literature relate to the demographic characteristics of the pedestrians, such as the age, gender and cultural background. Other factors relate to the characteristics of physiological environment in which pedestrians reside, such as precipitation, sunshine, temperature and wind. The research literature often also makes mention of factors related to the characteristics of the flow situation.

The focus of this study is on crowd movement dynamics during large-scale outdoor events. Therefore, especially studies considering the factors that are influence the operational movement behavior at these events are reviewed. Due to the space restriction the following section will only mention the findings that mention and/or underpin behavioral hypotheses which directly relate to the movement dynamics of crowds

In this paper the current body of knowledge is reviewed with respect to the insights which quantify how pedestrians' movements are influenced by the characteristics of the individual (section 2.1), their environment (section 2.2) their one-