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State-of-the-art crowd motion simulation models

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ABSTRACT

Currently, pedestrian simulation models are used to predict where, when and why hazardous high density crowd movements arise. However, it is questionable whether models developed for low density situations can be used to simulate high density crowd movements. The objective of this paper is to assess the existent pedestrian simulation models with respect to known crowd phenomena in order to ascertain whether these models can indeed be used for the simulation of high density crowds and to indicate any gaps in the field of pedestrian simulation modeling research.

This paper provides a broad, but not exhaustive overview of the crowd motion simulation models of the last decades. It is argued that any model used for crowd simulation should be able to simulate most of the phenomena indicated in this paper. In the paper cellular automata, social force models, velocity-based models, continuum models, hybrid models, behavioral models and network models are discussed. The comparison shows that the models can roughly be divided into slow but highly precise microscopic modeling attempts and very fast but behaviorally questionable macroscopic modeling attempts. Both sets of models have their use, which is highly dependent on the application the model has originally been developed for. Yet, for practical applications, that need both precision and speed, the current pedestrian simulation models are inadequate.

1. Introduction

Pedestrian crowd events are frequently organized. Assessing the safety of such events has been proven difficult. Not only the layouts of the infrastructure are different, also movements of pedestrians differ greatly between events. Where at festival terrains pedestrians wander freely between stages separated by wide open spaces, participants in a March move along a route towards the finish. At both above mentioned events high-density crowd situations occur, and hazardous situations might arise. Currently, simulation models are used to predict where, when and why hazardous instances arise. Many pedestrian simulation models have been developed to predict pedestrian movement. However, most models were developed and calibrated specifically for low density situations of a specific nature (e.g. movement in a shopping center, movement along a corridor, movement through bottlenecks). It is questionable whether models developed for specific low density situations are capable of simulating high density crowd movement. However, since hazardous situations do still occur frequently, simulation models calibrated and validated for pedestrian movement in crowds are necessary to predict and manage large-scale crowd movements.

Several scientists have reviewed the available pedestrian simulation models before. All reviews focus either on classifying the models according to the characteristics present within the model, the phenomena that can be simulated or the mathe-

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matical characteristics of the models. Papadimitriou et al. (2009) for instance assessed existing research on pedestrian behavior in urban areas, thereby providing a very comprehensive review of pedestrian movement models. Papadimitriou et al. (2009) did however not mention the relative applicability of the models on dense crowd movement. Schadschneider et al. (2009) also reviewed numerous models, classifying them in model categories. This review mainly discussed the features of the respective models with respect to simulating pedestrian motion in general. Helbing and Andersson (2010) worked in the opposite direction. They reviewed complex collective behavioral patterns visible within pedestrian crowds, while mentioning models that were capable of modeling those phenomena. In this review, the focus was on the phenomena instead of the models. Bellomo et al. (2012) are an example of the last sort of review which focusses on the mathematical properties of both traffic and pedestrian models. All of the above mentioned reviews mention a multitude of models. The authors hypothesize that models that are able to simulate a whole range of crowd movement phenomena, are better at predicting crowd motion. However, since none of the above mentioned reviews links the models directly to the phenomena occurring in dense crowd movement situations, the assessment of pedestrian simulation models with respect to crowd motion is still lacking an important behavioral dimension.

Within this paper the capabilities of contemporary pedestrian movement models have been assessed with respect to crowd movements. It provides a broad, but not exhaustive overview of the current literature on pedestrian simulation models of the last decades. The objective of this paper is to assess the current pedestrian simulation models with respect to the movement of crowds (not individual pedestrian movement) in order to show the differences between the modeling approaches and to indicate whether gaps in the field of crowd modeling research exist.

The outline of this paper is as follows. Section 2 defines the definition used in this paper when applying the word ‘crowd’. Section 2 briefly elaborates upon the research methodology. In Section 4 the crowd movement phenomena used in this review are elaborated upon, consisting of eight motion base cases and six self-organization movements. In Section 5 also a few additional characteristics of the simulation models will be compared to assess the models applicability. Section 6 subsequently describes the model (classes) that are part of the review, among other things cellular automata, social force models, velocity-based, continuum and hybrid models. For each set of models first the basic layout of the base model – that is the first proposed instance of a model without later adaptations – will be considered. The manners in which the environment, the agents (if present) and the interactions between agents and the environmental model are modeled are discussed. Furthermore, models that implement adapted versions of the base model are also elaborated upon. In Section 7 all models are compared with respect to the characteristics described in Sections 4 and 5. This paper ends with a discussion of the comparison results and concluding remarks in Section 8.

2. What is a ‘crowd’?

A search in literature shows that researchers use the word ‘crowd’ for almost every situation where more than two individuals are interacting with each other (Challenger et al., 2010). Since this paper uses a more specific interpretation of the word ‘crowd’, first its definition will be specified.

Several authors use the word crowd as a description for a multitude of individuals walking through the same space at a certain moment in time. However, the used definition of the word crowd differs greatly between papers. Where Hoogendoorn and Bovy (2004) use it to describe a number of individuals walking through a train station, Duncan (2009) uses the same word to describe pedestrian motion in front of a pop podium. To the writers’ knowledge no common definition for ‘a crowd’ exists within the field of transportation engineering. Even in sociology, where crowds have been researched for many years (LeBon, 1895; McPhail, 1991; Wijermans, 2011, etc.) the definition used is quite broad:

‘More than 2 people at the same location during the same time period’

Quantitatively, this definition does not give a point of reference for the engineering practice. Any movement involving the interaction of more than two individuals could be interpreted as a crowd movement by this definition. Since no common definition exists, the authors will first define the sort of ‘crowd’ movement that is assessed. In this paper following working definition has been used:

‘A crowd is a large group of individuals ($N \geqslant 100$ P)
within the same space at the same time
whose movements are for a prolonged period of time ($t >= 60$ s)
dependent on predominantly local interactions ($k \geqslant 1$ P/m^2).’

The numbers N (number of individuals), k (density) and t (time) are chosen in a way as to exclude movements during which interaction is non-existent or only present for very short periods of time.

Even when using the definition above the sort of crowds within the spectrum might differ greatly. Therefore, the sort of crowd that is used in the paper is further elaborated upon It is firstly assumed that during crowd movements pedestrians are in close contact with each other (interaction distance between individuals <1 m), making multiple split-second operational movement decisions. Secondly, the pedestrians in the crowds considered in this paper are under no external pressure to move, but they do have a tentative goal in mind towards which they are moving. Thirdly, the atmosphere at the location where the crowd movement takes place is assumed friendly. Therefore no additional tension or interactions between indi-