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Reply to comment

Crowd dynamics and safety Reply to comments on “Human behaviours in evacuation crowd dynamics: From modelling to “big data” toward crisis management”

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1. Introduction

The survey [13] presents an overview and critical analysis of the existing literature on the modeling of crowd dynamics related to crisis management toward the search of safety conditions. Out of this general review some rationale on research perspectives have been brought to the attention of the reader.

The content of this paper is also related to the authors’ knowledge acquired in the EU project [50] which focuses on security problems during evacuation from complex venues. Crisis management should assure that the evacuation process occurs in a reasonably short time and that the local density of the people involved in the evacuation remains below a safety threshold.

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The whole content of [13] relies on the concept that a crowd is a living system. Hence, human behaviors have to be taken into account both in crowd modeling and in crisis management. The analysis has shown that an interdisciplinary approach is necessary to tackle the aforementioned security problems.

Since the readership is broad, the modeling sections of [13] have been organized into two parts to deal, respectively, with general theoretical concepts and formalized equations. Therefore, devoted mathematicians can intensively focus on Section 4 and related bibliography, while the reader interested in applications can skip over this section and go directly to the following sections.

Focusing on modeling topics it has been shown in [13] that the mesoscopic approach based on theoretical tools of the kinetic theory and of evolutionary stochastic games appeared to be more flexible as the approach can capture the complexity features of living systems and overcome, at least in part, the drawbacks of the modeling at the microscopic and macroscopic scales.

Focusing on crisis management, paper [13] has examined the existing literature, at the level of both scientific papers and technical reports, on databases repository of simulations and has proposed some guidelines toward the design of a predictive engine to support the decision making. A new science is recently developing on this topic [38]. Indeed, researchers strongly motivate the design of devices to support and optimize the process of decision making [58], where, according to the approach reviewed in our paper, interactions are modeled by theoretical tools of game theory.

The sequential steps along which the content of [13] has been developed can be summarized as follows:

1. *Analysis the main features of a human crowd viewed as a "social" hence complex, system;*
2. *Strategy by which mathematical sciences can contribute to understand the behavioral dynamics of crowds;*
3. *Development of computational methods to simulate the dynamics through complex venues;*
4. *Description of crowd behaviors in extreme situations such as stress induced by perception of danger;*
5. *Detailed analysis of what has been done and should be done to respond to crisis situations.*

The comments proposed by various authors have shown that the aims of paper [13] have been well understood. Some of them also include specific questions and suggestions of research perspectives. The overall set of comments represent a valuable contribution to future research plans in the challenging research field under consideration. As it is natural, some comments show a conceptual overlap of topics, while some of them refer to different topics. Therefore, our reply will focus on the following specific topics:

- Multiscale problems;
- Social and learning models in crowd dynamics;
- Modeling and computational problems toward crisis management;
- Predictive models toward crisis management.

These topics are treated in the next sections which are not limited to a reply to comments, but also suggest a variety of possible research perspectives.

2. Multiscale problems

The scaling problem involves several challenging issues such as: Derivation of macroscopic models from the underlying description delivered by the kinetic theory approach; Selection of the appropriate scaling, namely hyperbolic [8] rather than parabolic [9]; Modeling collective behaviors from the underlying individual dynamics; A unified approach to modeling at all scales.

This problem has been mentioned in various comments [34,66,69], where the authors have posed some conceptual issues on the derivation of macroscopic models of crowd dynamics at the macroscopic scale from the underlying description at the microscopic scale. This analytic derivation has been obtained in [6] for a crowd in unbounded domain, based on a previous study concerning vehicular traffic [10]. However, a complete analysis of derivation of macroscopic models in bounded domains is not yet available.

In more detail, comments [34] and [66] pose the same problem concerning the selection of the hyperbolic scale rather that parabolic. We do agree with this comment as propagation of perturbation in a crowd moves with finite speed rather than by diffusion. Still, the possible derivation of degenerate parabolic models should be investigated