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Review

A landscape of crowd-management support: An integrative approach

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ABSTRACT

Of the many crowd behavior models, very few have been used in assisting crowd management practice. This lack of usage is partly due to crowd management involving a diversity of situations that require competencies in observing, sense-making, anticipating and acting. Crowd research is similarly scattered across disciplines and needs integration to advance the field towards supporting practice. To address these needs, we present INCROWD, an integrated framework detailing a high-level architecture of a decision-support system for crowd management and model development. It also offers a lens for categorizing crowd literature, allowing us to present a structured literature review.

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1. Introduction

The importance of understanding human behavior in crowds is undisputed. It is required for ensuring that proper support can be given to crowd managers in preparation and during a crowd event. The last decades proposals have been put forward to capture the idiosyncrasies of crowd behavior in a variety of ways to understand (parts of) crowds. These understandings or models come in different forms, ranging from extremely formal (e.g. computational models) or implicit knowledge (e.g. mental models of experts). The crowd models that are grounded in science originate from very different disciplines and practices, including psychology, sociology, theoretical physics, applied mathematics, artificial intelligence, and computer science. Despite having helped researchers better understand crowd behavior, there are only few examples where these models have actually been used to assist in crowd management (with some exceptions, including e.g. Ball, 2007). There is thus a substantial gap between crowd research and crowd management practice.

Crowd management practice involves accessing and interpreting a wide variety of information sources, predicting crowd behavior as well as deciding on the use of a range of possible, highly context-dependent intervention mechanisms. In the context of this paper, decision-support for crowd managers denotes any computer-assisted support on each of these tasks. Both crowd research and crowd management practice have developed and improved tremendously in their attention for preparing crowd events. Automated tools are increasingly being offered for particular aspects of crowd management, but much more is needed (Challenger et al., 2009b).

We argue that the lack of adequate decision-support is partly due to the status of the majority of current crowd models. Firstly, most models are not ready for use: they are (if at all) tested for acceptability in science, but not for usability in practice. Secondly, most models reflect a particular discipline and thus target only one specific element of crowd management, i.e. acting, observing, interpreting, predicting and deciding. To truly provide decision support for crowd management, a new approach is needed that integrates data gathering, assessment and prediction of crowd situations, and evaluating decisions regarding interventions. Crowd research has the potential to support crowd management in a better way by taking an integrated view in the development of models that are operationally usable. This would allow crowd management to benefit from the wide variety of existing knowledge and tools (models) regardless of the different (disciplinary) forms in which they appear. This can be achieved, for example, by connecting and using both expert insight and social theory to predict the further development of a crowd while being fed information from a pattern detection algorithm to interpret data from cameras at a crowd site.

In particular, we see potential for improving support *during* an event, i.e. in real-time. In our view, we should make use of the strengths of both humans and technology. Human expertise and experience remains unbeaten in rapidly assessing (complex) situations. Technology on the other hand, can rapidly acquire, process and digest large amounts of information, which, in our view, is under-exploited. We perceive integrated semi-automatic decision-support as *the* next step in increasing the safety and success of crowd events.

In this paper we aim to give guidance towards integrated crowd management support by providing a decision-support framework inCrowd. inCrowd is an integrated framework for crowd interaction (actuating and sensing), mining, predicting, and making decisions to manage the behavior in a crowd, relating to the diverse practices of crowd management (observing, interpreting, predicting, decision-making). The framework functions as an architecture for a decision-support system for crowd management as well as model development framework towards operational support. Moreover, in this paper the inCrowd framework is also used for identifying areas in need of more research by classifying existing literature on crowd-behavior understanding and management, simultaneously allowing us to substantiate our claim that an integrative approach is needed.

We organize this paper by first providing an overview of crowd research as communicated in other review papers. We continue by looking at how crowd management is practiced today in Section 2. In Section 3 we discuss the means of operational support for crowd management, concentrating on the core elements of our framework and illustrating how operations can be supported in real-time, i.e., *operations engineering*. In Section 5 we focus on the importance of supporting model development and show that model development and operational crowd management are actually closely related. The framework then allows us to provide a status report on the status of the current literature in Section 6, where we assess and categorize 237 papers. Finally, we come to our conclusions in Section 7.

1.1. Background: existing reviews

Numerous review papers on understanding crowd behavior are available in the literature. For instance, Reicher (2001) and Challenger et al. (2009b) provide a (historical) overview including different schools of thought in the psychology of crowds (theoretical models). Bryan (1999) studies the maturity of human behavior in the context of fire. Others consider state-of-the-art techniques, such as the development of intelligent distributed surveillance systems and image processing technologies (Valera and Velastin, 2005), recognition and wearable sensors (Atallah and Yang, 2009) or advocate a particular type of crowd modeling (Hughes, 2003). A majority of these review papers addresses emergency evacuation, either to highlight the importance of taking a more integrative approach of the relevant connected research fields (Santos and Aguirre, 2004; Sime, 1995; Venuti and Bruno, 2009), to reflect on existing guidelines for facility design (Stanton and Wanless, 1995), or to provide insights into the most often used methods of modeling (Gwynne et al., 1999; Alsnih and Stopher, 2004).

Each review paper targets its own (disciplinary) crowd niche, the exception being the report of Challenger et al. (2009b) that covers a range of mathematical models, theoretical crowd-behavior models and crowd-simulation tools (i.e., predicting techniques),

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