Using Crowd Modelling in Evacuation Decision Making

B.J. Vreugdenhil
HKV Consultants
vreugdenhil@hkv.nl

N. Bellomo
Politecnico di Torino
nicola.bellomo@polito.it

P.S. Townsend
Crowd Dynamics International
Paul.Townsend@crowddynamics.com

ABSTRACT

Public spaces are created to be used, and large crowds gather in many buildings and external spaces. Maintaining a high level of safety for these people is of utmost importance. Cameras are used for security reasons by control room personnel, who also monitor crowd movements in case of emergency. Crowd modelling can be used to detect and analyse time dependent and space dependent crowd behaviour. Despite the large amount of raw visual information being processed, crowd modelling has not been dedicated yet to evacuation decision making. Predictive information can assist the decision maker in assessing the situation in the early stages, potentially preventing the need for an evacuation. If evacuation is inescapable, a decision maker can use crowd modelling to define the quickest and safest evacuation routes. This kind of decision support will reduce the number of deaths that occur before and during an evacuation.

Keywords

Evacuation, decision making, crowd modelling, decision support

INTRODUCTION

Places like airport terminals, cruise ships, metro stations and football stadia are characterised by a high concentration of people. In case of an emergency, for example a fire or failing structures, an evacuation might safeguard the crowd. In that case, fast evacuation is vital for the prevention of casualties. A sad example of a crowd disaster occurred during the Love Parade, an electronic dance music festival in Duisburg (Germany). On 24 July 2010, 21 people died in the crowd; 510 persons were injured (Helbing and Mukerji, 2012). A large amount of real time data on crowds, like video footage, was available for security reasons. Helbing and Mukerji (2012) state that some 500 videos were available for the post analysis of this disaster alone.

Evacuation planning, training and real time decision making are critical to safety in public spaces. There are many information sources for crisis decision making, such as crowd characteristics, the status or availability of possible routes, the presence of guiding crew and the possibilities of dynamic signage. Information about crowd density, crowd movements and about the (predicted) duration of different stages in the planned process is crucial for the evacuation decision making process. Despite the available crowd models and despite the large amount of real-time raw visual information on crowds, like video footage, this information has not been dedicated yet to be used by decision makers in the control rooms, in case of an emergency.

This paper describes the evacuation process in constrained spaces, including available data and how this data can be used in evacuation decision making.

EVACUATION DECISION MAKING

Evacuation process

Evacuation can be defined as a "physical movement of people of a temporary nature, that collectively emerges in coping with community threats, damages or disruptions" (Quarantelli,1984). Van Duin, Bezuyen and Rosenthal (1995) also involve the processes of alarming, warning and preparing in the definition, as well as the departure itself, the temporary stay and return of people, animals, and personal belongings. Thus evacuation decision-making requires an interpretation of the threat and depends merely on the process of sense-making (Boin et al, 2005).

The support to evacuation processes covers various aspects. The first one consists in general protocols, optimised by past experience, which are applied in a variety of situations, namely for different venues, generally specialised for similar environments, e.g. buildings, undergrounds, airports, etc., which require somewhat different strategies. More refined protocols can be obtained by further specialisation for well-defined venues. From the point of view of a responsible commanding officer, the evacuation process globally follows six main steps, as shown in figure 1.

Evacuation decision support

To assess the need for evacuation in a certain situation, decision makers should know deviations from usual behaviour. By getting an actual operational picture in which quantified crowd information is available, they would be supported in sense making. For example, in many stadium control rooms during a football match, dedicated police officers spend their time watching closed-circuit television (CCTV) video streams. They keep eyes on disturbances that could lead to larger problems or undesirable movements in the crowds. During the match, decision makers have an overview of the situation, mainly based on visual information. Additional information, such as crowd behaviour prediction, can make this process more resilient by increasing situational awareness of crowd dynamics over wider areas than humans could monitor and predict during a crisis.

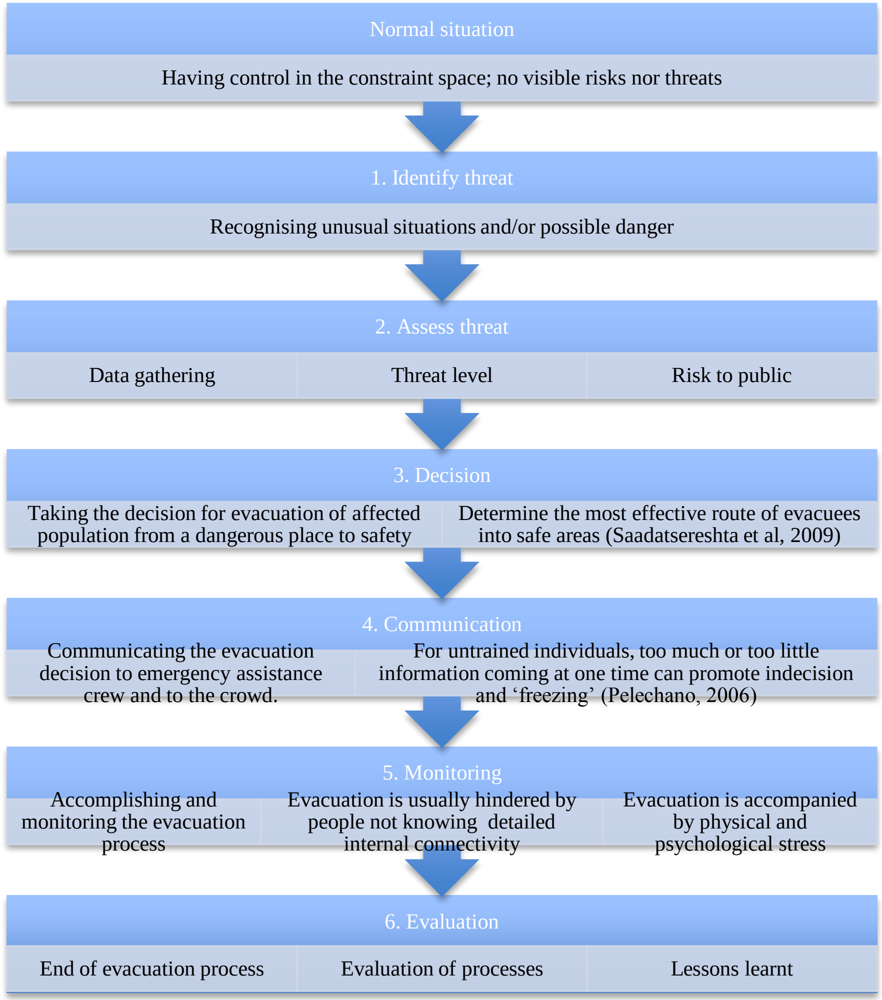

Figure 1 – Steps involved in evacuation process

CROWD BEHAVIOUR

The dynamics of a crowd can be modelled by mathematical tools (Bellomo and Dogbe, 2011). Subsequently, computer simulations can provide a forecast of the movement of crowds, which can be applied to evacuation processes. This challenging and strategic objective needs not only advanced mathematical tools, but also a deep understanding of human behaviour and the use of technological devices to detect the main features of the crowd.

The emerging collective behaviours observed in reality

People in a crowd interact by rules related to their ability to develop a moving strategy based on their individual strategy and on the strategies of others. Interactions between individuals generate collective behaviours, which are the output of nonlinearly additive interactions, not distinct individual behaviours. The most studied example refers to rational and irrational behaviours. In a rational situation each individual has a personal strategy to reach the exit avoiding walls and overcrowded area. Irrational behaviour may be generated by presence of danger. Hence, the individual dynamics depends not only on individual based interactions, but also on the local density. In dangerous conditions, individuals are attracted by the stream, both in velocity direction and speed. These are known as nonlinear interactions.

Understanding interactions is important both in view of validation of models and to develop optimal strategies for evacuation dynamics.

Crowd behaviour during evacuation

Certain conditions, for example overcrowding, avoiding congestion or following others, do create emergent behaviour during evacuation. Among others:

- emergence of a qualitatively new dynamics through non-linear interactions of many individuals;
- the ‘faster-is-slower’ effect: increase of the individual speed but toward congested area, rather than the optimal directions, which corresponds to an increase of evacuation time;
- breaking of cooperative behaviours due to anxious reactions to an event.

These features are detected in irrational evacuation dynamics. We refer to the aforementioned example by stressing that the attraction toward the stream is an example of emerging new dynamics, which appears in danger conditions. People move as quickly as possible towards highly dense areas, even pressing against others in confined space. Unfortunately, this implies that they reduce their speed, hence the ‘faster-is-slower’ effect.

CROWD MODELLING

Definition

For modelling crowds, we need a sufficiently large number of individuals in a space with walls, obstacles and inlet-outlet doors or passages. We define crowd modelling to be a differential or computational system, suitable to provide the dynamics in time and space of a set of variables, describing the state of the system. Referring to Bellomo, Knopoff, and Soler (2013), the crowd model should have the following specific features:

- Ability to express a strategy: Individuals are capable of developing specific strategies, depending on their own state and on that of the surrounding entities;
- Heterogeneity and hierarchy: The ability to express a strategy is heterogeneously distributed and includes different walking abilities and different objectives. The hierarchy defines leaders and followers within the crowd;
- Nonlinear interactions: Interactions are nonlinearly additive, involving immediate (and sometimes more distant) neighbours. Individuals move using the visibility domain in front of them.
- Social communication and learning ability: Individual’s strategic ability and the characteristics of mutual interactions evolve in time due to the tendency to adapt.
- Influence of environmental conditions: Crowd dynamics is affected by the quality of environment and the geometry of the crowd’s domain. The interaction rules are influenced by such conditions.

State of the art

The existing literature on crowd modelling is reported and critically analysed in the survey by Helbing, (2001) and Bellomo and Dogbe (2011), as well as in the recently published book by Cristiani, Piccoli and Tosin (2014). From the literature, we learn that the classical modelling approaches can be developed at three observational and representational scales:

- Microscopic description, which refers to individually identified entities. The overall state of the system is delivered by individual position and velocity of persons in a crowd.
- Macroscopic description, where the state of the system is described by gross quantities, namely density, linear momentum, and kinetic energy, regarded as dependent variables of time and space. These quantities are obtained by local average of the microscopic state.
- The intermediate mesoscopic description, is based on kinetic theory methods, where the microscopic state of persons is still identified by the individual position and velocity, however their representation is delivered by a suitable probability distribution.

Larger scale models generally eliminate the heterogeneous behaviours exhibited at the low scales. Hence, a multi-scale approach is required, where the dynamics at the larger scale needs to be properly related to the dynamics at the smaller scale.

Winter (2012) already attempted to validate and analyse behaviour aimed on simulating crowd movements. Current simulation software serve crisis managers during training and exercise by providing a 3D Common Operational Picture (COP) in the command centre and on mobile devices in the field (Ahmad, 2012). Decision makers can use evacuation simulators for enclosed spaces and thus train the awareness of the allocation of responsibilities, communication information flow during an evacuation (Comptdaer, 2007).

REQUIREMENTS FOR CROWD MODELS

Modelling and simulation can contribute to the decision processes in real evacuation (Wagoum et al. 2012). The analysis of the state of the art indicates that additional challenging work is needed to achieve these objectives. Below we indicate some requirements that the modelling approach should satisfy and subsequently we provide some reasoning based on specific examples.

In general, models are required to have the ability to depict emerging behaviours far from steady cases. These should not be artificially imposed in the structure of the model; rather, they should be induced by interactions at the micro-scale. However, this is a pre-requisite for crowd modelling, which, in itself, is not sufficient to derive models useful for support decisions in evacuation processes.

To address this, we list the following requirements:

1. The description at the microscopic scale should include the four main trends to which people are subject to:
    - avoiding walls and obstacles
    - trend toward the exit
    - search of less crowded areas
    - attraction from the main stream

    The stimuli are perceived at a distance and change of direction is anticipated.
2. The distribution of the intensity of these trends over individuals should be heterogeneously distributed. Moreover, the overall populations could be subdivided into groups corresponding to different walking abilities and objectives, e.g. moving toward different exits.
3. Modelling interactions at the microscopic scale should explain how interactions modify the aforesaid trends and in particular how people select between search of less crowded areas and attraction from the main stream. This can be explained in that people may choose a route that is less congested, thinking that this will result in a faster exit time. Alternatively, one may follow other individuals, assuming that they are more knowledgeable regarding faster or safer routes.

4. Models should include parameters, at least one, suitable to assess the quality of the walking area, which corresponds to different mean walking speeds.
5. The role of complex exit paths should be taken into account, with passage through different areas each of them with different quality.
6. Importantly, the integration with real-time data, such as the interpretation of sensor data (CCTV stream analysis, crowd counting etc.) that enables the model output to be specifically related to the current data, thus aiding decision support.

These requirements show that only the mesoscale approach can assure at least some of them. Indeed, the paper by Bellomo, Bellouquid, and Knopoff (2013) can be regarded as a first step toward the design of models consistent with the aforementioned requirements. These models have continued to be developed in line with these assumptions as part of the eVACUATE project, with the specific purpose of application to decision support. The developed models are now being implemented on real venues, in liaison with the security, and control room staff, such that behavioural parameters can be taken into account as a variable for decision making.

In the eVACUATE system, the sensor data is fed to the model in real-time, and a simulation developed from the crowd model predicts congestion during evacuation, based on the specific initial conditions indicated by the live data. These models then feed back the results to control room staff via a Common Operational Picture (COP), adding to the information already available from live CCTV feeds. The COP will display visual maps of the venue, visual statistics such as crowd densities, predicted densities, evacuation routes, sensor data, all on an integrated bank of computer screens. This leads to additional situational awareness before or during evacuation, aiding the decision support process.

CONTRIBUTION OF CROWD MODELLING IN EVACUATION DECISION MAKING

There are two methods considered to address the requirements for evacuation decision support as follows:

- Simulations are run 'live' using real-time data gathered in a venue or space
- Many simulations are completed with various parameters and the results are selected in real-time from a database

These methods are depicted in Figure 2.

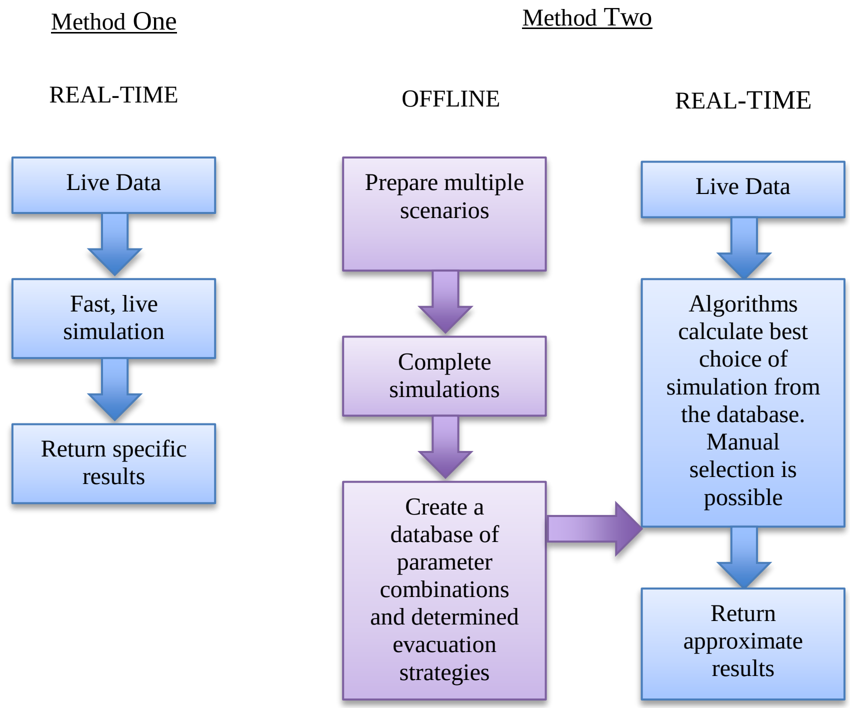

Figure 2. Methods for decision support using crowd simulation results

The first method is required to run simulations much faster than real-time to feedback the results in near-real time. However, because many features of crowd modelling are difficult to translate into simulation code that is computationally efficient enough for this task, and also require calibration, testing and validation, not all detailed modelling features can be included in this method.

The second method compensates this by allowing detailed features to be incorporated, but only provides an approximation to the forecast of crowd movement, crowd behaviour and optimal strategy because it is unlikely that the detected parameters can exactly match the precise initial conditions pre-calculated. Both methods can be considered; in fact, they could be used in conjunction to reduce error margins, and to incorporate crowd behaviours such as leader following patterns and attraction to/away from the main stream.

CONCLUSION AND FUTURE WORK

The information available to decision makers in assessing and monitoring evacuation can be supplemented by forecasts of movement and optimal strategies. This additional information is made possible, given the wealth of raw data that can be gathered and processed to provide initial conditions for crowd models. Such models have been considered in terms of required modelling scales, hybrid crowd models, and the inclusion of evacuation behaviours. These crowd models have already been implemented in computer simulations that are used to forecast the required crowd movement and strategy for a specific venue, and specific scenario. We have shown the derived methods for using such simulation in decision support.

The next step will be to compare different evacuation strategies and to compare the effect and efficiency of the crowd modelling in decision making. This will be achieved by organised end user training and exercises in the eVACUATE project that will be evaluated.

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