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Methods for measuring collective behaviour in evacuees

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ABSTRACT

Emergency evacuations often depend on social interactions among individuals. However, very little is still known about how and when they do so. This paper proposes quantitative methods for the analysis of collective behaviour in evacuees. The methods are applied to evacuation experiments in a multimodal transport station. In total 110 potential evacuation groups of 2–3 members and 30 potential evacuation groups of 6–9 members are analysed. Results show that the proposed methods provide (1) quantitative evidences of collective behaviour and (2) measurements of the behavioural cohesion in individuals during response and movement phases of evacuation.

1. Introduction

Early attempts to analyse evacuation process have given way to complex modelling simulations incorporating behavioural parameters. As the use of evacuation modelling grows, the questions associated with their use also change (Cuesta et al., 2016). These questions have moved on from asking whether the evacuation models should be used at all (Kuligowski and Gwynne, 2005; Tavares, 2009) to whether their accuracy (Lord et al., 2005; Alvear et al., 2014), reliability (Ronchi et al., 2013) and new applications (Cuesta et al., 2014; Capote et al., 2013) are acceptable for life safety. A key aspect in this enhancement is the availability of sufficiently detailed, comprehensive and relevant data-sets (Gwynne, 2009). A number of data-sets exist describing the performance of individuals during an evacuation (Shi et al., 2009; Kobes et al., 2010; Fang et al., 2012; Cuesta and Gwynne, 2016). A new data-set and methods need to address an area of research interest for it to be relevant and to make a contribution. Of particular concern is the collective behaviour among evacuees.

It is well known that we are affected in our decision-making by what others around us are doing. Our behavioural response to ambiguous threat cues is influenced by the response of others exposed to the identical cues (Latane and Darley, 1968; Nilsson and Johansson, 2009; Kuligowski, 2016). Several studies have shown that people behaviour in emergencies tends to be cooperative (Jones and Hewwitt, 1986; Fahy et al., 2011, 2012; Gwynne et al., 2006). Emergent norm theory (ENT) explains that collective behaviour can occur whenever people find themselves in a situation where they are confused or do not know what to do (Turner and Killian, 1987). Individuals work together to redefine the situation and propose a new set of actions, which is the product of milling and keynoting process (Kuligowski, 2016). The common identity in response to the same threat would explain this. There are evidences and theories that support the idea that individuals form a group before evacuating, and then continue their evacuation together until they reach safety (Kuligowski, 2016). For instance, in Beverly Hills Club fire incident social groups tended to escape or succumb together (Feinberg and Johnson, 2001).

The affiliative behaviour model states that evacuation often takes place within people to which the person has previous ties (Sime, 1980, 1995) and the organizational and situational contexts can influence the formation of groups during evacuation (Jones and Hewwitt, 1986). Given this, it is possible to state that the evacuation is a social process in that people are likely to make consensus decision, decide a plan of action and act together (Aguirre et al., 1998; Connel, 2001). This social process can have important implications which should be taken into account in life safety assessments.

Collective behaviour in evacuees is important when using evacuation models or simulation tools. The majority of current evacuation models simulate each individual as if they were not influenced by others (Kuligowski, 2016). There are methods for modelling the collective behaviour (Gwynne et al., 2006; Guo et al., 2011, 2012). However, to the authors' knowledge, these are not supported by empirical data.

Despite current literature provides very useful information to interpret fundaments of collective behaviour during evacuation, this information is based on anecdotal recollections of actual evacuees (interviews and surveys), as well as theoretical frameworks (Gwynne et al., 2006) and modelling approaches without testing.

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In other words, there is a lack of quantitative research on collective behaviour during evacuation process (i.e. collecting empirical data that are analysed using mathematically based methods, in particular statistics).

This paper proposes simple mathematically based methods (using statistics) for the analysis of actual collective behaviour in evacuees. Two methods are presented: the Method 1 for small evacuation groups (of more than five members) and the Method 2 for very small evacuation groups (of less than five members). A case study about the application of the methods is presented. The case study consists of the analysis of evacuation experiments in a multimodal transport station and it involves the analysis of 140 potential evacuation groups. The last part of the paper discusses the results and limitations of both methods.

The scope of the present work is to provide to researchers, engineers, designers, model developers and model users these quantitative methods for further research to better understand the collective behaviour and the impact of social interactions among individuals during evacuation.

2. Methods

The collective behaviour (consensus and uniformity in individuals) denotes a reduction in the behavioural variability. Let X be a continuous random variable that measures a behaviour during evacuation. Hence, we establish the following postulate: *The smaller the statistical dispersion of the variable X intragroup, compared to the statistical dispersion of the same variable X in all groups, the greater the collective behaviour.*

2.1. Method 1

The most common examples of measures of statistical dispersion are the range, the mean difference, the variance, the sample standard deviation, the interquartile range, etc. However, these measures are contrasted with location or central tendency of the variable. Another measure is the coefficient of variation (CV) that is a dimensionless (unit-free) measure of the dispersion of probability distribution. More specifically, it is a measure of variability relative to the mean.

The coefficient of variation for a selected *i-th* evacuation group is:

$$CV_i = \frac{s_i(X)}{m_i(X)} \quad (1)$$

where

$s_i\,(X)$ = Standard deviation estimation of the variable X for the *i-th* group;

$m_i\,(X)$ = Mean estimation of the variable X for the *i-th* group.

The coefficient of variation for all the evacuation groups of the scenario is:

$$CV_t = \frac{s_t(X)}{m_t(X)} \quad (2)$$

where

$s_t\,(X)$ = Standard deviation estimation of the variable X for all the groups in the scenario;

$m_t\,(X)$ = Mean estimation of the variable X for all the groups in the scenario.

The aforementioned postulate can be expressed by the following statistical hypothesis:

$$H_0: \; UCV_i < LCV_t$$
$$H_1: \; UCV_i \nless LCV_t$$

where UCV_i is the upper confidence interval for the CV_i and LCV_t is the lower confidence interval for the CV_t. There are various methods available in the literature for estimating the confidence interval for the CV (Gulhar et al., 2012; Panichkitkosolkul, 2010; Sappakitkamjorn and Niwitpong, 2013). Fig. 1 illustrates examples of the H_0 and H_1 results.

If the null hypothesis fails to reject, we can confirm the collective behaviour. Then it is possible to measure the degree of behavioural cohesion in the selected group by Eq. (3). The closer the γ_{CBi} value to 1, the greater the cohesiveness. For instance, a value of 1 would represent a perfect synchronization among individuals.

$$\gamma_{CB_i} = 1 - \frac{CV_i}{CV_t} \quad (3)$$

2.2. Method 2

Group sizes are usually small and they must be considered as small samples for statistical testing (N = [5,25]). Nevertheless, evacuation groups with fewer members are likely to emerge in a wide range of evacuations. Such groups are extremely small samples ($N \leqslant 5$). The Method 2 addresses this problem by the comparison of the means of two new variables. The first new variable is the absolute difference of the primary variable X intragroup denoted as ΔX_{IN}. The second new variable is the absolute difference of the primary variable X intergroup denoted as ΔX_{OUT}. The absolute differences of the variable X intragroup are given by:

$$\Delta X_{IN_{il}} = \left| X_{ik} - X_{ij} \right|_{k=[j+1,n_i]}^{j=[1,n_i-1]} \quad (4)$$

where

i = the i-th group;

k,j = the k-th (j-th) group members;

l = the counter of the proposed new variable: $l = \left[1, \binom{n_i}{2}\right]$

The set of values $\Delta X_{IN_{il}}$ for all groups in the scenario will represent a sample ΔX_{IN_r}, where i = [1, n_{IN}] and n_{IN} is the total number of absolute differences intragroup for the total number of groups n_g:

$$n_{IN} = \sum_{i=1}^{n_g} \binom{n_i}{2} \quad (5)$$

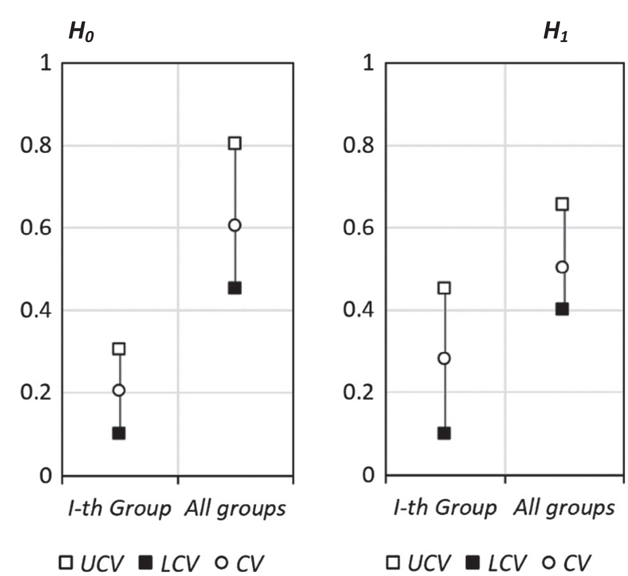

Fig. 1. Potential results of the statistical hypothesis.