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The Role of Herding Behaviour in Exit Choice during Evacuation

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Abstract

Modelling of human behaviour during emergencies is an important issue to be investigated to improve the safety of transportation infrastructures. This behaviour can be influenced by both the environment (i.e. social influences) and characteristics of the users of infrastructures. The main aim of this paper is to investigate the social influences that push a user to manifest a herding behaviour during evacuations. A behavioural model based on discrete choice models is proposed by using data collected through an on-line survey. This approach is able to highlight the heterogenic tastes of decision makers that may influence this choice in exit behaviour. The results show that decision makers are influenced by both people close to the exit and their socio-economic characteristic.

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Keywords: Evacuation Modelling, Exit Choice, Herding Behaviour

1. Introduction

Recent terroristic attacks (i.e. Madrid 2004 and London 2005) and accidents in tunnels and undergrounds, (i.e. Burnley, 2007, Mont Blanc tunnel 1999, King's Cross, 1987; Zurich, 1991) have shown that existing transportation infrastructure is not always able to provide adequate safety conditions during evacuations (Fridolf et al., 2013). Increasing the safety level of infrastructure in case of emergency requires knowledge about human behaviour (Low, 2000).

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Performance Based Design (PBD) is an available approach to predict the safety level of transportation infrastructures. It is based on the comparison of the Available Safe Egress Time (ASET) and Required Safe Egress Time (RSET) (Nelson and Mowrer, 2002; Purser, 2003). In order to estimate RSET, different macroscopic and microscopic evacuation models and simulation tools are available to test the performance of an infrastructure during emergencies (Gwynne et al., 1999; Hensher et al., 2005; Johnson, 2005; Kuligowski et al., 2010; Zheng et al., 2009). These tools are largely used to evaluate the safety level of both new and existing transportation terminals and tunnels (Weidmann et al. 2014). Among the most recent applications, Le Glatin et al. (2014) implented one of these tools to evaluate the process of evacuation from London Bridge station (London Underground) after the redevelopment of the station realised as part of the Thameslink Programme. Liu et al. (2014) studied the performance of different cross-passageways for new rail tunnel during emergencies. The accuracy of these models, however, is limited by the lack of knowledge regarding human behaviour during these types of events (Lovreglio et al., 2014b). Thus, new studies on human behaviour are required in order to improve the validity of these models (Lovreglio et al., 2014b).

Different behaviours have been observed during evacuations including: herding behaviour (Helbing et al., 2000; Low, 2000; Pan, 2006), cooperative behaviour and competitive/selfish behaviours (Cirillo and Muntean, 2013; Heliövaara et al., 2012; McLean et al., 1996; Muir and Cobbett, 1995). Several theories have been proposed in order to explain the social interactions at the base of these behaviours, including: the role-rule theory (Canter et al., 1980; Tong and Canter, 1985), the affiliative theory (Sime, 1985) and the social influence theory (Deutsch and Gerard, 1955; Nilsson and Johansson, 2009) (Fridolf et al., 2013). Another more general theory that could be integrated to explain social interactions is Caldini's social proof theory (Cialdini, 1993).

This work focuses on herding behaviour in exit choice, which is one of the most important decisions during evacuations (Lovreglio et al., 2014a). Herding behaviour occurs whenever people behave as a group by putting aside their ability to act as individuals (Saloma and Perez, 2005). In the exit choice context, herding behaviour means that the decision-maker chooses the most congested exit only because that is the most popular choice, rather than an exit with less people which may ensure a lower evacuation time. This behaviour is directly influenced by social influences that occur during evacuations (Pan, 2006).

This work focuses on the possibility of explaining herding behaviour through the theories of social influence and social proof. Firstly, this paper gives an organic vision of this behaviour according the existing literature. An approach based on Random Utility Models is used to model herding behavior in exit choice. This approach is applied to the data collected by Lovreglio et al. (2014a) according to methodology that is based on "a priori" face-to-face interviews.

This work starts with a review of the social influence theory and the social proof theory and how these can be correlated with and lead to herding behaviour. A summary on the approaches used until now to model herding behaviour is presented and a case study based on data collected by Lovreglio et al. (2014a) is described. The model estimated is described and a behavioural analysis is presented. Finally, some suggestions are provided to overcome the limitations presented in this work.

2. Social Interactions and Herding Behaviour

Social Influence theory splits the social interaction among users of an infrastructure into normative and informative social influences (Nilsson and Johansson, 2009). Normative social influences concern the "influence to conform to the positive expectations of another" (Deutsch and Gerard, 1955). This means that people in general are afraid of standing out or making fools of themselves by not complying with prevalent social norms (Nilsson and Johansson, 2009). Informative social influences deal with the "influence to accept information obtained from another as evidence about reality" (Deutsch and Gerard, 1955). In regard to this aspect of social influence, people may be seen as sources of information about how to react during situations characterized by uncertainty (Kinateder, 2012).

Literature argues that these social influences (i.e. informative and normative) may be an important environmental factor during evacuations as a way to deal with the perceived uncertainty associated with these situations (Kinateder, 2012; Lovreglio et al., 2014a; Nilsson, 2009). Thus, during evacuations other people may be seen as both a source to understand what is happening and an example of how to behave (Informative Social Influence). On the other hand, the social norms that emerge during emergencies may also force people to behave differently in order to avoid embarrassment (Normative Social Influence).

Another theory that can be useful to explain the social interaction that occurs during emergencies is Cialdini's social proof theory (Pan et al., 2007). This theory argues that people use to determine what is correct by finding out what other people think is correct (Cialdini, 1993). This kind of social influence occurs whenever people question the best behaviour to adopt in unclear or ambiguous circumstances.

These theories are useful to explain herding behaviour as a decision-maker's tendency of putting aside his or her ability to function as an individual in order to behave as a part of a group by transferring control over his actions to others (Helbing et al., 2002; Saloma and Perez, 2005). According to Helbing et al. (2002) the transition between the rational normal behaviour and the apparently irrational panic behaviour is directly related to the level of nervousness of a decision-maker, even if herding behaviour can be seen as the result of a rational process. In fact, this behaviour is also observed in non-panic contexts. Pan (2006) argues that many different factors can influence this behaviour and that the main factor is the perceived uncertainty related to the lack of the information that people need to judge a situation and make a decision (Kuligowski, 2013). Other factors are the perceived importance (severity of a situation as perceived by an individual), the perceived urgency (time available to make a decision), the stress level and the stress threshold (Pan, 2006). Kunreuther et al. (2002) argues that herding behaviour occurs whenever individuals have little experience dealing with high-stakes decisions. Saloma and Perez (2005) also state that the occurrences of herding behaviour increase by lack of self-confidence or training.

Herding behaviour is a perfect instance of social proof theory because under uncertainty people may interpret group behaviour as the correct one. Furthermore, this behavior can be shown as an instance of Informative and Normative Social Influence. In fact, people can choose the more congested exit because they either think that the exit is the only one available (Informative Social influence) or they don't want to risk choosing an alternative route not previously chosen by the majority (Normative Social Influence).

3. Models of Herding Behaviour

The complexity of human behaviour during emergencies has led to the development of a variety of evacuation models (Kuligowski et al., 2010; Zheng et al., 2009; Gwynne et al., 1999; Johnson, 2005). These models are based on several approaches, which include cellular automata models, lattice gas models, social force models, fluid-dynamic models, agent-based models, game theoretic models, and approaches based on experiments with animals (Zheng et al., 2009).

Lovreglio et al., (2014c) provide an overview of the different approaches used to model herding behaviour. Some of these approaches relate the occurrence of herding behaviour with the degree of panic and the imitation tendency of individual accounted for by deterministic parameters (Helbing at al., 2000; Saloma and Perez, 2005). Other approaches are based on either agent or rule based models (Pan et al., 2007; Korhonen, 2011).

Almost all the models available in literature focus on deterministic approaches. This work deals with the possibility to model herding behaviours by using a probabilistic approach based on the Random Utility Model. RUMs have been widely used in econometrics and have had many useful applications in a diverse range of engineering fields. Different authors have used these models in pedestrian modelling (Lovreglio et al., 2014b; Ren-Yong and Hai-Jun, 2010; Antonini, 2006). The probabilistic approach offered by RUMs is better than the deterministic one, in modelling behavioural uncertainty related to discrete choice, because they can explain differences, heterogeneity and uncertainties of the choice process. On the contrary, the deterministic approach only captures average decision-makers's behaviour (Hensher et al., 2005; Train, 2009).

The present study makes use of a Mixed Binary Logit (MBL) model. In the MBL, the parameters of the utility functions are assumed to be randomly distributed. This allows accounting for the variations in the preferences of decision makers, and so to obtain higher degrees of fitting. MBL have been widely used in transportation studies and are well suited to predict discrete choice behaviour during evacuations (Lovreglio et al., 2014b). In this work, the dependent variable assumes a value of 1 if the most crowded exit is chosen instead of the least crowded one. The utility function for the two options can be written as:

$$U_{HB} = V_{HB}(\beta_i, X_i) + \varepsilon \quad (1)$$

$$U_{noHB} = V_{noHB}(\beta_j, X_j) + \varepsilon \tag{2}$$

Where U_{HB} and U_{noHB} are the utility functions respective of the most and the least crowded exits. Utilities are the sum of a systematic quantity (V_{HB}, V_{noHB}) depending on environmental and socio-economic variables (X_i) and a Gumbel distributed random residual (ε). Setting V_{noHB} equal to zero (as reference utility) creates the probability to evacuate through the most crowded exit to become:

$$\overline{P_{HB}} = \int \frac{\exp(U_{HB})}{1+\exp(U_{HB})} f(\beta_i, \alpha_j) d\beta_i \tag{3}$$

where f is the probability density function of β_i coefficients, and α_j represents the generic parameter of f.

4. Methodology

The methodology proposed in this work is divided into three main consecutive areas: Preliminary Analysis, Qualitative Analysis and Modelling and Behavioural Analysis (Fig. 1).

In the first step, an analysis of the data collected by Lovreglio et al. (2014a) is performed in order to check whether respondents showed a herding behaviour. Next, different hypotheses are proposed to explain the occurrence of this behaviour. Some preliminary models are estimated to test these hypotheses.

The second step involves face-to-face interviews. The main goal of these interviews is to understand if what is observed as herding behaviour and not the result of the behavioural uncertainty (Ronchi et al., 2013). Moreover, these interviews allow us to have a better understanding of the mental mechanisms that occur when people show herding behaviour.

The third step deals with the modelling and behavioural analysis step. The goals of this step are the determination of the optimal model and the behavioural analysis of this model based on the answers given by the interviewees using statistical criteria coming from the scientific literature.

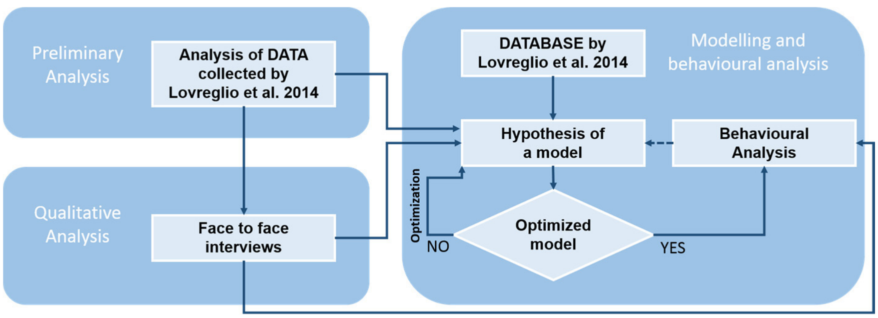

Fig. 1. Methodological scheme.

5. Case Study

The data used in this work includes stated preferences of 191 people concerning twelve different choice scenarios characterized by three variables:

- The position of the interviewee in the closed environment (NEAREX).
- The number of people present near the two exits (NPE).
- The number of people present near the interviewee (NPDM).

Figure 2 briefly illustrates the context of choice. The survey is fully presented in Lovreglio et al. (2014a).

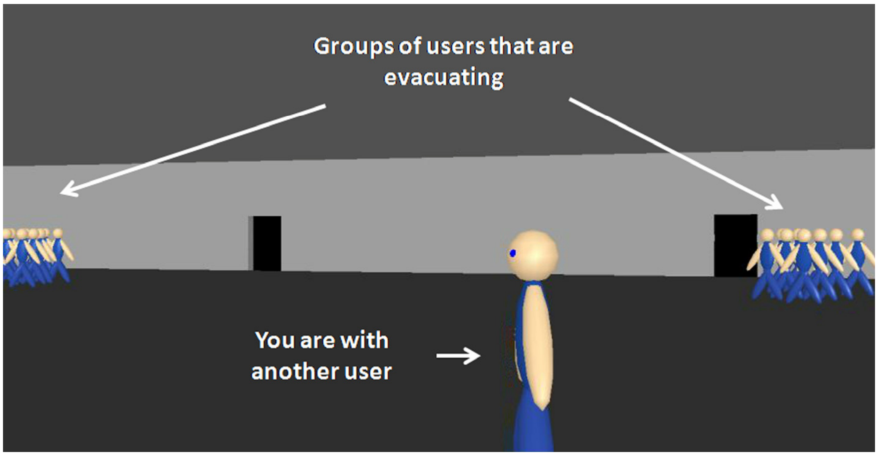

Fig. 2. Context of choice (Lovreglio et al., 2014a)

5.1. Preliminary data analysis

The model estimated by Lovreglio et al. (2014a) is a mixed logit model with several random parameters. One of these parameters is that associated with the number of people closest near to the two exits (NPE). Figure 3 shows the normal probability density function (PDF) of this parameter.

This PDF shows that NPE is not perceived uniquely as a disutility. In other words, sometimes some respondents choose the most crowded exit. Table 1 reports an analysis of the occurrences of this behaviour that have been collected.

The survey includes 12 scenarios of choices, but in only 10, there are different numbers of people near the two exits. Table 1 shows that, at times, respondents prefer the most crowded option. Table 2 shows how many times respondents choose the most crowded exit in each of the 10 scenarios. From the last column, it can be seen that the most crowded exit is chosen in some scenarios more often than in others (e.g. scenario 1 vs. scenario 5). This implies that both environmental variables and herding behavior affect the exit choice.

The next step of this work is to understand why and when people choose the most crowded exit and if this behaviour can be labeled as herding behaviour. Thus, a qualitative analysis based on face-to-face interview was made in other to find an answer to these questions.

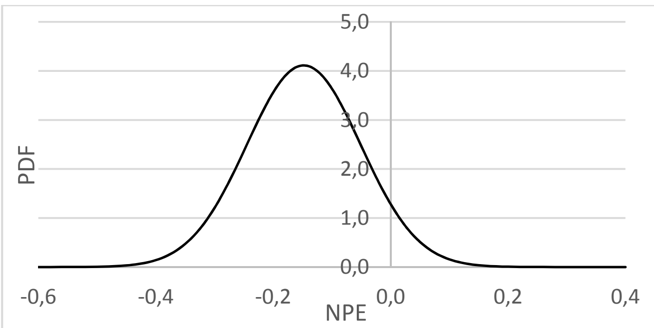

Fig. 3. Probability Density Function (PDF) of NPE parameter.

Table 1. Number of times in which the most crowded exit was chosen (NoT) vs. Number of respondents (NoR)

NoT	10	9	8	7	6	5	4	3	2	1	0
NoR	0	2	2	3	8	6	22	27	33	46	42

Table 2. N respondents who chose MCE for each scenario (NPE: number of people near exit 1/2; NPDM: number of people near decision maker; DM: decision maker; MCE: the most crowded exit; L: left; R: right; C: centre).

Scenarios	NPEExit1	NPEExit2	NPDM	DM Positions	N respondents who chose MCE
1	0	5	1	L	61
2	20	10	1	R	37
3	0	10	4	C	45
4	10	10	0	L	--
5	20	5	4	C	28
6	0	20	8	R	39
7	10	20	1	C	40
8	5	5	0	R	--
9	10	5	8	C	36
10	5	20	4	L	37
11	5	0	1	C	46
12	10	0	4	R	45

5.2. Qualitative analysis

A supplementary survey was carried out with 14 volunteers. They were asked to complete the same survey proposed by Lovreglio et al. (2014a). After this survey, a face-to-face semi-structured interview was performed with each of the volunteers. The main goals of these interviews are to understand both the overall strategy used by respondents and why they chose the most crowded exit during their survey.

During these interviews, the volunteers were asked about the main strategy they used to make the choices they made, the factors that influenced their choices and their general perception of the scenarios.

The main two strategies stated by the respondents were:

- Strategy A: I have chosen the least crowded exit in order to evacuate as soon as possible.
- Strategy B: I have chosen the most crowded exit to avoid evacuating alone.

People who follow strategy B stated that that was due to the uncertainty related to the situation of choice (i.e. the absence of signs) and of information about the places where the two doors lead. Thus, respondents tried to fill that gap using other people's behaviour as a source of information. This can be seen as a case of Informative Social Influences. However, no respondent stated that he/she would avoid choosing the least crowded exit because he/she fears making a counter-cultural choice by making a choice different from the majority. This can be because other agents involved in the virtual environment cannot see respondents' choice. Some respondents, that chose to follow strategy A, chose the most crowded exit when the least crowded was completely empty. They stated that this was due to the perception that this empty exit is not safe. Contrarily, respondents who follow strategy A, chose the least crowded exit when there were similar crowds near the exits and the least crowded one was also the nearest. As demonstrated, the distance of an exit could influence the choice.

It can be concluded that the face-to-face interviews have proved the presence of herding behaviour in the data collected by Lovreglio et al. (2014a). A better understanding of what influences the occurrences of this behaviour can be made through a binary mixed logit analysis.

5.3. Modelling

A Step-wise procedure is used to estimate the MBL that best fits the data. The model is estimated through the method of maximum likelihood and has an adjusted R2 equal to 0.27. The model includes the following variables:

- DIFM: difference between numbers of people close to the most crowded exit and to the least crowded one for male decision maker;
- DIFF: difference between numbers of people close to the most crowded exit and to the least crowded one for female decision maker;
- STUD: dummy variable, equal to 1 when decision maker states to be student;
- APM: dummy variable, equal to 1 when there is nobody close to the least crowded exit and the decision maker is male;
- APF: dummy variable, equal to 1 when there is nobody close to the least crowded exit and the decision maker is female;
- WEIGHT: weight of decision maker.

The results are presented in Table3.

Table 3 – Optimal Mixed Binary Model

Restricted log likelihood = -1531.855 Log likelihood function = -1109.101				
Variable	Coefficient	Standard Error	t-student	P-value
Random parameters				
DIF_M	-0.033	0.015	-2.194	0.028
DIF_F	-0.082	0.023	-3.617	0.000
STUD	-0.834	0.172	-4.840	0.000
Non-random parameters				
AP_M	0.377	0.131	2.890	0.004
AP_F	0.594	0.185	3.211	0.001
WEIGHT	-0.009	0.002	-3.632	0.000
Derived standard deviations				
NsDIF_M	0.053	0.014	3.721	0.000
NsDIF_F	0.096	0.021	4.517	0.000
NsSTUD	0.950	0.140	6.789	0.000

Three of these parameters have normal distributions (DIFM, DIFF and STUD). This model also shows systematic variations in decision-maker tastes due to gender (DIFM, DIFF, APM and APF). A panel data approach is used in order to consider the correlation between the replies of individuals who responded to the different scenarios proposed in the stated preference investigation (Train 2009). Finally, a number of 300 Halton draws are used to estimate the random parameters (Hensher et al., 2005).

6. Discussion and Conclusion

The model proposed in this work allows for the prediction of the probability of a person to manifest herding behaviour in exit choice. A more detailed interpretation can be done by analysing the signs of the estimated parameters. In general, the greater is the difference of the number of persons close to the most crowded exit and the least crowded exit, the lower is the probability of exhibiting herding behaviours. That means, when the difference is too big, a decision maker prefers the least crowded exit because the most crowded one requires high evacuation time. This tendency is more evident for females (DIFF<DIFM); however, DIFF and DIFM are both random parameters with a normal distribution (Figure 4). Figure 4 underlines that both parameters have a high probability to assume positive values. There are people who perceive this difference as a utility for herding behaviour.

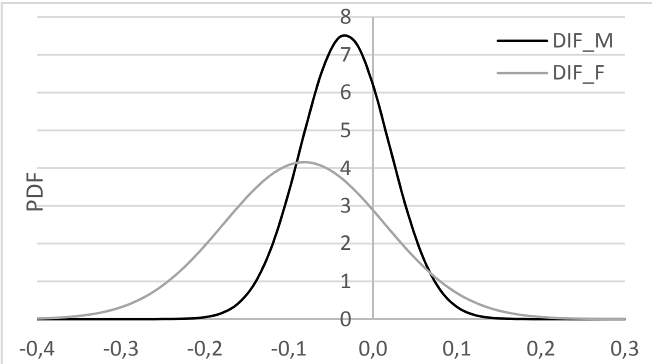

Figure 4 – Probability Density Function (PDF) of DIFM and DIFF parameter.

The model shows that in the case in which the least crowded exit has no people in the exit a decision maker is more likely to manifest herding behaviour. That may be due to the more perceived uncertainty as observed during the interview during the qualitative analysis (Section 5.2).

Other two social-economic variables that directly influence the occurrence of herding behaviour are depicted in the model (STUD and WEIGHT). The first one shows that students are less predisposed to manifest herding behaviour. This parameter, however, has its own normal distribution, that underlines the heterogeneity among the students. Moreover, the weight of decision maker is a disutility. That means people with a greater weight tend to avoid the most crowded exit. One explanation may be because these people may have greater difficulty in the interaction with a large number of people.

This work has the same limitations introduced by Lovreglio et al. (2014a). One of the main limitations of this study is the impossibility to recreate a real emergency by using an online survey. In fact, this technique does not allow reproducing the state of stress that is typical during emergency situations. Moreover, the sample used in this study is quite homogeneous (almost all respondents are students). These limitations may make the results of this study questionable (Nilsson, 2009; Myers, 2002).

This work shows that social influences are the basis of the occurrences of herding behaviour in exit choice during evacuations. An approach based on Random Utility Models is useful to model the human uncertainty related with this behaviour. In our experience, face-to-face interviews are useful both to have a general understanding of the problem and to get a model that fits the data better.

Clearly neglecting the influence of herding behaviour proved by our research can lead to particularly biased results in evacuation situations characterised by the presence of very large groups of persons, such those which may occur in transport infrastructures during peak periods. Hence to avoid tragedies such those remembered at the beginning of the paper – or at least to reduce their cost in terms of human lives – it is particular to provide transport infrastructure engineering simulation tools which take full account of the social influences in the decision making process under emergencies. Further work along this direction should include research on the relation between herding behaviour and features specific of transport infrastructure, for instance the particular geometry of tunnels.Discussion and Conclusion

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