A Review on the Influence of Social Attachment on Human Mobility During Crises

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ABSTRACT

Human behaviour during crisis evacuations is social in nature. In particular, social attachment theory posits that proximity of familiar people, places, objects, etc. promotes calm and a feeling of safety, while their absence triggers panic or flight. In closely bonded groups such as families, members seek each other and evacuate as one. This makes attachment bonds necessary in the development of realistic models of mobility during crises. In this paper, we present a review of evacuation behaviour, theories on social attachment, crises mobility, and agent-based models. We found that social attachment influences mobility in the different stages of evacuation (pre, during and post). Based on these findings, we intend to develop a multi-agent model of mobility during seismic crises, using the belief, desire and intention (BDI) agent architecture.

Keywords

Multi agent modelling, social attachment, affiliation, human behaviour, mobility

INTRODUCTION

The *mobility* of individuals during evacuations is of paramount concern during disasters. Quick thinking and decision making to move immediately towards a safe area saves individuals from danger. Mobility is influenced by: physical factors such as age, gender, body type; human factors such as emotions (calmness, level of fear, contagion) and cognitive aspects (knowledge and experience); environmental factors (presence of obstacles, obstruction, facilities promoting mobility); and social interactions and attachment, such as to family members or to specific places.

This paper focuses on the influence of *social attachment* and how it affects mobility in crisis situations. By social attachment we mean the strong and weak bonds produced by relationships and interactions of individuals with others, namely family members, close kin, friends, colleagues, authority figures (leaders), and even strangers. We also include the influence and affiliation to familiar objects, places and tasks (such as, personal belongings, the home and continuing to work, respectively) which are closely associated with these bond-related social interactions. The goal of our work is eventually to develop of a multi-agent model simulating human behaviour during crises situations, integrating social attachment. The simulator will be used to investigate the effects of attachment bonds on the mobility of individuals and emergent groups during evacuations in crisis scenarios. In particular it will look at the nuances where attachment is beneficial or detrimental in the evacuation of large populations during crises.

A computational *agent* is a discrete entity defined in terms of its attributes and behaviours. Wooldridge and Jennings describe agents to be autonomous, operating without direct human intervention, having social ability (i.e. interacts with other agents), able to perceive and respond to their environment, and exhibiting goal directed

behaviour (Wooldridge and Jennings, 1995). Gilbert and Troitzsch adds that agents can be constructed to simulate some simplified aspects of human intentions which can include beliefs, desires, motives and emotions (Gilbert and Troitzsch, 2005). Multi-agent systems (MAS) allow heterogeneous agents to cooperate according to complex modes of interaction (Ferber, 2007). MAS have been used to investigate several phenomena and have proven to be a powerful tool for modelling in the social sciences and other related fields (Kravari and Bassiliades, 2015). Among the MAS architectures, a belief, desire, and intention (BDI) approach is ideal for modelling people (Adam and Gaudou, 2016). From Adam and Gaudou, BDI attempts to capture the common understanding of how humans reason with: *beliefs* which represent knowledge of the environment and the agent's self or internal state, *desires* or the goals the individual decides to achieve, and the *intentions* which describe a set or sequence of steps needed to achieve the determined goals (Adam and Gaudou, 2016). Still from the same authors, BDI architecture allows an agent to *err*, by having subjective representations of the environment in terms of beliefs that can be incomplete, flawed or different from other agents, can communicate and reason with other agents, have the ability to explain behaviours, exhibit emotion, able to internalize norms, and capable of making independent decisions.

Agent based modelling (ABM) involves the representation of human behaviour in a geographic space, participating in social interactions within a computational environment. In our model agents represent humans and are autonomous and are endowed with mobility through human physical, cognitive, emotional and social attributes in the simulated space. Non-human objects such as pathways (doors, hallways, alleys and roads) and obstacles (walls, barriers, debris, natural features like rivers), define spatial geometry, delimit human agent behaviour, and can either facilitate or restrict movement and social interaction. Agent interactions can produce groups, or large crowds with characteristic behaviours emerging from particular situations such as evacuations during crises.

The structure of this paper is as follows. The next section presents the state of the art in behaviour modelling for crisis, and is further divided into subsections: trends in human behavioural modelling during crises, reactions to crisis, the stages of evacuation, mobility, and human behaviours observed during evacuations. The next section then presents the relevant social theories on attachment that explains these behaviours. Agent based models of social attachment are discussed in a further section. The paper closes with a discussion, conclusion and some ideas for future work.

STATE OF THE ART IN BEHAVIOUR MODELLING FOR CRISES

Trends in Behaviour Modelling for Crises

Human behaviours in evacuations are social in nature (B. Aguirre, 1983; Chu, Pan, et al., 2011) and understanding social and group processes during evacuations such as the activation of existing bonds during threat, formation of new ties leading to the creation of groups, and interactions between individuals and groups, can lead to the development of more realistic behavioural models.

A recent trend in crowd modelling is the development of intelligent agents incorporating social and psychological factors (Zhou et al., 2010). A fundamental understanding of these factors in the context of pedestrian evacuation behaviours is needed to develop more realistic computer simulations (E. Galea, 2003; Chu, Pan, et al., 2011). Current egress simulation tools however lack human and social behaviours (Chu, Pan, et al., 2011). Social group process modelling and evaluation of its impacts to human behaviour is also very weak (Zhou et al., 2010; Santos et al., 2004). Johnson et al. shares this view and stresses the need for the better psychological understanding of group behaviour on decision making (P. F. Johnson et al., 2011). Agents should have the capability of identifying themselves with a group and able to resist separation, as enhancements to current models (Samuelson, 2011). Peacock et al. also recommend that future research should investigate how interactions between people within groups alter individual speeds (R. Peacock et al., 2011). Considering these behaviours in the development of evacuation plans by cities and municipalities can greatly enhance plan effectiveness (Urata and Hato, 2012).

Reactions to Crisis

Disasters can be characterized by the time of occurrence and the availability of warning. Sudden onset events occur without warning and last a few seconds, such as earthquakes, terrorist attacks, industrial accidents, landslides, etc. (Norton et al., 2013). People are generally caught unaware and unprepared in these events. Longer duration events such as fire, tsunami, typhoons, floods can often be anticipated and warning is usually available, allowing people to prepare or evacuate.

Emotional reactions to crises are triggered by environmental or social cues and shape behaviour. These include fear, confusion, anger, bewilderment, etc. which either starts, hastens, stalls or stops evacuations. In a group, emotional cues are quickly detected by members and affect the behaviour of the group (Papelis et al., 2011). Without

appropriate cues and knowledge, people may wait and see or evacuate improperly (P. F. Johnson et al., 2011). The decision to evacuate can be facilitated by: (1) observations of the threat, (2) instructions to evacuate, (3) fear, (4) evacuation of friends and co-workers, and (5) previous evacuation experience (Averill et al., 2005). People tend to adjust their behaviour with respect to the severity of the threat, and generally do not evacuate at the same time (Sorensen, 1991).

Evacuation

Evacuation is the temporary mass physical movement of people that collectively emerge from coping with threats, damages or disruptions (B. Aguirre, 1983). Success in evacuating people to safety is characterized by the time needed to evacuate and the time available to reach safe areas (Averill et al., 2005; Kuligowski and Hoskings, 2010). Delayed evacuation has been the cause of many deaths during disasters such as in the September 11, 2001 terrorist attack on the World Trade Center (WTC) in the United States (Averill et al., 2005); and the 2011 Great East Japan earthquake and tsunami (S. Fraser et al., 2012). Stages of evacuation includes pre-evacuation, evacuation and post-evacuation. Most of the delays are from behaviours during the pre-evacuation stage such as seeking information, group formation, inaction due to freezing, or continuation of current activities due to non-recognition of the threat (Kuligowski and Hoskings, 2010). Helping or assisting mobility impaired individuals occurs during the pre-evacuation and egress phases. Although this increases the chances of survival of the mobility impaired, it delays the effective evacuation of the altruistic individuals and their group (Averill et al., 2005; R. Peacock et al., 2011; Daamen and Hoogendorn, 2011).

Gwynne notes that data on evacuations are needed in the development of plans, and are critical for the responsible engineering design of structures, but these are difficult to find, understand and apply (Gwynne, 2011). Gwynne traces this difficulty back to several factors: the relative immaturity of the domain, comparatively recent realisation of the importance of human behaviour in egress calculations, technical factors with respect to data collection methods, privacy and commercial sensitivity of results, and other procedural and political factors.

Mobility during evacuation

Most evacuation research is based on the mobility of normally able adults (Larusdottir and Dederichs, 2011). Therefore the developed plans are unrealistic, as they do not include the mobility impaired which comprise substantial portions of the population. Ten to twenty percent of the population of European countries for example have mobility impairments (Bengston et al., 2011). Globally, the ageing population (aged sixty years or over) is growing faster than any age group particularly in advanced countries and most live in urban areas (United Nations, 2015). Mobilities of elderly people diminish over time, impaired by decreased eyesight, hearing and wayfinding abilities (Bengston et al., 2011). Walking speed also decreases with age (Bohannon, 1997). Stairs provide a particular difficulty for disabled people during evacuations, as well as opening heavy doors (Bengston et al., 2011). Children need assistance during evacuations in locations such as from the home and in schools. Larusdottir and Dederichs found that evacuation characteristics of children, such as travel speeds in horizontal planes and down spiral stairs, and the flow through doors, is very different from those applied in simulations from literature (Larusdottir and Dederichs, 2011). Medical conditions such as arthritis, cerebral palsy or pulmonary, cardiac or other illnesses also limits mobility (Averill et al., 2005; Manley, 2012). Evacuating people with reduced mobility especially from multi-storey buildings is a difficult task (Adams and E. R. Galea, 2011). For tall buildings, most evacuations occur in staircases with longer evacuation routes, amplifying the possibility of failure due to fatigue and decline of physical strength of evacuees (Choi et al., 2011).

Altruism and helping behaviours are common during crises (Cocking et al., 2007). Groups with mobility impaired members, particularly the disabled, tend to remain together at the speed of the slowest member, and this clumping effect constricts pathways effectively slowing the evacuation speeds of other individuals and groups in the same location (Samuelson, 2011).

Evacuation speeds (meters/second) of individuals with different mobilities and scenarios of locomotion have been collected from several studies and are presented in Table 1. The use of a range of speeds rather than single values as attributes of agents in models can produce more realistic simulation results (R. Peacock et al., 2011). Changes in speed at different intervals during evacuations can be due to different interactions with other evacuees facilitated by differences in characteristics and physical abilities (Choi et al., 2011). Individuals carrying objects or persons during evacuations are generally slower (R. Peacock et al., 2011). In some cases evacuations can be triggered. For example, seeing a child in trouble could invoke a rapid response in another person.

The force of the disaster can also affect mobility. During an intensity six earthquake for example, many will find it difficult to remain standing (S. Fraser et al., 2012; H. O. Wood and Neumann, 1931; Grunthal, 1998), forcing

Table 1. Evacuation Speeds

Source	Mode	Category	Individual (m/sec)	Group (m/sec)
(Kady and Davis, 2009)	Crawl	All body types	0.65 - 0.90	
(Adams and E. R. Galea, 2011; Kady and Davis, 2009; S. A. Fraser et al., 2014)	Walk	Children Adult Elderly	0.56 - 0.84 0.91 - 1.73 0.70 - 1.11	- 0.88 0.75
(Adams and E. R. Galea, 2011; N. J. Wood and Schmidtlein, 2012)	Run	Children Adult Elderly	1.14 - 2.23 1.78 - 3.83 -	
(Shi et al., 2009; Boyce et al., 1999)	Disabled	All types	0.10 - 1.77	0.21 - 1.98
(Adams and E. R. Galea, 2011)	Rescue device	All types		0.55 - 1.5
(Larusdottir and Dederichs, 2011; R. Peacock et al., 2011; S. A. Fraser et al., 2014)	Stairs	Children Adult Elderly	0.25 - 1.4 0.056-1.7 0.21	

people to crawl instead of walking or running to exits. Debris can block pathways or completely trap individuals. Poor visibility from dust, smoke or absence of lighting/power can hinder mobility during evacuations. Congested pathways and exits due to crowding can also slow down egress (Choi et al., 2011).

Evacuation Behaviour

Averill et al.'s study of the September 11, 2001 terrorist attack on the WTC in the United States revealed several behaviours during the crisis (Averill et al., 2005). This well studied event can provide insights into earthquake, fire, and terrorist bombing incident-related behaviours as: (1) most of the building occupants felt the shaking of the building first, and the eventual collapse of the structures, similar to a very strong earthquake; (2) spread of fire and smoke in several floors; and (3) terrorist attack when the cause of the explosions became known (Averill et al., 2005). Pre-evacuation behaviours include: (1) talking to others; (2) gathering personal items; (3) helping other people; (4) searching for others; (5) talking on the phone; (6) moving between floors. Occupants sought information ('milling' behaviour) prior to evacuation from face-to-face conversations, telephone, television, or radio, e-mail or hand-held devices, and from building announcements.

Selfish behaviours are rare during disasters and what has been observed is the prevalence of altruism, with people helping others (Cocking et al., 2007). In the WTC event (Averill et al., 2005), many survivors reported giving and receiving help during their evacuation. Occupants helped others even when aware of the heightened risk, before proceeding with their own evacuation. Twenty percent (20%) reported being helped by someone and thirty percent (30%) helped others. Individuals helped others with mobility impairments induced by injury, disability, heath conditions, pregnancy and age. Sources of help included co-workers; manager/supervisor; floor warden, police officer/fire fighter and strangers. However, it should also be noted that some who helped other people perished due to delayed evacuation times and were caught in the structural collapse of the WTC Towers 1 and 2.

Helping behaviour between strangers was also reported by Drury et al. during the evacuation of survivors from the London bombing of 2005 (Drury et al., 2009). They note that instead of personal selfishness and competition, survivors helped each other despite being among strangers. Interestingly panic was not reported by the interviewed survivors.

Cooperative behaviours were modelled by Urata and Hato (Urata and Hato, 2012) to understand the complications produced by the delayed evacuation of residents during the 2011 Great East Japan Earthquake and Tsunami. Cooperative behaviour included: information exchange about dangers and safe places, and mutual assistance to aid individuals with low mobility.

Group interaction was observed by D'Orazio et al. from the analysis of earthquake evacuation video data (D'Orazio, Spalazzi, et al., 2014). The observed groups: exchanged information, moved closer together, and evacuated away

from danger. Individuals either followed other individuals (leader-follower behaviour) or formed groups (herding or flocking behaviour). Their work was conducted to address the lack of post-earthquake human behaviour data and studies especially during the pre-evacuation phase. This was also an attempt by the authors to relate human behaviours to the assessment of seismic risk at the urban scale. Benefits of this include providing appropriate policy measures for disaster risk reduction (Bernardini et al., 2016). The authors developed an agent based evacuation model by modifying Helbing's Social Force Model from the derived pedestrian behaviours.

Leader-follower behaviour was also implemented by Beck et al. in modelling crisis mobility of pedestrians during earthquakes in Lebanon and Argentina (Beck et al., 2014). Agents are able to perceive other agents, move and follow leaders.

Flight behaviour is one of the strongest features of mass behaviours in Italian earthquakes (Alexander, 1990). This anxious behaviour can traced back to previous hazard experiences such as the eruptions of Mount Vesuvius, existence of other hazards and the poor structural integrity of old buildings. During tremors, residents generally seek out family members, run outdoors and regroup with other members. Those away from home, return to check on family members and resulting damage to their dwellings.

Close family relationships is also highlighted in Jon et al.'s study of behaviours during the Christchurch, New Zealand and Hitachi, and Japan earthquakes (Jon et al., 2016). Notable behaviours included: (1) contacting family members, (2) protecting children, (3) going home, (4) going to the home of a relative, or friend. This agrees with the findings of Mikami and Ikeda who found that people during disasters tend to get together with family members; and try to ensure the safety of all members and evacuate together (Mikami and Ikeda, 1985). These behaviours were also reported by survivors in the 2011 Great East Japan earthquake and tsunami. However many people died unnecessarily due to delayed evacuation or non-evacuation from adressing social or parental responsibilities (S. Fraser et al., 2012). Heath et. al., in the study of household evacuation during the California 1997 floods, found that households with children successfully evacuate, more than those without (Heath et al., 2001). This can be explained by the need of parents to protect their children. The authors also found that some households treat pets as family members and owners prefer to stay with pets or due to the logistical difficulties of capturing or transporting pets, owners stay at home.

The aforementioned examples demonstrate the social nature of human behaviour during crisis evacuations. These are governed by social bonds that are either strong and fixed such as within family members or weak and dynamic with friends or colleagues, or strangers. These ties strongly influence behaviour when individuals evacuate as families, groups of strangers, or large crowds.

The novelty of the work is the incorporation of human bonds/relationships and social groups in a multi agent based model for crisis evacuations for a large city using real geographic data. This work advances previous works by considering: (1) different documented evacuation behaviours (grounded on social theories), (2) a large heterogeneous population of agents with different attachment bonds, demographic characteristics and mobilities, and (3) interactions within a large geographic area. If successful the work could have significant impact in validating and improving crisis management plans.

A summary of the behaviours during disasters is shown in Table 2. We categorized the behaviour into the three evacuation stages and give specific actions.

SOCIAL ATTACHMENT AND RELATED THEORIES

We define social attachment in the context of bonds between individuals. This is developed from childhood within the family and modified towards adulthood from social interactions. These attachment bonds regulate behaviour whenever social interactions occur. Evacuations, as social events, are either facilitated or hampered by these social ties. Attachment bonds can affect crisis behaviour by regulating fear (dampening or amplifying panic); create groups and crowds; promote altruism between strangers and among group members; and create orderly behaviour during egress.

The effects of social social attachment on evacuation behaviour can be explained by the following theories. These theories have been selected as being those that most accurately explain evacuation behaviours. (1) Normative Theory is presented as the default behaviour where the assumption is that behaviours in daily life are still the norm during disasters; (2) Emergent Norm Theory modifies Normative Theory and explains abnormal behaviours during crises events; (3) Panic Theory is the common explanation used to explain seemingly chaotic and unexplained behaviour; (4) Attachment Theory explains the calming effects that are provided by attachment figures enabling individuals to control fear thus avoiding panic; (5) Social Attachment Theory defines attachment specifically for disaster events, emphasizes the role of bonds with familiars, and proximity seeking behaviours; (6) Social Baseline

Table 2. Evacuation Behaviour

Stage	Behaviour	Action	Source
Pre-evacuation	Seeking information	Milling, talking to others (by phone, face to face)	(Averill et al., 2005; Bernardini et al., 2016; D'Orazio, Quagliarini, et al., 2014; Kuligowski and Hoskings, 2010)
	Seeking family members/other people	Calling, searching	(Jon et al., 2016; Mikami and Ikeda, 1985; S. Fraser et al., 2012; Alexander, 1990)
	Manage objects	Get belongings, shut down computers, turn off power/gas	(Averill et al., 2005)
	Freeze	Stay in place	(Prati et al., 2012; Lindell et al., 2016)
	Maintain activity	Continue working, driving	(Averill et al., 2005)
	Seek protection	Drop-cover-and hold on	(M. M. Wood and Glik, 2013; D'Orazio, Spalazzi, et al., 2014)
	Helping	Protect others, assist mobility impaired (children, pregnant women, elderly, disabled, injured)	(Urata and Hato, 2012; Kuligowski and Hoskings, 2010)
Evacuation	Flight	Move (walk, run, crawl), use stairs, elevator, head home, go to nearest exit or safe area	(S. A. Fraser et al., 2014; Kady and Davis, 2009; Kuligowski, R. D. Peacock, et al., 2015; Alexander, 1990; Averill et al., 2005; D'Orazio, Quagliarini, et al., 2014)
	Following	Follow leader, herding, flocking	(Beck et al., 2014; D'Orazio, Quagliarini, et al., 2014)
	Helping others	Assist mobility impaired	(Cocking et al., 2007; Averill et al., 2005)
Post Evacuation	Regrouping	Regrouping with family members, friends, colleagues	(Prati et al., 2012)
	Helping/Rescue	Returning to danger area to rescue family member, friend, colleague	(S. Fraser et al., 2012; D'Orazio, Quagliarini, et al., 2014)
	Recover objects	Return home to get supplies	(Prati et al., 2012)

theory explains the tendency of individuals to maintain close proximity and the role of risk assignment; (7) Social Defence Theory defines ideal types of members in a group to achieve optimal survival; (8) Self Categorisation Theory explains the process where individuals transition to become members of groups; Finally (9) Social Identity Theory describes the role of shared identities and bond formation between strangers, effectively addressing the limitations of Social Attachment Theory.

Other related theories such as social comparison theory (Festinger, 1954), decision making theory (Chu, Pan, et al., 2011; Mintz, 1951), contagion (Wijermans, 2011), social proof (Cialdini, 2006), and proxemics (Hall, 1990) will not be discussed as these do not directly deal with social bonds.

Normative Theory states that everyday social rules and roles that govern daily life can also be observed in emergency situations (Chu, Pan, et al., 2011). Examples of these are: respecting and helping elders, caring and prioritizing children, aiding the disabled, following traffic rules, following authority figures, and maintaining social organisation. Normative theory therefore assumes the predictability of human behaviour during disasters. Expected proper behaviour during disasters are prescribed in manuals and evacuation plans and practised in drills. Social norms are likely to be followed during slow evolving disasters where there is longer time available to evacuate (Frey et al., 2011).

Illogical behaviours however are observed during disasters and can be due to the differences in how individuals handle the stresses imposed by crises. Under extreme stress, cognitive reasoning is affected. For example, individuals may follow familiar but not optimal evacuation pathways or may forget about learned routes and exits from drills (Rai and Wong, 2009). Stresses during crisis also make individuals prone to cognitive biases, distorting judgement and decision making leading to undesireable consequences (Comes, 2016; D. Johnson and Levin, 2009; Murata et al., 2015).

Emergent Norm Theory posits that crisis destroys traditional normative guidelines defining appropriate behaviour, and individuals, because of the urgency of the situation. People are forced to interact and create new meaning or norms to guide behaviour (B. E. Aguirre et al., 1998). Also, once a dominant norm is defined, group members with differing opinions keep quiet for fear of group censure. Aguirre et al. (B. E. Aguirre et al., 1998) adds that enduring social relationships determine social interactions associated with the emergence of a dominant norm resulting from an instance of collective behaviour such as risk taking, use of resources and cooperation.

Panic Theory - Panic refers to inappropriate or excessive fear and/or flight (Mawson, 2005). It is where instinct, overwhelms socialisation, dissolves collective bonds, and survival becomes the objective of the individual resulting in competitive behaviours within the crowd (Strauss, 1944; Drury et al., 2008). Panic can be seen on two levels: (1) individual panic as disorganisation due to fear; and (2) mass panic as disorderly flight leading to disastrous results for crowds (Ma et al., 2011). Crowd stampedes for example are caused by panic leading to fatalities where people are crushed or trampled by the crowd (Helbing, Farkas, et al., 2000).

Mawson's review of the previous literature on panic yielded the following: (1) the following behaviours can be described as panic: manic or hyperactive behaviour, flight, aggression, desperate attacks on people, emotional explosion, agitation and motor restlessness, and immobility of freezing, (2) individuals experiencing panic are susceptible to social influence, such as being infected with fear, or mimicking the behaviour of others (looking when others run, escaping through the same exits as other people), and (3) deterioration of cognitive function and personality: temporary impairments in perception, cognition and control of motor impulses, difficulties in thinking, feelings of bewilderment, puzzlement, and confusion (Mawson, 2007).

According to Ma et al. panic prone individuals include: children, females, elderly, mobility impaired, those with strong beliefs, have poor knowledge, experiencing fatigue and weakened perception (Ma et al., 2011). Necessary conditions for panic to occur include: (1) a confining environment produced by structure, dark environment, or the crowd itself, (2) beliefs on the potential danger, and (3) triggers such as an earthquake or fire (Ma et al., 2011).

Many experts believe that mass panic is rare in disasters, largely a myth and unsupported by evidence (Cocking et al., 2007). Ma et al. however claim that panic exists in crowd disasters (Ma et al., 2011). Panic can be helpful in triggering flight allowing an individual to immediately seek shelter, the nearest exit and head to a safe area. Alternatively, it can be deadly, for example when the individual freezes delaying evacuation.

Social attachment can regulate fear and panic, thereby affecting evacuation behaviour. For example immediate flight is delayed when attachment is triggered such as seeking a relative or getting belongings. It can facilitate the flight of a calm parent upon hearing the cries of a crying child in panic (Heath et al., 2001).

Attachment Theory - Human beings as described by Bowlby have innate attachment behavioural systems motivating them to seek proximity to significant others (attachment figures) during times of need or threat (Bowlby, 1982; Ainsworth, 1989; Mikulincer and Shaver, 2007; Beckes and Coan, 2015). Attachment styles are described as

Table 3. Attachment figures and possible behaviours during evacuations

Attachment Figure	Examples	Example behaviour	Sources
Person	Child, spouse, parent, sibling, kin, friend, colleague, leader, mobility impaired, stranger	Seeking, calling, checking on the whereabouts, following, leading, helping, rescuing	(Jon et al., 2016; Averill et al., 2005; Drury et al., 2009)
Group	Family, relatives, friends, colleagues, authorities, crowd	Reuniting with members, following group (decision, direction), relocating to group's home, herding, , flocking	(Averill et al., 2005; Prati et al., 2012; Daamen, D. C. Duives, et al., 2014; D'Orazio, Quagliarini, et al., 2014)
Object	Personal property	Recovering personal property	(Averill et al., 2005; FSF, 2004)
Place	Home, exits, entrance, pathways, routes, designated safe area, elevator	Returning home, take familiar routes, head towards entrance, known exits/safe areas	(Jon et al., 2016; Prati et al., 2012; Cocking et al., 2007; Averill et al., 2005; D'Orazio, Quagliarini, et al., 2014)
Animals	Pets, farm animals	Staying home with pets, evacuating with pets	(Heath et al., 2001)
Task	Work, routine, driving, sleeping	Continuing with current task, getting luggage before evacuating aircraft during emergency	(Averill et al., 2005; FSF, 2004)
Information	News, announcements	Seek from conversations, radio, email, social media, etc.	(Averill et al., 2005; D'Orazio, Quagliarini, et al., 2014)

being secure, avoidant or ambivalent (Bretherton, 1994; Bowlby, 1982; Bowlby, 1988). Presence of attachment figures results in relieving and reducing stress and provides a sense of security (Ainsworth, 1989). Also, threats make individuals more aware of their attachment to a place and may influence decisions to stay or evacuate during dangerous situations (Anton and Lawrence, 2014). Attachment figures during evacuations are presented in Table 3.

Social Attachment Theory - Social attachment theory is based on Bowlby's attachment theory and is used to explain disaster scenarios. According to Mawson the response to a variety of threats and disasters is not to flee or attack but affiliation, or seeking the proximity of familiar persons and places, even if this involves approaching or remaining in a situation of danger (Mawson, 2005). Mawson also states that separation from attachment figures is a greater stressor than the physical danger itself. Whereas the presence of familiar persons and places have a calming effect.

Mawson argues that, this may provide an explanation of several evacuation behaviours such as the slow reaction of individuals within groups to warnings, delay in leaving work areas, and waiting for social group members before evacuating, and seeking family members.

The central ideas of this theory are: (1) the dominant motive in disasters is to maintain proximity to familiars, (2) flight involves the movement away from danger and towards people and places viewed as familiar, (3) flight-and-affiliation depends on perceived danger and social context (i.e. location and activities of familiars), (4) fear is diminished by proximity to attachment figures, (5) when an individual is close to attachment figures, in the presence of threat, intense affiliation behaviour is triggered, and does not cause flight, (6) moving as a group to maintain proximity during flight, (7) mild threats can induce flight-and affiliation behaviours when individuals are alone or with strangers (Mawson, 2005).

According to Mawson, there are four possible outcomes of individual and collective reaction to threat and disaster, presented in Table 4. (1) Top left: when attachment figures are present and the perceived degree of danger produces mild anxiety, affiliation is triggered producing increased attachment. Individuals tend to seek the proximity of familiar people and locations. (2) Bottom left: when attachment figures are present, and perceived danger is severe producing fear or terror, occasional or low-to-intense flight and affiliation is triggered resulting in orderly evacuation.(3) Top right: when attachment figures are absent, and the perceived degree of danger is mild, this

Table 4. Affiliative reactions to threat (Mawson, 2005)

		Attachment Figures (Predisposing Conditions)	
		Present	**Absent**
Perceived Degree of Danger (Precipitating Conditions)	**Mild Anxiety**	Affiliation (Increased attachment), Seek proximity with familiar people and locations	Low intensity Flight-and-Affiliation, orderly evacuation away from danger and towards the familiar
	Severe Fear/Terror	Occasional low-to-intense flight-and-affiliation; orderly evacuation	Intense flight-and-affiliation; mass panic

triggers low intensity flight-and-affiliation, resulting in orderly evacuation away from danger and towards the familiar, and (4) Bottom right: when the attachment figure is absent, and the perceived degree of danger is high, intense flight-and-affiliation is triggered resulting in mass panic.

Evacuation behaviours that can be explained by social attachment theory include: (1) individuals with close ties seeking each other and evacuating as a group, (2) movement to familiar exits and doorways (entrance), (3) delayed evacuation start (departure), (4) slow evacuation speeds, (5) slow reaction to warnings and waiting for primary group members, (6) reluctance to leave ones home, (7) preservation of social organisation, (8) mutual aid and cooperation, (9) calmness during evacuation, (10) going home, (11) seeking other survivors (formation of groups), and (12) reuniting with familiar people and surroundings (Mawson, 2005).

Cocking et al. identify the strength of social attachment theory over the panic model to be its emphasis on the maintenance of social bonds and the co-operative nature of groups during disasters (Cocking et al., 2007). Cocking and colleagues however identified two main drawbacks: (1) the pessimistic implications for large groups as it is more difficult to ensure safe evacuation of all group members; and (2) it discounts the possibility of developing attachment bonds and the eventual co-operation between strangers.

Social Baseline Theory - This theory provides the neuroscientific explanation as to why humans form social ties and seek proximity (Coan, 2008). Beckes and Coan believe that human brains assume proximity to predictable social environments, and when proximity is maintained or re-established, the brain is less vigilant for detecting potential threats (Beckes and Coan, 2011). Also from the same authors, humans utilize social resources or social proximity to conserve costly cognitive resources through social regulation of emotion. This includes the distribution of the task of detecting environmental risks across individuals within groups, inter dependence in achieving goals and providing help during times of need.

Social Defense Theory - extends Bowlby's and Mawson's attachment theories. Ein-Dor et al. claim that having some secure, anxious and avoidant members in a group provides unique survival advantages (Ein-Dor et al., 2010). Secure individuals are good leaders and are best at coordinating tasks. They are however slower to react to dangers because of proximity seeking behaviours. Anxious individuals are fast in detecting and reacting to danger and can act as sentinels of groups. Avoidant individuals are accustomed to looking out for their own interest and more likely rely on self-protective fight-or-flight reaction in times of danger. Primarily motivated to save themselves, they are the first to open exits, break windows and can define routes for others in the group to follow. This theory may help to explain the different behaviours found in a group of individuals.

Self Categorisation Theory - refers to the process where a person categorizes oneself as an individual or a group member involving a process of de-personalisation where the individual stereotypes themselves in line with the group. This process or self-categorisation as a group member makes crowd behaviour possible (R. H. Turner and Killian, 1987) resulting in a physical crowd of individuals who only share physical location; and the psychological crowd where people act together. Social behaviour observed in emergencies is a consequence of emergent self-categorisation rather than a function of pre-existing bonds, prior interpersonal relationships or interactions (Drury et al., 2008; Daamen, D. Duives, et al., 2014). Also, from the same study, this makes individuals transition and adapt to become part of a psychological crowd useful in surviving mass emergencies and disasters. This differs from self defense theory in that self categorisation theory focuses on a person identifying with a group rather than characteristics of individuals in a group.

Social Identity Theory corrects the limitation of the social attachment theory in the explaining behaviour with unfamiliar people, objects and places. Social attachment theory suggests that people may display panic behaviour

Table 5. Theories on Affiliation

Sources	Theory	Idea	Behaviour
(Chu, Pan, et al., 2011)	Normative	Social norms and bonds persist during disasters, social structure is retained	Normal, helping, cooperation
(B. E. Aguirre et al., 1998)	Emergent Norm	Dissolution or suspension of existing norms, creation of new norms (non traditional) from social interaction	Non-traditional/Illogical
(Mawson, 2005; Strauss, 1944; Drury et al., 2008; Ma et al., 2011; Helbing and Johansson, 2013)	Panic	Breakdown of existing bonds and norms (social and cultural)	Herding, irrational, selfish, disorderly and competitive
(Bowlby, 1982; Mikulincer and Shaver, 2007)	Attachment	Bond formation from childhood developed towards adult life	Proximity seeking
(Mawson, 2005)	Social Attachment	Activation of attachment bonds during threat	Proximity seeking, cooperation
(Beckes and Coan, 2011)	Social Baseline	Instinctive development of social bonds to maximize social resources and distribution of risk	Proximity seeking, cooperation, sentinel
(Ein-Dor et al., 2010)	Social Defense	Variation in attachment styles between groups is optimal to ensure survival during disasters	Leadership, cooperation, sentinel, anxious
(R. H. Turner and Killian, 1987)	Self Categorisation	Individuals' transition to become members of the psychological crowd, shared fate	Cooperation
(Drury et al., 2009; Sivers et al., 2016; Tajfel and J. C. Turner, 1986)	Social Identity	Development of bonds between strangers in unfamiliar locations and disaster situations	Helping

when with strangers. This is contrary to observed helping behaviour among strangers during disasters. Social identity theory accounts for the development of bonds between strangers in unfamiliar places precipitated by events. Shared social identity increases supportive behaviour and coordination during emergency situations (Drury et al., 2009). Helping behaviour such as aiding the elderly and injured individuals or rescuing people under rubble can be explained by social identity theory.

A summary table of the theories is presented in Table 5. It can be concluded in this section that social attachment can influence evacuation behaviour during disasters and crisis events. Each theory provided an explanation on how attachment influences evacuation behaviour. However a full explanation of this influence can not be attributed to a single theory but a combination of each idea presented to get a full understanding of this effect. Also, the effect of culture on attachment behaviour needs to be considered. Reactions of individuals to disasters can vary between cultures and result from different attachment styles influenced by their unique socio-cultural contexts (Rothbaum et al., 2000; Marsella and Christopher, 2004; Otto, 2008).

AGENT BASED MODELS OF SOCIAL ATTACHMENT

Agent based models have been implemented to simulate human behaviour during evacuations. Some models are implemented guided by data from observations and surveys. Social theories used in most models are often not explicitly stated. We will try to show in the following models how the previously mentioned theories are used to model agent behaviour.

Social Force Model - models pedestrian behaviour during panic and normal situations (Helbing, Frakas, et al., 2002). Repulsive and attractive forces define the relationships between agents. Attractive forces can represent the close bonds between family members, or pull of a safe area. Panic and herding behaviour are observed. Roan (Roan, 2013) implements a modified version of the social force model and simulated trampling during stampedes. Herding and trampling during stampedes shows panic and emergent norm theories at work.

Earthquake Pedestrian's Evacuation Simulator (EPES) models pedestrian (children, adult and disabled) behaviour during an earthquake (D'Orazio, Quagliarini, et al., 2014). Social attachment theory is implemented through the

bonds that maintain cohesion in pedestrian groups (clans), and the attraction to safe areas. The social force model is modified to reflect panic and conditions during an earthquake. Herding and collision avoidance are replicated in the model.

Evacuation Simulation with Children, Authorities, Parents, Emotions, and Social Comparison (ESCAPES) is an airport evacuation tool implementing social attachment with different agent types, and emotional, informational and behavioural interactions implemented with the Belief, Desire and Intention architecture (Tsai et al., 2011). Agents include travellers, families and authorities. Interaction between agents include: spread of knowledge, emotional contagion and social comparison. During evacuations, parents immediately seek to gather their family before proceeding to an exit, children exclusively follow their parent and travel slower. (Tsai et al., 2011)

Exitus focuses on the evacuation behaviour of individuals with mobility impairments (Manley, 2012). Agents include non-disabled, motorized and non-motorized wheelchair users, visually impaired, hearing impaired and stamina impaired. Social attachment theory is implemented through agent bonds resulting to seeking and helping behaviours.

Multi-Agent Simulation for Egress Analysis (MASSEgress) simulates individual behaviour through sensing, decision making, behaviour selection and motor control. Interaction between agents define social behaviour. Panic and emergent norm theories are implemented resulting in queuing, competition, herding, and leader following behaviours (Pan, 2006).

Social Agent for Egress (SAFEgress-2014) implements social attachment theory and models occupants affiliated to social groups, defined by a unique structure and group norm (Chu, Parigi, et al., 2014). Factors implemented include group intimacy, leadership and separation distance. High-intimacy groups include couples or families. Low-intimacy groups can represent co-workers.

Social Agent for Egress (SAFEgress-2015) - implements the social attachment theory by modelling evacuation of social groups, and emulating human capabilities of perception and navigation (Chu, 2015). Different agent behaviours modelled include: (1) following perception to evacuate; (2) following knowledge to evacuate; (3) navigating with group members; (4) navigating with entire social group; (5) following the crowd to evacuate; and (6) following authority's instructions.

Social Identity Model Application (SIMA) - implements the social categorisation and identity theories with the focus on helping behaviour. It has two main components implemented in sequence: social identity (establishing social identity), and helping behaviour. Pedestrians who do not share a social identity with a group head straight for safety without caring for others (Sivers et al., 2016).

Okaya and Takahashi's, RoboCup Rescue Simulation - is an evacuation based on the BDI architecture and Helbing's agent behaviour model and developed using the RoboCup Rescue Simulation v. 1 (RCRS) platform (Okaya and Tokahashi, 2011). Agents in the model are adults, parents and children. Results showed delayed evacuation times for parents who take care of their children. The results of evacuation simulations reveal (1) family members evacuate together; (2) guidance during evacuations affects crowd behaviours; and (3) evacuation takes more time when congestion occurs. This model implements the attachment and social attachment theories.

Lou, et al.'s Model - is a simulation for normal and emergency scenarios for a Singapore train station (Luo et al., 2008). Social group and crowd related behaviours are modelled from social psychology, such as social attachment theory. Individual agents are categorized into roles as staff, civilian, or tourist; age group: child, adult, or elderly; on social relationship: strong tie, normal tie, or individual; and based on personality: altruist, common person, or avoidantist. Behaviours include: wander, flock, evade, lead, follow, seek, individual escape, group escape, idle, help, and run aimlessly. In the normal situation, people wander individually or as a group.

STEPS by Mott MacDonald Ltd is a microsimulation tool for pedestrian movement and can be used for normal and emergency conditions (evacuation mode) (Waterson and Pelliser, 2010). Agent attributes include free walking speed, awareness, patience, association to other members of a family group and pre-movement time. This model implements the social attachment theory.

Wang et al.'s Model developed an optimisation method for emergency evacuation and considered social bond effects (Wang et al., 2009). They considered the disorder and blocking effects caused by social bonds during evacuations. According to them, close bonds such as with family members and familiar colleagues in a company help keep order in evacuation. This is manifested in queuing behaviours making evacuations smooth and efficient. Loose bonds between unfamiliar individuals can increase competitiveness resulting in pushing and shoving behaviours triggering disorder, blocking and delay in the evacuation. This model implements the social attachment theory.

A summary of the models is shown in Table 6.

Table 6. ABM implementing social attachment during crises

Source	Implementation	Theory	Agents	Behaviour
(D'Orazio, Quagliarini, et al., 2014)	EPES	Social Attachment, Panic	Pedestrian (child, adult, disabled), clan	Herding
(Tsai et al., 2011)	ESCAPES	Attachment, Social Attachment	Family members, travellers, authorities	Follow Parent, Drag into Shop, Find Child, Find Other Parent
(Manley, 2012)	EXITUS	Attachment, Social Attachment	Nondisabled, motorized wheelchair users, nonmotorized wheelchair users, visually impaired, hearing impaired, stamina impaired	Helping
(Luo et al., 2008)	Lou et al.	Social Attachment, Social identity	staff, civilian, tourist, child, adult, elderly	Wander, flock, evade, lead, follow, seek, escape (individual, group), idle, help, run aimlessly
(Pan, 2006)	MASSEgress	Panic, Self Identity	Individuals	Competition, queuing, herding, leader-follower
(Okaya and Tokahashi, 2011)	Robocup Rescue	Social Attachment	Adult, parent, child	group evacuation, guidance
(Chu, Parigi, et al., 2014)	SAFEgress (2014)	Social Attachment	Family, couple, co-worker	Group evacuation
(Chu, 2015)	SAFEgress (2015)	Social attachment	Building occupants	Navigating with group, following (crowd, authority)
(Sivers et al., 2016)	SIMA	Social Identity, Self Categorisation	Pedestrians	Helping
(Helbing, Frakas, et al., 2002; Helbing and Johansson, 2013; Roan, 2013)	Social Force	Panic, Emergent Norm, Social attachment, Normative	Pedestrian, family	Panic, herding, trampling, queuing, cooperation, self organisation,
(Waterson and Pelliser, 2010)	STEPS	Normative	Family	Walking, association
(Wang et al., 2009)	Wang et al.	Social attachment	Family	queuing, pushing and shoving

CONCLUSION AND FUTURE WORK

In this paper, we have shown that attachment bonds are activated by threat during disasters and regulate the instinctive selfish flight behaviour, pushing the individuals to consider others instead. Indeed, individuals seek the proximity of attachment figures for security and comfort, while their absence produces more anxiety than the threat itself. The social nature of evacuations (facilitating or delaying them) and the impact of attachment on mobility makes it important to model social attachment.

We have presented several theories to explain the role of attachment in human mobility. Each theory offered a piece of the puzzle, a unique perspective in explaining different behaviours during evacuations. This provides us with a strong foundation to build agent-based models for crisis scenarios. Agent-based models of evacuation already exist that have integrated social and psychological aspects of human behaviour, but they usually lack in accounting for group dynamics and strong ties. Social attachment bonds have been implemented by some simulations of egress behaviour, but there is room for improvement of their realism.

We argued that the BDI multi-agent architecture provides an opportunity to integrate attachment bonds in human agents' beliefs, desires and intentions during crisis situations. The ideas discussed in this paper lay the groundwork for the development of our multi-agent model and simulator of the influence of social attachment on human evacuation behaviour during seismic crises. This model will be used to experiment with different disaster evacuation scenarios and observe the resulting behaviours of a simulated population of agents. The goal is to study the impact of different demographic features and attachment strengths and styles on human mobility during evacuation. Results will be compared to those obtained by previous studies.

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