Survey on Crowd Behaviour Evacuation Modelling during Emergency Event

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***Abstract*—In the event of natural disasters, catastrophes or war, efficient tools are needed to produce evacuation plans to evacuate the crowd safely. Disaster is an unplanned situation that can happen anywhere and anytime. The worst case is when disasters happen on large gatherings which can increase risk of death during egress evacuation. When an emergency arises, crowds will evacuate to the nearest exit they know of. There are many risks involved during an emergency when it is unplanned. Research on crowd evacuation pay less attention to the realism of crowd behavioural factors which influence the evacuation result. As such this has prompted a novel crowd evacuation model as a potential solution for realistic crowd behavioural evacuation modelling through a combination of crowd behaviour, evacuation planning and path finding.**

Keywords: Emergency evacuation, crowd behaviour evacuation modelling, evacuation plan, path finding

I. INTRODUCTION

Natural or man-made disasters have had ruinous impacts on the lives and livelihood of people and places throughout the world. Disaster in public places often involve crowds that are either in indoors, outdoors or even those in vehicles. Disaster will often lead to emergency situations, crowd panicking and a need for a safe route for evacuation. Most of the studies on crowd modelling during an emergency event assumed simplistic crowd behaviour factors during evacuation [1]. The deficiencies in modelling human behaviour during an egress evacuation has been highlighted numerous times by authorities in fire engineering and social sciences [2]. Panic and stress are the most prevalent behaviour factors discussed in past studies [3], [4], [5]. Panic is a crowd psychological behavioural factor that is due to lack of information given during the emergency time to evacuate, subsequently causing more havoc [6] and making the crowd unmanageable. The primary method to prevent panic is by proper evacuation planning and efficiency in managing the crowd [6]. To achieve this, the management has to be ready with dynamic planning infrastructure to provide support during the devastation. For example to properly handle a crowd disaster in a shopping complex, the management has to be ready to reroute the crowd safely and dynamically during the disaster by providing immediate routing information and infrastructure ready to support dynamism of signage.

Past studies of emergency evacuation planning have revealed that there are three crowd behavioural factors that can influence evacuation results namely psychological, environmental and physical factors [3], [1]. Crowd psychological behaviour should be considered to ensure the smoothness of evacuation in terms of crowd safety and fast evacuation. There are three types of crowd models, these are the microscopic, macroscopic and mesoscopic models. Based on a study conducted by Radianti *et al.* [7], microscopic models look at a crowd as an individual and a separate entity, meanwhile for macroscopic models, crowds are described through their density and average flow. Mesoscopic models describe the relationship between macro (collective patterns) and micro (inter-individual interactions) [8]. Referring to Table 1, most of the studies focus on microscopic models but the discussion in their studies leans more towards group (macro) instead of individuals (micro). Thus, a further study on individual behaviour has to be in place to understand how much it is able to influence towards a realistic crowd evacuation result.

In this paper, the study on crowd behaviour evacuation modelling is determined by individual behaviour which will contribute towards the crowd evacuation in terms of crowd behavioural factors and approaches in the context of emergency evacuation and route finding. This study also highlights adoption of emotional ant modelling for the crowd behaviour and path finding algorithm for safest route which takes blocking agent into consideration. This work however is different from the study presented in Table I as this study adopt novel features of existing work on crowd psychological behaviour to the agent based with safest path finding and evacuation.

The paper is organized into three different sections as follows. Section II will discuss crowd evacuation modelling in terms of the three crowd behavioural factors, approach and the limitation of considering crowd psychological emotion to the agents for simulation of existing study. As for Section III, the existing features of evacuation plans and path finding will be discussed. Lastly, Section IV will wrap up and summarize the important outlooks and future novel crowd behaviour model in emergency evacuation.

II. CROWD EVACUATION APPROACH AND MODELLING

Modelling a large scale crowd in the existing studies usually does not focus on the individual character. Instead the main focus is more towards treating the crowd as a whole to reduce computational cost involved. Normally for a small to medium scale crowd, researchers are able to model the behaviour of the individuals in the crowd and such approaches usually integrate more details into the crowd model and support investigation of crowd dynamism at the individual level [14].

TABLE I. SUMMARY OF CROWD BEHAVIOURAL FACTORS AND OTHER COMPONENTS IN CROWD EVACUATION MODELLING

Ref	Approach	Type	Behavioural factors a	Behavioural factors b	Behavioural factors c	Crowd guidance	Model type	Simulation performance: Scalability # of agents	Simulation performance: Execution efficiency
[6]	Heuristics	micro	✗	Limited	✗	yes	i	12500	na
[3]	Heuristics	micro	✓	✓	✓	yes	g	small scale	rt
[1]	Heuristics	micro	✓	Limited	✓	yes	g	550	nrt
[9]	Heuristics	micro	✓	✓	✗	no	i	10×10^4	rt
[10]	Heuristics	micro	✓	✓	✗	yes	i	small scale	nrt
[11]	Heuristics	micro & mesos	✓	Limited	✗	no	i & g	small scale	nrt
[12]	mathematical	macro	✓	Limited	✓	no	g	10×10^4 to 10×10^6	na
[13]	mathematical	micro	✗	Limited	✓	yes	g	small scale	na

a = physical; b = psychological; c = environmental; i = individual; g = group;
rt = real-time; nrt = not real-time; na = not available.

A. *Crowd Evacuation Approach*

There are several approaches in crowd modelling. The overall simulation mechanism that controls how the simulated individual or group in crowd performs is reflected by these approaches. These approaches treat crowds as a collection of heterogeneous or homogeneous entities which interact with each other. There are three major modelling approaches with different modelling granularity that we will discuss here in brief.

The first model is the flow-based approach which neglects individuals as its features. This approach is useful in estimating the flow of the evacuation process for huge and dense crowds (large-scale). Another approach is entity-based approach where individuals are modelled as a set of homogeneous entities which treat individuals in a crowd as particles, such as Helbings social force model [4]. The motions of the entities are usually influenced by some global or local laws that are introduced to represent various behavioural factors influences on an individuals movement in a crowd for models that adopt this approach. Also, this model can generate some global emerging phenomena such as jamming and flocking [14].

Lastly is the agent-based approach where each individual is treated as an independent agent with certain capabilities to behave in the simulated world. There are rule sets for each agent to follow and the agent can make his own decision independently based on some local information that are relevant to the agent [4]. In this approach, more behavioural factors can be inserted for simulation. As such, crowd modelling and simulations using the agent-based approach have attracted interest from many researchers as it can adopt behavioural factors and at the same time can simulate from small to large scale crowds [3], [6], [12], [13]. To differentiate an agent and an entity, in general an agent is more complex than an entity due to its own attributes and states such as moving speed, emotion, social ties and others that represent various behavioural factors. An agent also has reasoning capabilities and certain levels of cognitive that sensitive to its surroundings, assess the current situation and make decisions compared to the homogeneous entities in an entity-based crowd model which already have predefined global or local laws that need to be followed.

In the following section, the discussion will be more on existing studies of crowd behaviour modelling during mass evacuation and the realism of integrating crowd emotions in the model proposed.

B. *Crowd Evacuation Behavioural Factors*

Extensive work has been done on crowd pedestrian modelling and simulation studies. In this paper, we discuss three main behavioural factors involved in most crowd modelling studies. These are the physical, psychological and environmental factors.

The evacuation model proposed by Zheng *et al.* [15] has considered the effects of selection of an exit and social forces on the movement of pedestrians. Meanwhile, a study from Chu *et al.* [1] has conjectured a reasonable and sufficient platform to model a range of evacuation behaviours of occupants, namely SAFEgress. Helbings social force model (cellular automata) and agent-based models use multiple agents with their own profile [6], [13]. Incorporation of psychological and physiological elements affecting individual and collective behaviours should also be in the evacuation models [16]. Nevertheless, there are still many open issues due to the complexity of individual and crowd behaviours [14]. To imitate the crowd dynamism, there are a number of studies that consider external characteristics of crowds such as poses, appearance, movement patterns, individual positions; physical, social and psychological factors [14].

From the review study, crowd emergency evacuation has limited emotion factors adapted to their model for crowd behaviour which imitates the real emotion of crowds during a disaster. The study from Langner and Kray [6] shows that there are limited emotions involved in their study which they highlighted in their paper to incorporate individual profiles such as capabilities, physical properties and behaviour under stress for more realistic results. Meanwhile the study from Narain *et al.* [12], which adds collision avoidance as one of the realistic factors to the crowd also does not integrate crowd emotion into their model. A massive crowd can exhibit uncontrolled actions that could harm anyone around as a result of unpredictable behaviour and influence of the actions of each individual against another individual in the crowd [16]. Most of the studies presented in Table 1 agree that the individual factor does influence the crowd behaviour by choosing the micro type [3], [6], [13], [4]. Nevertheless, very few studies take in-depth consideration of individual crowd emotions towards evacuation.

Helbing's studies are based on observations of pedestrian crowds in both normal and panic situations. According to his studies, the transition of pedestrian behaviour from rational to irrational (panic behaviour) is influenced by fluctuation of strengths and desired speed which is also known as nervousness [4]. In his social force model, panic motion can appear due to any variation of the parameter changes on pedestrian motion.

A study from Abdelhak *et al.* [10] has proposed multi agent individual based models (IBM) for pedestrian motion in general with the assumption that pedestrians characteristics will be affected by environment disruption and can cause the transition of pedestrians to panic behaviour. She claims that this approach is more realistic because the feeling of fear by panicking pedestrians has forced them to change their priorities and behaviour to escape from danger. In her IBM system, an individual, wall or any moving obstacles within the simulation environment is considered an agent. Thus in her IBM, the agent can be a mobile or a static entity depending on the characteristics of the entity it models.

There is also another study of human behaviours using a mixed geometry-based method and ant colony algorithm for crowd evacuation model. In the Wang *et al.* [5] model, character information is not presented in grids positions because he believed that in order to have a better simulation on the complex interactions among individuals, the character's movement and the choice of path need to follow geometric rules with no predefined speed and directions. In his large-scale crowd evacuation model, his simulation is accelerated to real-time rates. Wang *et al.* [5] in his model highly considered human behaviours to calculate the best evacuation path, including human warning time, autonomous avoidance and preferential path selecting. This is because without considering the diverse human behaviours, the evacuation paths will exhibit an unnatural crowd evacuation pattern.

Besides the geometry-based method, the biological inspired agent (ant colony model) whose transition behaviour is modelled using fuzzy logic to analyze the emotion model of crowds is also being studied. Banarjee *et al.* [17] proposed a model to fabricate an emotion based analytical model of crowd behaviour which in turn seems to be more realistic in uncertain environments. Large crowd gatherings such as these at a world cup football match or hajj pilgrimage, normally involve people from different cities [12], [17], [9] thus four different cognitive behaviours of crowd are used which is anger, selfish mindedness, confusion and sadness to cater for this condition [17].

Based on Table I, Sharma [3] has not limited his study to only stress and panic in the psychological factors. His system, AvatarSim, considered an additional emotion, anger. AvatarSim is a multi-agent system built to simulate real-life scenarios where people behave according to their level of panic or stress attributes. AvatarSim simulates emergency egress behaviour and its validation was done through the use of radio frequency identification detection (RFID). The AvatarSim model comprises of three models which are the fuzzy agent-based model, the geometrical model and the social force model which enable it to model human social behaviours such as queuing, competitiveness and herding behaviour. Findings from the studied literature based on the aforementioned crowd behavioural evacuation modelling components are summarized below. The behavioural factors explained in Table I may consist of one of the following items:

1) Physical factors: speed, wait time, goal, fitness
2) Psychological factors: sad, anger, panic, stress, confused, selfish minded
3) Environment factors: layout, smoke, smoothness

III. Discussions

There are three categories of evacuation planning approaches, namely linear programming, heuristic and warning systems. Linear programming approach use network flow which has exponential running time and suffer from high computational complexity and therefore is not practical to implement for large transportation networks [18]. Heuristics approaches however originally only computes the shortest path from source to the nearest exit. The Lu *et al.* [18] study had considered capacity constraints in his optimization of this approach to support large scale evacuations and to reduce complex network routing. The third type is warning systems which are normally used by local authorities to convey simple threat messages to the folks for evacuation. The native style of warning system can cause more panic as it tends to provide limited information such as 'please leave the place as soon as possible' without providing any directions. This can cause more congestion when people try to evacuate all at once.

Other than evacuation planning approaches, path finding is another branch that indirectly impacts to behavioural factors. A simple example can be found at large building complexes such as shopping complexes or attractions like universal studios which have been designed with static display directions for effective path finding to desired destinations and discloses the current location of that particular person in the complex layout. This kind of information from the static display is helpful for people to plan their movement and actions in unfamiliar environments. According to Kray *et al.* [19], good way finding will help users experience an environment in a positive way and facilitate them getting from one point to another. Way finding algorithm was first developed to provide simple directions, for example, in university campus, large complexes (airport, office buildings, hospitals) and even on gadgets such as PDA, GPS and etc., [19] to provide route to the destinations.

In case of mass evacuation, static signage tends to be ignored which causes crowds to leave the place all at once without considering congestion and blocking all the way to the exit. A study from [20] has considered dynamic signage in the study with evidence that the dynamic warnings can have better option than static ones. Realizing the important role provided by dynamic public display to create awareness and clear information to the crowd, improvement should be done to fully utilize the facilities. For the case of emergency evacuation, the information can be relayed quickly to a large crowd by using public display. For example if a fire or an explosion occurs in a crowded stadium, public displays would give clear directions on proper evacuation procedures. Although people would be

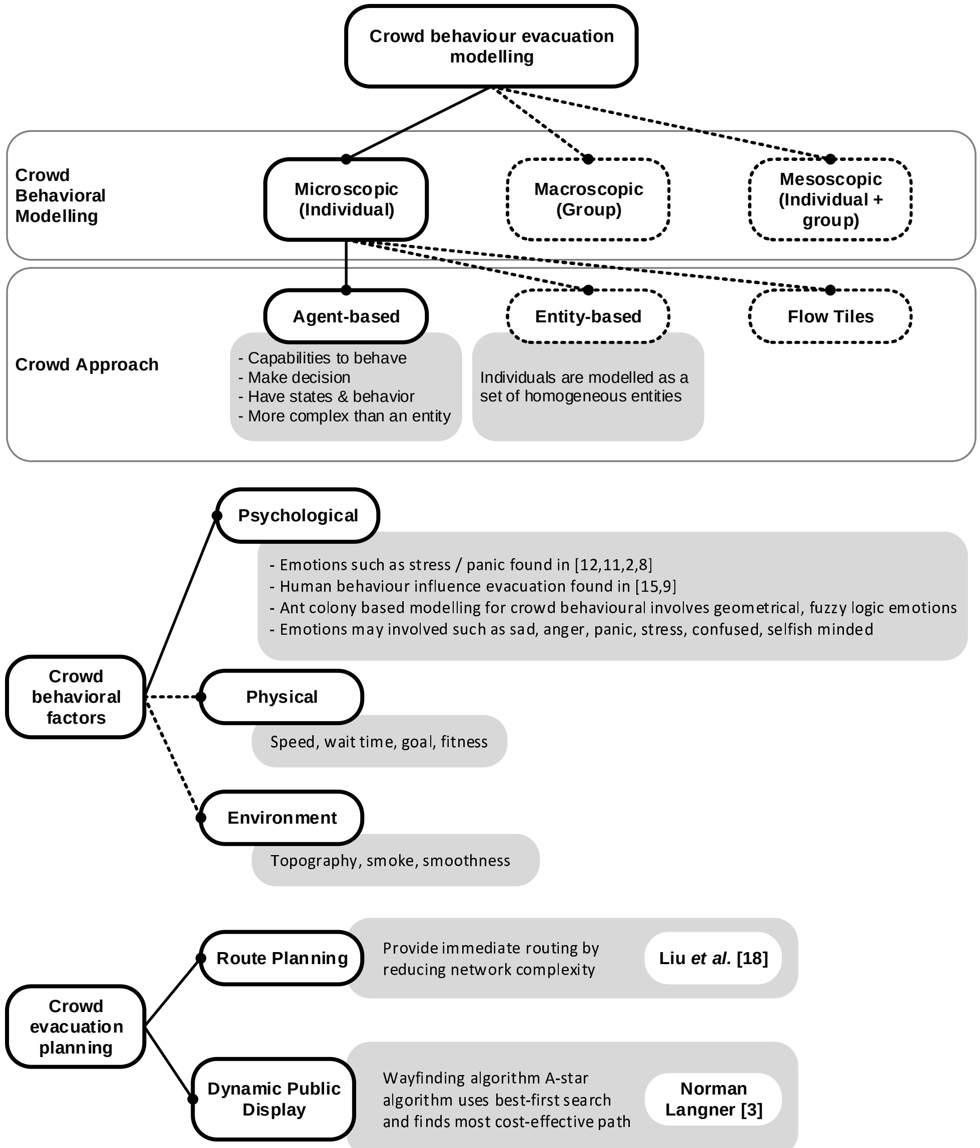

Fig. 1. Overview of the survey paper

panicking, they are still able to see their surrounding, so a large display will have a high chance of attractions attention.

There are two categories of way-finding algorithms, informed search strategies and uninformed [6]. Way-finding algorithms at first can only create successor states and distinguish between non-target-state to target but later on the heuristics approach was used instead. The A-star algorithm uses the best-first search and finds the most cost-effective path [5]. The shortest path isn't always the most cost-effective path such as Dijkstra or Floyd-Warshall Algorithm which calculate for the shortest path [19]. Langner and Kray [6] and Kray *et al.* [19] used the A-star algorithm for routes calculation. The A-star algorithm resembles human behaviour in its calculation due to its heuristic component.

IV. Conclusion

From the literature we have studied so far, we can deduce some of the outlooks on research directions as presented in Figure 1 on the overview of the survey paper. Firstly, the crowd behaviour modelling selection, either by individual or group or a combination of both plays a major role in defining an appropriate crowd behaviour solution. Based on pros and cons represented by the study done, individual behaviour does play a very important role in influencing decisions made either by groups or other individuals during an emergency evacuation. The microscopic model with an agent-based approach may have significant impact in crowd evacuation modelling since individual characters or emotions and profiles will be integrated by each agent for a more realistic simulation. Additionally, unrealistic assumptions should be excluded to induce high quality crowd evacuation modelling which include large-scale simulations which treat groups as whole instead of individual-based approaches to build up more details and crowd dynamism at the individual level.

Secondly, the three behavioural factors discussed namely psychological, physical and environmental discussed have some common ground when discussing about psychological behavioural factors being considered in their model. Many previous studies had integrated panic or stress in their crowd behavioural models that focused on human behaviour during emergencies. As crowd evacuation modelling studies progress and considering its complexity, more studies are trying to integrate realistic individual behaviour into the crowd during the evacuation. This is because it is believed that crowd emotions would influence the evacuation pattern and have their own big contribution towards the reality of crowd evacuation. This is shown in studies which highly consider crowd emotions by adopting ant based modelling into their proposed model. The evolvement of realistic crowd behavioural modelling is in demand to solve disasters throughout the world.

Thirdly, evacuation planning is another important area to consider, because when a disaster happens, immediate route planning becomes very crucial. Immediate route information can be made available if we are able to reduce the computational complexity and are able to support large-scale crowds. To support the route finding efficiency and to reduce panic, dynamic public displays can be introduced to relay a quick message and route information to the crowd. The way-finding algorithm known as A-star algorithm which has heuristics components in it can be further explored to produce better evacuation result with the integration of evacuation planning approaches.

In conclusion, human intelligence and psychology play a major role in the process of evacuation. Human intelligence and psychology integrated into the novel model of crowd behaviour evacuation model can result in a more accurate and reliable evacuation solution.

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