Impact of Passenger Group Dynamics on an Airport Evacuation Process Using an Agent-Based Model

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***Abstract*—The safety of passengers is a major concern to airports. In the event of crises, having an effective and efficient evacuation process in place can significantly aid in enhancing passenger safety. Hence, it is necessary for airport operators to have an in-depth understanding of the evacuation process of their airport terminal. Although evacuation models have been used in studying pedestrian behaviour for decades, little research has been done in considering the evacuees' group dynamics and the complexity of the environment. In this paper, an agent-based model is presented to simulate passenger evacuation process. Different exits were allocated to passengers based on their location and security level. The simulation results show that the evacuation time can be influenced by passenger group dynamics. This model also provides a convenient way to design airport evacuation strategy and examine its efficiency. The model was created using AnyLogic software and its parameters were initialised using recent research data published in the literature.**

Keywords—group dynamics; agent-based model; airport; evacuation; simulation

I. INTRODUCTION

In recent years, air passenger traffic is growing at a steady pace despite difficult global economic environment [1]. Besides managing the needs and expectations of passengers, the airport operators also spend significant resources and time in ensuring the safety of passengers who use their airports. In the light of recent terrorist incidents and turmoil, this has become a top priority. In such emergency situations, having an effective evacuation procedure could substantially mitigate the effect of threat and associated risk for the passengers and staff. Hence, an in-depth understanding of the evacuation procedure, specific to each airport in the context of its existing infrastructure is of utmost importance. Such knowledge also aids airport operators to analyse the impact of the incident on other operations of the airport.

In previous studies of pedestrian evacuation, a vast majority of researchers chose to use computer modelling techniques instead of the full-scale evacuation practice [2-5]. The major concerns of a real evacuation trial are: (1) the potential threat of injury to volunteers; (2) the lack of realism reaction during experiment (for example, the arising stress and panic); (3) the limit of reproducible results in repeat experiments; and (4) full-scale evacuation can be too expensive and time-consuming. As a result, many of the phenomena and laws during an evacuation are only carried out by model simulations [2, 3, 5]. Although it has been proven that social interactions greatly influence crowd behaviours and decision making, far too little attention has been paid to group dynamics when developing passenger flow models under both normal and emergency conditions [4, 6-9].

Different from other building environments, an airport is considered as a complex system that comprises multiple stakeholders and social interactions [10]. For example, before boarding the flight, passengers are required to pass mandatory processes which include check-in, security process and Customs. Therefore, the security level varies in the airport, which needs special consideration during the evacuation. To model pedestrian behaviour in such a complex environment, the agent-based modelling technique is one of the best choices. In agent-based models, pedestrians follow some pre-determined rules of behaviour, which allow pedestrian-agents in the model system behave naturally and autonomously. This unique characteristic makes agent-based modelling particularly suitable for study of pedestrian behaviour in complex environments [11].

This paper aims to evaluate the impact of group dynamics on passenger flow during the evacuation process in an international departure terminal using the agent-based modelling method. The remainder of the paper is organised as follows. Section 2 reviews previous work related to pedestrian evacuation. Section 3 demonstrates the construction and configuration of the agent-based evacuation model in the context of an international airport. Section 4 provides the simulation results and analysis, while Section 5 summarises the major findings.

II. RELATED WORK

Gwynne, et al. summarised 22 different evacuation models in their review [12]. Based on the nature of model application, those models are categorised into three different categories: optimization, simulation and risk assessment. Optimization models try to find out the optimal evacuation path, exit or flow characteristic, simulation models tend to demonstrate the behaviour and movement observed in the evacuation, while risk assessment models attempt to define potential hazards and bottlenecks in the evacuation process.

Santos and Aguirre also presented a critical review of emergency evacuation simulation models [4]. They pointed out that one common shortcoming of the reviewed models lay in the absence of inclusion of social psychological relevant group level characteristics. However, they also noticed that in some extreme situations where mass behaviour exists, most potential evacuees do not have enough opportunities to interact with their fellow group members, thus in those situations, the distinction between group and individual level evacuation behaviour is less meaningful.

Bonabeau [11] summarised the benefits of the agent-based model: (1) agent-based modelling (ABM) captures emergent phenomena; (2) ABM provides a natural description of the system; (3) ABM is flexible. These advantages make agent-based modelling ideal for simulating evacuation process. By using an ABM for fire escape, the author demonstrated how a column in front of the emergency exit unexpectedly reduced the injury and increased the speed of the pedestrian flow. The simulation result is verified by real-world experiments and indicated that the ABM can capture the emergent phenomenon in a natural way.

Based on an enhanced cellular automation model, Schultz, Lehmann [13] proposed a stochastic model to evaluate pedestrian dynamics under emergency cases in airport terminals. They stated that airports are divided into public and non-public area. Thus different security levels are required. They also suggested that a managed guidance system is necessary during the emergency situation, because in a static guidance system, the pre-defined routes cannot be guaranteed to be safe for evacuees.

Zheng, Zhong [2] discussed the advantages and disadvantages of seven evacuation modelling techniques. Those methods include cellular automata models, lattice gas models, social force models, fluid dynamic models, agent-based models, game theory models, and approaches based on experiments with animals. They concluded that all agent-based models are microscopic. They are more computationally expensive compared to other models but have the ability to model heterogeneous humans. They pointed out that a new trend in crowd evacuation models is based on the combination of multiple approaches because of the complexity of pedestrian behaviour. In this paper, a similar hybrid approach has been adopted in the proposed model in which heterogeneous agents are created according to the agent-based mindset, while the pedestrian movement is governed by the customised social force algorithm.

In this paper, a new evacuation model which incorporates group dynamics will be introduced. The model is created using the agent-based model and simulates an evacuation event in an airport. It is assumed that the panic behaviour does not exist in the evacuation so that the pedestrian group behaviour can be preserved and analysed.

III. Methodology

In an agent-based model, three key elements need to be identified and modelled: agents, their environment, and their interactions with other agents and the environment [14]. In addition to this, Gwynne, et al. suggests that it is essential to consider the configurational, environmental, procedural and behavioural aspects when proposing evacuation model [3].

In the real-world, the occurrence time of most emergencies is unpredictable. Hence, in our model the point of triggering of emergency needs to be set externally by the user rather than predefining it. It provides more flexibility to the model. This implies the model not only simulates the evacuation process, but also the normal airport operations as well. This section describes the setup of the evacuation model by (1) introducing the airport environment and passenger behaviour under non-emergency situation; (2) the configuration and procedure during the evacuation process; and (3) passenger behaviour during evacuation.

A. Airport Environment and Pedestrian Setting

The model environment is an international airport departure terminal, which is divided into landside and airside. The landside of the terminal is open to the public, while the airside of the terminal is only accessible for passengers. Fig. 1 illustrates a high-level description of passenger departure processes in the model. Passenger activities are categorised into processing and discretionary activities [15]. Processing activities are mandatory for passengers before boarding the plane. On the landside of the terminal, passengers check-in for their flights, and pass through security check and Customs before entering airside and boarding. Discretionary activities are considered as any other activities undertaken by passengers during non-processing time [15, 16]. It can happen between two

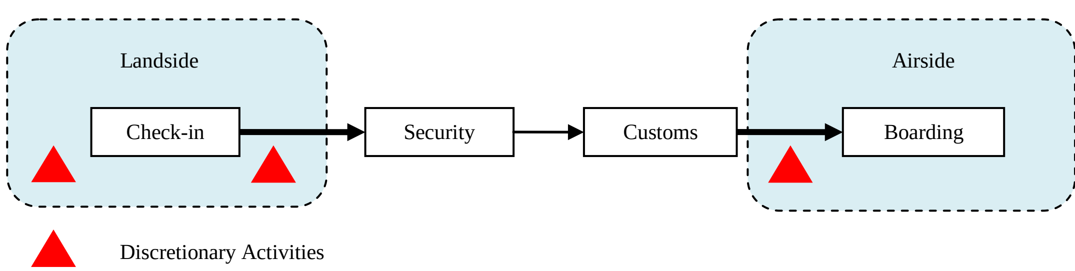


Fig. 1. Airport departure processes.

sequential mandatory activities as shown in Fig. 1. Examples of discretionary activities in the proposed model include random walking, store browsing, having food and using other airport services. Retail shops and airport services are located at both landside and airside to emulate the real-world scenario.

Pedestrians in the model are categorised into passengers and wavers. Passengers are those who will board on the plane, while wavers are fellow companions, who accompany the passengers to the airport but do not board on the flight. The model takes the departure flight schedule and passenger number for each flight as inputs. The attributes of the agents such as group size, speed, flight schedule and class, and shopping preference are initialised. The interactions between the agents and the environment are defined. Based on the flight schedule, the agents are appropriately introduced in the environment. Detailed micro-activities in each process (check-in, security and Customs) is modelled based on observational data collected by the Human System team of the Airports of the Future project [15].

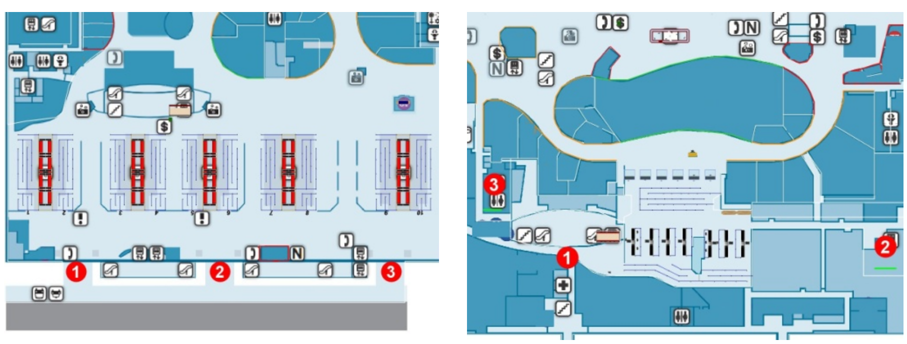
B. Configuration and Procedure During Evacuation

Fig. 2 shows the layout of the airport departure terminal used in the simulation. As can be seen from the terminal layout, three emergency exits (marked as red circles) are available on both landside (level 4) and airside (level 3) of the terminal. In the event of an evacuation, passengers will be notified by an emergency alarm, and then they will make their way to the nearest exit under the guidance of building wardens and airport staff. Passengers will remain at designated assembly points until it is safe for them to re-enter the building.

In our simulations, we presume there are three security levels (these could be adapted based on the operating conditions of the airport). Passengers who have not been examined by the security personnel are categorised as having security level 1 status; passengers that passed security but not the Customs have security status level 2; passengers that pass both security and Customs possess security status level 3. In our model, it is assumed that only certain exits are accessible to people depending on their security level status as described below.

The landside of the terminal is the public area. The crowds on the landside are treated to be on security level 1, along with all outgoing passengers who have not cleared the security check. They will choose one exit among the three located on level 4 that has the minimum walking distance while evacuating the airport. Situations are more complex on the airside of the terminal. On the airside, there are two mandatory processes: security and Customs, and different security levels are imposed on them. Passengers belonging to security level 2 will evacuate through exit 2 on level 3, and passengers with security level 3 will evacuate through exit 3 on level 3.

In the simulation, once the emergency ceases passengers returning into the terminal will keep their security level status intact, so that they can continue to finish their remaining processes rather than doing them from the beginning. However, the simulation is flexible and different policies can easily be implemented and tested (e.g. the policy that all passengers must be re-scanned on entry, regardless of their security levels when they are evacuated). TABLE I. summarises the corresponding exits for pedestrian with different security levels.



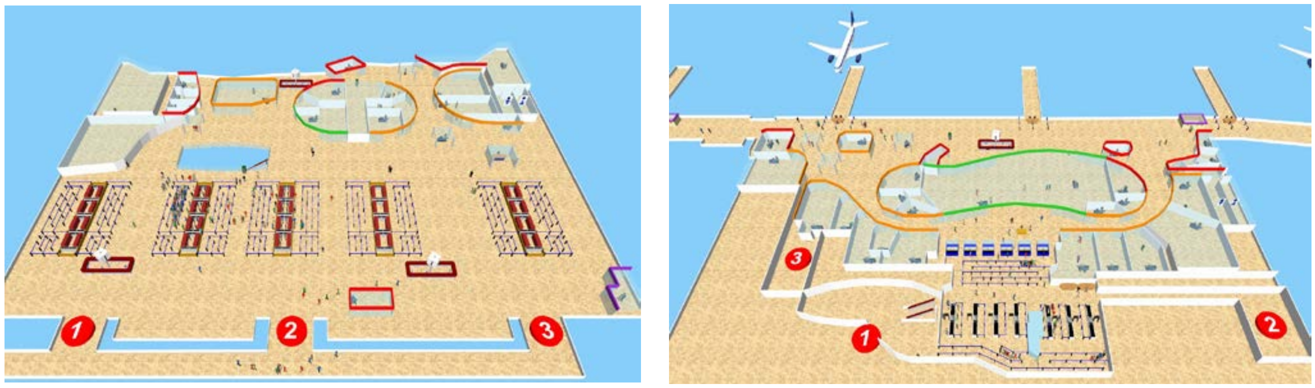
(a) (b)

Fig. 2. Airport environment defined in our simulation. The exits are marked as red circles. (a) check in area and retail (landside); (b) Security, Customs, Boarding and retail (airside).

TABLE I. EXITS ASSIGNED FOR PASSENGERS OF DIFFERENT SECURITY LEVELS.

Security Level	**1**		**2**	**3**
Domain	**Security unchecked**		**Security checked; Customs unchecked**	**Customs checked**
Emergency Exits	Exit 1,2,3 on Level 4	Exit 1 on Level 3	Exit 2 on Level 3	Exit 3 on Level 3

Fig. 3. Typical response followed by passengers during evacuation.



(a) (b)

Fig. 4. Similar to Fig. 2, but illustrates the environment in 3D, along with passengers.

C. Behaviour Responses to Emergency Evacuation

The likely behavioural response of the evacuees is essential to the model. There are two levels of behavioural responses: global and local [17]. The global behaviour level outlined the general escape strategy. At the start of the evacuation alarm, passengers and airport staff will spend some time to respond to the signal. After recognising the situation, passengers need to decide the evacuation option, for example, available exits and the closest distance to the exit. Passenger groups with different opinions may spend more time on discussion. This period of time is described as response time. After making the decision, passengers will move towards the chosen exit, during this period, the movement time is recorded. Due to potential congestion in front of the exits, it is possible that passengers need to wait before they make their way out. Another reason that could lead to longer waiting times is that passengers travelling in groups will wait for fellow passengers to regroup around the exit area. They generally ensure that all group members are safe and would like to evacuate together.

The evacuation time for a pedestrian (passenger) is defined as the time when the evacuation alarm set off to the time that the pedestrian leaves the exit. Typical steps passengers take during an evacuation can be seen from Fig. 3.

On the local behaviour level, based on individual's personal attributes such as age and travel purpose, pedestrians have different degrees of knowledge about what to do when evacuating. Therefore, people in the model have varying response times to the evacuation alarm. During the movement, passengers in the same group will compromise their speed to the slowest group member in order to travel at the same speed.

IV. RESULT AND ANALYSIS

The 3D simulation environment of an international airport departure terminal is shown in Fig. 4. The model is built on AnyLogic 6.8 platform to simulate the daily operation of the airport. Activities of each agent in the system were updated successively according to preset characteristics within a discrete-event structure of AnyLogic simulation software. The model is validated by using the face validation and statistical validation methods. The face validation is based on the knowledge of domain experts. The 2D/3D animation of the model not only gives an overview of the simulation, but also aids in face validation. In the animation, passenger behaviour such as walking, waiting and grouping can be directly seen. The interaction between passengers and the airport environment in different areas like check-in, security and border processing can also be analysed. By comparing the visualised crowd behaviour with the experience of airport experts, the processes and structures of the model can be assured.

Statistical validation is conducted by comparing key figures generated from the simulation model with the observation data from the airports. Since the collection of observation data from a real airport environment is extremely labour intensive and time consuming [16], available data are limited in the areas of interests such as average queuing time and total dwell time at each departure process. After the data comparison, parameters in the model are calibrated in order to adjust the model output data to the observation data within tolerable differences (differences between average observation times and simulated times less than 2 minutes). TABLE II. compares the actual and the simulated time obtained at each process. It shows that the simulation is reflective of the actual situation.

TABLE II. COMPARISONS OF QUEUE AND DWELL TIMES AT CHECK-IN, SECURITY AND CUSTOMS BETWEEN THE ACTUAL TIME AND THE SIMULATION.

Domain		Queue times [min]		Dwell times [min]	
		Actual	Simulation	Actual	Simulation
Check-in	Min	0.58	0.48	1.95	3.60
	Max	42.81	56.85	53.56	62.00
	Average	12.88	12.58	16.65	18.76
Security	Min	1.23	0.74	1.90	3.28
	Max	17.09	8.39	21.06	20.02
	Average	3.75	3.53	6.88	7.86
Customs	Min	0.33	1.16	0.55	2.13
	Max	15.46	30.22	18.58	36.40
	Average	4.80	5.57	6.00	7.50

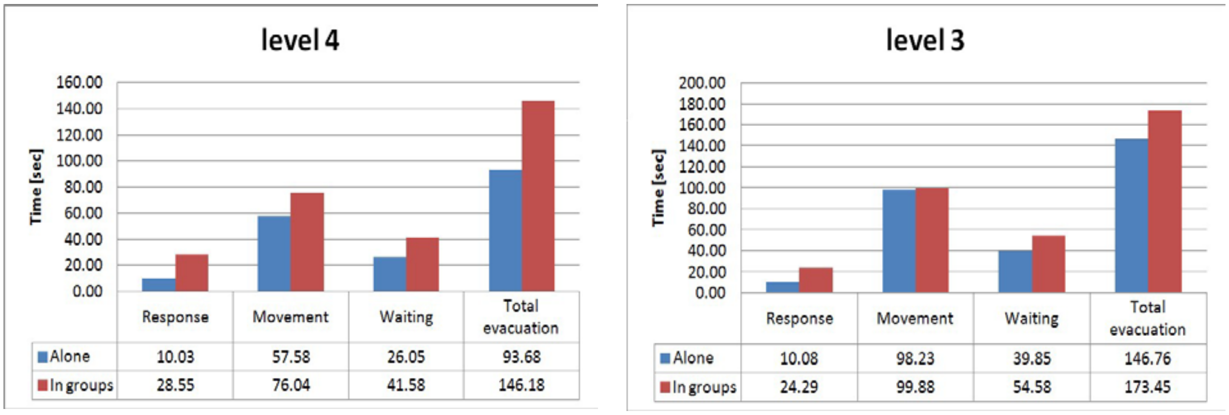
In order to demonstrate the general behaviour of passengers and ensure the reliability of the experimental results, the evacuation event is set at 7:30 AM, one of the peak times of the day to collect more sample data. TABLE III. summarised the distribution of passengers in the airport departure terminal when the evacuation starts. The results are collected from five experiments. On average, there are approximately 1000 passengers in the simulation system at 7:30 AM. In the condition of passengers travelling alone, on average 218 passengers (22% of the total passengers) are found on level 4, while 782.2 passengers (78%) are on level 3. These figures changed to 361.2 (36%) and 644.6 (64%) under the condition that passengers are travelling in groups. One of the most distinctive characteristics of an agent-based model is that agents are able to act autonomously in the simulation environment. This advanced feature strongly reflects the real-world human behaviour. As a result, even at the exact time-point of several experiments, the agent number in the system, agents' positions and their undertaking activities can be different.

The differences in building layouts, passenger numbers and activities require the evacuation process to be analysed separately on level 4 (the landside) and level 3 (the airside). Fig. 5 compares the time distribution of the evacuation event on both levels between the setting of passengers travelling (1) alone; (2) in groups. It is shown that the total evacuation time of passengers travelling in groups is longer than that of passengers travelling alone. On both level 4 and level 3, passengers in groups spend 146.18 and 173.45 seconds to finish the evacuation. The figures are 93.68 and 146.76 for passengers travelling alone, which are 36% and 15% shorter in comparison. Distinct time differences can be found on all sub-events of the evacuation process on level 4 as well as the response time and waiting time on level 3. This result of response time indicates that the initial response of passengers who travelling in groups is slower than those travelling alone. For it can take longer time for passengers in a group to communicate with each other and make decisions in response to the evacuation signal. The waiting time for passengers who travel alone is mainly caused by the congestion in front of the exit. While for group travellers, the waiting time is not only due to the congestion, but also the time associated with 'regrouping'. Therefore, the waiting time for passengers travelling in groups is reasonably higher.

On both level 4 and level 3, passengers spent the majority of their evacuation time on the evacuation movement. Because of the group dynamic, larger groups are supposed to move slower than small groups or individual travellers [4, 18]. This behaviour is well illustrated on level 4. Passengers travelling in groups on level 4 spend approximately 20 seconds longer in moving during the evacuation. However, movement times under the two different settings on level 3 are very close. A possible explanation for such a phenomenon is that the pathways to the exits on level 3 are narrower than those at level 4 (as can be seen from the highlighted areas in the density map illustrated in Fig. 6). Severe congestion was observed all along passageways through to exit on level 3. Thus, passengers travelling alone had to slow down due to congested passageways and their speed was comparable to those travelling in groups. On the other hand, passengers on level 4 had more open space, which allowed those individual travellers to advance towards the exit quickly.

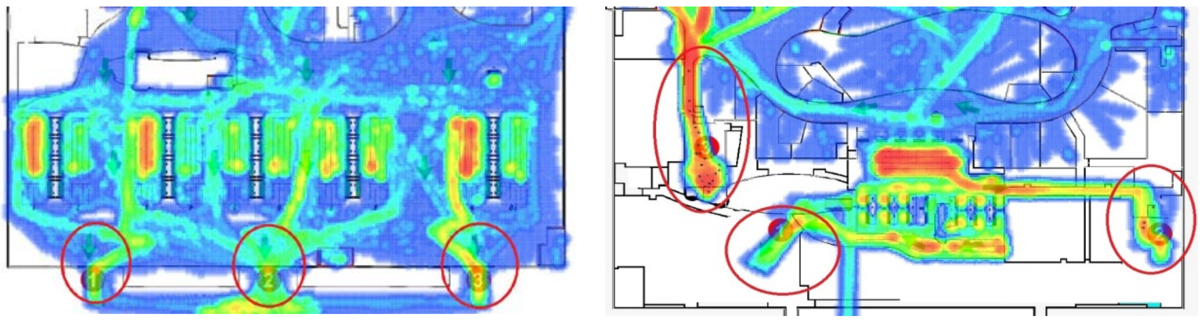
TABLE III. DISTRIBUTION OF AGENTS IN THE AIRPORT TERMINAL UNDER THE SETTING OF PASSENGERS TRAVELLING: (1) ALONE; AND (2) IN GROUPS.

Number of agents in the experiment						
	Passenger travelling alone			Passenger travelling in groups		
Exp No.	**level4**	**level 3**	**Total**	**level4**	**level 3**	**Total**
1	219	771	990	343	654	997
2	222	768	990	378	626	1004
3	212	789	1001	328	678	1006
4	217	786	1003	381	629	1010
5	220	797	1017	376	636	1012
Avg.	218	782.2	1000.2	361.2	644.6	1005.8



(a) (b)

Fig. 5. Average evacuation time of passengers on: (a) level 4, landside; and (b) level 3, airside for the two different settings.



(a) (b)

Fig. 6. Pedestrian density map during the evacuation process. (a) level4; (b) level 3.

V. Conclusions

The simulation of the evacuation process in the airport terminal shows that the agent-based model can be used to analyse pedestrian group dynamics in a complex environment. Based on passenger's locations in the airport, three security levels are differentiated, which require passengers to evacuate through different exits. The simulation results suggested that passengers with group dynamics spend longer time in making decisions, moving to the exits and waiting for other group members during the evacuation.

This simulation technique prevents the potential risks in real practical trials and reduces research expense. Moreover, the simulation results provide valuable information such as how passengers react to an evacuation signal, which route to choose in the evacuation and the average time for passengers to finish the evacuation. The simulation is also to report congestions through the 3D visual demonstration during the evacuation. The evacuation model offers an expedient way for airport managers to propose and test evacuation plans. Given the information of flight schedule and passenger number, the evacuation simulation can be run at any time of day and the simulation results will provide valuable information for them to respond proactively to any potential congestion.

However, a few limitations of this pilot study need to be acknowledged. First, the proposed model is not designed for the extreme evacuation situation. Under extreme cases, there is no guarantee that the pre-defined escaping routes are safe for the evacuees. Second, evacuation subjects in the model are all passengers. However, in the real-world, there are large numbers of airport staff that need to be considered as well. As part of future research, we would like to consider a phased evacuation approach i.e. only areas directly threatened will be evacuated first and areas at lesser risk will be evacuated later. Furthermore, different exit strategies employed at various airports could also be trailed using this framework. The dissemination of evacuation information among passengers and further addition of attributes to agents (such as age, gender, spatial cognition) will also be explored.

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