Solving Optimization Problems in Emergency Evacuation

Dinh Thi Hong Huyen*, Hoang Thi Thanh Ha, Michel Occello

Abstract—In this paper, we propose a method to solve the optimization problem in an emergency evacuation. Specifically, when passengers are waiting for their flight in the lounge and a fire breaks out. How to evacuate all passengers to a safe place with the minimum total evacuation time? To solve the problem, we propose a method based on the multi-agent multi-level model MAS-GiG [1], combined with the shortest path algorithm to guide passengers to evacuate to a safe place. Additionally, we address issues that arise during the evacuation process, such as reducing the speed of groups when two or more groups collide, and changing the evacuation plan when the routes to the exit are blocked. We compare the proposed method with the method in [2] to provide specific evaluations and future research directions. The testing environment is the departure hall, 1st floor of Danang International Airport.

Index Terms—emergency evacuation, multi-level multi-agent model, MAS-GiG model, optimization, group.

1. Introduction

EMERGENCY evacuation is a critical issue in emergency management and protecting human lives. In emergencies, particularly in cases of fires, an emergency evacuation can save thousands of lives. However, the evacuation process can become difficult and dangerous if it is not planned and executed efficiently.

To optimize the emergency evacuation process, many studies have proposed optimization models to increase the speed and improve the efficiency of evacuation. We proposed a method to solve the optimization problem in an emergency evacuation. The approach uses a multi-level multi-agent model MAS-GiG to guide the evacuation, combine with the shortest path finding algorithm, and determine the appropriate movement speed of each passenger group to minimize the evacuation time.

There have been many related studies, such as predicting pedestrian motion and emergent behavior [3], finding paths for each pedestrian to avoid static or dynamic obstacles and other pedestrians in the environment [4], [5], [6]. According to [7], the authors proposed a method for simulating pedestrian crowd movement in a virtual environment. The method can generate each pedestrian's trajectories in each group independently to reach several goal points within a reasonable computational time. In the paper [8], the authors planned at both global and local levels to enhance route choice based on barriers. A model simulating crowd movement, modeling the behavior of pedestrians in different groups by creating separate trajectories for each individual in the group [9]. According to the paper [10], the authors have developed a computational model that utilizes risk prediction data to determine optimal evacuation routes, the shortest and safest paths to the nearest exits in the event of a building fire. It employs the Fire Dynamics Simulator to provide predictive data on smoke propagation within a structure and utilizes the A* algorithm to search for the fastest escape routes.. Evaluating and optimizing evacuation plans [11], [12], [13], [14]. Studying human behavior in emergencies [15], [16], [17]. According to [18], the authors provided a broad overview on proposed approaches on human behavior analysis in group and crowd level, a detailed of some most recent state-of-the-art methods along with extensive experiments and comparison. In [19], the authors presented a new evacuation planning algorithm for buildings with multiple exits based on an indoor road network model.

We propose a modeling method that combines the multi-level multi-agent model MAS-GiG with the Dijkstra's algorithm for finding the shortest path. Specifically, we address the following issues: First, we construct a scenario file that includes relevant environmental object factors, such as information about waiting for areas, waiting area structure, objects in the waiting area including entrances, exits, shops, restrooms, seating areas, etc.; Flight information, such as flight identification, the number of passengers on the flight, departure time, departure gate, whether the flight is delayed or not; and information about fires such as when they occur, propagation level, location, etc. Second, we propose a MAS-GiG model for the application, which includes determining the AEIO [20] (Agent; Environment; In-

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teraction; Organization) structural components for the application, such as agent design, environment construction, interaction design, and organization design; Using environmental data (application scope), based on the number and distribution ratio of passengers in the lounges, and fire data, determine the levels of the MAS-GiG model for the application. Third, to determine the shortest path from a position of a group of passengers to an exit, we use graph theory to model the 2D space as a path graph G = <V, E>, where V is the set of vertices and E is the set of edges. Based on graph G, we apply Dijkstra's algorithm to select the shortest path among all possible paths from the position of the group of passengers to an exit. Fourth, dividing the environment space in order to determine the scope of each level in the application; And fifth, reducing the speed of groups when two or more groups collide, and changing the evacuation plan when the routes to the exit are blocked.

2. Problem Description

After passing through the security checkpoint, passengers enter the lounge. The number of passengers in the lounge is increasing more and more, and each passenger can do what they like, such as sitting in the waiting area, walking around, shopping, dining, etc. At that time, the fire occurred at a location inside the lounge. How to evacuate all passengers to safety as quickly as possible?

The problem is stated as follows: Find a way to evacuate N passengers from the starting locations (locations within the lounge) to the destination locations (safe areas) in order to minimize the total travel time. The problem is described as an optimization problem with parameters, constraints, and an objective function as follows:

The parameters

- N is the number of passengers that need to be evacuated.

- The moving speed of passengers on the path from the lounge to a safe location may vary depending on factors such as the width of the path and the density of passenger distribution on the path. The moving speed on path j is v_j, where j = 1, 2, ..., m.

- The time required for passengers to move on each path depends on the moving speed of that path. The moving time on path j is $t_j = d_j/v_j$, where d_j is the length of path j.

- The capacity of each evacuation path limits the number of passengers that can be evacuated on that path, denoted as c.

- n is the total starting locations, m is the total number of destinations, i is the i-th starting location, and j is the j-th destination.

Decision variables

The decision variables in emergency evacuation problems are x_{ij}, with i = 1, 2, ..., n and j = 1, 2, ..., m. The variable x_{ij} is a binary variable that determines whether the passenger at starting location i-th is evacuated to the safe location j-th or not. If yes then x_{ij} = 1, otherwise x_{ij} = 0.

Constraints

- Each passenger must be evacuated from a starting location to a destination location.

$$\sum_{j=1..m} x_{ij} = 1, with \quad i = 1, 2, .., n \tag{1}$$

- The total number of evacuated passengers at any given time must not exceed the capacity of the evacuation path.

$$\sum_{j=1..m} x_{ij} \leq c, with \quad i = 1, 2, .., n \tag{2}$$

- The number of passengers evacuated from each starting location must not exceed the number of passengers at that location

$$\sum_{j=1..m} x_{ij} \leq N_i, with \quad i = 1, 2, .., n \tag{3}$$

- The number of passengers evacuated to each destination location must not exceed the number of passengers that need to be evacuated to that location.

$$\sum_{i=1..n} x_{ij} \leq M_j, with \quad j = 1, 2, .., m \tag{4}$$

Where N_i is the number of passengers that need to be evacuated from starting location i, and M_j is the number of passengers that need to be evacuated to destination location j.

Objective function

Minimize the total moving time

$$min \sum_{i=1..n} \sum_{j=1..m} t_{ij} * x_{ij} \tag{5}$$

Where t_{ij} is the time it takes for a passenger to move from location i to safety location j.

3. Proposed method

To solve the optimization problem, we propose a method that combines modeling and simulation approaches using a multi-level multi-agent model MAS-GiS for coordination and guidance to evacuate all passengers to safe locations along the shortest paths, minimizing the total evacuation time. We experiment with a 2D space where each position has coordinates (x_i, y_i), the length of each road segment is d_i, the movement speed of each agent representing a passenger is v_i, and the time for an agent to move through a road segment of length d_i with speed v_i is t_i. Constraints (1), (2), (3), and (4) are satisfied. The objective function (5) is optimized, which means evacuating all passengers from the lounge to safe locations along the shortest paths, minimizing the total evacuation time.

3.1. Solve the problem based on the modeling approach

When a fire occurs in a lounge, passengers will choose the nearest exit to evacuate. However, the majority of passengers are not aware of the exits in the lounge, a large number of passengers are in a narrow space, and limitations of the pathways, congestion can easily occur at corners or intersections of paths or safe exits, reducing the evacuation speed, prolonging the total evacuation time, and increasing the risk to people.

To solve the problem using a modeling approach, we propose a multi-level multi-agent model MAS-GiG, with the AEIO architecture and a hierarchical group model to coordinate and guide the evacuation of passengers from different areas in the lounge to safe places.

3.2. The multi-level multi-agent model MAS-GiG

3.2.1. AEIO architecture

A multi-agent model based on the AEIO architecture consists of four components: A (Agents) - the agents; E (Environment) - the environment including the shared space of agents; I (Interactions) - the interactions between the agents and agents interact with environment objects; and O (Organizations) - the organizational mechanisms. Four AEIO components in the application include:

a. Agents

Each agent in the application represents a passenger. His behaviors are autonomous, reactive, and interactive. He is characterized by a set of attributes P, knowledge K, roles R, and acts in the environment by a set of actions A.

b. Environment

The environment is a space where agents operate. The environment consists of objects distributed within it and the relationships between them. These objects either affect the agents or are affected by them. In the application, environmental objects include seats, walkways, shops, restrooms, entrances, exits, etc.

c. Interactions

Interactions in the application include interactions on the same level (horizontal) and interactions on different levels (vertical). Horizontal interaction is the interaction between the group representative and the group members, interactions between group members themselves. A group representative interacts with another group representative of the same level. Vertical interaction is the interaction between a group representative and a group representative at a higher or lower level. Interactions are performed by sending/receiving messages.

The structure of a message in the MAS-GiG model for the application is based on the interaction protocol in MASH [21], which is a two-layer Message and Frame interaction mechanism. This mechanism is similar to the two layers of Network and Datalink in the seven-layer model of the OSI computer network [22].

d. Organization

The organization in the MAS-GiG model for the application includes group structure and relationships. In a group, there is a representative and members. A group member at a level is a representative of a group at a lower level adjacent to it.

3.2.2. Multi-level group model

According to [23], the multi-level group model is formed by a bottom-up mechanism and is described as follows:

- Level 0, agents at level 0 are called basic agents, representing a passenger in the application. At this level, there is no organization or group structure.

- Level 1, this is the first group level, where each group member is an agent at level 0. Agents belong to the same group when they are within the same range.

- Level $n (n \geq 2)$, level n is the n-th group level, where each group member is a representative of a group at level (n-1)-th. Agents at level n belong to the same group when they are in the same range.

3.2.3. The formation of levels

The formation of levels in the MAS-GiG model is carried out as follows:

- Level 0, agents at level 0 are called basic agents, representing a passenger in the application.

- Level 1, a group at this level is formed from agents at level 0 that are in the same range r.

- Level $n (n \geq 2)$, each agent at level n represents a group at level (n-1)-th. The group at level n-th is formed according to formula 6.

$$\begin{cases} G_{(n-1)i(i=1..g)} \xleftarrow{\text{Representatives}} I_{ni(i=1..m)} \\ G_{nk(k=1..g)} = \left\{ \left(I_{ni(i=1..m)}, I_{nj(j=1..m)} \right) : I_{ni} r I_{nj} \right\} \end{cases} \tag{6}$$

With r is the range in which agents belong to the same group. Each I_{ni}, I_{nj} is the representative of the groups $G_{(n-1)i}$, $G_{(n-1)j}$ at level (n-1)-th, m is any natural number representing the number of agents at level (n-1)-th, and g is the number of groups at level n-th.

3.2.4. Choose group representative

The selection of a group representative is based on the perception score of each agent. The perception score includes knowledge about the environment - a_{ek}, personal experience in emergency evacuation - a_{pe}, and decision-making time - a_{dt}. The agent with the highest perception score in the group is chosen as the group representative. The perception score of each agent is calculated according to formula 7.

$$K_a = a_{ek} + a_{pe} + a_{dt} \tag{7}$$

3.3. The space division problem

Dividing the environment space in order to determine the scope of each level in the application. The space is a bounded space and is denoted as SE. The referred subspaces are independent spaces and they have a topological relationship with each other, denoted as S_{ai} (i = 1, 2, 3, ..., n). The S_{ai} subspaces satisfy the following conditions:

$$SE = S_{a1} \cup S_{a2} \cup \cdots \cup S_{ai} \cdots \cup S_{an}, \quad n \geq 0 \tag{8}$$

$$\begin{aligned} &S_{ai}, S_{aj} \subset \mathrm{SE} : S_{ai} \cap S_{aj} = \emptyset, \mathrm{i} \neq \mathrm{j} \\ &and \quad \mathrm{i, j} \in \{1, 2, 3, \cdots, n\} \end{aligned} \tag{9}$$

This means that the S_{ai} subspaces are subsets of the SE space (8) and these subspaces do not intersect each other (9).

Illustration of space division in an application, the lounge5 is a space, dividing the lounge5 into smaller areas, Area51, Area52, and Area53, such that:

$$\begin{cases} \text{Lounge 5} = \text{Area51} \cup \text{Area 52} \cup \text{Area 53} \\ \text{Area51, Area52, Area53} \subset \text{Lounge 5} \\ \text{Area 51} \cap \text{Area52} \cap \text{Area53} = \varnothing \end{cases}$$

3.4. Applying the MAS-GiG model to the application problem

3.4.1. Determining the levels of the MAS-GiG model for the application problem

Based on the spatial structure of the departure terminal and the data on passenger distribution in the waiting area, we propose the number of levels of the MAS-GiG model for the application. There are five levels: individual level (Indie), group level (Group), area level (Area), lounge level (Lounge), and airport operator level (AirportOperator).

- Level 0 is individual level (Indie), at this level each agent represents a passenger, they have an equal role.

- Level 1 is the first group level, this is the Group level. Agents in the same group are within the same range r. Each group has a group representative and group members. The group representative in the application is the GroupLeader.

- Level 2 is the second group level which is the Area level. Each agent at this level is a representative of a group at the group level. The area representative is Guide.

- Level 3 is the third group level which is the Lounge level. Each agent at this level is a representative of a group at the Area level. The lounge representative is GuideLeader.

- Level 4 is the fourth group level, which is the operator level. Each agent at this level represents a group at the lounge level. The representative for the emergency management system operating department is called the Airport Operator (AO).

3.4.2. Implement evacuation problem

According to paper [1], the interaction mechanism in the multi-level MAS-GiG model is implemented based on the roles of each level. This demonstrates the hierarchy within the system while also enhancing the management and supervision of the system. Therefore, the implementation of the evacuation plan based on the MAS-GiG model follows a hierarchical approach, considering the roles of agents at each level within the system. The evacuation plan is carried out based on this mechanism.

Firstly, passengers are grouped based on their location distance, with one group representative selected according to equation (7). Then, based on the passenger distribution data, fire data, and lounge structure, areas are determined for the groups according to equations (8) and (9). Similarly, each area has a representative selected using equation (7) from the group representatives. Each lounge has a representative determined using equation (7) from the area representatives.

Secondly, all the groups evacuated within the same area move in the order of the shortest path length from their location to the exit with the same speed.

In case there are two or more areas leading to the same exit, the moving order is similar to the order of the groups, meaning the area closest to the exit moves first.

Resolving issues that arise during the evacuation process: When multiple groups collide with each other while moving, the proposed method implements a solution by reducing the moving speed from the collision group to the groups moving along the same route. Once the collision is resolved, the moving speed of these groups is adjusted back to their initial speeds.

When moving, if a route or intersection is blocked, the suggested method to deal with it is: Cease the evacuation of the groups that have planned to move along this route; The Airport Operator establishes a new evacuation plan based on the current positions of the groups and the available exits. Then he sends the new evacuation plan to the lounge's representatives. When the lounge's representatives receive the new plan they send the new evacuation plan to the area's representatives. When the area's representatives receive the new evacuation plan they send it to the group's representatives, and when the group's representatives receive the new evacuation plan they instruct the members of their groups to evacuate according to the new evacuation plan.

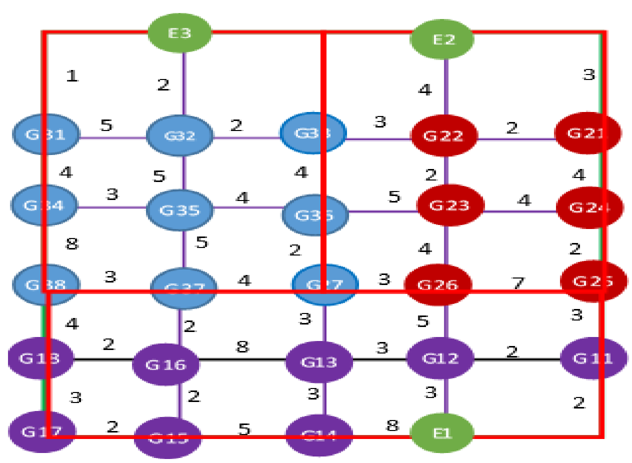


Fig. 1: Abstract description of lounge 5

Illustration of evacuation planning using MAS-GiG combined with the shortest path from a position to an exit. AO is the operator level representative who manages and monitors the entire system. Fig. 1 shows an abstract representation of lounge5 with Guideleader5, managed and monitored by AO. There are three areas, A51, A52, and A53. Area A51 has exit E1, represented by Guide51. Area A52 has exit E2, represented by Guide52. Area A53 has exit E3, represented by Guide53. Abstract descriptions of passenger groups from G11 to G18 are in area A51. Groups from G21 to G26 are in area A52. Groups from G31 to G39 are in area A53. The evacuation plan is executed as follows: The movement order between groups is predetermined based on the distance from each group to the exit. All three areas implement the evacuation plan simultaneously in order. In area A51, groups move in order from $G11 \rightarrow G12 \rightarrow G13 \rightarrow G14 \rightarrow G15 \rightarrow G16 \rightarrow G17 \rightarrow G18$, the corresponding distances from each group to exit E1 being 2, 3, 6, 8, 13, 14, 15, 16. In area A52, groups move in order from $G21 \rightarrow G22 \rightarrow G23 \rightarrow G24 \rightarrow G25 \rightarrow G26$, the corresponding distances from each group to exit E2 being 3, 4, 6, 7, 9, 10. In area A53, groups move in order from $G31 \rightarrow G32 \rightarrow G33 \rightarrow G34 \rightarrow G35 \rightarrow G36 \rightarrow G37 \rightarrow G38 \rightarrow G39$, the corresponding distances from each group to exit E3 being 1, 2, 4, 5, 7, 8, 10, 12, 13. The movement of each group follows the shortest path determined by the group's representative. The total evacuation time of lounge5 is equal to the total of evacuation time of the area with the longest evacuation time. For example, the total evacuation time of area A51 is 68.75s, the total evacuation time of area A52 is 34.8s, and the total evacuation time of A53 is 55.3s. Therefore, the total evacuation time of lounge 5 is 68.75s.

4. 4. Experimentation and result evaluation

4.1. The passenger data

Passenger distribution data in the lounge is based on the distribution ratio in the paper [24] . The distribution of passengers enter the lounge three times: 6:00 am, 10:00 am, and 6:00 pm within the time from 2 hours and 50 minutes to 1 hour before takeoff. We assume that approximately 300 passengers are distributed to each lounge based on the passenger distribution ratio at 6:00 am, and the location of each passenger is randomly assigned.

4.2. Environmental parameters

According to the paper on emergency evacuation standards from the National Institute of Standards and Technology of the United States [25], the size of the emergency exit doors is 45 pixels representing the real size is 3 meter. We assume that 100% of the evacuees are normal, able-bodied individuals with awareness and good health.

4.3. Experiment

We used the MASH simulation tool [21] to develop and experiment with the proposed method, testing it at the departure hall, 1st floor of Danang International Airport (see Fig. 2).

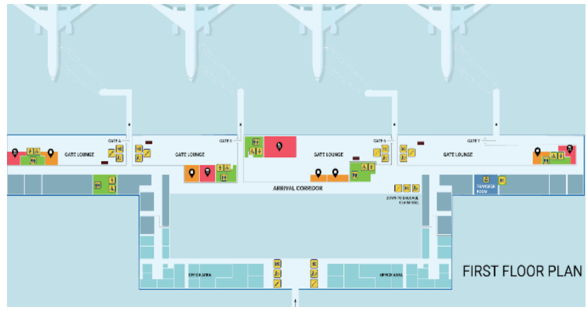


Fig. 2: Abstract description of lounge 5

The departure terminal consists of four lounges, from lounge 4 to lounge 7, each with a similar structure consisting of an entrance, boarding gates, and an exit to the common corridor. The arrangement of different areas in each lounge is based on their actual structure, such as waiting for areas, shops, restaurants, restrooms, and passageways. The exit to the common corridor, the entrance, and the boarding gate are three exits.

Each lounge has its own evacuation plan. The total evacuation time of the departure terminal is equal to the total evacuation time of the lounge with the longest evacuation time. The evacuation time of each lounge is calculated by the total evacuation time of the exit with the longest evacuation time.

4.3.1. Testing within the scope of one lounge

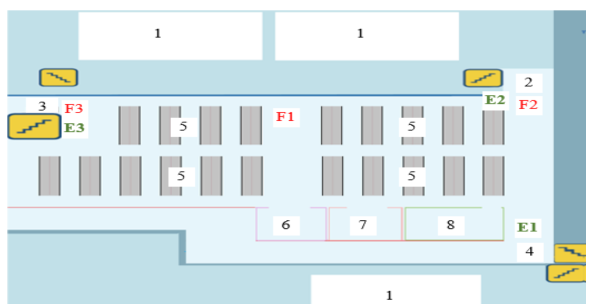


Fig. 3: The structure of lounge 5

A brief description of the symbols in Fig. 3 includes the safe area (1), exit door to board the aircraft (2), lounge entrance (3), exit to the common corridor (4), waiting area (5), shop (6), restaurant (7), restroom (8). The exit to the common corridor (4), exit door to board the aircraft (2), and lounge entrance (3) are three exits E1, E2, and E3. Three fire locations are F1, F2, and F3 (see Fig. 3).

We conducted experiments within the scope of lounge 5 for the proposed method, with the speed is around 1.12m/s for each agent. The total number of agents in the lounge is about 300 agents.

a. Scenario 1

Scenario 1, fire is at a location not coinciding with any exit. In this case, all three exits are used to evacuate passengers. Fig. 4 shows the simulation interface for scenario 1.

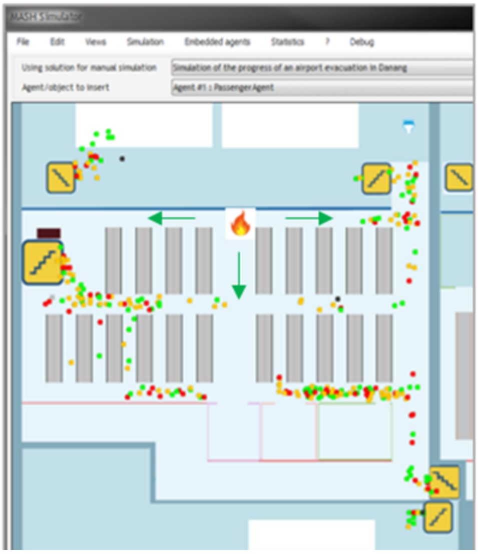
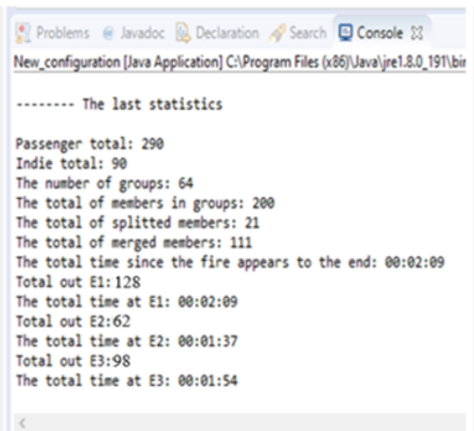


Fig. 4: The structure of lounge 5



Problems Javadoc Declaration Search Console

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-------- The last statistics

Passenger total: 290
Indie total: 90
The number of groups: 64
The total of members in groups: 200
The total of splitted members: 21
The total of merged members: 111
The total time since the fire appears to the end: 00:02:09
Total out E1: 128
The total time at E1: 00:02:09
Total out E2:62
The total time at E2: 00:01:37
Total out E3:98
The total time at E3: 00:01:54

Fig. 5: The structure of lounge 5

The results show that the total number of agents generated in the lounge is 290, and the total number of groups created is 64. The total evacuation time for exit E1 is 129 seconds, with 128 agents moving towards E1. The total evacuation time for exit E2 is 97 seconds, with 62 agents moving towards E2. The total evacuation time for exit E3 is 114 seconds, with 98 agents moving towards E3. Therefore, the total evacuation time for lounge 5 is 129 seconds (see Fig. 5).

b. Scenario 2

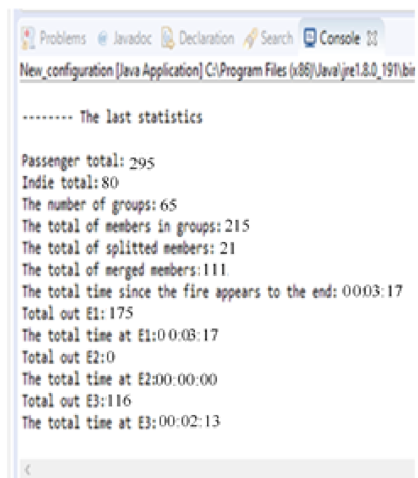
Scenario 2, a fire occurs at a location coinciding with the aircraft exit door. In this case, exit E2 is not used for passenger evacuation. Fig. 6 shows the simulation interface for scenario 2.

In this scenario, the fire occurs at location F2, so passengers can only be evacuated to the remaining two exits, E1 and E3 (see Fig. 6).

The results show that the total number of agents generated in the lounge is 295, and the total number of groups created is 65. The total evacuation time for exit E1 is 197 seconds, with 175 agents moving towards E1. The total evacuation time for exit E2 is 0 seconds, with 0 agents moving towards E2. The total evacuation time for exit E3 is 133 seconds, with 116 agents moving towards E3. Therefore, the total evacuation time for lounge 5 is 197 seconds (see Fig. 7).

Similarly to scenarios 1 and 2, in scenario 3, the fire occurred at F3, and passengers only moved to exits E1 and E2.

Fig. 6: The structure of lounge 5



Problems Javadoc Declaration Search Console

New_configuration [Java Application] C:\Program Files (x86)\Java\jre1.8.0_191\bin

-------- The last statistics

Passenger total: 295
Indie total: 80
The number of groups: 65
The total of members in groups: 215
The total of splitted members: 21
The total of merged members: 111
The total time since the fire appears to the end: 00:03:17
Total out E1: 175
The total time at E1: 00:03:17
Total out E2: 0
The total time at E2: 00:00:00
Total out E3: 116
The total time at E3: 00:02:13

Fig. 7: The structure of lounge 5

4.3.2. Testing within the scope of four lounges

Similar to the experiment within the scope of a lounge, we conducted experiments for four lounges. We tested the proposed method and the method in the paper [2] ten trials for each method. The number of agents generated in each lounge was 300 agents. The average movement speed of agents for both methods was 1.12m/s. We calculated the average total evacuation time for each method for each scenario.

a. Experiment with the same number of groups

Scenario 1, fire is at a location not coinciding with any exit. The number of groups in the proposed method is equivalent to the number of groups generated in the method [2], which is 64 groups. The total evacuation time of both methods for three corresponding scenarios is the same (see Table 1).

TABLE 1: Results of the experiment with equal group numbers.

Methods	The number of groups	L1 seconds	L2 seconds	L3 seconds
MAS-GiG [2]	64	157	199	192
Proposed method	64	159	197	194

b. Experiment with different numbers of groups

Scenario 2, a fire occurs at a location coinciding with the aircraft exit door. For the proposed method, the number of groups generated is about 74, while the number of groups generated in method [2] is 64. The results show that the proposed method has a higher average total evacuation time than the method in method [2] (see Table 2).

TABLE 2: Results of the experiment with a the number of groups in the proposed more than method in [2]

Methods	The number of groups	L1 seconds	L2 seconds	L3 seconds
MAS-GiG [2]	64	155	197	193
Proposed method	74	179	205	203

Scenario 3, a fire occurs at a location coinciding with the entrance to the lounge. For the proposed method, the number of groups generated is about 54, while the number of groups generated in method [2] is 64. The results show that the proposed method has a lower average total evacuation time than the method [2] (see Table 3).

TABLE 3: Results of the experiment with a the number of groups in the proposed less than method in [2]

Methods	The number of groups	L1 seconds	L2 seconds	L3 seconds
MAS-GiG [2]	64	158	195	189
Proposed method	54	153	177	183

The three experimental cases demonstrate that the number of groups affects the total evacuation time. For the proposed method, the more groups there are, the higher the evacuation time.

5. Discussion and Conclusion

Our proposed method and research approach in paper [2] share some similarities: both utilize the multi-agent multi-level MAS-GiG model combined with the shortest path to plan evacuation guidance, and both use the Dijkstra algorithm to determine the shortest path from a position of a group of passengers to an exit, evacuation guidance is given by level, evacuation plans are established by the command level and deployed to lower levels.

However, there are some differences between the two methods such as, for the proposed method, the group is formed when planning the evacuation, using a MAS-GiG model for the application, and using a path graph to perform the evacuation plan. The method in [2] forms the group before planning the evacuation, uses two MAS-GiG models for the application, and does not mention the path graph when implementing the evacuation plan.

The advantages of the proposed method are the formation of a flexible group, which is convenient when evacuation plans are changed due to the spread of fire. The proposed method applies evacuation in various places such as shopping centers, movie theaters, airports, train stations, etc. where there is no emergency management system. The evacuation plan uses a suitable path graph for evacuation locations such as high-rise buildings with obstacles that cannot be overcome, such as walls.

The study proposed solutions to optimize emergency evacuation, such as: Proposing a multi-level multi-agent model MAS-GiG for monitoring and coordinating evacuation by levels; Determining the shortest evacuation route; Dividing waiting areas into multiple areas for convenience; Determining the departure time between passenger groups; Reducing the speed of groups when two or more groups collide, and changing the evacuation plan when the routes to the exit are blocked.

In this study, in addition to addressing the issues raised, we compared by experiment with the study [2] to determine the advantages and disadvantages between the two research methods, thereby making improvements in further studies

However, the study still has some limitations, such as: not considering the psychological characteristics of evacuees, and testing within a limited scope, such as train stations, the first floor of buildings, and Danang International Airport.

In future research directions, we will continue to study and experiment in places such as shopping centers and expand the application of the MAS-GiG model in social networks. In particular, we will address the issue of spreading fires and changing evacuation plans.

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