Emergency Route Planning with the Shortest Path Methods: Static and Dynamic Obstacles

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EMERGENCY ROUTE PLANNING WITH THE SHORTEST PATH METHODS: STATIC AND DYNAMIC OBSTACLES

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Abstract
In extreme cases, evacuation difficulties could cause casualties in a closed layout during an emergency. The existing emergency routes are designed based on the shortest path to the nearest egress in a vacant layout. This research aims to design an emergency route plan in a realistic closed layout with interior arrangements and crowds as static and dynamic impediments that cause movement divergence and misdirection that affect evacuation time. This research proposes an automated emergency route design using Cellular Automata (CA) based pedestrian simulation in a realistic layout. The simulation was integrated with the Pythagorean Theorem (PT) and Dijkstra's Algorithm (DA) to imitate human exit-finding behaviour during evacuation. The results showed that PT is viable in layouts with static obstacles, requiring 20% less travel distances and evacuation time than DA with similar experiment sets. However, the DA approach results have become on par with the PT in a layout with dynamic and static obstacles. DA outperforms PT in densely populated regions, while PT outperforms DA in less populated regions.
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Key Words: Emergency Route Plan, Shortest Path, Pedestrian Simulation, Pedestrian Evacuation, Pythagorean Theorem, Dijkstra’s Algorithm

1. INTRODUCTION

Complex layout and structures, narrow passageways, large crowds, lack of air circulation, and poor evacuation assistance have caused numerous accidents in the closed area [1-4]. Recent studies have shown that the entrapment of pedestrians is the leading factor of high casualties in closed areas during emergencies [5, 6]. During a panic situation, the pedestrians push, shove, and rush through the obstacle-filled layout toward the exit, which can induce physical collisions, mental confusion, shortness of breath, and severe injuries resulting from obstacle interference [7, 8]. The number and size of exits, the granularity of spatial components such as the number of obstacles, the arrangement of spatial components, and the number of pedestrians involved can affect evacuation [1, 9]. These parameters can hinder a pedestrian's ability to evacuate quickly and safely. There are two deadly incidents involving a closed space; 1) the stampede incident at Station Nightclub in Rhode Island in 2003 due to the pushing and shoving to escape from fire and 2) the crowd overflow at the New Year’s Eve celebration at Address Downtown Hotel in Dubai in 2015 [6, 10, 11]. Based on these incidents, the leading causes of the casualties are: lack of exits, big crowds that exceeded space allocation, and complex layout design. Hence, mitigation plans are required to lessen the casualty.

In this 21st century, many buildings are equipped with high-tech safety measures and evacuation plans. Globally, every local government has set some rules for developing and designing a building to withstand any disasters; fire, flood, earthquake, hijack, and natural or human-made incidents. For instance, in Malaysia, building developers must obtain the Certificate of Completion and Compliance (CCC) from government authorities to ensure the building is designed based on the original blueprint and safely constructed for inhabitation with incident prevention measures, evacuation procedures, and emergency fire plans. There are a lot of elements that need to be fulfilled for obtaining the certificate; 1) building’s structure foundation and mechanical system, 2) sewage system, 3) electricity supply and wiring system, 4) water supply and distribution system, 5) road planning and landscaping and 6) building safety system. Table I shows the criteria of layout design explicitly issued by the Malaysian Fire and Rescue Department.

Table I: Building standard in Malaysia [12].

Type of Premise	Requirement(s)
Library	More than 1000 m^2 (total floor area).
Hospital, Rehabilitation and Treatment Centre	i) 3 floors and above; each floor area exceeds 250 m^2. ii) 5 floors and above.
Hotel	i) Open balcony hallways design: a) 4 floors and above with more than 50 rooms. b) 6 floors and above. ii) Other design: a) 21 rooms and more.
Hostel and Dormitory	i) 4 floors and above; each floor area exceeds 250 m^2. ii) 6 floors and above.
Office	Elevation height exceeds 30 meters or 10,000 m^2 (total floor area).
Shop	2001 m^2 and more (total floor area).
Factory	i) One floor level with 2001 m^2 and more; installed with automatic spray system. ii) 2 floors; each floor is built as a separate room, single or terrace construction over 1000 m^2 (total floor area). iii) 3 floors and more. iv) Elevated Floors Factory Development Block for 2 floors and more with Open Balcony Approach; each space exceeds 7000 cubic meters. v) Special structures: a) Complex manufacturing factory: palm oil manufacturing, oil refinery, cement and concrete manufacturing, and many more. b) Factory with dangerous processing and manufacturing.
Assembly area	i) Building without central air conditioning system; 2000 m^2 and more. ii) Building with central air conditioning system; exceed 1000 m^2 or with 1000 loads of people and more.
Storage and general-purpose area	i) Underground parking structure; exceed 1000 m^2. ii) More than 7000 cubic meters. iii) 2 floors and more with more than 1000 m^2 (total floor area).

Table I shows that the designs for building construction focus on the structure rather than the interior planning. However, these features cannot prevent the casualty occurrences such as stampedes, entrapment, and other fatal incidents. Hence, mitigation plans for crowd movement control, spatial layout design, evacuation plans, realistic crowd emotion imitation, and many other solutions have been widely implemented [1-4]. Previous research has determined that there are also other critical parameters required for designing a building; 1) the number and size of exits, 2) the granularity of the spatial components, such as the number of obstacles, 3) the arrangement of the spatial components, and 4) the number of pedestrians involved [1, 4, 9]. These parameters can obstruct the pedestrian from moving towards the egress point during a panic.

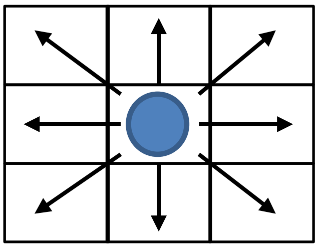
As technology advances, autonomous emergency route designs are proposed as mitigation plans. However, in general, the route will be designed based on a vacant layout, making it difficult to assist the pedestrians in evacuating during an actual panic situation because, realistically, the occupied layouts are often filled with furniture and people. Studies have shown that incorporating pedestrian behaviour and movement into layout design can validate and ensure pedestrian safety in a layout [13-15]. Previous research proposed designing an emergency route plan for chemical accident mitigation by combining chemical leakage parameters, meteorological conditions, and ammonia concentration with pedestrian behaviour

[16]. Meanwhile, another study proposed an emergency route design by incorporating route learning and space familiarisation for the evacuation process by improving the landmarks and training skills on the layout for navigation and exploiting human capability in the decision-making process [17]. There are also ideas for the safest path planning during the real-time evacuation process, such as highlighting the best evacuation strategy based on building characteristics, type of emergencies, and pedestrian reactions to improve pedestrian safety during evacuation [18]. This research aims to evaluate the shortest path approaches in pedestrian movement simulation by modelling realistic pedestrian behaviour and decision-making during evacuation while exploiting static and dynamic obstacles in a realistic spatial layout to design a realistic emergency route plan.

2. MICROSCOPIC APPROACH: CELLULAR AUTOMATA MODEL

Pedestrian simulation is an artificial intelligence approach that mimics human behaviour and reaction that involves position transitioning, navigation, and collision avoidance. Many methods have been proposed for motion modelling, including Cellular Automata (CA), lattice gas model, Genetic Algorithm (GA), and Particle Swarm Optimization (PSO) [14, 15, 19-22]. Mainly, crowd movement is always represented as the macroscopic movement phenomenon. However, research shows that pedestrian motion and decision-making vary depending on the surrounding situation and neighbouring interaction [9, 15]. During the panic, the pedestrian will self-organize due to safety, fear, and desire for movement direction [7, 8, 14, 19]. Hence, the microscopic approach is a suitable model to mimic pedestrian interaction with surroundings while self-organizing [14, 15, 19, 20].

Cellular Automata (CA) is a discrete microstructure approach that can mimic the microscopic movement [13, 14, 23]. CA is a practical approach to modelling the local interaction for traffic management and travel distance optimization [21, 23]. Von Neumann first discovered this concept approach in the cell self-reproduction process and exploited in many computer simulation approaches to represent the object's movement on a grid. The Moore Neighbourhood was developed to improve the CA concept by allowing for dynamic movement of objects on the grid, as shown in Fig. 1.



(i-1, j-1)	(i, j-1)	(i+1, j-1)
(i-1, j)	(i, j)	(i+1, j)
(i-1, j+1)	(i, j+1)	(i+1, j+1)

Figure 1: Moore Neighbourhood approach for pedestrian movement transition.

Based on Fig. 1, the CA-based movement transition can mimic the local state of human actions and intelligence within the homogeneity composition of neighbouring cells:

(1) A pedestrian can only occupy a cell in the grid for every time step.
(2) Every pedestrian will have their own set of neighbourhood cells and continuously react to the surrounding neighbourhood cells for every step.
(3) Every pedestrian will avoid collision with the neighbour cells, obstacles, walls, and other pedestrians.
(4) The pedestrian will always look for the nearest exit during evacuation.
(5) The wall and obstacles will be the static interference that will remain permanent in the layout, while the pedestrians will be the dynamic interference.

3. SHORTEST PATH APPROACH

During an evacuation, pedestrians will rush towards the nearest egress while avoiding collisions and speeding up their movement. Therefore, the shortest path approach can be exploited in CA-based movement simulation to mimic pedestrian decision-making during an evacuation by selecting the nearest exit. There are many shortest path approaches, such as Dijkstra's Algorithm (DA), Floyd–Warshall algorithm, and A* search algorithm for graph theory solutions involving intersection and Euclidean geometry solutions using Pythagorean Theorem (PT) for high dimensional space that consists of vector for magnitude and direction [16, 18, 24-27]. In this research, the Pythagorean Theorem (PT) and Dijkstra's Algorithm (DA) were chosen and analysed to determine a viable approach for designing an emergency route plan with obstacles.

3.1 Pythagorean Theorem (PT)

PT algorithm represents a 90-degree right-angle's triangle. This 2-dimensional geometry approach can measure angle and distance that mimic the human eyes' range and estimate egress distance. The measurement is based on the equation in Eq. (1).

$$c = \sqrt{a^2 + b^2} \tag{1}$$

Each neighbouring transition will involve finding the shortest distance between the unoccupied neighbour cells and the nearest egress. Algorithm 1 shows the PT approach shortest distance pseudocode in movement simulation.

Algorithm 1: Navigation and movement transition pseudocode for PT approach.

Pseudocode Pedestrian Shortest Distance Navigation in PT approach

```
Procedure PT_NearestExit (G, s);
begin
Step 1:
   G = (V, E), directed or undirected
   create vertex set Q  where each vertex u ∈ Q and u = V exit
   positive edge distance {dₑ : e ∈ E}
   counter m for step counting
Step 2:
   for each vertex u where u ≠ s do:
       dist(u)  = ∞
       prev(u)  = nil
   dist(s)  = 0
Step 3:
   while s is defined do:
      while Q is not empty do:
       for each u of Q do:
            path = dist(s)  + d(s,u)
            if path < dist(u)  then
                    dist(u)  = path
                    prev(u)  = u
            end if
            if path ≥ dist(u)  then EXIT
       remove(u)
       end for
      end while
   count m
   end while
return dist( ), prev( ), counter m
end
```

Based on Algorithm 1, the shortest distance calculation will form a graph G that shows the availability of exit points V with every edge E connecting the V to the pedestrian's origin s. The nearest exit *u* will be determined by comparing the edge distance d_e. The calculation will have resulted in the closest distance *dist*( ) for the nearest exit selection *prev*( ) from the origin. The selection of a neighbour cell for movement transition is based on the unoccupied eight possible neighbour cells in the Moore Neighbourhood transition approach. The distance of each unoccupied neighbour cell is measured from the central middle cell (origin *s*) to the nearest selected egress. The unoccupied cell with the closest distance to the chosen egress will be selected for movement transition. This navigation and shortest distance approach will be terminated when the origin *s* = egress point. The number of steps *m* taken by the pedestrian from the origin to the destination is calculated. Time taken *t* by the pedestrian to travel from the origin to the destination will be calculated for both normal and panic situations.

3.2 Dijkstra's Algorithm (DA)

DA represents the vertexes' network. The DA approach can imitate the movement transition process by finding the distance between the source and destination nodes (vertexes). Algorithm 2 shows the DA approach shortest distance pseudocode in movement simulation.

Algorithm 2: Navigation and movement transition pseudocode for DA approach.

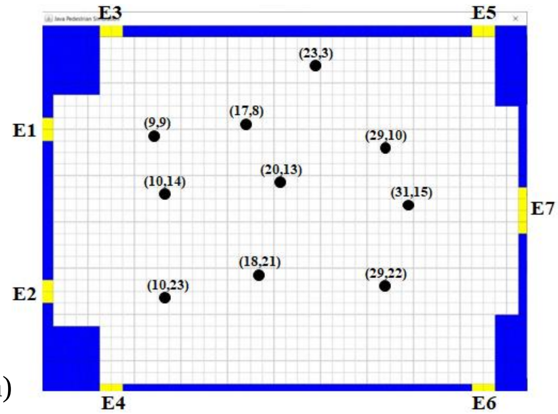
Pseudocode Pedestrian Shortest Distance Navigation in DA approach

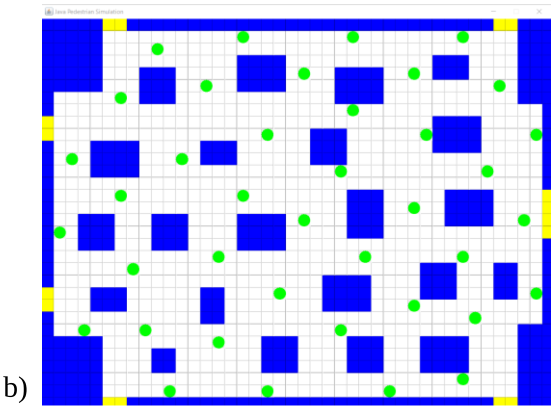
```
Procedure DA_NearestExit (G, s);
begin
Step 1:
   G = (V, E), directed or undirected
   create vertex set V where each vertex s ∈ V
   positive edge distance {d_e : e ∈ E}
   counter m for step counting
Step 2:
   for each vertex s in G where s ∈ V and s ≠ u do:
         dist(u) = ∞
         prev(u) = nil
   dist(s) = 0
Step 3:
   while s is defined do:
     while V  is not empty do :
        for each vertex s where s ≠ exit point, s = pedestrian do:
          while s is defined do :
             s = prev(u)
             for each vertex u where u ∈ V and u ≠ s do:
                 path = dist(s) + d(s,u);
                 if  path < dist(u)  then
                            dist(u) = path
                            prev(u) = s
                 end if
                 if path ≥ dist(u)  then EXIT
             remove (u)
             end for
          end while
        decrease(V,s)
        end for
     end while
    count m
   end while
return dist( ), prev( ), vertex set V, counter m
end
```

Based on Algorithm 2, the shortest distance calculation will form a graph *G* that shows the availability of vertex set *V* with every edge *E* connected to the pedestrian's origin *s*. The origin s will be the element of V that must be available as the pedestrian will continuously find the nearest vertex after reaching a vertex from $prev(u)$, where u is the destination of the previous vertex. The process of finding the nearest destination node in this approach is adapted from the PT approach measurement, refer to Eq. (1), as the angle and distance to the nearest destination node can be measured with a geometry approach. The nearest vertex s can be determined by comparing the edge distance d_e from s to u. The calculation will have resulted in the closest distance $dist(\ )$ for the nearest exit selection $prev(\ )$ from the origin. Graph G will keep the available origin s in the updated set V. The movement network is continuously formed to find the nearest destination node until the last node selected s = egress point. The number of steps m taken by the pedestrian from the origin to the destination is determined. Time taken t by the pedestrian to move from the origin to the destination will be calculated for both normal and panic situations.

4. EXPERIMENTAL SETUP

The layout structure used in this research is based on the closed area hall in Universiti Sains Malaysia and is replicated in homogenous grid cells. The layout was recorded as 24 m × 18 m without the wall. Previous research suggested the standard adult human grid cell size is 0.4 m × 0.4 m [13, 28-30]. However, other researchers suggested ≈ 0.4 m – 0.6 m for a grid cell due to the evolution of human body proportion to occupy a space and make a dynamic movement [31-33]. Hence, in this research, each cell was set to 0.6 m, and the grid was constructed with 42 × 32 grid cells with additional extra cells to form the walls and doors for simulation purposes. Fig. 2 a shows the grid cells' design for the selected layout.





Note: The blue colour rectangles are the walls and obstacles, the black colour rounds are the pedestrians, the green colour rounds are the DT's vertexes, the yellow colour rectangles are the doors and the white colour rectangles are the floor. The doorways will be tag as; E1 = Exit 1, E2 = Exit 2, E3 = Exit 3, E4 = Exit 4, E5 = Exit 5, E6 = Exit 6, E7 = Exit 7

Figure 2: a) standard grid setup for overall experiments; b) static obstacles arrangement in the layout.

Based on Fig. 2 a, the black cells represent the randomly spawned pedestrian origins and are constantly used throughout the experiments. The normal movement speed for pedestrian modelling is set to 1.0 m/s to mimic the self-sufficient and structured movement. The panic movement speed is set to 3.0 m/s to mimic unruly behaviour and sudden movement [7, 20, 34]. The existence of static obstacles in the spatial layout was simulated and arranged to represent the furnishings arrangement, as shown in Fig. 2 b. The vertexes randomly spawned in the layout for the DA approach experiments. The layout was enhanced by adding 200 pedestrians to represent dynamic obstacles. Based on Fig. 2 b, the blue cells indicate the obstacles, and the green cells indicate the vertexes distribution in the layout.

The whole experiments were conducted for each shortest path approach:

(1) Experiment 1 – Simulation on a vacant layout.

(2) Experiment 2 – Simulation on a layout with static obstacles.
(3) Experiment 3 – Simulation on a layout with static and dynamic obstacles.

Each experiment was set to run for 10 sets with ten pedestrian origins. The pedestrian will proceed to one of seven available exits in the layout, as shown in Fig. 2 a. The experiment will measure the actual distance (m) from the pedestrian origin to the selected egress and the travel distance (m) by measuring the movement transition while determining the travel time (s) in normal and panic situations.

5. RESULT AND DISCUSSION

During a real-life emergency, the existing features such as the furniture, layout's structure design, and the existence of pedestrians can contribute to substantial impediments that hinder pedestrian mobility. An early hypothesis shows that the movement disruptions can increase the distance scalar (travel distance) towards the nearest egress point compared to the displacement vector (actual distance). The increasing movement transition will elongate the evacuation time and promotes collision events that will lead to high casualties. Hence, the emergency route design based on the vacant layout will not efficiently assist the pedestrian during evacuation. This research has constructed a realistic layout design and cooperated with CA-based pedestrian simulation to mimic the actual situation. Pythagorean Theorem (PT) and Dijkstra's Algorithm (DA) are each integrated into the pedestrian simulation for finding the feasible shortest path approach in the designated experiments. Table IV shows the result of Experiment 1 as the benchmark experiment with a vacant layout for the PT and DA approach.

Table IV: Results for pedestrian simulation in a vacant layout using PT and DA approaches.

		PT					**DA**				
	Origin	**Dest.**	**Actual dist.** (m)	**Travel dist.** (m)	**Time** (s)		**Dest.**	**Actual dist.** (m)	**Travel dist.** (m)	**Time** (s)	
					N	**P**				**N**	**P**
Set 1	(20, 13)	E3	19.10	15.6	15.6	15.15	E5	21.40	19.8	19.8	16.53
Set 2	(23, 3)	**E5**	**14.32**	**7.8**	**7.8**	**12.57**	**E5**	**14.32**	**9.0**	**9.0**	**12.97**
Set 3	(10, 23)	E4	8.94	6.6	6.6	12.18	E2	10.0	9.6	9.6	13.17
Set 4	(31, 15)	**E7**	**10.05**	**5.4**	**5.4**	**11.78**	**E7**	**10.05**	**17.4**	**17.4**	**15.74**
Set 5	(9, 9)	**E1**	**9.0**	**9.0**	**9.0**	**12.97**	**E1**	**9.0**	**11.4**	**11.4**	**13.76**
Set 6	(17, 8)	E3	13.6	12.0	12.0	13.96	E6	30.48	33.0	33.0	20.89
Set 7	(29, 22)	E6	12.04	4.8	4.8	11.58	E5	23.41	40.2	40.2	23.27
Set 8	(18, 21)	E4	15.62	13.2	13.2	14.36	E5	28.32	24.6	24.60	18.12
Set 9	(10, 14)	**E1**	**11.18**	**10.8**	**10.8**	**13.56**	**E1**	**11.18**	**13.2**	**13.20**	**14.36**
Set 10	(29, 10)	E7	12.65	6.6	6.6	12.18	E5	12.81	9.0	9.0	12.97

i. Dest. – Destination, ii. Actual dist. – Actual distance, iii. Travel dist. – Travel distance, iv. N – Normal, v. P – Panic

Based on Table IV, 10 sets of experiments with different pedestrian origin coordinates (refer to Fig. 2 a) were simulated. The result shows that both shortest path approaches resulted in different egress for evacuation even though the pedestrian was moving in a vacant layout. However, Table IV shows that Sets 2, 4, 5, and 9 recorded a similar egress selection for both PT and DA approaches with equal actual distances. However, the travel distances for the sets as mentioned earlier were different. Hence, a graph comparison is plotted in Fig. 3 to show the comparison of actual distance and travel distance from Table IV for both PT and DA approaches.

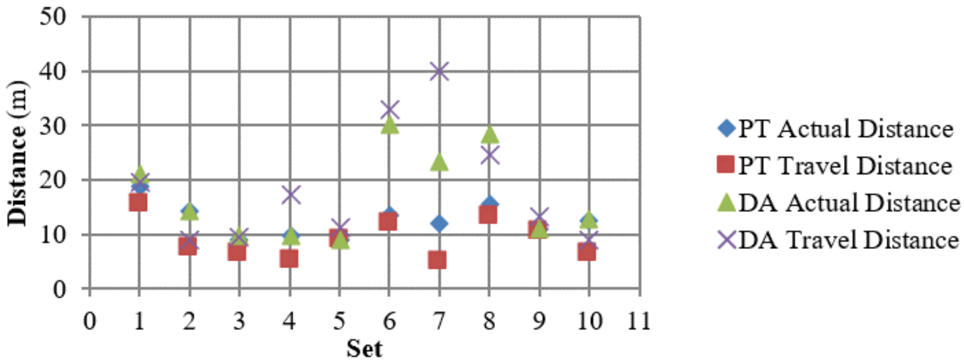


Figure 3: Comparison of the actual distance and travel distance for PT and DA approaches in the pedestrian movement simulation for a vacant spatial layout.

Based on Fig. 3, the PT approach is constantly recorded less travel distance than the actual distance except for Set 5, with similar travel and actual distance. While in the DA approach, 50 % of the result exhibits a shorter travel distance than the actual distance. In the DA approach, the pedestrian will travel farther than the actual distance by selecting different neighbour cells than the PT approach to reach the nearest vertex during movement transitions. Hence, justified the result in Table IV, for which the entire route generated with the DA approach shows a longer evacuation time than the PT approach. Based on Experiment 1, the PT approach can design a consistent shortest emergency route compared to the DA approach.

The existence of furnishing as the static obstacles in the layout can cause movement diversion and substantial effects during evacuation. The pedestrian will face challenges finding the nearest egress while avoiding the static obstacles. Table V shows the result of Experiment 2 to show the impact of the static obstacles during the evacuation process for the PT and DA approach.

Table V: Results for pedestrian simulation in a layout with static obstacles using PT and DA approaches.

		PT					DA				
	Origin	Dest.	Actual dist. (m)	Travel dist. (m)	Time (s)		Dest.	Actual dist. (m)	Travel dist. (m)	Time (s)	
					N	P				N	P
Set 1	(20, 13)	E3	19.10	15.6	15.6	15.15	E5	21.40	19.8	19.8	16.53
Set 2	(23, 3)	E5	14.32	7.8	7.8	12.57	E5	14.32	9.0	9.0	12.97
Set 3	(10, 23)	E4	8.94	6.6	6.6	12.18	E2	10.0	9.6	9.6	13.17
Set 4	(31, 15)	**E7**	**10.05**	**6.6**	**6.6**	**12.18**	E7	10.05	17.4	17.4	15.74
Set 5	(9, 9)	E1	9.0	9.0	9.0	12.97	E1	9.0	11.4	11.4	13.76
Set 6	(17, 8)	E3	13.6	12.0	12.0	13.96	**E6**	**30.48**	**35.4**	**35.40**	**21.68**
Set 7	(29, 22)	**E6**	**12.04**	**6.0**	**6.0**	**11.98**	E5	23.41	40.2	40.2	23.27
Set 8	(18, 21)	E4	15.62	13.2	13.2	14.36	E5	28.32	24.6	24.60	18.12
Set 9	(10, 14)	E1	11.18	10.8	10.8	13.56	E1	11.18	13.2	13.20	14.36
Set 10	(29, 10)	E7	12.65	6.6	6.6	12.18	E5	12.81	9.0	9.0	12.97

i. Dest. – Destination, ii. Actual dist. – Actual distance, iii. Travel dist. – Travel distance, iv. N – Normal, v. P – Panic

Based on Table V, Experiment 2, with static obstacles in a layout, the pedestrian chose similar egress points during pedestrian simulation, resulting in the same actual distance as shown in Experiment 1 for PT and DA approaches. However, due to the movement perturbation by the static obstacles, the pedestrian experienced the diversion during movement transition and causing a farther travel distance than recorded in Experiment 1. The detour had increased the evacuation time, as shown in PT's Sets 4 and 7 and DA's Set 6. Based on the result, static obstacles have a high impact on the PT approach's shortest distance, causing a 20 % increment in travel distance. In comparison, the DA approach has only recorded a 10 % of route changes. However, the 20 % extended travel distance in Sets 4 and 7 in the PT approach show reduced travel distance and shorter evacuation time than the DA approach in the same set experiments. Hence, even though the DA approach shows less travel distance, the PT approach is able to construct the shortest emergency route in a layout with static obstacles.

Simulation with a realistic layout can mimic the actual evacuation process. The existence of static and dynamic obstacles can hinder and cause significant challenges to the pedestrian to escape compared to the vacant and static obstacles' filled layout. Table VI shows the significant result of Experiment 3. The main purpose of this experiment is to investigate the impact of static and dynamic obstacles in the evacuation process for the PT and DA approach.

Table VI: Results for pedestrian simulation in a layout with dynamic and static obstacles using PT and DA approaches.

		PT					DA				
	Origin	**Dest.**	**Actual dist.** (m)	**Travel dist.** (m)	**Time** (s)		**Dest.**	**Actual dist.** (m)	**Travel dist.** (m)	**Time** (s)	
					N	**P**				**N**	**P**
Set 1	(20, 13)	**E5**	**21.40**	**22.2**	**22.2**	**17.33**	E5	21.40	22.2	22.2	17.33
Set 2	(23, 3)	E5	14.32	10.2	10.2	13.37	E5	14.32	10.2	10.2	13.37
Set 3	(10, 23)	**E2**	**10.0**	**10.8**	**10.8**	**13.56**	E2	10.0	10.8	10.8	13.56
Set 4	(31, 15)	E7	10.05	18.0	18.0	15.94	E7	10.05	18.0	18.0	15.94
Set 5	(9, 9)	E1	9.0	12.6	12.6	14.16	E1	9.0	12.6	12.6	14.16
Set 6	(17, 8)	**E6**	**30.48**	**42.0**	**42.0**	**23.87**	E6	30.48	42.0	42.0	23.87
Set 7	(29, 22)	**E5**	**23.41**	**47.4**	**47.4**	**25.64**	E5	23.41	47.4	47.4	25.64
Set 8	(18, 21)	**E5**	**28.32**	**27.0**	**27.0**	**18.91**	E5	28.32	27.0	27.0	18.91
Set 9	(10, 14)	E1	11.18	15.6	15.6	15.15	E1	11.18	15.6	15.6	15.15
Set 10	(29, 10)	**E5**	**12.81**	**11.4**	**11.4**	**13.76**	E5	12.81	11.4	11.4	13.76

i. Dest. – Destination, ii. Actual dist. – Actual distance, iii. Travel dist. – Travel distance, iv. N – Normal, v. P – Panic

Based on Table VI, Experiment 3 with static and dynamic obstacles in a layout shows extreme changes in the PT approach as 60 % of the result recorded a different egress selection than Experiment 2 (refer to Table V) and caused a longer travel distance. In contrast, the DA approach has no changes in egress selection and travel distance. The existence of static obstacles and other pedestrians as dynamic obstacles created significant diversion compared to the vacant layout and the layout with static obstacles only. Fig. 4 shows the comparison of travel distance recorded for all experiments from Table IV, V, and VI for both PT and DA approaches.

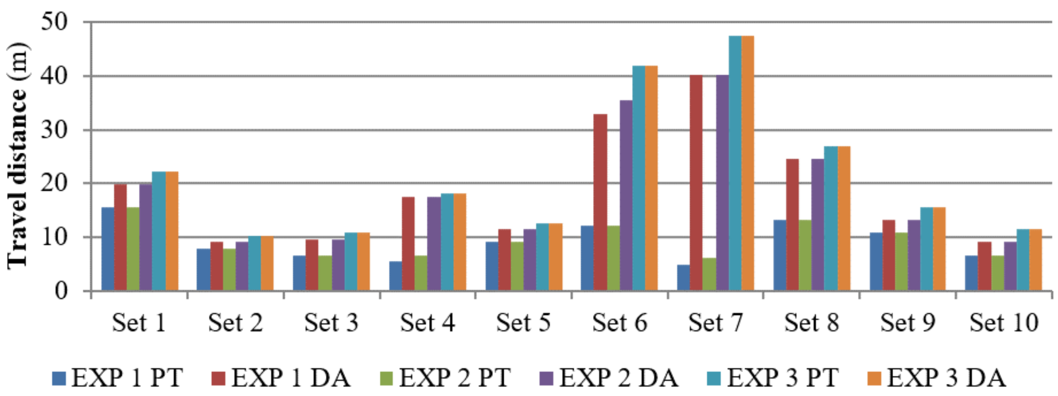


Figure 4: The travel distance for both PT and DA approaches in the pedestrian movement simulation for all experiments.

Based on Fig. 4, the PT approach shows a significant travel distance in a vacant layout and a layout with static obstacles. However, the PT-based evacuation path had become on par with the DA-based evacuation path in the layout with static and dynamic obstacles that resulted in a similar travel distance for every experiment set. Hence, the evacuation times recorded for both approaches are identical. Overall, in Experiments 1 and 2, the PT approach outperformed the DA approach in terms of egress selection with nearest actual distance, travel distance, and evacuation time. However, the presence of static and dynamic obstacles in Experiment 3 hampered movement and became the crucial factor that increased the travel distance and evacuation time in the PT approach. During the PT approach, the pedestrian will divert the movement farther from the former direction in Experiments 1 and 2. This situation happened due to the collision avoidance and distance recalculation towards the nearest exit that affected the movement transition, path direction, and egress selection. However, during the DA approach, the pedestrian will divert the movement towards the nearest neighbours around the closest vertex. The DA algorithm was designed to find the nearest vertex for every movement transition instead of the nearest egress. Hence, the DA approach shortest path method will produce a similar route to Experiments 1 and 2 but increased travel distance and evacuation time due to collision avoidance with other pedestrians.

The PT and DA shortest distance approaches are ideal in pedestrian movement simulation for finding the nearest egress during evacuation in a realistic spatial layout scenario. However, the DA approach significantly benefits the emergency route design based on the movement pattern, the increment of layout size, the number of obstacles, and the number of pedestrians in a layout compared to the PT approach. DA approach shows better movement transition when involving highly densely populated regions, while PT is the excellent approach in the less populated regions.

4. CONCLUSION

The integration of realistic pedestrian simulation and layout environment can assist the future emergency route plan design and reduce the number of casualties. From the studies and findings, it can be concluded that:

1) Realistic features in a spatial layout can affect the emergency route development by diverting the pedestrian movement direction, increasing the travel distance towards the nearest egress point, and delaying the evacuation time.
2) The PT approach shows more advantages in finding the nearest egress with a short evacuation time in a vacant layout and a layout with static obstacles.
3) DA approach shows comparable results with the PT approach during the simulation in a layout with static and dynamic obstacles.

Hence, overall, the PT approach is suitable for constructing emergency routes in vacant layouts, layouts with static obstacles, and layouts with static and dynamic obstacles in less densely populated regions. The DA approach is not suitable for a vacant and static obstacles-filled layout but is ideal for constructing an emergency route in a densely populated layout region with static and dynamic obstacles. The emergency route plan of a realistic layout can be improved for faster evacuation assistance by integrating the PT and DA approaches for future research development in designing a dynamic simulation approach.

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