Numerical Simulation of Evacuation Process in Malaysia By Using Distinct-Element-Method Based Multi-Agent Model

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Abstract. In Malaysia, not many researches on crowd evacuation simulation had been reported. Hence, the development of numerical crowd evacuation process by taking into account people behavioral patterns and psychological characteristics is crucial in Malaysia. On the other hand, tsunami disaster began to gain attention of Malaysian citizens after the 2004 Indian Ocean Tsunami that need quick evacuation process. In relation to the above circumstances, we have conducted simulations of tsunami evacuation process at the Miami Beach of Penang Island by using Distinct Element Method (DEM)-based crowd behavior simulator. The main objectives are to investigate and reproduce current conditions of evacuation process at the said locations under different hypothetical scenarios for the efficiency study of the evacuation. The sim-1 is initial condition of evacuation planning while sim-2 as improvement of evacuation planning by adding new evacuation area. From the simulation result, sim-2 have a shorter time of evacuation process compared to the sim-1. The evacuation time reduced 53 second. The effect of the additional evacuation place is confirmed from decreasing of the evacuation completion time. Simultaneously, the numerical simulation may be promoted as an effective tool in studying crowd evacuation process.

Keywords: Numerical simulation, evacuation process, distinct element method, microscopic model, crowd behavior simulator.

1. Introduction
Following from the 2004 Indian Ocean Tsunami tragedy, the government of Malaysia had enforced the relevant disaster management agencies to look in detail the matter. The initial measures taken was the needs to readdress the tsunami mitigation problems towards better mechanism in such a manner that tsunami rescue works could be performed in an efficient and effective manner [4,5]. In conjunction to that, the tsunami emergency plan had been established which covered: (1) evaluation awareness, preparedness of the community, local and state agencies in combating tsunamis; (2) enhancement of public awareness through education of community; and (3) the formulation of tsunami evacuation planning. Among the mentioned countermeasures, a greater attention is directed to a good planning of tsunami evacuation.
Evacuation planning is a procedure that involves the movement of people to a safer place. Currently, evacuation drills have been put in place and conducted annually by the Malaysian Meteorological Department (MMD) since 2006. The drill is one of the good indicators that an evacuation will go smoothly and successfully. Moreover, the drill also is an important awareness tool to familiarize the public with evacuation procedure. However, drills alone are not enough in preparing an effective tsunami evacuation planning since it is quite time consuming, costly and furthermore, the drill is quite rigid which cannot deal with various conditions on site flexibly. Hence, in conjunction to have a better evacuation planning, performed the numerical simulation of current conditions of evacuations process on selected areas by considering different kind of scenarios [3]. By conducting evacuation process for different kind of scenarios, better planning of evacuation may be derived.

This paper focuses on the evacuation process optimization through numerical simulation by using Distinct-Element-Method (DEM) based multi-agent models namely Crowd Behavior Simulator for Disaster Evacuation model (CBS-DE) [1,2]. The author investigates current condition of evacuation process against tsunami and try to figure out the weaknesses in its possession. Hence, from the weaknesses highlighted, the suggestion of improvements will be made.

2. Crowd Behavior Simulator For Disaster Evacuation (CBS-DE)

Fundamental equations
The equation of motion for simulating each individual behavior which consists of translational and rotational equations are governed by the following equations:

\[ m_i \mathbf{v}_i = \mathbf{F}_{mi} + \mathbf{F}_{ci} \]
\[ I_i \mathbf{\omega}_i = \mathbf{T}_i \]

where \( m_i \) is the mass of the person \( i \), \( \mathbf{v}_i \) is the velocity of the person \( i \), \( \mathbf{F}_{mi} \) is the autonomous driving force of the person \( i \), \( \mathbf{F}_{ci} \) is the interacting force acting on the person \( i \), \( I_i \) is the moment of inertia of the person \( i \), \( \mathbf{\omega}_i \) is the angular velocity of the person \( i \), and \( \mathbf{T}_i \) is the torque acting on the person \( i \).

Autonomous driving force
The autonomous driving force is \( \mathbf{F}_{mi} \) terms are:

\[ \mathbf{F}_{mi} = m_i \mathbf{a} \]

where \( \mathbf{a} \) is the acceleration vector. The equilibrium walking velocity is affected by number density of human. Therefore, the magnitude of the maximum equilibrium walking velocity \( v_{\text{max}} \) is given as follows:

\[ v_{\text{max}} = v_{\text{limit}} - \gamma \cdot c_k \]

where \( v_{\text{limit}} \) is the magnitude of the specific equilibrium velocity, \( \gamma \) is the proportional coefficient depend on the congestion condition in designated area, \( c_k \) is the number density of persons inside the psychological perception area.

Interacting forces
The estimation of the interacting force is made by Voigt model and by referring to perception domain (Fig. 1). The total interacting force acting on the person \( i \) is described as follows:

\[ \mathbf{F}_{ci} = \mathbf{F}_{d(\rho \rho)} + \mathbf{F}_{d(W \rho)} + \mathbf{F}_{ps,i} \]
where $F_{dp/ps}^{i}$ is the physical repulsive force acting on the person $i$, $F_{dW/p}^{i}$ is the physical repulsive force between the virtual wall element ($W$) and the person $i$, $F_{ps/ps}^{i,j}$ is the psychological repulsive force acting on the person $i$.

![Diagram](image.png)

**Figure 1. Schematic diagram of perception domain.**

### 3. Results and discussion

**EVACUATION PROCESS**

The Miami Beach of Penang Island is selected as the site of the present study. The length of shoreline is approximately 270 meters and the width is about 30 meters. Fig. 2 shows the computational domain of the study which is illustrated by a bird’s-eye view. The Miami Beach is located in sea-front delta with a hill on its back. The hill has an approximately 23 meters in height above the sea level. And this height is considered as adequate level of setting an evacuation place against tsunami. Table 1 shows the distribution of population observed by field survey in the Miami Beach at a peak time.

![Map](image.png)

**Figure 2. Bird’s eye view of computational domain.**
Table 1. Distribution of population observed during field survey in the Miami Beach (Peak time).

| Category | Sex | Age      | People | Ratio [%] | Velocity [m/s] |
|----------|-----|----------|--------|-----------|---------------|
| 1        | Male| 10-39    | 93     | 27.93     | 1.38          |
| 2        | Female| 10-39  | 53     | 15.92     | 1.14          |
| 3        | Male| 40-69   | 4      | 1.20      | 0.99          |
| 4        | Female| 40-69  | 93     | 27.93     | 1.20          |
| 5        | Male| >70     | 41     | 12.31     | 1.04          |
| 6        | Female| >70    | 3      | 0.90      | 0.89          |
| 7        | Child   | 5-9    | 46     | 13.81     | 1.06          |
| Total    |        |         | 333    | 100 %     |               |

Simulation setup

The evacuation process is started after receiving the verbal evacuation signal propagated concentrically from the S-point with speed of 1.50 m/s and completed after all people reach at altitude of 7 meters above the sea level which is based on the observed tsunami record in 2004. The initial arrangements of the persons are assigned randomly around the beach area. In the present simulation, we do not consider a special attractive force between flocks, such as a family, friends and a couple. To simulate a flock behavior, a psychological attractive force between persons should be incorporated. Here, we assumed that each person walks independently without any special psychological attractive force.

Investigation of evacuation process

For the initial condition of evacuation planning, the evacuation place is designated in the end of the main road leading from coast as shown in Fig. 3. This simulation is named as the sim-1. The people are instructed to evacuate toward the designated evacuation place. The illustration snapshots of the sim-1 are shown in Fig. 4. The graph of the time taken versus accumulative number of people who have completed the evacuation process is plotted as shown in Fig. 5. The time required to complete the evacuation process of the sim-1 is 312 seconds.

From sim-1, the efficiency of evacuation process can be obtained. Therefore the deprivation area for quick evacuation has been disclosed. The interruption area for smooth evacuation was detected in the east end of the Area C and in the west end of the Area A. The significant factor of the delay in the evacuation process was the initial position of persons who are remote from the designated evacuation area. The proposals toward the quick evacuation are shown in the following section.

Figure 3. Evacuation route and movement direction of people for the sim-1.
Improvement of evacuation planning

The late persons who are in the inconvenient area have been investigated in the alternative scenario. The alternative scenario is identified as the sim-2 for shortening the path between original location of people and the evacuation place, and in the same time, the completion time of evacuation is expected to be reduced. The evacuation route of the sim-2 is shown on Fig. 6. In the sim-2, persons arranged in the Area C are specified to evacuate to the new evacuation place, which is placed at the east end of the residential area. Whereas, the persons who in the Area A and B, evacuate to the same evacuation place as the sim-1. The illustration snapshots of the sim-2 are shown in Fig. 7. Fig. 5 shows the accumulated number of people who have completed the evacuation for the sim-1 and the sim-2.
viewpoint of the evacuation completion time, a decrease of 53s is found in the sim-1 compared with the sim-2. From these results, the effect of the additional evacuation place is confirmed from decreasing of the evacuation completion time.

![Evacuation route and movement direction of people for the sim-2.](image)

Figure 6. Evacuation route and movement direction of people for the sim-2.

![Snapshot of the sim-2.](image)

Figure 7. Snapshot of the sim-2.

Assessment of initial position of visitor to the evacuation place

Three main factors that influence the evacuation process are as follows: (1) distance from initial position of person to the evacuation area; (2) type of human; and (3) surrounding area. In practice, the information of human type composition can be useful to develop an effective evacuation planning. Children and elders have slower average walking velocities in comparison to adults. Therefore, new evacuation area can be proposed to be built closer to the area that has higher percentage of elders and children composition to ensure quick evacuation process. The moving distance of each person for the duration of n-th computational time marching steps can be given by :-
\[ L_n = \sum_{k=1}^{n} (u_{h_i} \cdot t) \Delta t \]  

in which, \( n \) is the time step, \( t \) is unit tangent vector along to moving direction. The improvement by proposed the new additional evacuation area closest at Area C will be the reasonable choice.

4. Conclusion

In this study, the process of the evacuation planning has been shown through the numerical simulation for the evacuation against tsunami at the Miami Beach, Penang, Malaysia by using the CBS-DE simulator based on the Distinct Element Method (DEM). In the process of the evacuation planning, the inconvenient area has been revealed firstly, then the alternative planning for the improvement of the inconvenient area has been investigated, and the effect of the alternative planning has been shown quantitatively. The evacuation time had been decrease 53 second after introduced new evacuation area.

From the simulation results, the positions of each person have been tracked with detail information as discussed previously. Through the detail information obtained, a realistic virtual space by CG can be made. As shown in Fig. 8, the typical snapshots of evacuation process have been captured. This kind of the CG will be considered to be a useful tool for explaining the evacuation planning to the public, because CG movie has an advantage in the visual sense and people will be able to image evacuation process easily.

![Typical snapshot of CG movie for evacuation process at Miami Beach.](image-url)
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