The 5th Student Conference on Research and Development –SCOReD 2007
11-12 December 2007, Malaysia

Feasible Route Determination Using Ant Colony Optimization in Evacuation Planning

Arief Rahman, and Ahmad Kamil Mahmood

***Abstract*-- The most complex aspect of people movement on emergency condition is how to select the shortest way out from multi exit ways in the multi-floors building. The purpose of this paper is to demonstrate how an Ant Colony Optimization (ACO) can be used in evacuation planning. Modified ACO applied as the algorithm to determine the feasible route during emergency evacuation. Physical obstacle during building evacuation such as bottleneck or disaster problem has been considered in transitional probability rule of ACO. By creating exit sign (an agent) with ACO as the algorithm, this agent decides the feasible route and guides the occupant during the evacuation. Two scenarios present to observe the performance of two different approaches in making decision during evacuation. When the obstacle appeared, route selection based on ACO algorithm has faster total evacuation time significantly than familiarity of environment exit method.**

Index Terms--Ant colony optimization, multi-agent, exit sign and evacuation planning.

I. Introduction

EVACUATION procedure and system in multi-floors building became very important since many occupants should be protected from unpredicted disaster such as fire or earthquake. So that, every public building has to implement the emergency preparedness and evacuation process, including building facilities and exit emergency plan. Emergency evacuation route should be defined precisely and supported by clear instruction display to all the occupants in the building.

The most complex aspect of people movement on emergency condition is how to select the shortest way out from multi-exit ways in the multi-floor building [1]. Beside the physical factors like running speed, distance, and building facilities, there are also several human behavior factors affected on their decision to choose the available routes. Those are familiarity of building environment (cognitive map) [1], interaction and cooperation within the group [2], leadership factor among the occupants [3], etc.

Now, many computer simulations have been developed to represent evacuation process as well as real condition. As in [4], 22 computer simulations has been reviewed and classified into 3 categories. Most of them have developed the evacuation simulations, the rest tried to optimize the evacuation process and measure the risk. Most of existing computer simulations for evacuation process use mathematical model or formula to simulate crowd movement in the large area of multi-floors building. Some attributes like walking speed, space sizes, stairways dimension, room density, occupant interactions, etc are combined and calculated using computer simulation to find optimal evacuation process. Some examples of existing evacuation simulation are EXODUS [5], SIMULEX [6], ESM [7], and EVACNET [15]. Therefore, they have same parameters, maximizing number of safety people and minimizing total evacuation time as two main success parameters on evacuation simulation.

Even the experimental evacuation drill can be representing the real emergency condition, arranging the evacuation drill still need practical and financial issues [4]. Development of some computer simulation is one of the alternatives to apply some experimental studies during evacuation condition. By using computer-based evacuation model, some related factors of evacuation process could be predicted with small participation from occupants, low cost experiment and assure safety in the building [8].

Guidance or instruction is necessary and important for occupants on panic situation. Exit sign is one of guidance to find the route alternatives but it is not more than static label. A leader among group of evacuees can also be a guide and the response from the followers should be higher than exit sign [9]. Communication and instruction can be delivered interactively by the leader. However, the decision taken by leader is based on the familiarity against building environment [3]. So this alternative of guidance unable to determine the decision based on whole building situation. And it is also not easy to find the leader in every group and in panic situation.

In this article, we modify ACO algorithm as based-method on computer simulation (IntelSign), to find the feasible route during building evacuation. Two scenarios are presented to observe the performance of two different approaches in making decision during evacuation. We define the hypothesis of research as follow: "By considering the physical obstacle, total evacuation time given by ACO algorithm exit method will be shorter than total time given by familiarity of environment exit method".

II. Ant Colony Optimization

A. *Ant System*

Ant is social insect that lived together in a colony system [10]. Effective cooperation to find the food or source is one of

Arief Rahman is with the Department of Information and Computer Science, Petronas University of Technology (UTP), Perak, Malaysia.
Ahmad Kamil Mahmood is with the Department of Information and Computer Science, Petronas University of Technology (UTP), Perak, Malaysia (e-mail: kamilmh@petronas.com.my)

the famous ability of ant system behavior. Ant, the blind animals, enables to track shortest paths between its nest to feeding sources and back [11]. It is found that every ant has pheromone, the medium that used to communicate information among ants during along their track of journey [10]. Each ant marks the path by a trail of pheromone with varying quantities of pheromone on the ground. Then, next ant enables to track the marked path and to decide to follow with certain probabilistic value and also strengthen the chosen path by putting new pheromone by itself [10]. This kind of communication way called as *stigmergy* process [10]-[11].

Ants start the tour to find the shortest route by choosing a defined node or town randomly and one node will place by one ant. Node selection by an ant decides using probabilistic function called state transition rule, by considering visibility (inversion of distance) and the amount of pheromone on the trail [10]. Transition probability of ant system, from node i to node j for k^{th} ant, is defined as below [10]-[11]:

$$p_{ij}^{k}(t) = \frac{[\tau_{ij}]^{\alpha}.[\eta_{ij}]^{\beta}}{\sum_{k\ \varepsilon\ allowed\ k}[\tau_{ij}]^{\alpha}.[\eta_{ij}]^{\beta}} \tag{1}$$

where $\tau_{ij}(t)$ as the intensity of trail on edge (i , j) at time t and η_{ij} as the visibility of an ant ($\eta_{ij} = 1/d_{ij}$).

The trail intensity is updated according to the following formula [10]:

$$\tau_{ij}(t+n) = p.\tau_{ij}(t) + \Delta\tau_{ij} \tag{2}$$

where p is a coefficient represents the evaporation of trail between time t and t + n (p value must be <1 to avoid unlimited accumulation of trail), and quantity per unit of length of trail substance lain on edge (i,j) is:

$$\Delta\tau_{ij} = \sum_{k=1}^{m}\Delta\tau_{ij}^{k} \tag{3}$$

Reference [10]-[11] shows that ant-cycle algorithm is defined as below:

1. Initialization process and place m ants on n selected nodes.
2. Starting point initialization by setting up tabu list index = 1 for each ant.
3. Next node selection, applied transition probability rule and updated the tabu list.
4. Move ant and compute the length.
5. Update the shortest route found and updated the amount of pheromone once ant completed their tour.
6. Apply the evaporation process, set the tabu list empty and repeat the above process until number of cycle has fulfilled.

B. Proposed modification to the Ant System

In order to apply ACO on evacuation process, a new factor is added by considering the physical obstacle in building evacuation such as fire location, damaged facilities, bottleneck problem and obstacle on the exit corridor. A route, which the physical obstacle occurred on it, should not be chosen with low probability.

Transitional probability rule as given in (1) determine the next route will be chosen by ant during route detection. By adding a new variable, traffic on the node i to j (ω_{ij}), we proposed the modification of ACO's transitional probability rule as given in (4).

$$p_{ij}^{k}(t) = \frac{[\tau_{ij}]^{\alpha}.[\eta_{ij}]^{\beta}.[\omega]^{\lambda}}{\sum_{k\ \varepsilon\ allowed\ k}[\tau_{ij}]^{\alpha}.[\eta_{ij}]^{\beta}.[\omega]^{\lambda}} \tag{4}$$

where α, β, λ are parameters that control the relative importance of those 3 variables of transitional probability rule.

Traffic variable (ω_{ij}) defines as the inversion of physical obstacle ($1/pob_{ij}$) where pob_{ij} is weight of physical obstacle from node i to node j. the value of pob_{ij} must be set as a ratio (i.e., the utilization of corridor or staircase). Traffic variable will not update during ant algorithm process but it will update during the simulation.

III. EVACUATION SIMULATION

A. Building definition

Computer simulation for evacuation is developed to assess the ACO modification. Some scenarios have been designed as the real problem representation. One of student's hostels in our University has chosen as a case problem on the simulation. This building has 4 levels of floors, each floor has 4 blocks of rooms, each block has 12 rooms (excluding 1 bathroom and 1 kitchen in every block), and each room has 2 occupants. Fig. 1 describes the layout of the building and Fig. 2 provides the detail layout of building.

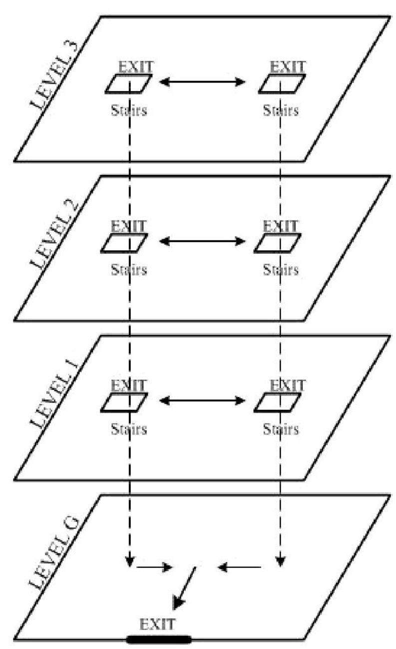

Fig. 1. Hostel schematic, exits and staircases position.

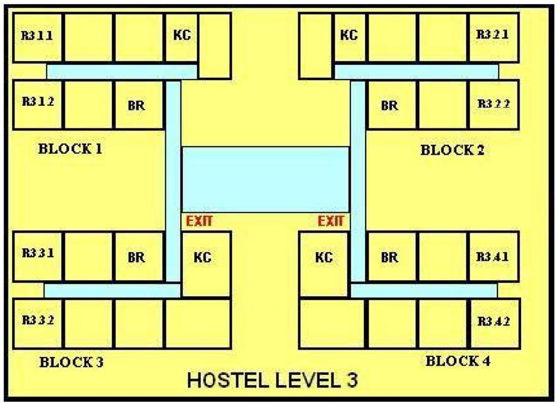

Fig. 2. Hostel's detail layout for level 3 (KC: Kitchen, BR: Bathroom, R3.1.1: room number)

In order to simulate the evacuation process and to identify available routes in the building, a network model presenting the route is presented [12]. Starting point of each block presents by one node on the network. Node 1 is representation of room location on block 1 level 3, node 2 for block 2 level 3, node 5 for block 3 level 3, and node 6 for block 4 level 3. Node 25 represents the exit door on ground floor and node 31 represents assembly point as the ending point of evacuation. Fig. 3 describes the detail network of 4 levels building's route, as below.

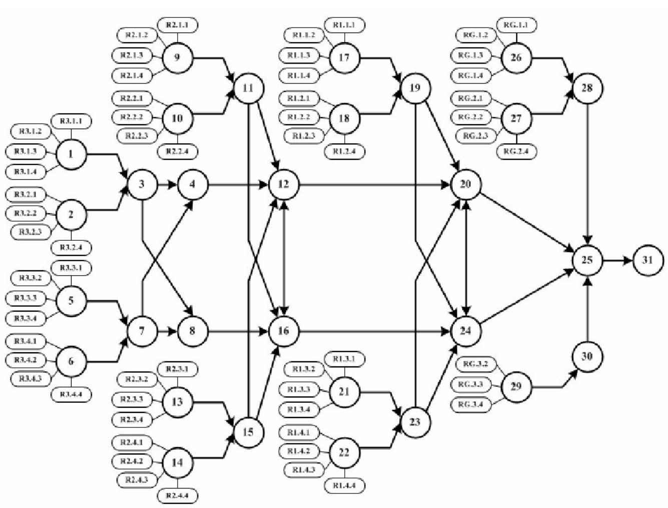

Fig. 3. Network model of 4 levels building's route definition.

B. Agents Architecture

The action rule definition intends to obtain the action rule of occupant as the main actor in simulation. We create and modify the exit sign as an agent, not only as the static display but it play the important function as a dynamic guidance during evacuation. A part of Prometheus methodology has applied to describe the agent attributes, agent action rule and interaction between agents [13]. Fig. 4 shows the interaction between agents.

1) Agent Occupant

This agent is the response agent and received the information from other agents. The goal of this agent is to achieve the end point or assembly point through some corridor and staircase. This agent start to walk generated by the randomize order and its life time will end when achieve the assembly point. Agent occupant received information against feasible route by agent exit sign through feasible route protocol. Initial position of each agent provide in building database. Some action rules such as alert response, walking, interacting with exit sign and overtaking, are applied to this agent.

2) Agent Exit Sign

The main function of this agent is to calculate the feasible route and share the output on feasible route protocol. Agent exit sign receives information from obstacle protocol which is generated by agent staircase and corridor. Once, the simulation clock is on then exit sign process an action rule to run the ACO algorithm.

3) Agent Corridor

Number of occupant in-line or walk through on the corridor is calculated by agent corridor. This agent is able to detect the disaster location, if any. The main information provides by this agent is to update obstacle protocol based on real time queuing and disaster status. The action rule applied to this agent is to calculate the physical obstacle status (pob_{ij}) on each corridor.

4) Agent Staircase

Agent staircase has main function as same as agent corridor. This agent update the obstacle protocol based on real time condition on each staircase on the building.

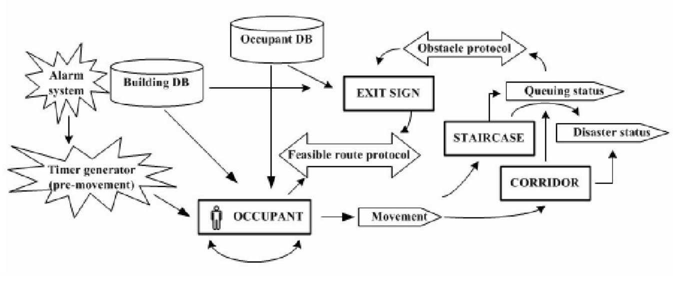

Fig .4. Evacuation system overview diagram

C. Experimental setup

There are 2 main phases in evacuation modeling, time to start and time to move (time to evacuate and pass though the exit) [14]. Clearance time (T_{clear}) equal to time to start movement ($t_{premove}$) and time to move and pass through exits emergency (t_{move}), so not just simply T equal to t_{move}. In this simulation, time to start movement generated by random order following the normal distribution (mean = 62 sec and standard deviation = 40 sec).

Reference [6] shows the physical attributes of people. Each people is defines as male with average high is 160 cm and the walking speed is 1.8 m/s. The average body size is 0.5m x 0.5m (a square).

The drawing scale to present the building layout is 1:200 meters. Average room dimension is 3 m x 3 m, corridor width is 1.5 m, and staircase width is 2 m.

Total clearance times to evacuate all the occupants in the building (clearance time or T_{clear}) and number of safe occupants achieve to assembly point, are main parameters used by this simulator.

The average of actual duration was taken by normal walking from level 3, block 1, room no.1 (R3.1.1) to exit door on ground floor is 54.7 sec. Then, t-test (paired to sample for means) applied to validate the simulator as below on table I.

TABLE I
T-TEST FOR ACTUAL DURATION VERSUS SIMULATION OUTPUT

	Simulator	*Actual*
Mean	53	54.7
Variance	7	1.81
Pearson Correlation	-0.58997144	
Hypothesized Mean Difference	0	
df	10	
t Stat	**-1.56317145**	
P(T<=t) one-tail	**0.074538609**	
t Critical one-tail	**1.812461102**	

From t-test interpretation ($t_{stat} < t_{critical}$), the duration time taken from simulation is valid to represent the actual duration on normal walking speed.

D. Problem and Scenario

Determine the feasible route on evacuation is main objective of this research by modifying ACO algorithm and compare with normal evacuation process. The normal evacuation process is following the human behavior during emergency condition. Most of people will follow their experience in making decision to take the shortest route. Familiarity of environment or building layout, followed the safety procedure and evacuation drill, are some experience to built their cognitive map of the building [2]. Then, comparing this behavior, follow their experience to determine the evacuation route, with the feasible route which is determined by ACO algorithm is the first scenario to be simulated.

Guidance during emergency evacuation is the very important information in making decision to take the shortest route. Exit sign is one of the guidance on the building to show the evacuation route to assembly point. Leader has played important contribution during evacuation and he/she able to show the evacuation route base on his/her experience or familiarity of environment [3]-[9]. Nevertheless, on multi-floors building, the decision made base on local area identification could be faced the obstacle to the next area or floor. Exit sign and leader could be classified as local based decision making on the multi-floors building. Observing the performance of evacuation process guided by ACO during evacuation and compared with the performance of evacuation without guidance is the motivation of this scenario. By creating virtual obstacle such as fire or bottleneck in line of staircase, we would like to know that ACO able to guide the occupant based on overall condition and levels on the building.

IV. RESULTS

Simulation ran with 180 occupants from 4 different levels and every occupant (as an object in simulation) has specific position which was defined by user. Fig. 5 shows the simulator's preview.

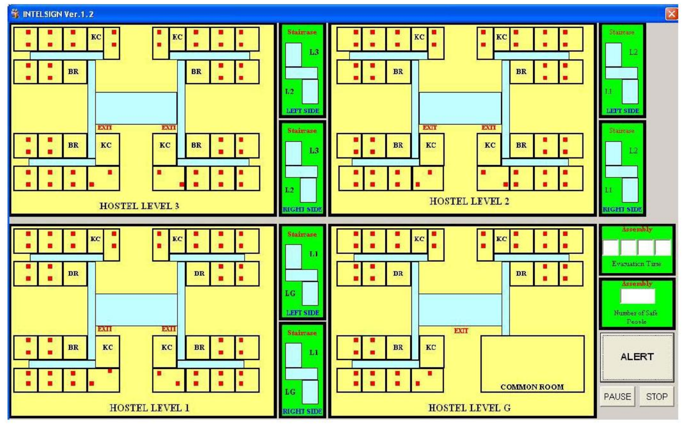

Fig. 5. IntelSign Ver.1.2 preview

A. Scenario 1

IntelSign has been designed to simulate some certain scenarios. By choosing the exit method based on environmental familiarity on the input menu, the first scenario ready to run. The input menu is shown on Fig. 6 The first exit methods, familiarity of environment, has specific evacuation route, occupant will take the nearest staircase and exits from their current position (i.e., occupant from R3.1.1 will take the route on the network model: 1 – 3 – 4 – 12 – 20 – 25 – 31)

When ACO algorithm applied to determine the feasible route, the result route defined by ACO has same result as Environmental familiarity condition has defined (i.e., occupant from R3.1.1. also took 1 – 3 – 4 – 12 – 20 – 25 – 31). And all the occupants took the same route as Environmental familiarity rule. As seen on table II, the total duration time on evacuation both familiarity of environment exit methods and ACO algorithm determination are not difference significantly ($t_{stat} < t_{critical}$).

TABLE II
T-TEST FOR TOTAL CLEARANCE TIME TAKEN BY FAMILIARITY OF ENVIRONMENT VERSUS ACO ALGORITHM (SCENARIO 1)

	Familiarity	*ACO*
Mean	179.8	183
Variance	18.7	51.5
Pearson Correlation	-0.46724384	
Hypothesized Mean Difference	0	
df	4	
t Stat	**-0.718421208**	
P(T<=t) one-tail	**0.256112629**	
t Critical one-tail	**2.131846782**	

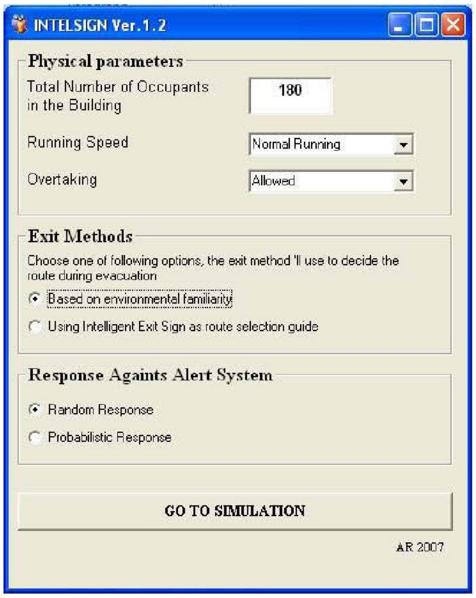

Fig. 6. Setting up the scenario of simulation

By following experience in making decision during evacuation should be take the shortest route and usually the route was taken is straight forward. It shows that the route determine by ACO has same route as route decided by following experience. Familiarity of environment has formed by routine processes, recognizing the past experience, retrieving successful experience and carry out the routines [2]. However, this scenario applied by ignoring any possible obstacle appeared in the building area.

B. Scenario 2

This scenario intend to show the difference in making decision during evacuation between local based decision and the decision calculated based on overall condition in fired building. So, we assumed that an obstacle was occurring at the end of left staircase - level 2 (node 20 on the network model). Fig. 7 describes the location of an obstacle.

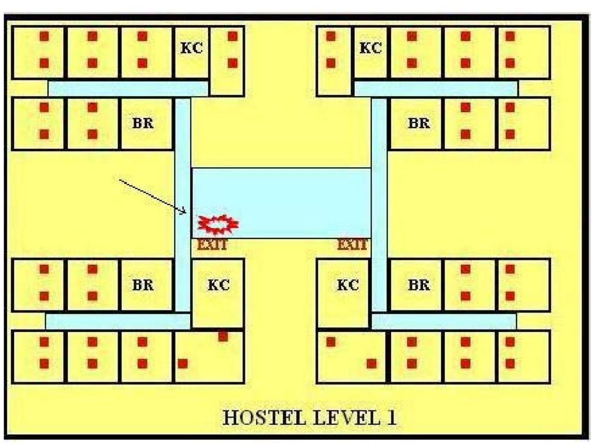

Fig. 7. Obstacle is created on scenario 2

If an occupant run through on left side staircase L2 – L1 (Level 2 going down to level 1), he/she have to run back to another staircase on the right side.

Scenario 2 ran with both familiarity of environment exit method and ACO route determination. And table III shows the analysis of those two methods using t-test. Total clearance time of Familiarity of Environment exit methods is different significantly with total clearance time guided by ACO algorithm ($t_{stat} > t_{critical}$).

TABLE III
T-TEST FOR TOTAL CLEARANCE TIME (SCENARIO 2)

	Familiarity (Obst)	*ACO (Obst)*
Mean	263.1	224.9
Variance	57.21111111	34.32222222
Pearson Correlation	-0.393416476	
Hypothesized Mean Difference	0	
df	9	
t Stat	**10.74458945**	
P(T<=t) one-tail	**9.81047E-07**	
t Critical one-tail	**1.833112923**	

During simulation occupant who followed familiarity of environment exit method, selected the nearest corridor and staircase around him/her. Route 1-3-4-12-20-25-31 and 2-3-4-12-20-25-31 has chosen by occupant started from block 1 and block 2 on level 3, route 9-11-12-20-25-31 and 10-11-12-20-25-31 chosen by occupant from block 1 and block 2 on level 2, route 17-19-20-25-31 and 18-19-20-25-31 taken by occupant from block 1 and 2 on level 1. When an obstacle occurred on node 20, most of them who followed above route based on their familiarity trapped on the staircase, they must turn back and selected the other route through node 24-25-31.

While a physical obstacle appeared on node 20, pob_{i20} was defines equal to 1. ACO exit method determined the feasible route by avoiding node 20. Even a few occupants on the simulation were trapped on node 20 (an occupant as an agent possible to ignore the route informed by agent exit sign), most of the occupant selected the feasible route through node 24-25-31, i.e.: 1-3-4-12-16-24-25-3 was determined as the route should be chosen by occupant from block 1 on level 3.

V. CONCLUSSION

The modified ACO algorithm has performed better to determine the feasible route in evacuation planning. In making decision during emergency, occupant have to decide their action quickly and by following their instinct and current experiment is not enough to get the feasible route. The shortest route doesn't mean the feasible route. Local based decision will also not assure the occupant to take the feasible route during evacuation. The evacuation planning could be determined not only the shortest route but also considered the feasible route.

Furthermore, the exit sign to determine the route has potential opportunity to be developed on large scale application in evacuation planning.

VI. REFERENCES

[1] S. M. Lo, H. C. Huang, P. Wang, and K. K. Yuen, "A game theory based exit selection model for evacuation," *Fire Safety Journal*, vol. 41, pp.364-369, 2006.

[2] X. Pan, C. S. Han, K. Dauber, and K. H. Law, "Human and social behavior in computational modeling and analysis of egress," *Automation in Constraction*, vol.15, pp.448-461, 2006.
[3] N. Pelechano, and N. I. Badler, "Modelling crowd and trained leader behavior during building evacuation," *IEEE Computer Society*, pp. 80-85, 2006.
[4] S. Gwynne, E. R. Galea, M. Owen, P. J. Lawrence, and L. Filippidis, "A review of the methodologies used in computer simulation of evacuation from the built environment,." *Building and Environment*, Vol. 34, pp.741-749, 1999.
[5] S. Gwynne, E.R. Galea, M. Owen, P. J. Lawrence, and L. Filippidis, "A systematic comparison of buildingEXODUS predictions with experimental data from the Stapelfeldt trials and the Milburn House evacuation," *Applied mathematical modelling*, vol. 29, pp. 818-851, 2005.
[6] P. A. Thomson, and E. W. Marchant, "A computer model for the evacuation of large building populations," *Fire Safety Journal*, vol. 24, pp. 131-148, 1995.
[7] T. S. Shen, "ESM: a building evacuation simulation model, " *Building and environment*, vol. 40, pp. 671-680, 2004.
[8] R. Muhdi, A. Garrett, A. Ravikant, J. Davis, G. Dozier, and D. Umphress, "The application of evolutionary computation in evacuation planning," in *Proc. 2006 IEEE ITSC.*, pp. 600-605.
[9] Y. Murakami, K. Minami, T. Kawasoe, and T. Ishida, "Multi-agent simulation for crisis management," in *Proc. 2002 IEEE workshop on knowledge media networking.*
[10] M. Dorigo, V. Maniezzo, and A. Colorni, "Ant system: optimization by a colony of cooperating agents," *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 26, No.1, 1996.
[11] M. Dorigo, and K. Socha, “An introduction to ant colony optimization,” IRIDIA., Bruxelles, Technical report series, 2007. [Online]. Available : http://iridia.ulb.ac.be/~mdorigo/ACO/publications.html
[12] H. A. Taha, *Operations Research, An Introduction, 7th edition.* New Jersey: Pearson Education, 2003, p. 220-237.
[13] L. Padgham, and M. Winikoff, *Developing intelligent agent systems, a practical guide,* West Sussex: John Wiley & Sons Ltd , 2004.
[14] G. Proulx, "Evacuation time and movement in apartment buildings," *Fire Safety Journal*, vol. 24, pp. 229-246, 1995.
[15] T. M. Kisko, “EVACNET4 - A program to determine the minimum building evacuation time,“ University of Florida. [Online]. Available : http://www.ise.ufl.edu/kisko/files/evacnet/

VII. BIOGRAPHIES

Arief Rahman was born in Banjarmasin, Indonesia, in 1977. He received bachelor degree in Industrial Engineering from Sepuluh Nopember Institute of Technology (ITS), Indonesia.

He is pursuing postgraduate study at Petronas University of Technology (UTP), Computer and Information Science department. He also is currently with the ITS and a member of human factor laboratory in ITS. His current research interests are in human behavior modeling as a part of human factor, combinatorial optimization, and DSS methodologies.

Dr. Ahmad Kamil Bin Mahmood has a Phd. in Information Systems and M.Sc in Statistics and Actuarial Science which he earned from the University of Salford, UK and the University of Iowa, USA respectively. He is attached to Universiti Teknologi PETRONAS, Perak, Malaysia as a senior lecturer and he is also the Head for the Computer and Information Sciences (CIS) Department.

He has served in the Banking and Oil & Gas industries at various capacities for more than 10 years, mostly in information systems development related activities to make the organizations becoming efficient and effective. He can be reached at kamilmh@petronas.com.my