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Research Article

Applied Artificial Bee Colony Optimization Algorithm in Fire Evacuation Routing System

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Every minute counts in an event of fire evacuation where evacuees need to make immediate routing decisions in a condition of low visibility, low environmental familiarity, and high anxiety. However, the existing fire evacuation routing models using various algorithm such as ant colony optimization or particle swarm optimization can neither properly interpret the delay caused by congestion during evacuation nor determine the best layout of emergency exit guidance signs; thus bee colony optimization is expected to solve the problem. This study aims to develop a fire evacuation routing model "Bee-Fire" using artificial bee colony optimization (BCO) and to test the routing model through a simulation run. Bee-Fire is able to find the optimal fire evacuation routing solutions; thus not only the clearance time but also the total evacuation time can be reduced. Simulation shows that Bee-Fire could save 10.12% clearance time and 15.41% total evacuation time; thus the congestion during the evacuation process could be effectively avoided and thus the evacuation becomes more systematic and efficient.

1. Introduction

Commercial buildings such as shopping complexes have a greater risk of indoor fire according to its features such as complex structure and diverse functions [1, 2]. Early in the fire initial phase, human behavior is of utmost importance as to survival [3, 4]. The human behavior can be defined as sets of actions taken based on individuals' perception of a situation, intention to act, as well as preaction considerations [5]. Since there is a matter of death and life in the face of fire, the likelihood of a safe escape is of central importance in buildings' fire safety features. However, the occupants have to lean on themselves or be saved from danger by others prior to building' fire safety features in the initial phase of a fire [6]. Therefore, other professional emergency assistance comes later. Accordingly, there is need to elucidate how individuals behave in the face of a fire. The human behavior considering how they behave during an escape can be articulated as "evacuation behavior." Recent studies in this sphere have shown that humans' perception based on a situation along with an action performed is the consequence of decision-making/behavioral process [7] compared to a stimulus-response to any change in the environment per se [8]. Studies from building fire and community evacuations during disasters [9–15] have indicated that research in evacuation behavior sphere is at the pivotal point of its history, and studies have discerned confident signal to act, interpreted the situation, assessed the risk, and then made a decision accordingly [16]. From processual vantage point, some certain constituents might influence each stage of above-mentioned processes. Evacuation is an effective emergency response that protects human population from the catastrophic events and unexpected disaster. Evacuation models and interpretations in safety science have been extensively studied, covering topics of calculation and estimation of evacuation time. However, there is a lack of theory and accessible data on human behavior for use by generated evacuation models [17]. Human behavior in a fire has been extensively studied from various perspectives as summarized in Table 1. Although many studies have been extensively conducted in this field, some assumptions about the existing paradigm of fire safety, particularly in building area, are not consistent with knowledge generated in the literature [18, 19]. Therefore, there is a substantial need for incorporating new scientific heuristic/metaheuristic knowledge, which can be supplemented. The key for fire evacuation success is a well-planned route [20]. The evacuation process is challenging as the situation becomes unorganized and chaotic when fire happens in a building. It is filled with uncertainties where the people affected often lack a complete picture of hazards and potential escaping route. Experimental studies indicate that 38% to 77% in the visibility of the signage could be highlighted comparing dynamic signage systems to the conventional static emergency signage ones [21]. For example, a survey studied occupants in Portuguese buildings revealed that 43% occupants were unsure what action to take during the fire, 12% did not evacuate until they saw the smoke, and 25% started to evacuate once the alarm was heard [22]. The people affected need to decide which route to follow; thus the situation becomes more chaotic [16]. The survival of evacuees largely depends on the level of ease in finding an escaping route. During fire, the psychic stress level of evacuees will increase and this can consequently impair their cognitive processes and their responses to fire [20]. It is essential to determine the best locations to install escaping guidance signs and to develop a proper fire evacuation plan, which can be achieved using swarm intelligence that is well known for its effectiveness and accuracy in finding the optimum paths in many sorts of computational problems [5].

The rapid growing interests in solving optimization problems induced the trend of applying natural metaphors, where a problem given is modeled in the way that it can be handled by a classical algorithm [6]. Classical optimization techniques have imposed limitations in solving operational problems because they depend on the type of variables used in modeling and the constraint functions such as nonlinear or linear equations [7]. The efficiency of classical optimization algorithms also largely depends on the number of variables, solution size, and structure of solution spaces; thus they are inefficient in solving large-scale and highly nonlinear or combinatorial problems [7]. Besides, many assumptions are required on the original parameters such as rounding variables and softening constraints, but in many situations these assumptions are hard to validate [8]. The desired algorithm shall be easy to tailor and to model the reality [9]. The motivation to solve this problem has induced nature-inspired algorithms such as simulated annealing, genetic algorithms, and tabu search [6]. Bee Colony Optimization (BCO) algorithm is a branch of swarm intelligence inspired by the real honey bee foraging behavior, where the honey bees search for nectar (food source) around their hive and they share valuable information such as distance, time, location, quantity, and quantity of the food source with other bees inside the hive [6]. The existing fire evacuation routing models using various algorisms such as ant colony optimization or particle swarm optimization can neither properly interpret the delay caused by congestions during evacuation nor determine the best layout of emergency exit guidance signs [10, 11]; thus bee colony optimization is expected to solve the problem. This study aims to develop a fire evacuation routing model "Bee-Fire" using artificial bee colony optimization and to test the routing model through a simulation run.

2. Fire Evacuation Routing and Artificial Bee Colony Optimization (BCO)

2.1. Fire Evacuation Planning and Emergency Exit Guidance. Fire evacuation is a process of movement from the hazard place to a safe place [19]. The evacuation process can be characterized into three phases including cue validation phase, decision-making phase, and refuge phase. The cue validation phase and decision-making phase are also referred to as the preevacuation phase while the refuge phase is also termed movement phase [1]. The preevacuation phase is much more decisive on survival than the actual movement. Decision needs to be made in a timely manner but in most evacuation situations evacuees were confused on which path to follow [20]. The main paradigms in evacuation studies are optimization-based methods that help legislators to generate evacuation plans by offering useful tools such as network optimization models, scheduling optimization models, and routing optimization models [3]. The quickly spread of fire can cause the best escape route changes, which makes the situation more chaotic and unorganized [18]. Most evacuees use the routes that they are familiar with [13]. In conditions of low visibility, low environmental familiarity, and high anxiety, evacuees need to rely on the emergency exit guidance signs [5].

2.2. Artificial Bee Colony Optimization (BCO) and Applications. To overcome the limitations in classical optimization techniques, artificial bee colony optimization (BCO) as a type of swarm intelligence inspired by bee collective intelligence for honey bee collection was proposed by [14] to solve numerical optimization problem [15]. BCO algorithm is based on the behavior of honey bees in finding nectar sources around their hives, where bees communicate through waggle dance [23]. BCO is still considered a new branch of swarm intelligence [24], which was originally to comprise the multiagent system [25]. BCO algorithm has a main advantage compared to other algorithm that it consists of multiple control parameters. BCO algorithm has gained more attention due to its simplicity and it was widely used to solve many types of engineering problems recently [25]. It was used to solve the ride matching problem and routing protocol problem in wireless sensor network [26]. Honey bees can be classified as social insects living together in colonies as a dynamical system [6]. BCO algorithm is based on the foraging behavior of the bee colony. Where a bee in the colony exploits a food source and then flies back to the hive bringing some nectar from the food source and shares the information through dancing [27]. The dance area is a common area in the

Table 1: Summative evaluation of the research into human behavior in a fire.

Factors used in analysis of building evacuation	Output/tools/methods
The spirit of the times [23–25]	Occupant density and travel speed were two core factors. Findings have led to minimum width of evacuation staircases, a maximum flow rate capacity for fire exits, and required number of fire exits. Occupant response shelter escape (ORSET) model was introduced. The emergence of new factors such as personality, capacities and architectural design of the building.
Movement velocity [24, 26]	Methods of documenting the time needed for movement purposes were introduced. Calculation tools were emerged, which later on have been become a codes of practice for fire engineering.
Linking fire and human behavior [10]	Revealed that size of a fire is related to personnel's behavior after or before commencing. The factor of human behavior came to attention. Revealed that people want to walk through smoke when making their escape to save other family members.
Evacuation of the functionally impaired [27–30]	High-rise buildings were at the center of research in fire evacuation. Two methods were introduced: (1) Safe use of elevators, (2) the defend-in-place strategy.
Studies about WTC/11 [29, 31]	Evacuation of the functionality impaired came in handy in WTC/11 disaster (i.e., self-evacuation and safe use of elevators). New factors were uncovered: escape and pre-evacuation times, pre-evacuation actions, the flow rates in staircases. The evidence gathered has become a High-Rise Evacuation Evaluation Database (HEED).
Preevacuation time [27, 30]	It has been revealed that pre-evacuation time is more important than moving to safe place. It has been uncovered that a delayed evacuation and number of death are interconnected. However, pre-evacuation times are less documented or quantified.
Evacuation modeling [32, 33]	Evacuation simulation models were emerged. However, few of them are based on human evacuation behavior, only focusing on routes and time to interpreting data documented. Since during the fire, there are some uncertain and incomprehensible behaviors, then there is a need to operationalized occupancy risks in further case studies and analyses must be allied to floor plans.
Way finding during evacuation [25]	Conducting case studies have become of utmost important approach. Architectural constructions, spatial connections, and layouts have been highlighted that they can be confusing and generate unnecessary stress to occupants. Nevertheless, little of the research about way findings seems to be concentrated on fire safety engineering and fire evacuation.

hive and the dance duration is proportional to the amount of nectar at the food source. The two essential elements in a bee system are food sources and foragers [25]. The value of a food source depends on many factors such as its richness, energy concentration, distance/proximity to the bee hive, and the ease of extraction, but the "profitability" of a food source is normally represented by the amount [14]. Foragers can be categorized into three groups [6]: (a) unemployed foragers, (b) employed foragers, and (c) experienced foragers.

The unemployed foragers continually look out for food sources to exploit. Scout bees and onlookers/recruit bees are two types of unemployed bees [28]. Scout bees only search nearby the hive without any knowledge and the percentage of scout bee varies from 5 to 30%. Onlooker/recruit bees attend to a waggle dance and start searching for food using the knowledge from the waggle dance. When an onlooker/recruit bee exploits and finds the food source, it will become employed forager who memorizes the distance between the food source and the hive, location of the food source, and the food source profitability. After it takes some nectar from the food source, it returns to the hive and unloads it to the food area in the hive. After that, there will be three possible options related to the residual amount of nectar for the foraging bee [14]: (a) if the amount of nectar decreases below a level or exhaust, the foraging bee will abandon the food source and become an unemployed bee; (b) if the amount of nectar is still sufficient, it will continue to forge without sharing about the food source information with other bees in the hive; and (c) the employed forager can also go to the dancing area in the hive to perform waggle dance to share the information of the food source. An experienced forager can be an inspector who controls the recent status of food source discovered, or it can be a reactivated forager using the information from waggle dance performed by other bees, or it can be a scout bee searching for new food sources if the whole food source is exhausted, or it also can be an onlooker/scout bee [14]. In artificial bee colony algorithm, a solution for the optimization problem is represented by the food source position and the amount of nectar [29]. Similar to the real bee colony in nature, the artificial bee colony also consists of employed bees, scout bees, and onlooker bees. In BCO algorithm, half of the bees in the colony are set as employed bees and the other half are onlooker bees. The number of food sources is also assumed to be equal to the number of employed bees in the colony. If the bees abandon a food source, the employed bee allocated for that food source will become a scout bee and will continue a random search for a new food source [29]. During the past decades, there were a few algorithms inspired by bee colony [5]. After the bee colony system was introduced, many researchers and practitioners have made improvements and extensions on the original algorithm to develop further application of bee colony optimization. BCO algorithms are able to solve complex optimization problems using multi-agent system represented by artificial bee colony [26]. BCO algorithms can solve optimization problems in different areas such as robotics, transportation systems, evacuation routine, tower crane operation, and construction site layout planning. For instance, Teodorović and Dell' Orco applied bee swarm intelligence to solve the complex problem in transportation system and proposed bee colony optimization metaheuristic to solve uncertain combinatorial problems as well as deterministic combinatorial problems [26].

3. Research Methods and Procedures

In this research, a combination of qualitative and quantitative methods has been triangulated including a questionnaire survey, a model development, and a case study. The information gathered from the questionnaire survey was used to form the framework of the case study. Prior to modeling and simulation process, the questionnaire survey was used for a comprehensive conceptualization of the evacuees behavior [33], which was aligned to experienced-based combination of microsociological theories, behavioral statements, and the identification of real-world entities [33] known as simuland (i.e., information materials). The modeling and simulation processes need to be well articulated considering some steps, respectively [34], simuland, referent materials (i.e., observations/theory), conceptualizing the model, implementing the model, and configuring the model. A "Bee-Fire" fire evacuation routing model was developed in this study. The questionnaire form was designed into three separate sections where the first section is to collect the demographic information of respondents. The second section is related to the fire evacuation routing inside a building. The last section is to collect information regarding emergency exit guidance signs. A total of 500 questionnaires have been distributed through post office and 103 valid forms were returned forming a satisfactory responding rate at 20.6%. The demographic profiles of respondents are presented in Table 2. SPSS v22 and Smart PLS2.0 were used to assist the analysis of questionnaire survey. Besides, a case study was carried out at a leading cinema building in Kuala Lumpur with heavy crowds. This case study was used to test run the developed model through simulation to find the optimum fire excavation route inside the building and to plot the best locations for fire emergency exit guidance signs. The case study was carried out with various potential evacuation routes and estimated traveling durations. The location of case study is 1-Utama Shopping Centre, Damansara, Petaling Jaya, 47800 Petaling Jaya, Selangor, Malaysia, and the building has been operated for 20 years. The cinema was chosen for test run because it consists of a huge number of people with congestion. In specific, the purposes of the case study are (a) to visualize the floor plan of the cinema in a simulation, (b) to identify possible fire evacuation routes within the cinema, (c) to determine the locations and travel distances of emergency exits, and (d) to determine and visualize the optimum fire evacuation routing solution. The simulation was carried out to demonstrate the application of the developed model in real situation and to test its workability using software named *VISSIM* (German acronym for Traffic in Towns: SIMulation), which tends to be an innovative simulation tool concerning design of actuated control systems which models links, junctions, and small networks at the highly detailed resolution.

Table 2: Demographic profiles of respondents.

Demographic characteristic	Frequency	Percentage (%)
(1) *Gender*		
Male	45	43.7
Female	58	56.3
(2) *Age*		
Below 18	10	9.7
19–30	66	64.1
31–50	17	16.5
51–70	10	9.7
(3) *Educational level*		
Secondary school or lower	9	8.7
Diploma	12	11.7
Degree	65	63.1
Masters	11	10.7
Doctorate	6	5.8

The respondents participated in the questionnaire survey consisting of 45 (43.7%) males and 58 (56.3%) females. Majority of the respondents (66 or 64.1%) are ranged from 19 to 30 years old, followed by 17 (16.5%) people from 31 to 50 years old. Both age groups below 18 and 51–70 have the same number of respondents (10 or 9.7%). The educational levels for the respondents were categorized into five groups including secondary school or lower, diploma, degree, masters, and doctorate. Majority of the respondents (65 or 63.1%) completed their higher education with degree, followed by 12 (11.7%) diploma, 11 (10.7%) masters, 9 (8.7%) secondary school or lower, and 6 (5.8%) doctorate.

4. Model Development

The development process is divided into four sections. The first section explains the framework of steps in the development process. The second section focuses on how to use BCO algorithm to determine fire evacuation routes as well as configuring the underlying conceptual framework of the evacuees' behavior. The third section designs the test run, and the last section details the processes in generating routing solutions for fire evacuation. Similar to the foraging behavior of bees, it assumes that the evacuees randomly pick up the nearest routes surrounding them.

4.1. Framework of Steps. The framework of steps shown in Figure 1 consists of two main components including the BCO algorithm and the simulation mechanisms. Prior to

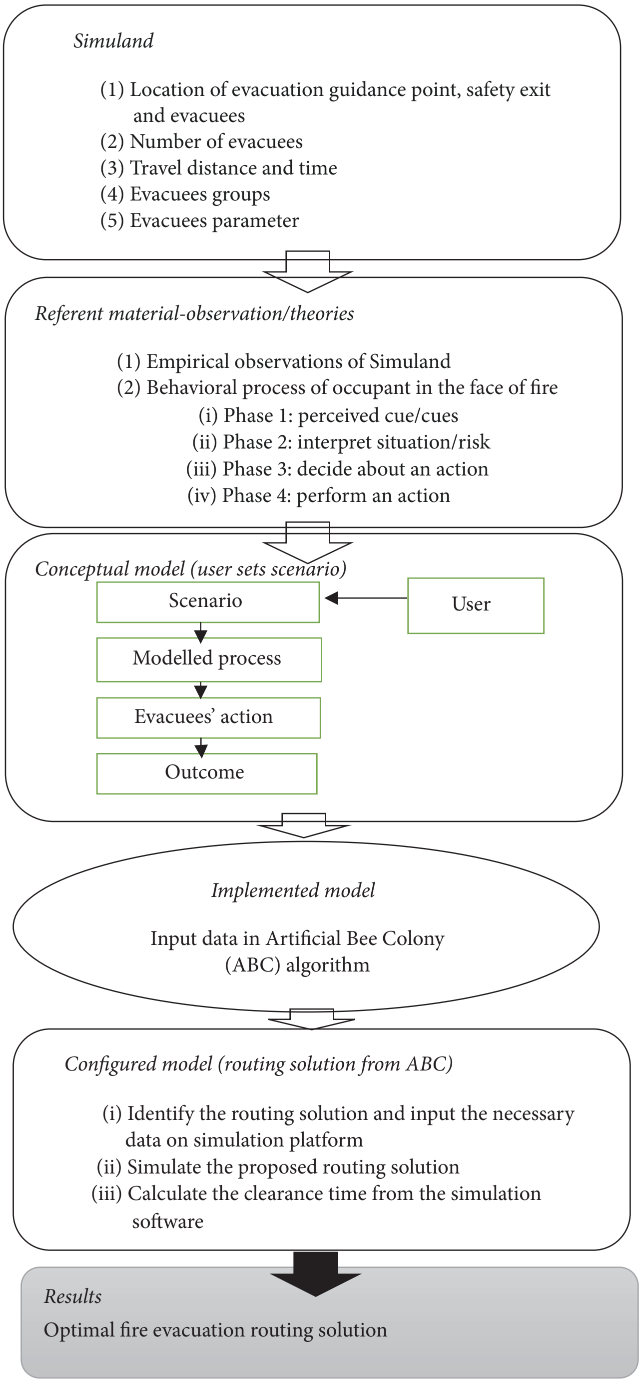

Figure 1: Framework of steps in fire evacuation routing model "Bee-Fire."

incorporating BCO algorithm, there is a need for articulation of the information available known as simuland including the number and locations of emergency exits, the travel distances, number of evacuees, grouping of evacuees, parameters of evacuations, and locations of emergency exit guidance signs [33]. To do so, empirical observations of simuland, scientific theories, and isolated behavior statements were incorporated. Moreover, the modeling and simulation process were adopted and deployed accordingly. BCO algorithm establishes the routing solution for fire evacuation by controlling the artificial multiagents whose behaviors and movements are inspired by the employed bees, onlooker bees, and scout bees. The routing solutions generated by BCO algorithm were then transferred into the simulation mechanism to simulate the movements of evacuees and to quantify the time for each fire evacuation process. The simulation software used was VISSIM. The clearance time (times taken for 95% of evacuees to evacuate) obtained from VISSIM represents the amount of nectar in BCO algorithm. There are various types of quickest path route choice algorithms applicable including FPETool, EVACNET4, TIMTEX, WAYOUT, STEPS, PedGo, PEDROUTE/PAXPORT, Simulex, GridFlow, ASERI, buildingEXODUS, EXITT, and Legion, which are movement method-based, partial behavioral, and behavioral models to describe the sophistication of model's simulation techniques. The complexity of these modeling techniques deployed to simulate the egress occasion as well as occupant behavior throughout the evacuation is always a limitation.

Notably, these models rely on both movement methods and validation techniques. From user perspective about the degree of sophistication, it is highlighted that despite the availability of the particular data available, the validation techniques used by each model must be examined accordingly. Models available on a consultancy basis such as PathFinder, EESCAPE, Myriad, ALLSAFE, CRISP, and EGRESS also vary in purpose, validation techniques, and movement methods. In addition, there are some newly introduced methods so called "way-finding systems" [35] and "active signage" [36]. The way-finding indeed encompasses four-stage mechanisms such as orientation, route decision, route monitoring, and destination recognition. On the other hand, an important step in the way-finding process is known as the use of the emergency signage in order to indicate preferred routes of egress, the possible way of alerting the occupants are using of the flashing lights.

VISSIM was incorporated in this study because its simulation system consists of two separate programs: the Kernel of VISSIM which is the traffic flow model and the signal control model. VISSIM could solve all above-mentioned problems in way-finding processes covering active signage and dissuasive signage. Interestingly, the VISSIM as a master program is featured in sending second-by-second detector values to the signal control program. The detector values were used by the signal control to decide the current signal aspects. The first step is to collect data for VISSIM such as locations of emergency exits, locations of evacuees, locations of emergency exit guidance points, number of evacuees, travel distances, time to arrive emergency exits, and evacuation parameters. In Step 2, a floor plan is drawn up to scale in order to ensure the accuracy during simulation. The floor plan must include at least the locations of emergency exits, emergency exit guidance points, and evacuee groups. In Step 3, the optimal solution for the fire evacuation route is determined using BCO algorithm. Finally, VISSIM runs the simulations twice to compare, where the first simulation does not use any emergency exit guidance (the evacuees are assumed to evacuate from the building randomly without any guidance and help) and the second simulation uses the routing solution generated by BCO algorithm. Results of simulations will compare the total clearance time used by the evacuees escaping from the building.

4.2. Fire Evacuation Route Using BCO Algorithm. BCO algorithm helps solve complex combinatorial optimization problems and each artificial bee generates one solution for a problem. The position of food source near the hive represents a potential solution, while the amount of nectar represents the quality and fitness of the solution. The fitness value of the associated solution is calculated in the following:

$$\mathrm{fit}_i = \frac{1}{1 + f_i}. \quad (1)$$

BCO algorithm assumes that 50% bees inside the hive are onlookers and another 50% are employed bees. It also assumes that the total number of onlooker bees and employed bees is equal to the total number of solutions. To initiate, BCO algorithm generates a randomly distributed initial population $P(C = 0)$ of SN solutions representing the food source positions, where SN denotes the size of population. Each solution zi ($i = 1, 2, \ldots, \mathrm{SN}$) is a D-dimensional vector. D is the number of products of input size and cluster size for each data set. After initialization, the population of the positions is subjected to repeated cycles [$C = 1, 2, \ldots$, Maximum Cycle Number (MCN)] of the search processes of employed bees, onlooker bees, and scout bees. In the case of fire evacuation, the amount of nectar within the food source is represented by the reciprocal of the total time used by 95% evacuees to evacuate from the building (clearance time). The scout bees and employed bees choose the food sources randomly and the probability of each food source or fire evacuation route is the same. Onlooker bees choose the food source based on the probability proportionally to the amount of nectar within the food source $F(\theta)$. The probability of the food source located at θ_i is calculated in the following:

$$Pi = \frac{F(\theta_i)}{\sum_{k=1}^{s} F(\theta_k)}. \quad (2)$$

$F(\theta_i)$ represents the amount of nectar at the food source I (reciprocal of clearance time for number i fire evacuation routing solution within the simulation platform). S is the possible number of food sources near the hive (the number of possible fire evacuation routing solutions). The employed bees continue to forge the same food source if it has the shortest distance to the hive but big amount of nectar. The loyalty (reciprocal of P_b) of the employed bee to a particular food source (fire evacuation routing solution) is calculated in the following:

$$P_b = e^{-(O_b - O_{\min})},$$
$$O_b = \frac{T_{\max} - T_b}{T_{\max} - T_{\min}}, \quad (3)$$

where $T_{\max}$ is largest total travel distance by an employed bee; $T_{\min}$ is smallest total travel distance by an employed bee; $O_{\min} = T_{\min}/(T_{\max} - T_{\min})$; thus the higher the loyalty to choose the same routing solution, the lower the P_b value. The routing solution with the lowest P_b value is then considered the optimal fire evacuation routing solution.

Figure 2: Floor plan of cinema in VISSUM.

4.3. Case Study and Simulation. The case study conducted at a cinema inside a shopping centre is to simulate fire evacuation process and to identify the evacuees groups, emergency exit guidance sign locations, travel distances, and possible emergency exits. The cinema contains up to 1070 people during the peak hour. The cinema covers 1873 square meters consisting of 5 screen rooms and 6 public facilities including offices and toilets. There are 6 emergency exits within the cinema and the occupants inside the cinema are categorized into groups A to F1. Figure 2 presents the floor plan of this cinema where the human icons represent the occupant groups and the green rectangles are the coverage areas of each group coded from A to F1. The green arrows represent the emergency exit guidance sign points and the evacuees evacuate to emergency exits following the emergency exit guidance signs. Table 3 lists all possible routing solutions while getting the sensitivity measure for each factor trajectory-based sampling method was used to capture the spread of each input, which tends to restrict the number of model runs.

4.4. Optimal Routing Solution for Fire Evacuation. BCO algorithm determines the P_b value for each possible routing solution, which denotes the loyalty of an employed bee to a particular food source. In order to calculate P_b value, the O_b value needs to be identified first by determining the longest and shortest routes. The higher the loyalty, the lower the P_b value. The routing solution with the lowest P_b value is then considered the near-optimal fire evacuation route. In order to prevent bias, O_b values are fixed at 1.000. The calculations of O_b and P_b values for evacuees groups A to D are demonstrated in Table 4, and the values for the rest evacuees groups E to

Table 3: Possible routing solutions in VISSUM.

		Route	Distance (m)
		(1) Evacuees Group A	
Exit 1	Shortest route	A-26-EXIT 1	23.9
	Longest route	A-38-36-34-32-27-16-10-8-6-EXIT 1	143.9
Exit 2	Shortest route	A-38-37-EXIT 2	12.9
	Longest route	A-2-5-7-9-11-12-13-15-17-28-30-33-35-37-EXIT 2	191.5
		(2) Evacuees Group B	
Exit 1	Shortest route	B-26-EXIT 1	26.2
	Longest route	B-38-36-34-32-27-16-10-8-6-EXIT 1	149.6
Exit 2	Shortest route	B-38-37-EXIT 2	18.7
	Longest route	B-2-5-7-9-11-12-13-15-17-28-30-33-35-37-EXIT 2	197.9
		(3) Evacuees Group C	
Exit 1	Shortest route	C-26-EXIT 1	14.4
	Longest route	C-38-36-34-32-27-16-10-8-6-EXIT 1	152.6
Exit 2	Shortest route	C-38-37-EXIT 2	21.7
	Longest route	C-2-5-7-9-11-12-13-15-17-28-30-33-35-37-EXIT 2	95.7
		(4) Evacuees Group D	
Exit 1	Shortest route	D-26-EXIT 1	25.7
	Longest route	D-38-36-34-32-27-16-10-8-6-EXIT 1	156
Exit 2	Shortest route	D-38-37-EXIT 2	25.1
	Longest route	D-2-5-7-9-11-12-13-15-17-28-30-33-35-37-EXIT 2	100.6
		(5) Evacuees Group E	
Exit 1	Shortest route	E-24-26-EXIT 1	35.6
	Longest route	E-31-32-27-16-10-8-6-4-EXIT 1	125.1
Exit 2	Shortest route	E-31-33-35-37-EXIT 2	44.0
	Longest route	E-20-18-10-8-6-4-3-38-37-EXIT 2	137.6
Exit 3	Shortest route	E-31-32-29-EXIT 3	34.0
	Longest route	E-31-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 3	189.0
Exit 4	Shortest route	E-31-29-EXIT 4	34.3
	Longest route	E-31-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 4	189.3
Exit 5	Shortest route	E-31-32-27-EXIT 5	36.8
	Longest route	E-31-33-35-1-2-5-7-9-11-12-13-15-17-EXIT 5	172.8
		(6) Evacuees Group F	
Exit 1	Shortest route	F-24-26-EXIT 1	38.0
	Longest route	F-31-32-27-16-10-8-6-4-EXIT 1	119.6
Exit 2	Shortest route	F-31-33-35-37-EXIT 2	38.6
	Longest route	F-20-18-10-8-6-4-3-37-EXIT 2	137.6
Exit 3	Shortest route	F-31-29-EXIT 3	28.6
	Longest route	F-31-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 3	183.6
Exit 4	Shortest route	F-31-29-EXIT 4	28.9
	Longest route	F-31-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 4	183.9
Exit 5	Shortest route	F-31-27-EXIT 5	31.4
	Longest route	F-31-33-35-1-2-5-7-9-11-12-13-15-17-EXIT 5	141.4
		(7) Evacuees Group G	
Exit 1	Shortest route	G-24-26-EXIT 1	26.5
	Longest route	G-31-32-27-16-10-8-6-4-EXIT 1	130.5
Exit 2	Shortest route	G-31-33-35-37-EXIT 2	49.5
	Longest route	G-20-18-10-8-6-4-3-37-EXIT 2	129.5
Exit 3	Shortest route	G-31-29-EXIT 3	39.5
	Longest route	G-31-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 3	194.4
Exit 4	Shortest route	G-31-29-EXIT 4	39.7
	Longest route	G-31-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 4	194.7

Table 3: Continued.

		Route	Distance (m)
Exit 5	Shortest route	G-31-27-EXIT 5	42.2
	Longest route	G-31-33-35-1-2-5-7-9-11-12-13-15-17-EXIT 5	178.2
Exit 6	Shortest route	G-20-18-16-EXIT 6	46.2
	Longest route	G-31-33-35-1-2-5-7-9-11-12-13-14-EXIT 6	170.1
		(8) Evacuees Group H	
Exit 1	Shortest route	H-24-26-EXIT 1	30.7
	Longest route	H-31-32-27-16-10-8-6-4-EXIT 1	127.4
Exit 2	Shortest route	H-31-33-35-37-EXIT 2	46.4
	Longest route	H-20-18-10-8-6-4-3-37-EXIT 2	129.5
Exit 3	Shortest route	H-31-29-EXIT 3	36.4
	Longest route	H-31-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 3	191.3
Exit 4	Shortest route	H-31-29-EXIT 4	36.6
	Longest route	H-31-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 4	191.6
Exit 5	Shortest route	H-31-27-EXIT 5	39.1
	Longest route	H-31-33-35-1-2-5-7-9-11-12-13-15-17-EXIT 5	175.1
Exit 6	Shortest route	H-20-18-16-EXIT 6	46.2
	Longest route	H-31-33-35-1-2-5-7-9-11-12-13-14-EXIT 6	167.0
		(9) Evacuees Group I	
Exit 1	Shortest route	I-26-EXIT 1	13.4
	Longest route	I-7-9-11-12-13-15-17-28-30-33-35-1-2-EXIT 1	157.3
Exit 2	Shortest route	I-26-4-3-38-37-EXIT 2	51.1
	Longest route	I-7-9-11-12-13-15-17-28-30-33-35-37-EXIT 2	133.4
Exit 5	Shortest route	I-22-20-18-17-EXIT 5	45.5
	Longest route	I-7-9-11-12-13-15-17-EXIT 5	81.6
Exit 6	Shortest route	I-22-20-18-14-EXIT 6	55.8
	Longest route	I-26-4-3-38-36-34-32-27-16-EXIT 6	106.7
		(10) Evacuees Group J	
Exit 1	Shortest route	J-26-EXIT 1	16.3
	Longest route	J-7-9-11-12-13-15-17-28-30-33-35-1-2-EXIT 1	159.8
Exit 2	Shortest route	J-26-4-3-38-37-EXIT 2	54.0
	Longest route	J-7-9-11-12-13-15-17-28-30-33-35-37-EXIT 2	135.9
Exit 5	Shortest route	J-22-20-18-17-EXIT 5	42.5
	Longest route	J-7-9-11-12-13-15-15-EXIT 5	84.1
Exit 6	Shortest route	J-22-20-18-114-EXIT 6	52.8
	Longest route	J-26-4-3-38-36-34-32-27-16-EXIT 6	109.6
		(11) Evacuees Group K	
Exit 1	Shortest route	K-6-EXIT 1	26.6
	Longest route	K-7-9-11-12-13-15-17-28-30-33-35-1-2-EXIT 1	149.7
Exit 2	Shortest route	K-6-4-3-38-37-EXIT 2	51.7
	Longest route	K-7-9-11-12-13-15-17-28-30-33-35-37-EXIT 2	125.8
Exit 5	Shortest route	K-22-20-18-17-EXIT 5	52.6
	Longest route	K-7-9-11-12-13-15-15-EXIT 5	74.0
Exit 6	Shortest route	K-22-20-18-14-EXIT 6	62.9
	Longest route	K-26-4-3-38-36-34-32-27-16-EXIT 6	115.3
		(12) Evacuees Group L	
Exit 1	Shortest route	L-6-EXIT 1	31.6
	Longest route	L-7-9-11-12-13-15-17-28-30-33-35-1-2-EXIT 1	154.3
Exit 2	Shortest route	L-6-4-3-38-37-EXIT 2	56.7
	Longest route	L-7-9-11-12-13-15-17-28-30-33-35-37-EXIT 2	130.4
Exit 5	Shortest route	L-22-20-18-17-EXIT 5	50.1
	Longest route	L-7-9-11-12-13-15-15-EXIT 5	78.6

Table 3: Continued.

		Route	Distance (m)
Exit 6	Shortest route	L-22-20-18-114-EXIT 6	60.4
	Longest route	L-26-4-3-38-36-34-32-27-16-EXIT 6	116.9
		(13) Evacuees Group M	
Exit 1	Shortest route	M-23-24-26-EXIT 1	30.1
	Longest route	M-23-22-20-18-28-30-33-35-1-2-EXIT 1	116.5
Exit 6	Shortest route	M-13-14-EXIT 6	29.8
	Longest route	M-23-24-26-3-38-36-34-32-27-16-EXIT 6	121.7
		(14) Evacuees Group N	
Exit 1	Shortest route	N-23-24-26-EXIT 1	33.6
	Longest route	N-23-22-20-18-28-30-33-35-1-2-EXIT 1	123.7
Exit 6	Shortest route	N-13-14-EXIT 6	25.8
	Longest route	N-23-24-26-3-38-36-34-32-27-16-EXIT 6	116.0
		(15) Evacuees Group O	
Exit 1	Shortest route	O-23-24-26-EXIT 1	28.1
	Longest route	O-23-22-20-18-28-30-33-35-1-2-EXIT 1	118.2
Exit 6	Shortest route	O-13-14-EXIT 6	29.8
	Longest route	O-23-24-26-3-38-36-34-32-27-16-EXIT 6	123.4
		(16) Evacuees Group P	
Exit 1	Shortest route	P-23-24-26-EXIT 1	34.4
	Longest route	P-23-22-20-18-28-30-33-35-1-2-EXIT 1	124.5
Exit 6	Shortest route	P-13-14-EXIT 6	22.8
	Longest route	P-23-24-26-3-38-36-34-32-27-16-EXIT 6	129.7
		(17) Evacuees Group Q	
Exit 1	Shortest route	Q-23-24-26-EXIT 1	31.6
	Longest route	Q-23-22-20-18-28-30-33-35-1-2-EXIT 1	121.7
Exit 6	Shortest route	Q-11-12-13-14-EXIT 6	44.5
	Longest route	Q-23-24-26-3-38-36-34-32-27-16-EXIT 6	126.9
		(18) Evacuees Group R	
Exit 1	Shortest route	R-23-24-26-EXIT 1	39.7
	Longest route	R-23-22-20-18-28-30-33-35-1-2-EXIT 1	131.2
Exit 6	Shortest route	R-11-12-13-14-EXIT 6	35.9
	Longest route	R-23-24-26-3-38-36-34-32-27-16-EXIT 6	126.0
		(19) Evacuees Group S	
Exit 1	Shortest route	S-23-24-26-EXIT 1	35.7
	Longest route	S-23-22-20-18-28-30-33-35-1-2-EXIT 1	125.8
Exit 6	Shortest route	S-11-12-13-14-EXIT 6	42.5
	Longest route	S-23-24-26-3-38-36-34-32-27-16-EXIT 6	124.9
		(20) Evacuees Group T	
Exit 1	Shortest route	T-23-24-26-EXIT 1	38.9
	Longest route	T-23-22-20-18-28-30-33-35-1-2-EXIT 1	129
Exit 6	Shortest route	T-11-12-13-14-EXIT 6	36.4
	Longest route	T-23-24-26-3-38-36-34-32-27-16-EXIT 6	134.2
		(21) Evacuees Group U	
Exit 5	Shortest route	U-17-EXIT-5	17.1
	Longest route	U-10-8-6-4-3-38-36-34-32-27-EXIT 5	150.7
Exit 6	Shortest route	U-EXIT 6	12.8
	Longest route	U-17-28-30-33-35-1-2-5-7-9-11-12-13-14-EXIT 6	171.8
		(22) Evacuees Group V	
Exit 5	Shortest route	V-17-EXIT-5	8.5
	Longest route	V-16-10-8-6-4-3-38-36-34-32-27-EXIT 5	155.7

Table 3: Continued.

		Route	Distance (m)
Exit 6	Shortest route	V-16-EXIT 6	21.0
	Longest route	V-17-28-30-33-35-1-2-5-7-9-11-12-13-14-EXIT 6	163.2
		(23) Evacuees Group W	
Exit 3	Shortest route	W-28-29-EXIT 3	13.7
	Longest route	W-27-16-10-8-6-4-3-38-36-34-32-29-EXIT 3	169.4
Exit 4	Shortest route	W-28-29-EXIT 4	14.0
	Longest route	W-27-16-10-8-6-4-3-38-36-34-32-29-EXIT 4	169.7
Exit 5	Shortest route	W-EXIT 5	4.5
	Longest route	W-28-30-33-35-1-2-5-7-9-11-12-13-15-17-EXIT 5	160.3
		(24) Evacuees Group X	
Exit 3	Shortest route	X-29-EXIT 3	9.0
	Longest route	X-27-16-10-8-6-4-3-38-36-34-32-29-EXIT 3	173.8
Exit 4	Shortest route	X-29-EXIT 4	9.3
	Longest route	X-27-16-10-8-6-4-3-38-36-34-32-29-EXIT 4	174.1
Exit 5	Shortest route	X-27-EXIT 5	11.2
	Longest route	X-30-33-35-1-2-5-7-9-11-12-13-15-17-EXIT 5	154.8
		(25) Evacuees Group Y	
Exit 5	Shortest route	Y-18-17-EXIT 5	18.2
	Longest route	Y-19-21-24-26-4-3-36-34-32-27-EXIT 5	111.9
Exit 6	Shortest route	Y-18-16-EXIT 6	30.7
	Longest route	Y-19-21-24-26-4-3-36-34-32-27-16-EXIT 6	138.7
		(26) Evacuees Group Z	
Exit 5	Shortest route	Z-18-17-EXIT 5	23.7
	Longest route	Z-19-21-24-26-4-3-36-34-32-27-EXIT 5	118.2
Exit 6	Shortest route	Z-18-16-EXIT 6	36.2
	Longest route	Z-19-21-24-26-4-3-36-34-32-27-16-EXIT 6	145.0
		(27) Evacuees Group A1	
Exit 3	Shortest route	A1-29-EXIT 3	14.0
	Longest route	A1-30-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 3	174.7
Exit 4	Shortest route	A1-29-EXIT 4	14.3
	Longest route	A1-30-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 4	175.0
Exit 5	Shortest route	A1-27-EXIT 5	18.2
	Longest route	A1-30-33-35-1-2-5-7-9-11-12-13-15-17-EXIT 5	158.5
		(28) Evacuees Group B1	
Exit 3	Shortest route	B1-29-EXIT 3	17.7
	Longest route	B1-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 3	150.3
Exit 4	Shortest route	B1-29-EXIT 4	20
	Longest route	B1-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 4	150.6
Exit 5	Shortest route	B1-27-EXIT 5	19.8
	Longest route	B1-33-35-1-2-5-7-9-11-12-13-15-17-EXIT 5	134.1
		(29) Evacuees Group C1	
Exit 2	Shortest route	C1-33-35-37-EXIT 2	30.8
	Longest route	C1-32-27-16-10-8-6-4-38-37-EXIT 2	122.6
Exit 3	Shortest route	C1-32-29-EXIT 3	26.4
	Longest route	C1-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 3	141.8
Exit 4	Shortest route	C1-32-29-EXIT 4	26.7
	Longest route	C1-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 4	142.1
Exit 5	Shortest route	C1-32-27-EXIT 5	25.3
	Longest route	C1-33-35-1-2-5-7-9-11-12-13-15-17-EXIT 5	125.6
		(30) Evacuees Group D1	
Exit 2	Shortest route	D1-33-35-37-EXIT 2	29.1
	Longest route	D1-32-27-16-10-8-6-4-38-37-EXIT 2	126.4

Table 3: Continued.

		Route	Distance (m)
Exit 3	Shortest route	D1-32-29-EXIT 3	30.2
	Longest route	D1-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 3	140.1
Exit 4	Shortest route	D1-32-29-EXIT 4	30.5
	Longest route	D1-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 4	140.4
Exit 5	Shortest route	D1-32-29-EXIT 5	30.5
	Longest route	D1-33-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 5	140.4
		(31) Evacuees Group F1	
Exit 2	Shortest route	F1-35-37-EXIT 2	16.5
	Longest route	F1-34-32-27-16-10-8-6-4-3-37-EXIT 2	158.6
Exit 3	Shortest route	F1-34-32-29-EXIT 3	42.6
	Longest route	F1-35-1-2-5-7-9-11-12-13-15-17-28-29-EXIT 3	127.5

F1 are summarized into Table 5, where the optimal routing solution for each evacuees group is in bold. The evacuees can evacuate through more than one emergency exit and they are not necessarily to choose the route with the shortest distance to the emergency exit. For example, the evacuee group M chooses emergency Exit 1 (30.1 m) instead of emergency Exit 6 (29.8 m), which is because choosing emergency Exit 1 can prevent the four evacuee groups (M, N, O, and P) from using the same exit (Exit 6) to avoid the congestion at that door.

5. Analysis and Discussion

5.1. Survey Results. Findings from the questionnaire survey are interpreted in this section. The developed fire evacuation model and simulation results are presented in the next section. Majority of the respondents agreed (32 or 31.10% strongly agree and 59 or 57.30% agree) that additional emergency exit guidance signs are required. Those respondents who have more fire evacuation experiences are more familiar with fire evacuation processes. According to Table 6, the P values of most variables such as "you are aware about fire evacuation procedures," "the route to the assembly point is hard to find," "require assistance when evacuate from building," "the information provided by fire action plan in building is clear enough," and "additional emergency exit guidance signs are required" are higher than 0.05; thus these variables are not significantly affected by the age of respondents. On the other hand, only "fire evacuation signs which mark fire evacuation routes and exits are clear enough" is affected by the age factor carrying a significant P value at 0.027; thus post hoc test was conducted according to which differences among age groups are generally weak, but between age ranges 19–30 and 31–50 are stronger than other pairs. ANOVA tests for gender and education were also conducted but all P values were above the 0.05 level indicating no impact from these two factors and thus are not tabulated here.

Figure 3 presents the results of the Partial Least Square (PLS) function where each circle in the PLS-SEM diagram represents the coefficient of determination (R_2) for each variable. The $R2$ values analyze the effect of one variable to another, where 0.75 represents substantial, 0.50 is moderate, and 0.25 is weak. Most determination coefficients of the 5 variables are below 0.25 except the R_2 values of "characteristics of respondent" towards "experience of involvement in fire" and "fire knowledge level of respondents" towards "required assistant during fire," which are 0.319 and 0.870, respectively.

Composite reliability test results shown in Table 7 indicate a satisfactory internal consistency reliability of this research, where the values are all above 0.6. Table 6 also indicates a satisfactory convergent validity where all the Average Variance Extracted (AVE) values are above 0.5.

5.2. Fire Evacuation Modeling. Optimal routing solutions for each evacuee group are visualized in Figure 4, where the optimal routing solution for each evacuee group is identified by P_b values. The reciprocal of a P_b value represents the loyalty of the employed bee to forage the same food source, where in this research it represents the most frequently used fire evacuation routing solution.

The smaller the P_b value, the higher the quality of the evacuation route. The emergency exit with the lowest P_b value is the optimum fire evacuation routing solution for that particular evacuees group. For instance, Evacuees Group A has a shorter traveling distance to emergency Exit 2 (12.9 m) compared to emergency Exit 1 (23.9 m); thus emergency Exit 2 has a smaller P_b value compared to emergency Exit 1. An evacuees group inside the cinema can evacuate to more than one emergency exit. For example, the Evacuees Group G has six possible emergency exits to evacuate from the cinema, and the results from BCO algorithm show that there are two emergency exits with the same lowest P_b value (emergency Exits 1 and 4), which means either emergency Exit 1 or 4 is the optimal routing solution for the Evacuees Group G. More than one emergency exit can prevent the evacuees group from being congested in the same emergency exit. The visualized routing solutions in Figure 4 help reduce the overall clearance time with minimum travel distance. For example, the emergency Exit 1 for Evacuees Group M has a smaller P_b value than emergency Exit 6 although the travel distance to emergency Exit 1 is higher than the travel distance to emergency Exit 6, because choosing emergency Exit 1 can avoid the four evacuee groups (M, N, O, and P) to

Table 4: Calculations of O_b and P_b values for evacuees groups A to D.

	Group A		
Emergency exits	O_b Value	$O_{\min}$ Value	P_b Value
EXIT 1	$O_b = \frac{T_{\max} - T_b}{T_{\max} - T_{\min}}$ $O_b = \frac{143.9 - 23.9}{143.9 - 23.9}$ $O_b = 1$	$O_{\min} = \frac{T_{\min}}{T_{\max} - T_{\min}}$ $O_{\min} = \frac{23.9}{143.9 - 23.9}$ $O_{\min} = 0.199$	$P_b = e^{-(O_b - O_{\min})}$ $P_b = e^{-(1-0.199)}$ $P_b = 0.449$
EXIT 2	$O_b = \frac{T_{\max} - T_b}{T_{\max} - T_{\min}}$ $O_b = \frac{191.5 - 12.9}{191.5 - 12.9}$ $O_b = 1$	$O_{\min} = \frac{T_{\min}}{T_{\max} - T_{\min}}$ $O_{\min} = \frac{12.9}{191.5 - 12.9}$ $O_{\min} = 0.072$	$P_b = e^{-(O_b - O_{\min})}$ $P_b = e^{-(1-0.072)}$ $P_b = \mathbf{0.395}$
	Group B		
Emergency exit	O_b Value	$O_{\min}$ Value	P_b Value
EXIT 1	$O_b = \frac{T_{\max} - T_b}{T_{\max} - T_{\min}}$ $O_b = \frac{149.6 - 26.2}{149.6 - 26.2}$ $O_b = 1$	$O_{\min} = \frac{T_{\min}}{T_{\max} - T_{\min}}$ $O_{\min} = \frac{26.2}{149.6 - 26.2}$ $O_{\min} = 0.212$	$P_b = e^{-(O_b - O_{\min})}$ $P_b = e^{-(1-0.212)}$ $P_b = 0.455$
EXIT 2	$O_b = \frac{T_{\max} - T_b}{T_{\max} - T_{\min}}$ $O_b = \frac{197.9 - 18.7}{197.9 - 18.7}$ $O_b = 1$	$O_{\min} = \frac{T_{\min}}{T_{\max} - T_{\min}}$ $O_{\min} = \frac{18.7}{197.9 - 18.7}$ $O_{\min} = 0.104$	$P_b = e^{-(O_b - O_{\min})}$ $P_b = e^{-(1-0.104)}$ $P_b = \mathbf{0.408}$
	Group C		
Emergency exit	O_b Value	$O_{\min}$ Value	P_b Value
EXIT 1	$O_b = \frac{T_{\max} - T_b}{T_{\max} - T_{\min}}$ $O_b = \frac{152.6 - 14.4}{152.6 - 14.4}$ $O_b = 1$	$O_{\min} = \frac{T_{\min}}{T_{\max} - T_{\min}}$ $O_{\min} = \frac{14.4}{152.6 - 14.4}$ $O_{\min} = 0.104$	$P_b = e^{-(O_b - O_{\min})}$ $P_b = e^{-(1-0.104)}$ $P_b = \mathbf{0.408}$
EXIT 2	$O_b = \frac{T_{\max} - T_b}{T_{\max} - T_{\min}}$ $O_b = \frac{95.7 - 21.7}{95.7 - 21.7}$ $O_b = 1$	$O_{\min} = \frac{T_{\min}}{T_{\max} - T_{\min}}$ $O_{\min} = \frac{21.7}{95.7 - 21.7}$ $O_{\min} = 0.293$	$P_b = e^{-(O_b - O_{\min})}$ $P_b = e^{-(1-0.293)}$ $P_b = 0.493$
	Group D		
Emergency exit	O_b Value	$O_{\min}$ Value	P_b Value
EXIT 1	$O_b = \frac{T_{\max} - T_b}{T_{\max} - T_{\min}}$ $O_b = \frac{156.0 - 25.7}{156.0 - 25.7}$ $O_b = 1$	$O_{\min} = \frac{T_{\min}}{T_{\max} - T_{\min}}$ $O_{\min} = \frac{25.7}{156.0 - 25.7}$ $O_{\min} = 0.197$	$P_b = e^{-(O_b - O_{\min})}$ $P_b = e^{-(1-0.197)}$ $P_b = \mathbf{0.448}$
EXIT 2	$O_b = \frac{T_{\max} - T_b}{T_{\max} - T_{\min}}$ $O_b = \frac{100.6 - 25.1}{100.6 - 25.1}$ $O_b = 1$	$O_{\min} = \frac{T_{\min}}{T_{\max} - T_{\min}}$ $O_{\min} = \frac{25.1}{100.6 - 25.1}$ $O_{\min} = 0.332$	$P_b = e^{-(O_b - O_{\min})}$ $P_b = e^{-(1-0.332)}$ $P_b = 0.513$

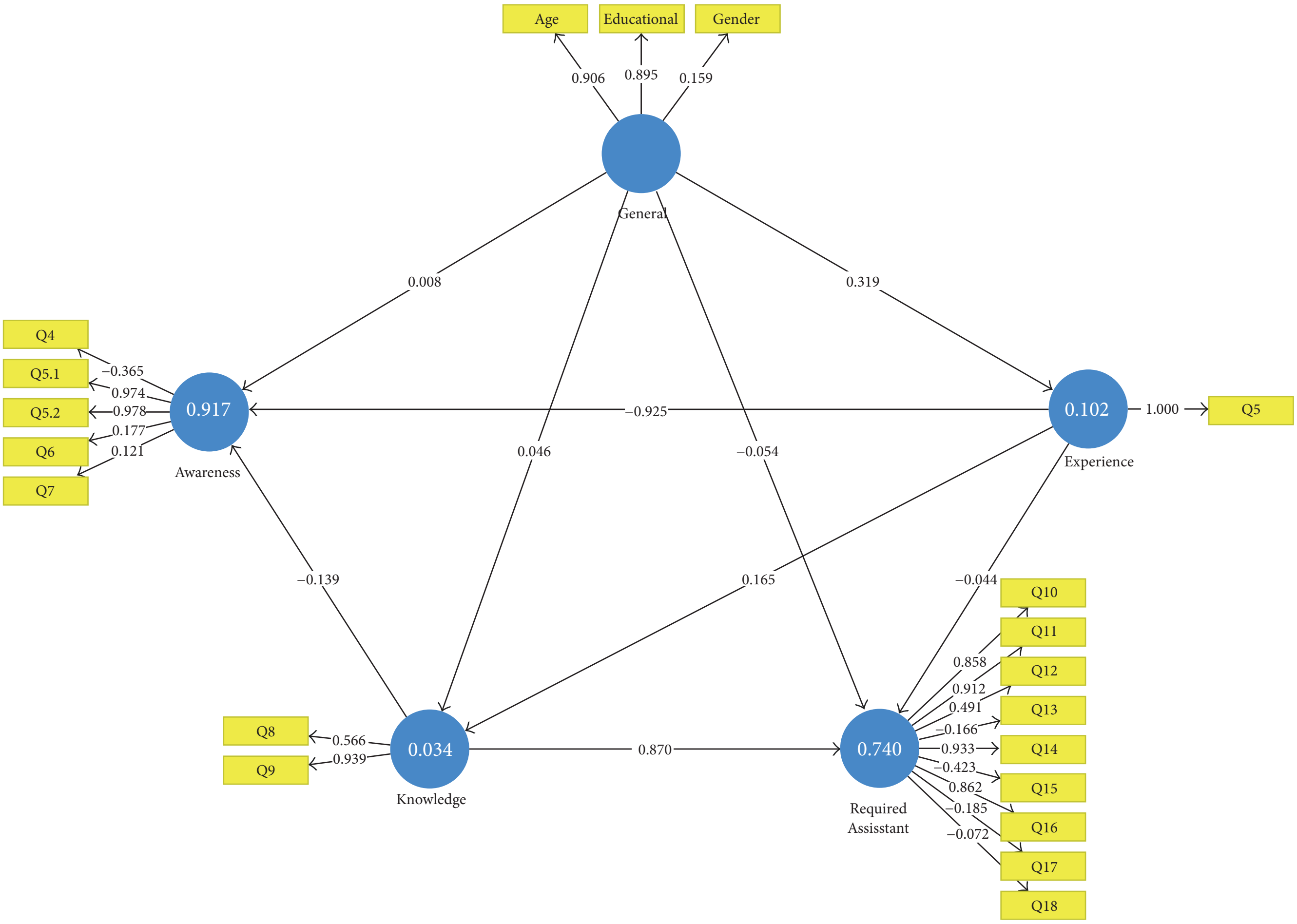

Figure 3: Partial Least Square (PLS) SEM diagram.

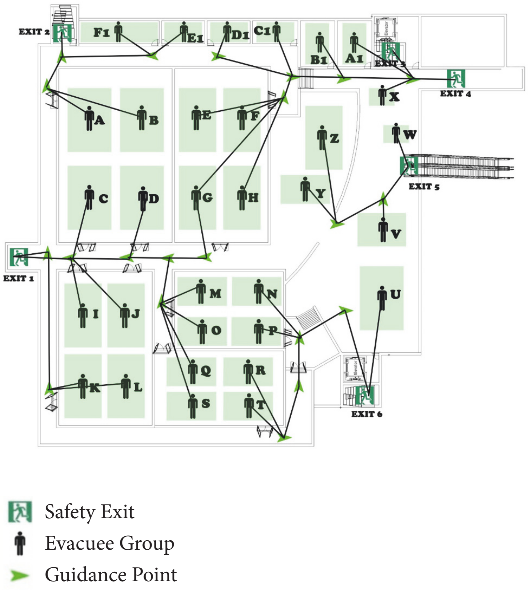

Figure 4: Visualization of routing solutions using “Bee-Fire” model.

Table 5: Summary of all routing solutions.

Evacuee Group	Emergency exit	Travel distance (m)	P_b value
A	1	23.9	0.449
	2	12.9	**0.395**
B	1	26.2	0.455
	2	18.7	**0.408**
C	1	14.4	**0.408**
	2	21.7	0.493
D	1	25.7	**0.448**
	2	25.1	0.513
E	1	35.6	0.548
	2	44.0	0.589
	3	34.0	**0.458**
	4	34.3	0.459
	5	36.8	0.482
F	1	38.0	0.586
	2	38.6	0.543
	3	28.6	**0.442**
	4	28.9	0.443
	5	31.4	0.489
G	1	26.5	**0.475**
	2	49.5	0.683
	3	39.5	0.478
	4	39.7	**0.475**
	5	42.2	0.502
	6	46.2	0.534
H	1	30.7	0.505
	2	46.4	0.643
	3	36.4	**0.465**
	4	36.6	0.466
	5	39.1	0.490
	6	46.2	0.539
I	1	13.4	**0.404**
	2	51.1	0.684
	5	45.5	1.297
	6	55.8	1.101
J	1	16.3	**0.412**
	2	54.0	0.711
	5	42.5	1.022
	6	52.8	0.932
K	1	26.6	**0.457**
	2	51.7	0.739
	5	52.6	4.297
	6	62.9	1.221
L	1	31.6	**0.476**
	2	56.7	0.794
	5	50.1	2.133
	6	60.4	1.071
M	1	30.1	**0.493**
	6	29.8	0.522
N	1	33.6	0.534
	6	25.8	**0.490**
O	1	28.1	**0.503**
	6	29.8	0.506
P	1	34.4	0.539
	6	22.8	**0.455**
Q	1	31.6	**0.522**
	6	44.5	0.631
R	1	39.7	0.568
	6	35.9	**0.565**
S	1	35.7	**0.547**
	6	42.5	0.616
T	1	38.9	0.567
	6	36.4	**0.534**
U	5	17.1	0.418
	6	12.8	**0.399**
V	5	8.5	**0.340**
	6	21.0	0.426
W	3	13.7	0.402
	4	14.0	0.402
	5	4.5	**0.379**
X	3	9.0	**0.389**
	4	9.3	**0.389**
	5	11.2	0.398
Y	5	18.2	**0.447**
	6	30.7	0.489
Z	5	23.7	**0.473**
	6	36.2	0.513
A1	3	14.0	**0.401**
	4	14.3	0.402
	5	18.2	0.419
B1	3	17.7	**0.420**
	4	20.0	0.429
	5	19.8	0.437
C1	2	30.8	0.515
	3	26.4	**0.462**
	4	26.7	0.464
	5	25.3	0.473
D1	2	29.1	0.496
	3	30.2	**0.484**
	4	30.5	0.486
	5	28.8	0.490
E1	2	18.8	**0.424**
	3	35.2	0.534
F1	2	16.5	**0.413**
	3	42.6	0.608

use the same exit (emergency Exit 6) and thus can prevent congestion. The optimum route does not necessarily mean the shortest distance. For example, the evacuee group M chooses emergency Exit 1 (30.1 m) instead of emergency Exit 6 (29.8 m) because choosing the emergency Exit 1 can avoid the four evacuees groups (M, N, O, and P) from using the same exit leading to congestion.

5.3. Simulation Run. A simulation run using VISSUM was conducted after identifying the optimal fire evacuation route for each evacuees group. The total number of evacuees in the simulation engine is 1070. Among the 1070 people, 20% were considered children (below 12 years old) and 80% were considered adults. The proportion of gender was set into 50% male and 50% female. The speed of evacuees during fire evacuation process was set at 3–5 km/hour for adults and 1.5–3 km/hour for children. The first simulation was

Table 6: ANOVA and post hoc tests regarding respondents' age.

(a)

ANOVA test	Sum of squares	df	Mean square	F	Sig.
You are aware about fire evacuation procedures.					
Between groups	3.763	3	1.254	.939	.425
Within groups	132.296	99	1.336		
Total	136.058	102			
The route to the assembly point is hard to find.					
Between groups	2.168	3	.723	.540	.656
Within groups	132.589	99	1.339		
Total	134.757	102			
Require assistance when evacuate from building.					
Between groups	2.415	3	.805	.616	.606
Within groups	129.410	99	1.307		
Total	131.825	102			
Fire evacuation signs which mark fire evacuation routes and exits are clear enough					
Between groups	15.660	3	5.220	3.190	.027
Within groups	161.971	99	1.636		
Total	177.631	102			
The information provided by fire action plan in building is clear enough.					
Between groups	14.921	3	4.974	2.355	.077
Within groups	209.060	99	2.112		
Total	223.981	102			
Additional emergency exit guidance signs are required					
Between groups	2.162	3	.721	1.007	.393
Within groups	70.867	99	.716		
Total	73.029	102			

(b)

Post hoc test Tukey HSD regarding "fire evacuation signs which mark fire evacuation routes and exits are clear enough"

(I) Age	(J) Age	Mean difference $(I-J)$	Std. error	Sig.	95% confidence interval	
					Lower bound	Upper bound
Below 18	19–30	−.988	.434	.111	−2.12	.15
	31–50	−.141	.510	.993	−1.47	1.19
	51–70	−.800	.572	.503	−2.29	.69
19–30	Below 18	.988	.434	.111	−.15	2.12
	31–50	.847	.348	.077	−.06	1.76
	51–70	.188	.434	.973	−.95	1.32
31–50	Below 18	.141	.510	.993	−1.19	1.47
	19–30	−.847	.348	.077	−1.76	.06
	51–70	−.659	.510	.570	−1.99	.67
51–70	Below 18	.800	.572	.503	−.69	2.29
	19–30	−.188	.434	.973	−1.32	.95
	31–50	.659	.510	.570	−.67	1.99

Table 7: Reliability and validity for data.

Latent variable	Composite reliability	AVE
Awareness	0.650	0.517
Experience	1.000	1.000
General	0.740	0.549
Knowledge	0.741	0.602
Required assistant	0.659	0.508

Table 8: Comparison of clearance time for both simulations.

Simulations	Without emergency exit guidance points	Use emergency exit guidance points generated by "Bee-Fire"
Clearance time (time for 95% evacuees)	147.3 seconds	132.4 seconds
Total evacuation time (time for 100% evacuees)	192.1 seconds	162.5 seconds

conducted without using any guidance point so that the evacuees evacuated using the shortest routes to the nearest emergency exits. On the other hand, the second simulation used the emergency exit guidance points generated by "Bee-Fire" to compare with the first one, and the results are shown in Table 8.

The clearance time is the time used by 95% evacuees to evacuate from the cinema, while the total evacuation time is the time used by all the evacuees to fully evacuate from the cinema. Based on Table 8, the simulation with emergency exit guidance points has both shorter clearance time (132.4 seconds) and shorter total evacuation time (162.5 seconds) than that of the simulation without emergency exit guidance points (147.3 seconds and 192.1 seconds, resp.), which saved 10.12% clearance time and 15.41% total evacuation time, respectively. The longer clearance time without emergency exit guidance points was due to the congestion occurring at the emergency exits. Figure 4 marks the emergency exit guidance points by green arrows. The locations of green arrows mark the exact locations to lay out the emergency exit guidance signs in the real building. One limitation of this simulation run is that the model is not validated at the moment and it relies on enforcement of people route choice, which might be very difficult to achieve in real life.

5.4. Discussion on Results. This section discusses and compares the developed BCO Fire Evacuation Routing Model (Bee-Fire) with existing models produced by other scholars. Compared to the Hierarchical Multiobjective Evacuation Routing model developed by [9] which used the ant colony optimization (ACO) approach, the Bee-Fire developed in this study is more efficient because the BCO algorithm determines not only the shortest travel distance but also the total evacuation time by avoiding congestions. The ACO based Hierarchical Multiobjective Evacuation Routing model developed by [9] does not consider congestion, and if the model cannot properly interpret the congestion effect, the routing performance may be considerably deviated from its optimal [2]. Besides, one of the challenges for evacuation planning is the unorganized and confusing situation during an accident but, unfortunately, building designers often have insufficient information on potential accidents and hazards [1] and thus a good fire evacuation model should be able to lay out those fire emergency exit guidance signs. Compared to the particle swarm optimization (PSO) based behavioral and probabilistic fire evacuation model produced by [10], Bee-Fire developed in this study has the advantages that it can directly lay out those guidance signs. During fire, the condition inside the building will become chaotic with low visibility, low environmental familiarity, and high anxiety; thus evacuees highly rely on the emergency exit guidance signs [4].

6. Conclusion and Recommendations

This study developed a fire evacuation routing model "Bee-Fire" by applying artificial bee colony algorithm to find the optimal fire evacuation routing solutions for evacuees; thus the total evacuation time can be reduced. The developed model can also determine the best locations for fire emergency exit guidance signs. Through a simulation run in a real cinema, the workability of the developed model was validated and evidenced to be able to prevent congestions during the evacuation process leading to a more systematic and efficient evacuation process. Bee-Fire is able to find the optimal fire evacuation routing solutions; thus not only the clearance time but also the total evacuation time can be reduced. Simulation shows Bee-Fire could save 10.12% clearance time and 15.41% total evacuation time; thus the congestion during the evacuation process could be effectively avoided; thus the evacuation becomes more systematic and efficient. One limitation of this model is that the simulation software "VISSUM" does not simulate emotion levels and behaviors of evacuees during a fire and thus needs updating. Another limitation is that the excluded-volume effect could not be guaranteed in this model. Finally, the model is not validated using real human experiments at the moment and it relies on enforcement of people route choice, which might be very difficult to achieve in real life. It is recommended that future study could compare this method with simple particle swarm optimization (PSO) and take into account the behavior and nervous level of evacuees during a fire to make the simulation more realistic and accurate.

Data Availability

Data generated or analysed during the study are available from the corresponding author by request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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