E-ISSN 2586-9027
Homepage : *https://tci-thaijo.org/index.php/SciTechAsia* Science & Technology Asia
Vol.31 No.1 January - March 2026 Page: [72-86]
Original research article

Simulation-Based Study of Fire Suppression Guidelines at Chatuchak Weekend Market Using the GAMA Platform

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Received 24 July 2025; Received in revised form 19 January 2026
Accepted 29 January 2026; Available online 27 March 2026

ABSTRACT

We developed an integer linear programming model in conjunction with simulation programming on the GAMA platform to plan fire suppression strategies, with a focus on resource allocation, specifically the number of firefighters and fire trucks, in order to minimize potential damage. This study uses the Chatuchak weekend market, located in Chatuchak District, Bangkok, Thailand, as a case study. The results from the model indicate that Zones 25 (Wood Carving, Spa, & Incense) and 28 (Second-hand Clothing, & Shoes) are the most difficult area for firefighters to access. Based on simulations conducted with GAMA, it was determined for example that if a fire starts in Zone 18 (Clothing, Camping Gear, & Leather Goods), two fire trucks, each carrying five firefighters, should be deployed. This approach results in the lowest median damage, affecting 15 shop units. The incident was resolved within 4 hours and 12 minutes on average. Conversely, if a fire starts in Zone 15 (Silverware, & Home Decoration), the optimal response involves deploying seven firefighters equipped with portable extinguishers on foot to be able to extinguish the incident within 1 hour and 47 minutes on average, and minimize damage to a median of 4.5 shop units. For fires in other zones, the simulation can similarly assign resource allocation and response strategies.

Keywords: Chatuchak weekend market; Fire suppression; GAMA platform; Integer linear programming model; Simulation

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1. Introduction

Currently, the world is experiencing a significant temperature rise, making wild-fires

more likely to occur. This is particularly true in areas like Thailand, where the climate is hot and dry, and most houses are still built with wood. Additionally, the use of electricity for daily activities increases the risk of fires, which can happen anywhere at any time, resulting in substantial loss of life and property, whether caused by natural events or human error.

Chatuchak Weekend Market is a popular market among both Thai and foreign tourists. It is located on Kamphaeng Phet 2 Road, Lat Yao Sub-district, Chatuchak District, Bangkok. It covers an area of 35 acres or approximately 88.5 rai, divided into 27 projects that can accommodate up to 8,000 stalls/shops, offering 8 types of products, including vegetables and fruits, clothing, pets, plants, prepared food, ready-to-eat food, fresh food, and miscellaneous goods.

On the evening of June 2, 2019, a fire broke out in the Chatuchak market area. The incident involved a single-story steel structure, with the source of the fire located at Project 25, Soi 3/2. Firefighters used water to extinguish the fire for more than an hour before it was finally put out. Fortunately, there were no injuries or fatalities. The fire caused damage to a total of 110 vendor stalls, covering an area of more than 8,000 square meters. One of the affected vendors stated in an interview that they operated a stall renting out children's clothing, which was located at Project 25, Soi 3/3 and 3/4, totaling 5 stalls. They suffered damage to 2 stalls because most of the clothing they sold was white, and after being exposed to smoke or water used to extinguish the fire, it could not be sold. This also led to damage in the remaining 3 stalls, with total damages amounting to no less than 1 million baht.

For this reason, awareness of fire hazards is extremely important as it helps us prevent and reduce the risk of fire outbreaks, as well as enabling us to handle emergency situations effectively. Additionally, the fire suppression plan serves as a manual that guides the actions of firefighters when a fire occurs, which helps the people in that area, as well as the firefighters themselves, to make quick and correct decisions in order to reduce confusion, minimize the chances of injuries and fatalities, and lessen damage to property.

Simulation is a tool used to mimic environments and various events without using real resources. This helps us test hypotheses, analyze impacts, and plan operations safely and efficiently. Simulations are applied in many studies/research areas, such as studying population behavior, medical research and development, industry and production, resource management, education, and training. Simulating various resources like energy, water, and materials in different scenarios helps us sustainably and effectively plan/solve resource management issues sustainably and effectively.

Ban et al. [1] simulated the COVID-19 outbreak scenario by programming on GAMA, which is a platform capable of simulating epidemic scenarios, allowing for a better understanding of the details and an insight into the scenes of the outbreak.

Moreno-Espino et al. [2] proposed an intelligent agent-based simulation to study fire propagation across multiple environments. Their model aimed to predict how fire spreads under various conditions, offering valuable insights for fire prevention strategies and resource deployment in emergency scenarios.

Fire Emergency Response (FER) is

a complex system that consists of fire incidents, fire stations, fire trucks, and road network components. Reference [3] has simulated the FER system using Agent-Based Modeling (ABM) combined with Geographic Information Systems (GIS) [4] to integrate the characteristics and behaviors of each spatial component and spatial operations. References [5, 6] proposed ABM on the GAMA platform for simulating evacuation from fires within public buildings by adding new types of agents including water to extinguish fire and smoke, fire extinguishers to generate water or carbon dioxide for fire suppression, firefighters to use water and extinguishers to put out fire and smoke, and to assist people in evacuation, etc. Daudé et al. [7] developed a simulation model named ESCAPE, which aimed to explore urban population awareness and evacuation behavior in response to disasters. GAMA was used to model evacuation scenarios based on real-world data, providing a tool to evaluate the effectiveness of emergency response strategies.

Taillandier [8, 9] introduced a new plug-in that has been integrated into the GAMA platform to simulate microscale traffic, detailing driver behavior while considering the road infrastructure and traffic signals, lane changing by drivers, and adherence to traffic laws. Furthermore, Taillandier and colleagues have continued to develop a cognitive agent architecture in [10, 11] using the user-friendly GAML (GAMA Agent-based Modeling Language), which is capable of managing complex agent behaviors [12, 13]. Lastly, Taillandier et al. [14] presented a simulation framework that integrates geographic data, agent-based modeling, and multi-scale control [15] using the GAMA platform. This allows for the development of sophisticated simulations suitable for studying complex emergency scenarios like fire outbreaks in urban areas. Of course, the choice of simulation tools suitable for various applications depends on the objectives and types of simulations to be developed.

The Chatuchak market presents a uniquely challenging environment for fire suppression due to its extremely high spatial density and its complex network of pedestrian and vehicle routes. The market consists of thousands of small shop units arranged in tightly packed zones, many of which are inaccessible to fire trucks and can only be reached on foot. To address these access-time constraints, we develop an integer linear programming (ILP) model that explicitly incorporates mixed access conditions. The GAMA platform is then employed to simulate fire incidents and the behavior of firefighters under realistic movement dynamics. This integrated framework generates feasible resource allocation strategies and evaluates them in a dynamic environment, enabling us to examine the impacts of both environmental changes (fire spread) and behavioral variations (firefighter movement and response). The combination enables zone-specific fire suppression guidelines that account for both optimal resource allocation and operational feasibility in a highly congested open-air market—an aspect that has not been adequately explored in previous research.

2. Materials and Methods

GAMA (Generalized Agent-based Modeling Architecture) was developed by a team of researchers [16] at the International Institute for Learning and Research and is one of the development projects based on a collaborative concept among developers worldwide (open-source project) to enable researchers and analysts to create and simulate scenarios based on mathematical models in various situations occurring in the real world, which relate to population movements, natural resource management, and the environment, particularly the occurrence of floods, fires, or even the spread of diseases during epidemics. Users can present and test various case studies to understand the behavior of the system being studied. The language used in GAMA is GAML, which is easy to understand, allowing users to create models easily.

GAMA has the capability to create ABMs, which allows users to create agents that simulate the behavior of populations or various components in the environment or other specified factors. Key components include:

1. Custom Scenarios: GAMA allows users to create and set scenarios for simulation according to their needs, such as simulating the movement of cars in a city or the spread of diseases in a population.
2. Mathematical modeling: GAMA has tools to create and define the models used, which can be modified/ improved at any time based on the observations and experiments of the users.
3. Analysis and experimentation: GAMA allows users to experiment with different scenarios and analyze the results of the simulations to provide supportive data for decision-making in planning and solving various problems.
4. Creating and sharing models: GAMA is an open-source platform designed to support open usage, allowing other users to utilize, improve, or extend it according to their needs.

Moreover,

- GAMA allows users to combine different simulation methods, such as using both multivariate and agent-based approaches.
- GAMA has tools that assist in the analysis of data and statistics related to simulation.

For more information, readers can visit GAMA Platform website (http://gama-platform.org). Since GAMA is a continuously developed platform with regular system updates, it ensures that GAMA is a modern platform capable of effectively meeting users' demands.

In creating a map of Chatuchak market, we used Geographic Information System software, or QGIS (Quantum Geographic Information System), to assist in creating the map and defining the boundaries according to the following steps.

1. Find the map of Chatuchak market from OpenStreetMap database [17].
2. Define the area to be studied from OpenStreetMap.
3. Use QuickOSM to create an automatic sample shapefile.
4. Improve the obtained shapefile to be more complete by cleaning the road lines to connect using a plugin called GRASS until it is ready for use (as shown in Fig. 2) to proceed with integrating the shapefile into the GAMA platform.

The area in Chatuchak market consists of main and secondary routes that connect to the main route, as shown in Fig. 1.

Fig. 1. Route within the Chatuchak market area obtained from Google Maps.

Fig. 2. Shapefile created from QGIS.

From Fridays to Sundays each week, there are a lot of tourists using the services, which makes the area crowded. If a fire occurs within the market, it will make it much more difficult for firefighters to access the incident site.

Here,

1 is the sub-fire station of Chatuchak market.

2-3 and 32 are the Chatuchak plaza zone.

4 and 6 are the collectibles, Thai music, and book zones.

Fig. 3. Various zones within Chatuchak market (referenced from the website www.mixtchatuchak.com).

5 is the zone for antique home decor, silk, and picture frames.

7 and 26 are the fashion clothing and youth jewelry zones.

8-9, 11-14, and 20 are the clothing, jewelry, bags, and shoes zones.

10 is the handicrafts, books, and miscellaneous zone.

15-16 and 19 are the silverware and home decoration zones.

17-18 are the clothing, camping gear, and leather goods zones.

21 is the postcard, souvenirs, pets, and pet supplies zone.

22-24 are the artificial flowers, weaving crafts, and handicrafts zones.

25 and 30 are the wood carving, spa and incense zones.

27-28 are the second-hand clothing and shoes zones.

29 is the art and painting zone.

31 is the Mixt Chatuchak mall zone.

The market stalls are divided into 32 shopping zones, as illustrated in Fig. 3. To prepare for potential fire incidents, designated access points for fire trucks and firefighters have been established at yellow nodes (nodes 1–32), each positioned along roads or pedestrian walkways. These access points are represented in a connected

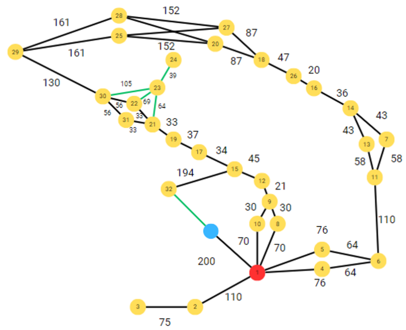

Fig. 4. Connected graph illustrating the firefighters' access routes to different zones, along with the corresponding distances (in meters).

graph in Fig. 4. Fire trucks are stationed at node 1 (marked in red). In the graph, black lines represent roads accessible by vehicles, while green lines indicate pedestrian walkways. Blue nodes are included to represent intersections between roads and pedestrian paths. Notably, nodes 23 and 24 are not directly accessible by fire trucks, requiring firefighters to reach these areas on foot in the event of a fire.

From Fig. 4, we can represent it by an adjacent matrix A of size 32×32 where each element of the matrix is either 0 or 1, defined by

$$a_{ij} = \begin{cases} 1, & \text{if node } i \text{ is adj acent to node } j; \\ 0, & \text{otherwise.} \end{cases}$$

For a_{ij}, we specify the distance in meters between node i and node j with the value d_{ij} construct a matrix D called the distance matrix. The matrices A and D are important parameters of this model.

In the context of shortest path determination for firefighting robots, a heuristic approach such as particle swarm optimization [18] and a search-based method like the A* algorithm [19] has been employed within firefighting frameworks. In this work, we formulate the shortest path problem as an ILP model to identify the market zones that are most difficult for firefighters to access during a fire event. The optimal solution to this model will be obtained using IBM ILOG CPLEX Optimization Studio (CPLEX) Version 12.8, which will be presented in the next section.

Let us now introduce the sets, parameters, and decision variables of our model as follows:

N denotes the set of nodes indicating the locations of the sub-fire station and the market zones, $N = \{1, 2, \ldots, n\}$ as shown in Fig. 4. In this case, $n = 32$, where Node 1 is the sub-fire station, while Nodes 2 through 32 are the market stalls/shops.

a_{ij} represents the elements of the adjacent matrix A for each $i, j \in N$.

$$p_{ij} = \begin{cases} 1, & \text{if } a_{ij} = 1 \text{ and the} \\ & \text{ edge } (i, j) \text{ is a walkway;} \\ 0, & \text{otherwise,} \end{cases}$$

for each $i, j \in N$ In other words,

$r_{ij} = 1 - p_{ij}, \ \forall i, j \in N.$

d_{ij} represents the elements of the distance matrix D for each $i, j \in N$.

v_r represents the speed of the fire truck in reaching various nodes in meters per second.

Since the roads in Chatuchak market are narrow, the fire truck speed is assumed to be 10 km/h, which equals $v_r = 2.78$ m/s.

v_p represents the running speed of firefighters when responding to fire incidents at various nodes in meters per second. Here, we define the running speed of firefighters to be 7 km/h, which is $v_p = 1.94$ m/s.

x_{ij} is a binary decision variable such that

$$x_{ij} = \begin{cases} 1, & \text{when traveling from node } i \text{ to node } j\text{ ;} \\ 0, & \text{otherwise,} \end{cases}$$

for each $i, j \in N$.

Objective function:

$$z_k = \min \sum_{i \in N} \sum_{j \in N} \left(\frac{r_{ij}}{v_r} + \frac{p_{ij}}{v_p} \right) d_{ij} x_{ij}. \tag{2.1}$$

Constraints:

$$\sum_{j \in N} a_{ji} x_{ji} = \sum_{j \in N} a_{ij} x_{ij}, \ \forall i \in N - \{1, k\}, \tag{2.2}$$

$$\sum_{j \in N} a_{1j} x_{1j} = 1, \tag{2.3}$$

$$\sum_{i \in N} a_{ik} x_{ik} = 1, \tag{2.4}$$

$$x_{ij} \in \{0, 1\}, \forall i, j \in N. \tag{2.5}$$

The Eqs. (2.1)-(2.5) are defined according to the descriptions in Table 1. Therefore, the optimal solution of the model is represented by

$$k^* = \arg \max_{k \in N - \{1\}} z_k. \tag{2.6}$$

For simulation study, we focus on approaches to fire suppression in two ways:

1. Firefighters responded to the incident on foot with fire extinguishers.
2. Firefighters responded with fire trucks, each carrying 5 firefighters.

To determine which approach will minimize the amount of damage caused, fire simulations were divided into two scenarios: a fire occurring in Zone 18 and Zone 15 (as shown in Fig. 3), respectively. The simulation parameters are listed in Table 2 based on ranges and values in the relevant literature [20-22].

Readers can study from our code written through the link: https://github.com/BondChadnon/Firefighter-Project.git. By accessing the models folder with the file name JJfirefighter.gaml. Caution should be exercised in configuring some parameters. For example, fire speed needs to be tested or considered along with other factors such as wind direction, wind speed, etc. Tests conducted by our experiments found that if fire_speed is set to > 0.5, the simulation lacks realism. However, the numbers of firefighters and fire trucks that are appropriate for responding to incidents must be tested through simulations in each situation, which will be presented in the next section.

Table 1. Descriptions of the objective function and model constraints.

Constraint	Meaning
(2.1)	z_k represents the minimum travel time of a firefighter from node 1 to node k.
(2.2)	The sum of flow into a node equals the sum of flow out, for all nodes except the start and end nodes 1 and k, respectively.
(2.3)	The starting node 1 has no incoming flow and exactly one outgoing flow.
(2.4)	The ending node k has no outgoing flow and exactly one incoming flow.
(2.5)	x_{ij} is a binary decision variable that takes the value of either 0 or 1.

3. Results and Discussion

From the previous section, we formulated an ILP model to identify the zones that are most difficult for firefighters to access. In this section, we present the results obtained by solving the model using CPLEX, as shown in Table 3. Column (i) is obtained by assuming that all edges are walkways, i.e.,

$$p_{ij} = a_{ij} \text{ all } i, j \in N,$$

whereas column (ii) is computed using p_{ij} and r_{ij} as defined for the graph presented in Fig. 4. Based on the results, it can be concluded that the zones located at nodes 25 and 28 are the most difficult to access, with both having the same access time of 335.052 seconds (5.584 minutes) by running and 233.813 seconds (3.897 minutes) by fire truck.

In terms of market topology, road connectivity, and pedestrian interference, Zones 25 and 28 are located along major roads within the market but are the farthest from the sub–fire station. Although Zone 28 is adjacent to Kamphaeng Phet 3 Road near Chatuchak Park, direct vehicle penetration into the zone is severely restricted by the internal market layout. Similarly, the opposite side of Zone 25 is connected only through narrow pedestrian corridors that are inaccessible to fire trucks. As a result, fire engines must stop along the main road, and firefighters are required to proceed on foot to reach specific locations within Zone 25. This indirect access substantially increases response time and makes these zones among the most difficult areas for timely fire suppression, which is consistent with the results obtained from CPLEX.

Let us next present a simulated fire incident in the market area using the GAMA platform. This paper explores the results of two problem cases.

3.1 A fire incident at Zone 18

Let f and t be two parameters representing the appropriate numbers of firefighters and fire trucks, repectively, required to cope with a fire incident. Note that in the GAMA implementation, the parameters f and t are named Fireman_ex and FireTruck_ex, respectively, in the code. These parameters are determined in Subsections 3.1.1 and 3.1.2.

3.1.1 Determination of parameter f

Firefighters are set to walk from the assembly point to the fire-starting point required 234.021 seconds (3.9 minutes) according to Table 3, which is the same as the time taken to travel along the shortest route used by GAMA. We conducted 10 tests and calculated the average (AVG), standard deviation (SD), maximum value (MAX), and minimum value (MIN) as shown in Table 4. When the average time taken by firefighters to respond to incidents is plotted against the number of firefighters using a line graph, it can be illustrated in Fig. 5. When the number of firefighters is 10 or more, the time taken tends to decrease linearly. In conclusion, ten is the appropriate number of firefighters to respond to such incidents, i.e., $f = 10$ which takes an average of only 272 minutes, or 4 hours and 32 minutes.

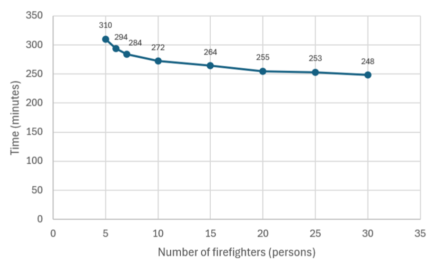

Fig. 5. Average time taken by firefighters to suppress fires.

3.1.2 Determination of parameter t

The procedure to obtain t is analogous to that used for finding f, with the focus shifted from firefighters to fire trucks. The corresponding results are presented in Table 5. Note that firefighters reach the

Table 2. Key parameters for fire simulation using the GAMA platform.

Parameters	Meaning	Configuration	Unit
min_speed_fireman, max_speed_fireman	The speed of the firefighter	Random value between 5 and 9	Kilometers per hour
min_speed_truck, max_speed_truck	The speed of the fire truck	Random value between 8 and 10	Kilometers per hour
fire_speed	Flame spread rate	0.45	Kilometers per hour
fire_dist	Distance for the spread of fire	100	Meter
min_fire_spread_rate, max_fire_spread_rate	The speed of distribution of firefighters	Random value between 0.1 and 1	Meters per second
fire_radius_risk	Distance of fire spread from the ignited store to nearby at-risk stores.	10	Meter
fire_radius_effect	Maximum radiance in fire spread	50	Meter
fire_ratio_radius_distance	Fire spread distance multiplier (fire_radius_risk) used to generate random values.	Random value between 1 and 2	Meter
step	Time duration of each fire spread step	10	Second
building_risk	The number of at-risk stores	Default value=0	Stall
building_on_fire	The number of stores affected by fire includes both successfully extinguished and uncontrollable cases.	Default value=0	Stall
building_burned	The number of uncontrollably burned stores	Default value=0	Stall

fire site at Zone 18 by fire truck in approximately 2.722 minutes (see Table 3).

To estimate t, we conducted a total of 10 tests and then used AVG and MEDIAN of the time taken to respond to incidents as shown in Table 5, represented by line graphs in Figs. 6-7. After that, the rate of change of the AVG and MEDIAN (%Change) was calculated. The results are presented in Table 6. From the table, it can be seen that the %Change between using 1and 2 fire trucks sharply decreased by 5.26% and 7.41%, respectively. Observe that both are a continuously decreasing trend, although the %Change between 4 and 5 fire trucks decreased even more. However, fire trucks are a high-cost resource, so there is no necessity to use as many as 5 trucks. It can be concluded that we should use 2 fire trucks to respond to such incidents, that is, $t = 2$ with transporting 5 firefighters per truck, totaling 10 people, and take an average of only 252 minutes or 4 hours and 12 minutes.

Let us next determine the amount of damage caused by the simulation with GAMA by setting the parameters in two cases: (a) $f = 10$ and (b) $t = 2$.

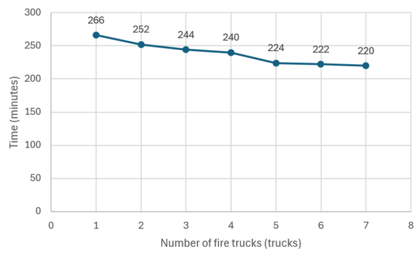

Fig. 6. Average time taken by fire trucks in responding to fire incidents.

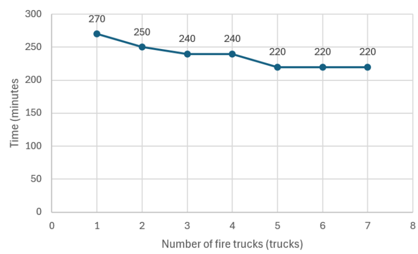

Fig. 7. Median time taken by fire trucks in responding to fire incidents.

When f set to 10, we simulated the scenario as provided in Fig. 8 and were able to assess the damage based on the number of shops, as shown in Table 7. The operational principle of GAMA is to first extinguish the fire at the point of ignition and then choose to extinguish the fire in the next shop/stall

Table 3. Firefighter Access Times.

Incident point (node)	Access time (seconds)	
	(i) Running	(ii) Fire truck
1	0	0
2	56.701	39.568
3	95.361	66.547
4	39.175	27.338
5	39.175	27.338
6	72.165	50.36
7	158.763	110.791
8	36.082	25.18
9	51.546	35.971
10	36.082	25.18
11	128.866	89.928
12	62.371	43.525
13	158.763	110.791
14	180.928	126.259
15	85.567	59.712
16	199.485	139.209
17	103.093	71.942
18	234.021	163.309
19	122.165	85.252
20	278.866	194.604
21	139.175	97.122
22	156.186	108.993
23	172.165	130.112
24	192.268	150.215
25	**335.052**	**233.813**
26	209.794	146.403
27	278.886	194.604
28	**335.052**	**233.813**
29	252.062	175.899
30	185.052	129.137
31	156.186	108.993
32	185.567	129.496

to suppress the fire incident as quickly as possible.

In Fig. 8, the green area is designated as the assembly point (located near the fire station), the gray area represents the buildings/shops/ stores/stalls, which we collectively refer to as ‘stores’ for ease of understanding from now on. Moreover, there are three agents: the red dot represents people in the market, the yellow dot represents firefighters, and the blue dot represents fire trucks (see Fig. 9).

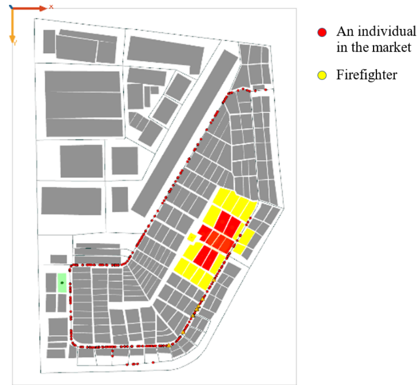

Fig. 8. A simulation of the Chatuchak market area with starting a fire in Zone 18 where $f = 10$.

Due to the number of stores, it should be an integer (or may be .5). Then, we apply the MEDIAN to measure in this case. From Table 7, it can be summarized that the number of stores that can extinguish fires, the number of stores at risk, and the number of stores that have suffered damage are 15, 35.5, and 16, respectively. After that, we defined $t = 2$ based on the simulation in Fig. 9, leading to the conclusion about the number of stores, as shown in Table 8.

To summarize our procedure, we include a concise flow diagram in Fig. 10 illustrating the integrated modeling-simulation process, from data preparation to the outputs of the ILP model and the GAMA platform. As indicated by the dashed arrow in the figure, the ILP results explicitly provide the travel times of firefighters and/or fire trucks, which are then passed to the GAMA simulation.

According to the diagram, we have $M_a = 16$ and $M_b = 15$. Since M_b is smaller, (b) with $t = 2$ fire trucks is chosen as the optimal strategy that minimizes damage.

Table 4. Time spent (minutes) in responding to fire incidents by the number of firefighters deployed.

Test	Number of firefighters used (people)							
run	5	6	7	10	15	20	25	30
1	290	280	280	280	260	260	250	250
2	330	290	290	260	260	260	250	250
3	290	310	280	260	270	250	250	250
4	330	300	280	290	260	260	260	250
5	310	290	290	270	270	250	250	240
6	310	310	280	270	270	260	260	250
7	330	300	280	260	270	250	260	250
8	290	290	280	260	260	250	250	250
9	290	280	290	290	260	250	250	250
10	330	290	290	280	260	260	250	240
AVG	**310**	**294**	**284**	**272**	**264**	**255**	**253**	**248**
SD	20	11.40	5.47	13.04	5.47	5.47	4.47	4.47
MAX	330	310	290	290	270	260	260	250
MIN	290	280	280	260	260	250	250	240

Table 5. Time taken (minutes) in responding to fire incidents based on the number of fire trucks used.

Test	Number of fire trucks used (trucks)						
run	1	2	3	4	5	6	7
1	260	260	240	230	230	230	220
2	270	250	240	240	230	230	210
3	260	250	250	250	220	220	230
4	270	240	260	240	220	210	220
5	270	260	230	240	220	220	220
6	270	260	260	250	220	210	230
7	270	250	250	230	230	220	220
8	260	250	240	240	220	220	220
9	270	260	240	240	230	230	220
10	260	240	230	240	220	230	210
AVG	**266**	**252**	**244**	**240**	**224**	**222**	**220**
SD	5.47	8.36	11.40	7.07	5.47	8.36	7.07
MAX	270	260	260	250	230	230	230
MIN	260	240	230	230	220	210	210
MEDIAN	**270**	**250**	**240**	**240**	**220**	**220**	**220**

3.2 A fire incident at Zone 15

Consider the fire source as Zone 15. The tests were conducted using GAMA similar to those described in Situation 3.1 together with $f = 7$ and $t = 1$. An example of fire origin simulation at zone 15 while searching for the value of the parameter f is visualized in Fig. 11. When setting $f = 7$ and $t = 1$ the result is as follows.

From Table 9, it can be summarized that if a fire occurs in Zone 15, the tableware, ceramic, silverware and home decor zone, we should use 7 firefighters to walk with fire extinguishers to respond to the incident. This minimizes the damage to 4.5 stores in total, and the total time taken to respond to the fire is 107 minutes or 1 hour and 47 minutes.

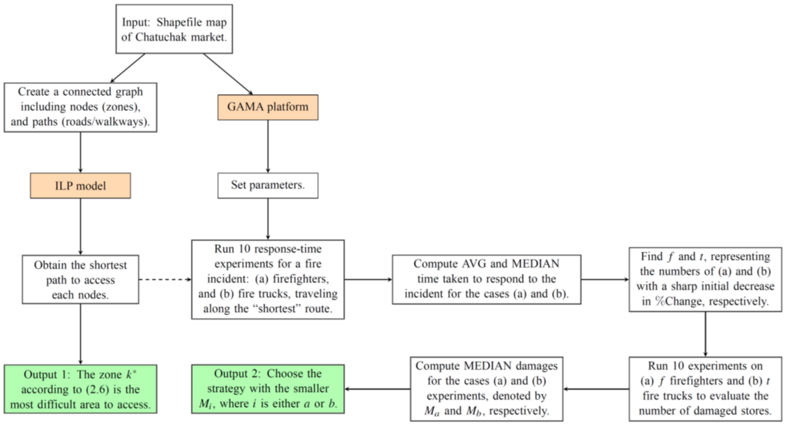

Fig. 9. Guidelines for fire suppression derived from our proposed method.

Table 6. The rate of change of the average and median time taken to respond to incidents.

Number of fire trucks used (trucks)	Time taken (minutes) to respond to the incident			
	AVG	%Change	MEDIAN	%Change
1	266	-	270	-
2	252	**-5.26%**	250	**-7.41%**
3	244	-3.17%	240	-4.00%
4	240	-1.64%	240	0.00%
5	224	-6.67%	220	-8.33%
6	222	-0.89%	220	0.00%
7	220	-0.90%	220	0.00%

Table 7. The number of stores affected by the fire in Zone 18 where $f = 10$.

Test run	Number of stores (stalls)		
	Fire contained	At risk	Damaged
1	15	33	15
2	19	40	22
3	14	33	15
4	15	37	17
5	13	30	15
6	23	47	29
7	24	55	26
8	21	49	25
9	15	33	15
10	14	34	15
MAX	24	55	29
MIN	13	30	15
MEDIAN	**15**	**35.5**	**16**

However, if we consider spatial factors, it can be seen that Zone 15 is located near the fire station, making it sufficient to use firefighters to respond to incidents on time. In contrast, Zone 18, which is further away, necessitates the use of fire trucks to

Table 8. The number of shops affected by the fire incident in Zone 18 where $t = 2$.

Test run	Number of stores (stalls)		
	Fire contained	At risk	Damaged
1	15	33	15
2	19	40	22
3	14	33	15
4	15	37	17
5	13	30	15
6	23	47	29
7	24	55	26
8	21	49	25
9	15	33	15
10	14	34	15
MAX	24	55	29
MIN	13	30	15
MEDIAN	**15**	**35.5**	**16**

Fig. 10. A simulation of the Chatuchak market area with starting a fire in Zone 15.

Table 9. Number of stores (MAX, MIN, MEDIAN) affected by the fire in Zone 15 where $f = 7$ and $t = 1$.

Value	Number of stores (stalls)		
	Fire contained	At risk	Damaged
(a) Define $f = 7$			
MAX	16	33	16
MIN	3	16	3
MEDIAN	4	18	4.5
(b) Define $t = 1$			
MAX	8	21	8
MIN	3	13	3
MEDIAN	6	19	6

respond, which aligns with the results obtained from the aforementioned study.

In addition, we also found that if a fire starts in the areas surrounding the fire station, such as Zones 4, 5, 6, 8, 9, and 10, the response of firefighters occurs quickly.

4. Conclusion

The benefits derived from this research will provide information to the fire department responsible for the Chatuchak market area in preparing and planning ways to respond to incidents, whether it's allocating firefighting resources or fire trucks appropriately to minimize potential damage that may occur in the future.

For future research development, parameters related to potential costs and operational constraints will be incorporated into the ILP model to enhance practical applicability. On the GAMA platform, we will introduce additional indicators and functional modules to simulate the behavior of people in the market and to incorporate other influencing factors, such as geographical characteristics and dynamic crowd conditions. These extensions will enable more realistic evaluation of operational feasibility and support the use of the framework for training and real-world planning.

Hopefully, this research would be able to serve as a model for practical simulation-based planning, which still requires decision-making and strategic planning from those responsible under the constraints of area congestion and resource limitations, whether it be the number of fire trucks, the number of firefighters, and that can be adapted for fire simulation in other high-risk areas, such as markets or congested areas in Thailand or abroad.

Acknowledgements

This research was supported by a research grant in mathematics and statistics under the Special Undergraduate Program of the Department of Mathematics and Statistics, Bachelor of Science in Management Mathematics, Faculty of Science and Technology, Thammasat University, for the 2024 academic year.

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