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Evacuation Operation Management System Using Multi-Objective Artificial Bee Colony

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ABSTRACT

Disaster risk reduction and management organizations create evacuation plans to make sure that impacted persons are swiftly and effectively moved to safer locations, like evacuation centers or shelters. This plays a crucial role in reducing the amount of fatalities and damage brought on by disasters. Disaster situations are characterized by a high degree of unpredictability, which makes it difficult to improve disaster relief efforts. Specific issues that develop during and after catastrophes should be able to be managed by the organization in charge of disaster management activities. This study developed a web-based mobile application that can be used as a system for emergency evacuation management. The Multi-Objective Artificial Bee Colony (MOABC) algorithm is considered to find optimal solutions to emergency evacuation sheltering. Upon trials with 80 test data each, it shows that an accuracy of 88.75% to 93.75% was gained. It can be concluded that the use of MOABC in identifying evacuation centers is an effective method for optimizing the multi-objective problem with parameters of population size and evacuation capacity. Additionally, the study presented the process of navigating the system wherein the users can easily identify the available evacuation centers. The study recommends integrating the Pareto-based ABC approach to seek better optimal solutions for evacuation optimization problem applications. Future work could also focus on the improvement of encoding and representation of solutions for spatial optimization problems.

Keywords: *disaster risk reduction, evacuation center management, Multi-Objective Artificial Bee Colony, relief operation management, shortest path*

Introduction

Disasters continue to pose difficult challenges to developing nations around the world. Apart from the usually high number of casualties, disasters also cause considerable damage to infrastructures and properties that result in huge economic losses. This is especially disastrous for local economies that are in the process of formation, greatly slowing down development in severely affected areas (Al-Nammari & Alzaghal, 2015). The Philippines is one of these countries that experience a large number of earthquakes, volcanic eruptions, typhoons, tsunamis, droughts, and flooding, among others. It is the fourth most disaster-prone country in the world, having endured a total of 274 natural calamities alone over the past two decades (Santos, 2016). For the Philippines and other developing countries that face disasters all year round, the need for efficient evacuation and relief operations as a strategy for handling emergencies and reducing disaster risks is obvious.

Disaster risk reduction and management agencies develop evacuation plans to ensure the quick and efficient relocation of affected people to safer places, such as evacuation centers or shelters. This is instrumental in lessening the number of casualties and damages caused by disasters. However, according to Niyomubyeyi et al. (2019), evacuation planning is a complex process that requires the participation of different individuals, groups, and agencies, and involves several aspects of management at different levels. A high level of uncertainty is characteristic of disaster incidents, which makes improving disaster relief operations challenging. The involvement of other groups and individuals further complicates the flow of operations for disaster management officials. The agency that's in charge of disaster relief operations should be able to manage specific situations that arise during and after disasters.

It is not easy to determine correct evacuation routes, shelter locations, and relief operations. A tool that has a spatial detection ability such as Geographic Information Systems (GIS), which offers excellent capabilities in the mapping process, is needed (Atmojo & Sachro, 2017). Used together with Dijkstra's algorithm, which finds the shortest path to a chosen destination, GIS can help determine the most optimal evacuation routes. Evacuation models generated through this process can also be used for incidents such as flooding due to dam failures.

Another powerful tool employed in multi-objective evacuation models (Kuligowski & Peacock, 2005; Murray-Tuite & Wolshon, 2012; Stepanov & Smith, 2009) is the multi-objective artificial bee colony (MOABC) algorithm, which aims to find the best alternatives for the allocation of facilities and optimal distribution of evacuees to shelters. This meta-heuristic algorithm provides a set of optimal solutions in a reasonable amount of time to efficiently solve complex problems (Tong & Murray, 2012) without the need for intervention by experts, who may have specific preferences that can influence the decision-making process of the algorithm.

This study focuses on the province of Laguna in the Philippines. The province has experienced earthquake-induced landslides, ground ruptures, and ground shaking. In the past three years, the province was ravaged by three strong typhoons: Tropical Depression Maring, Typhoon Ompong, and Tropical Storm Tisoy. These typhoons affected 25,480; 1,680; and 10,068 families, respectively. During these events, several evacuation centers had to be activated. According to the provincial disaster risk reduction management office, there are 166 reported evacuation centers in the province. The majority of the reported evacuation centers are barangay halls (45%) and public schools (37%). Only 15% of these establishments are exclusively used as evacuation shelters. When Taal Volcano from nearby Batangas province erupted earlier this year, a total of 951 families or 3,750 individuals were accommodated in evacuation centers in Laguna. However, reports indicated that 10,758 families, or a total of 40,202 individuals had to seek shelter somewhere else, not in evacuation centers. These incidents clearly indicate the need for the consolidation of updated information about evacuation shelters in preparation for similar future events.

This study aimed to develop a web-based mobile application that can be used as a system for emergency evacuation management. The Multi-Objective Artificial Bee Colony algorithm was considered to find optimal solutions to emergency evacuation sheltering.

Methods

Evacuation Route Planning Method

The Multi-Objective Artificial Bee Colony (MOABC) is another heuristic algorithm that, as its name suggests, takes its solution-searching ideas from honeybees. The “colony” employs three types of bees: employed, onlooker, and scout bees. Niyomubyeyi et al. (2020) described how the algorithm works like how bees decide on which food source(s) to select using a process that cycles between 1) the employed bees finding the food sources and taking samples to the “dance area”, where 2) the onlooker bees are waiting, who will then choose a food source by its quality. After a few cycles, in case the optimal food source has not been found yet, a “scout bee will do a random search on the problem space to find a new food source.”

The MOABC is a Pareto-based algorithm with an external archive to store non-dominated solutions. In a minimization problem, two solutions are non-dominated if none has a lower value than the other in any of the objectives. An updating technique is needed to ensure the incorporation of the most recent solutions discovered in the archive and to determine whether they predominate over other solutions, archive members, or vice versa.

The schematic diagram of the proposed method is given in Figure 3. The MOABC method is comprised of five parts: initialization, employed bees, onlooker bees, scout bees, and update the archive. These parts are explained in the following subsections respectively. The description of the MOABC Phases is shown in Figure 1. It contains five (5) phases including the initialization, employed bee, onlooker bee, scout bee, and the output solutions.

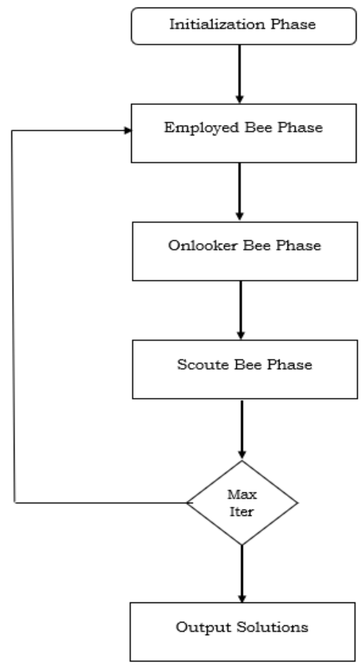

Figure 1. *MOABC Phases*

a. Initialization Phase
   - The first process of MOABC is initializing the population based on the given historical data. It will be initialized with the following parameter
     - Population – et al. evacuation centers
     - Number of generations/iterations
     - Limit – the maximum number of failures
   - After the initialization from the given parameter, it will generate initial solutions from the given population and also generate fitness from the solutions.

b. Employed Bee Phase
   - The second phase will be with employed bees wherein for each solution, a worker bee needs to generate a new solution. Then it will evaluate fitness from the solutions, afterward it will conduct a selection of fitness with the following criteria:
     - If the fitness value is higher than the best, set the value to best.
     - Otherwise, increment the trial value of the solution.
     - Next will be an update archive.

c. On Looker Bee Phase
   - The third phase is to generate probability from the generated fitness, for each onlooker bee, then select the best solutions from the current archive, after it will generate a new solution and then evaluate fitness from the solutions.
   - Conduct another selection of fitness:
     - If the fitness value is higher than best, set the value to best.
     - Otherwise, increment the trial value of the solution.
     - Then update archive.

d. Scout Bee Phase in the ABC: The employed bee turns into a scout bee when the food source is consumed (reaches the limit value).
e. Iteration Condition
    - If the current generation is less than the number of iterations, do bee phases.
f. End Phase
    - This phase presents archive solutions.

In dealing with the optimization of objects in finding the best evacuation center using MOABC, the proponent adopted the study of Staudt et.al. (2014) with the following equations as objective functions, probability function, solution generation, scout bee solution generation, and application of Pareto optimal.

Objective Functions

- Evacuation Supply Objective Function

$$F_{supply} = \sum_{j=1}{}^{n}\sum_{i=1}{}^{m} \frac{S_{ji}}{Smax_{ji}}$$

S_{ji} - is the current Supply Rate of the Evacuation Centre
- $Smax_{ji}$ - is the maximum Supply Rate of the Evacuation Centre
- This is based on warehouse utilization, which is the rate of warehouse capacity used
- The higher the rate the higher the supply of stock

- Population Capacity Objective Function

$$F_{capacity} = \sum_{j=1}{}^{n}\sum_{i=1}{}^{m} \frac{Cmax_{ji} - C_{ji}}{Cmax_{ji}}$$

- $Cmax_{ji}$- maximum capacity for the population of the evacuation center
- C_{ji} - the current population of the evacuation center

Probability Function

$$P_i = \frac{fit_i}{\sum_{i=1}{}^{sn} fit_i{}'}$$

- P_i - is the probability of the food source being selected by an onlooker bee
- fit_i - fitness
- sn - the number of food sources

Solution Generation

$$v_{id} = x_{id} + \varnothing_{id} \times (x_{id} - x_{kd}),$$

- Each employed bee Xi generates a new candidate solution Vi in the neighborhood of its present position
- where $Xj\{1,2,\ldots,n\}$ and $\Phi i,k$ is a randomly selected candidate solution ($i \neq j$), a random dimension index selected from the set, and a random number within [-1, 1]

Scout Bee Solution Generation

$$x_{i,k} = lb_k + \Phi_{i,k} \times (ub_k - lb_k)$$

- Used to generate a new candidate solution based on a given value
- Where ϕ = rand (0,1) is a random number based on a normal distribution, and is the lower and upper boundary of the dimension, respectively

$$fitness(x_k) \begin{cases} \frac{1}{1+x_k} & if \quad x_k \geq 0 \\ 1 + abs(x_k) & if \quad x_k < 0 \end{cases}$$

User-Interface Construction

The source of evacuation-related information was collected from the office of the PDRRMO. A formal letter was prepared and brought to the concerned offices to avoid problems. The data is formatted based on the appropriate parameters required during the preprocessing. A trade-off between the metaheuristic algorithm has been identified and assessed in terms of efficiency, effectiveness, and repeatability. The identified classifier is used to build the optimization model for identifying appropriate evacuation shelters and organized distribution of relief goods.

The last stage of the study was to apply the model to the integrated emergency evacuation and disaster relief management system. The system has the following capabilities: 1) adding evacuation centers, 2) recommending appropriate evacuation centers, 3) identifying the quantity and types of relief items, and 4) monitoring the status of evacuees.

Accuracy Testing of MOABC

The system used was evaluated and tested to see the performance of the applied algorithm which is the MOABC. Based on the common practices for determining the ratio of testing and training, the data set was split into 80:20. To test the MOABC, it used the given parameters in determining the optimal parameters to generate the highest accuracy such as:

Nectars: number of history data given for each population/evacuation center.

Population size: number of evacuation centers to be used by the system.

Trial Limit: number of trials before the solution is disposed of and will generate a new solution.

Max Epoch: is the maximum generation to generate the classifier.

Through these parameters, it helped in determining the optimal parameters to generate the highest accuracy.

The system would pick the evacuation center with the lowest objective value, each score that is given by the system would be used to determine the accuracy (positive score / total number test data). This was conducted three times to determine the average accuracy.

Study Area

This study was conducted in Laguna, an urbanized and densely populated province south of Metropolitan Manila, with a little over three million residents as per 2015 census (Violanta, 2017). The province occupies the crescent-shaped land embracing Laguna de Bay, the largest lake in the Philippines. This exposes it to several natural hazards such as flooding due to overflow from the lake and its tributary rivers caused by heavy downpours and made worse by improper waste management. The province is also affected by earthquake-induced landslides, ground rupture, and ground shaking, as well as by activities from volcanoes in nearby provinces.

Moreover, it is perennially visited by strong typhoons, the ones which greatly ravaged the province in the past three years were Tropical Depression Maring, Typhoon Ompong, and Tropical Storm Tisoy. These typhoons affected 25,480; 1,680; and 10,068 families, respectively. During these disasters, several evacuation centers had to be activated.

Results and Discussion

Implementation of Multi-Objective Artificial Bee Colony Algorithm for Organized Evacuation Sheltering

The system used MOABC to help the evacuees find evacuation centers based on the profile of the users and evacuation center information. The proponent evaluated the implementation of MOABC to evaluate its performance in helping the evacuees. Based on the common practices for determining the ratio of testing and training, the dataset was split into 80:20. To test the MOABC, it must evaluate through given parameters in determining the optimal parameters to generate the highest accuracy.

The proponent inserted training data in the system then it generated the classifier which contains the weight of each evacuation center based on their final objective value. Each entry of the test data would determine if the classifier is correct or not. Based on their given weight, the system would determine the objective output of the test data. Each entry would be multiplied by the weight of the given evacuation centers. The system would pick the evacuation center with the lowest objective value, each score given by the system would be used to determine the accuracy (positive score / total number test data).

Table 1 shows the given parameters in determining the optimal parameters to generate the highest accuracy such as nectars, population size, trial limit, and max epoch.

Table 1: MOABC Performance Evaluation Results

Testing	Nectars	Population Size	Trial_ Limit	Max_ Epoch	Trials	Accuracy
1	10	11	5	10	3	0.14
2	11	11	8	100	3	0.71
3	20	11	10	150	3	0.85
4	20	11	10	200	3	0.90
5	20	11	50	1000	3	0.89

This presents the different parameters in generating the model to achieve lower cost/objective output and corresponds to higher accuracy. Based on the testing from the previous table, the proponents experimented to see how the model works on generating high accuracy. Testing 1, shown in Table 1, has five trials and 10 epochs that gain only 0.14 accuracy, which means that the model is not better or intelligent enough to perform a good output.

The next trial (Testing 2) has eight trial limits with 100 epochs resulting in 0.71, although its accuracy increases are not good enough. For Testing 3 with 10 trial limits and 150 epochs, it gained 0.85 accuracy; then with 200 epochs it reached 0.90 accuracy, but when it has 50 trial limits and 1000 epochs, it caused decreasing accuracy. This indicates that, the optimization process of the model overbounds, that it cannot handle much higher accuracy. With these cases, to get a good model that has a good accuracy performance, it must only have 10 limits with 200-300 max epochs.

As the table presented above shows the optimal parameters in generating high accuracy for the implementation of the MOABC, the following illustration will help discuss and understand the objective output pertaining to the goal of the system to get the minimum number of population size or density based on the number of iterations, and determine the best evacuation centers needed by the evacuees.

Convergence Analysis

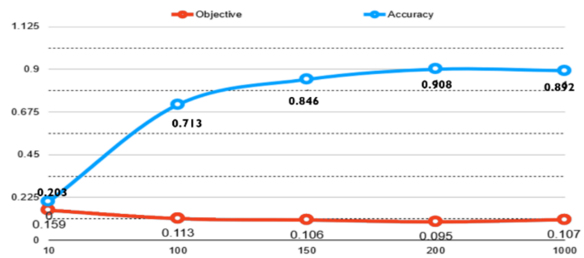

Figure 2. *Objective Output of MOABC Corresponding to the Number of Epochs*

Figure 2 shows the different parameters used to achieve lower cost/objective output and corresponds to higher accuracy. It can be observed that the more the number of iterations it gets, the higher the level of accuracy.

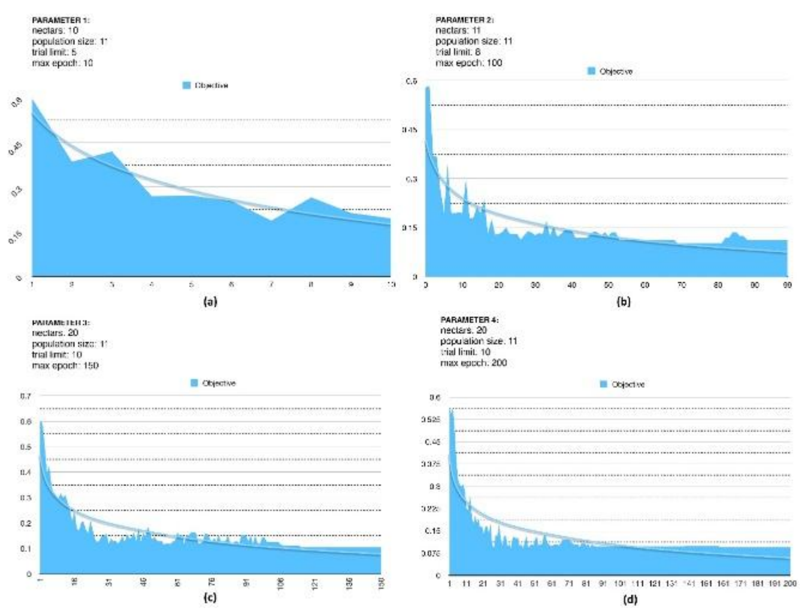

Figure 3. *Objective Output of MOABC Using Different Parameters*

The results of testing based on several parameters such as nectars, population size, trial limit, and epoch is shown in Figure 3. The first testing (a) reveals that maximum of 10 generations is not enough to generate a lower objective at 0.195. In the second testing (b), a max epoch of 100 and trial limit of 8 greatly improves the objective value to 0.113. The third test (c) shows that improving the higher maximum epoch by 150 and trial limit by 10 has a greater effect on the objective output compared to the previous parameters with a value of 0.113. However, in the fourth test (d), increasing the maximum epoch by 200 shows a greater effect on the objective output compared to the previous parameters with a value of 0.095.

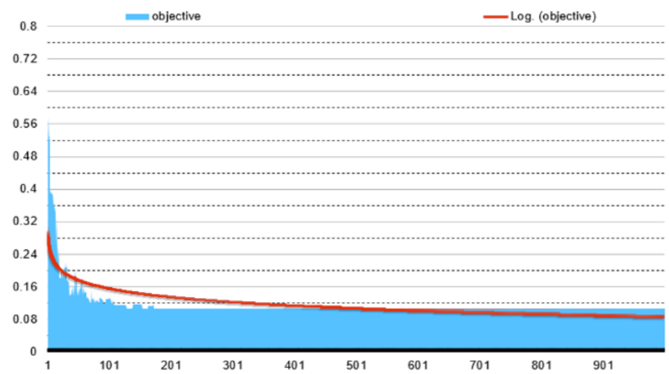

Figure 4. *Objective Output of MOABC with Max Epoch of 1000*

Finally, increasing the maximum epoch by 1000 as shown in Figure 4 shows the objective value plateauing and the objective value becomes higher than the previous Parameter 4, which means the model has reached its global minimum and is just having wasted training.

Evaluating the Performance of Multi-Objective Artificial Bee Colony Algorithm

The study applied the MOABC in identifying the evacuation centers for the evacuees based on the population size and maximum capacity. The researchers integrated the build model of MOABC for this purpose wherein Parameter 4 with 10 trial limit and 200 epochs gained 200 epochs and reached 0.9 accuracy. This was utilized to identify the available evacuation shelters. The proponent also conducted three trials with 80 test data in each trial. Results in Table 2 show an accuracy of 88.75% to 93.75%.

Table 2: MOABC Testing Results

Trial	Number of Errors	Accuracy
1	5	93.75%
2	9	88.75%
3	8	90%

Evacuation Center Selection

Figure 5 shows the process of using the system. When the user clicks the Get Location, the system shows the user's current location on the map. The user can also manually pin their location by pressing the desired location as presented in the figure.

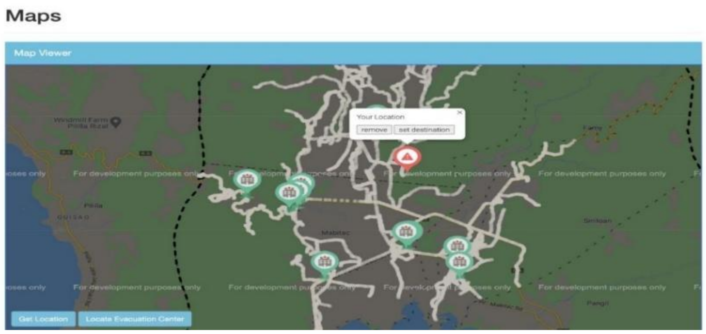

Figure 5. *Map Showing the User's Location and Available Evacuation Centers*

The browser will ask the user for permission to know the current location. The system will then display the pin that shows the user's location on the map.

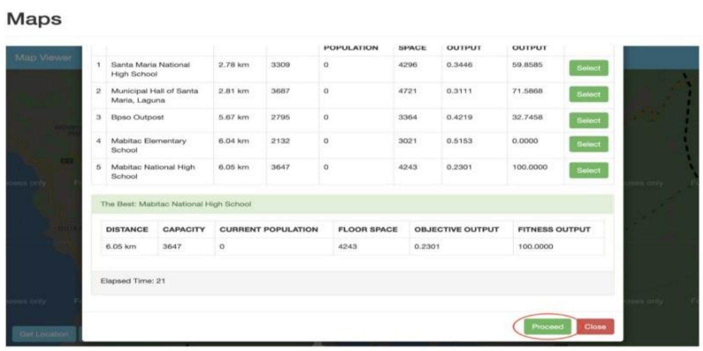

Figure 6. *List of Evacuation Centers Generated by the System*

Once the user clicks the Set Destination, the system will show recommendations of evacuation centers near his/her location as shown in Figure 6. These evacuation centers are the nearest and have the best-evaluated score from the Generated MOABC algorithm. The user may click Proceed to get the directions of the best evacuation center or select the nearest evacuation center.

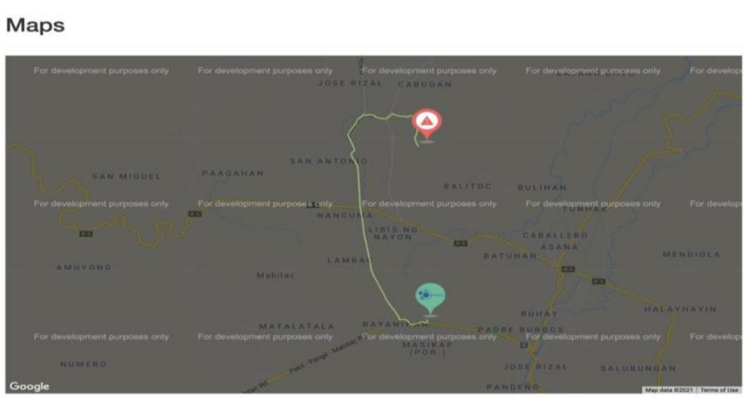

Figure 7. *The Generated Path from the User's Location Goes to the Evacuation Center*

After clicking Proceed, the system will show the generated path of the user's location and the chosen evacuation center as presented in Fig. 7. This will help the evacuees to track the exact location of the evacuation center, thus helping them to arrive there as early as possible.

Conclusion and Future Works

It can be concluded that the use of MOABC in identifying evacuation centers is an effective method for optimizing the multi-objective problem with parameters of population size and evacuation capacity. It helps to easily produce information to the community and officials on the available evacuation centers. With this, government officials like LGUs can easily recognize and organize the evacuation centers because of the developed system, Evacuation Operation Management System Using Multi-Objective Artificial Bee Colony.

Additionally, the study concludes that the MOABC algorithm method in the system can contribute effective services to the community by reaching them through a web portal and facilitating their needs during times of disaster. The community can now have a tool to communicate with the evacuation centers in terms of emergencies. As a result, the system is able to provide several evacuation centers. Thus, the users can select a route and evacuation centers that are suitable for their situation.

The development of an evacuation operation management system using a Multi-Objective Artificial Bee Colony is open for improvement. From the findings, and conclusions, and with its scope and limitation, this research can be extended to include task time uncertainty to generate a robust version multi-objective problem in identifying the evacuation centers. Moreover, the performance of the algorithm can be improved by integrating the Artificial Bee Colony algorithm with some variable locality search schemes to design a hybrid algorithm for better exploration of the search space. Moreover, this research can be extended to include other features in the system such as adding more linkages and connections to different NGOs, organizations, and companies to have more donors and supplies in terms of relief distributions. It can also be connected to social media to raise some awareness of the current situation of the evacuees to get more people to help the community and collaborate to have an immediate response to the needs in the evacuation centers.

Furthermore, it will also be beneficial if other researchers can touch on the other capabilities of multi-objective optimization wherein instead of MOABC alone, it is better to integrate the Pareto-based ABC approach to seek better optimal solutions for evacuation optimization problem applications. Future work could also focus on the improvement of encoding and representation of solutions for spatial optimization problems. For routing purposes, it can integrate the latest path-finding algorithm to utilize new features of the algorithm and include the other factors in going to the destination such as traffic and risk along with the evacuation path. Thus, this study can be taken a step further, instead of using the shortest path, it is recommended to venture on the quickest path.

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Conflict of Interest

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