

Disaster Resiliency through Evacuation Designation Simulation for Disaster Management based on Artificial Neural Network

Abstract—Disaster and the issue of COVID-19 pandemic are serious challenges to the community bringing a disruption of its function along with human, material, economic or environmental loss. The same way, various disasters have brought numerous problems affecting the ability of the community to cope using its own resources. Tsunami is one of the most fatal catastrophe that is both dangerous and destructive. This paper explores evacuation security issues through indexing designated evacuation shelter for communication facilities and reserves, etc.. Since machine learning is a significant part of almost all research and development today, a neural network approach using Multilayer Back-propagation is conducted to determine the overall emergency evacuation ability of the different evacuation shelters assigned. The study utilizes to index the Camarines Norte as a sample case utilizing data resources from the local Provincial Disaster Risk Reduction Management Council (PDRRMC) and Municipal Disaster Risk Reduction Office (MDRRMO). An assessment index system of evacuation designation was provided in the study and the result would help in designing the disaster evacuation plan. The assessment results show that the overall emergency evacuation ability failed to meet desired characteristics for Tsunami evacuation especially in areas B and G with 60 points which is the least favorable due to those areas are near coastal areas. However, the result also identified the best location for evacuation and weak areas that needs to be addressed. Lack of warning capability, emergency preparedness, and emergency response contribute to the weak ability of the designated evacuation shelters in the province making it vulnerable during Tsunami outbreak. It is highly recommended to address these areas and make a reliable evacuation plan based on the outcome of the study.

Keywords – risk reduction, disaster management, machine learning

I. INTRODUCTION

INCREASING attention is being paid to the impacts of natural disasters on humans as both society and technology develop. Numerous retroactive and proactive countermeasures have been introduced to reduce the number of casualties and other impacts caused by natural hazards. In addition to these natural disasters are the issues on COVID-19 pandemic as one of the threatening global disaster which brought greater psychological impact [7]. The development of emergency shelters has been proved to be one of the most effective methods to reduce casualties, as they can provide safe havens for evacuees before, during and after a disaster [12].

The recent earthquake produced the largest trans-oceanic tsunami and killed more people than any tsunami in history. Thailand is affected by tsunami and killed more than 5000 lives and severely damaged public utilities as well as commercial and living house establishments. The estimated total economic losses are exceeded US \$1.6 billion. In order to

overcome this shortcoming, both typical recurrent nature of disaster and the availability of technological, social, and organizational remedies must be an integral part of a recuperation and pre-disaster planning [1].

Another recent earthquake measured 9.0 on the Richter scale hit Japan on March 11, 2011. The earthquake generated a huge tsunami with wave height exceeding ten meters in some areas, and a maximum run-up height exceeding 40 meters. Record lists 15,885 fatalities, 2,623 persons still missing and 263,392 persons are living in refuge facilities. The total area inundated by the tsunami exceeded $560km^2$, which is comparable to the area of central Tokyo ($621km^2$). 127,305 houses were completely destroyed, and 272,941 were partially destroyed [9].

Evacuation is the process of transferring or temporarily relocating people at risk to a safe place. It is a procedure most often used in cases where the community or infrastructure could be possibly hit by hazards [8]. Therefore, it is a process of evacuating residents from any dangerous sites to safer destination in the shortest possible time which is of prime importance in emergency management. Untimely assistance and poor coordination at the operation level have always been the major problem in evacuation process during flash floods. A lot of people have to be safely evacuated at the shortest possible time to avoid loss of lives during disaster. Much effort has been done in producing manual evacuation guideline, developing evacuation system [2], developing simulation [14], and developing a wide variety of algorithms [11] to facilitate the evacuation operation for different types of disasters.

There are researches related to evacuation such as the use of modified discrete particle swarm optimization for solving flash floods evacuation operation. The paper focuses on evacuation vehicle routing solution using a modification of a discrete particle swarm optimization (DPSO) with a new search decomposition procedure. Comparative analysis of this algorithm and a genetic algorithm (GA) using the severe flash floods events datasets is performed. [15]. Another investigates on emergency trip destination implicating the evacuee behaviors using logistic regression model and neural network model in estimating the probability of evacuee choice of selecting evacuation destinations [1]. Moreover, other studies sought a different view on evacuation that is based on designing smart building evacuation using wireless scheme consists of intelligent integration supervisory system (IISS), smart emergency indicator boards (SEIB) and fuzzy logic evacuation method with particle swarm optimization (PS)) parameter tuning [3]. These are some of the researches that made evacuation research an important element in disaster management.

However, the above researches focus more on evacuation operation, human behavior, subway operations and others using fuzzy math method, genetic algorithm, and even swarm optimization. This study focuses on shelters and designated evacuation areas capability as to early warning, preparedness and response capacity. Camarines Norte is subjected to a case analysis because its geographical location makes it prone to disasters such as Tsunami, the Provincial Disaster Risk Reduction Management Council (PDRPMC) is very serious in its campaign for a better disaster preparedness plan. Artificial Neural Network (ANN) was utilized because it can be able to do mapping functions from input to output, has the self-study ability, which makes it fit for calculating complex problems. Evacuation designation provides the first line of defense during calamity such as Tsunami and so management of its operation determines the failure and success of an evacuation. Using the neural network model it is expected that evacuation designation capability reveals strengths and weaknesses allowing better emergency evacuation plan for disaster management.

II. SYSTEMS ARCHITECTURE/DESIGN

1) *Artificial Neural Networks*: An artificial neural network (ANN) is a computer program that models the human brain with units called neurons akin to the biological counterpart in the brain. This has applications in pattern learning, that is, training the algorithm with a relevant data set and utilizing it for future predictions.

An ANN is trained to give correct output to a specific problem. The ANN is fed the input data and output values and the initial weights to the connections are assigned randomly.

The ANN adjusts these weights between the neurons until it produces the correct output for the set of inputs it is given. Hence, accuracy of an ANN is affected by the number of data, more so than the number of variables. The interconnection weights are the mechanism used by the ANN to learn the solution to the specific problem, [4].

The basic implementation of an ANN involves 3 layers, viz. an input layer, a hidden layer and an output layer. The three layers function depending on the weight of the connections between them. A typical feed-forward neural network is depicted in Figure 1.

Training in a neural network can be supervised or unsupervised. The most popular algorithm for supervised training is the back-propagation algorithm developed by McClelland and Rumelhart [6]. Another consideration for an ANN model is reducing the error function, usually given by the mean squared error, which is easily computable and an accurate method of validating the training process.

2) *Assessment Index System Architecture*: The pattern of recognizing the capability assessment of the designated evacuation lies in the Neural network model built for the purpose. The neural network model in the network is identified based on the topology structure, input nodes, output nodes and number of layers. According to the Kolmogorov theorem, three layers back-propagation (BP) network, after enough learning can max approximation function. So three-layer structure of the BP neural network should be built [5]. The evacuation

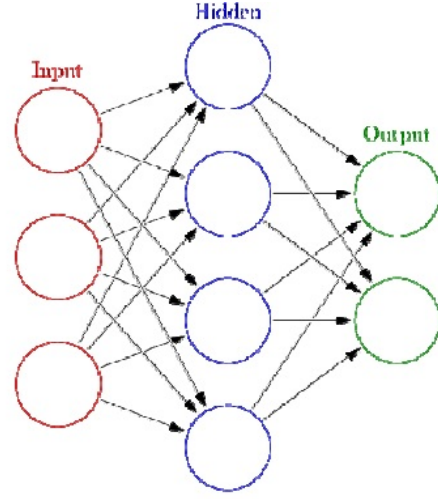


Fig. 1. A sample feed-forward neural network.

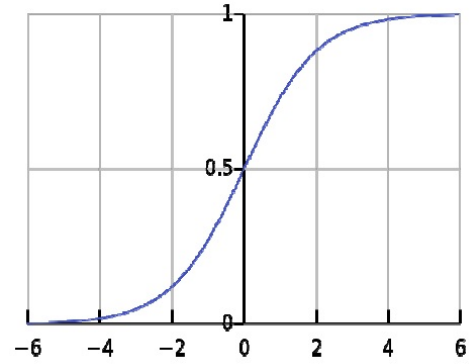


Fig. 2. The logistic sigmoid function used as the activation function.

ability is assessed using this approach and after investigation 14 evacuation designation in the province considers location factors and evacuation management factors. These 14 indexes are further breakdown into three which is the early warning capability, emergency pre-emptive evacuation preparedness, and emergency response capacity. These in turn will lead to the assessment index system of evacuation designation ability. Overall, these are the input, hidden layer and the output layer as shown in figure 3.

3) *Description for neural network evaluation index value*: The description of the evaluation index system is an important part of the system evaluation to elaborate justifiable assessment of the Evacuation designation ability of the different strategic shelters located in various area. It provides a top-view analysis from early warning capacity, emergency pre-emptive evacuation preparedness, and the emergency response capacity.

In order to clearly describe assessment index system of the emergency evacuation ability of evacuation management operation, the X_i are used to indicate as the i th indicators (i values range [1, 14], i value is positive integer) of assessment index system of the emergency evacuation ability of the assigned evacuation designation. At the same time, for the data processing method, because of its different value meaning, the

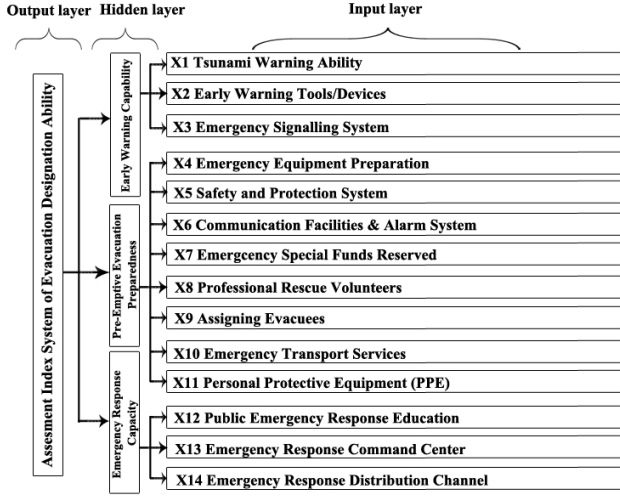


Fig. 3. Assessment Index system of Evacuation designation neural network.

TABLE I
DESCRIPTION FOR ASSESSMENT INDEX VALUE OF EVACUATION
DESIGNATION CAPABILITY

The serial number	Index code	The index name	Index value type	Remarks
1	X1	Tsunami warning ability	Logical	Whether there is a Tsunami warning capability
2	X2	Early warning tools or devices	Logical	Whether there is an early warning tools or devices in place
3	X3	Emergency signalling system	Logical	Whether there is a signal devices available like flags and others
4	X4	Emergency equipment preparation	Logical	Whether different equipments like boats and/or rafts and others are available
5	X5	Safety and protection system	Logical	Whether there are safety and protection system installed and/or available
6	X6	Communication facilities and alarm system	Logical	Is there a communication facilities and alarm system?
7	X7	Emergency special funds reserves	Logical	If there is any emergency special fund reserves
8	X8	Professional rescue volunteers	Logical	If there are rescue volunteers available
9	X9	Assigning evacuees	Logical	Whether there is evacuee assignment like senior citizens, person's with disabilities, etc.
10	X10	Emergency transport preparation	Logical	Whether there is a transport system preparation available
11	X11	Personal protective equipment (PPE)	Numeric	Personal protective equipment number
12	X12	Public emergency response education	Logical	Whether the public received emergency response education
13	X13	Emergency response command center	Logical	Whether emergency command center respond during emergency
14	X14	Evacuation Center Capacity	Numeric	Number of persons that can be sheltered

value index system is divided into logical type and numeric indicators. Using logical type index and the numeric index can actually reflect the evacuation designation's situation and simplify the calculation. For example, value of tsunami early warning capability is a logical type, which namely means the evacuation designation tsunami early warning ability value is 1, otherwise the value of 0 [13]; personal protective equipment (PPE) is numeric, it indicates the number of PPE tools in the evacuation designation. This has the advantages that values for complex evaluation index system of emergency assessment ability of evacuation designation operation, by using the logical type, can greatly reduce the workload and increase the credibility of evaluation results at the same time.

Through the processing method of the data above, the index values are between 0 and 1. In order to distinguish more effectively the strong and weak relationship of evacuation designation ability, it supposed to use the MATLAB program, namely $Px = f .* ones, f \in (0, 1)$, which will operate the emergency evacuation capacity equivalent to 0 to 100 points and implement the centesimal system evaluation to press the system closer to people's thinking habits. To make the emergency evacuation capacity of evacuation designation corresponding to a specific score and then the numerical size corresponds to the emergency evacuation capacity of the evacuation designation operation. Generally, more than 90 points for excellent emergency evacuation ability; between 80 to 90 points for good emergency evacuation capacity; between 70 to 80 points for general emergency evacuation ability; between 60 to 70 points for bad emergency evacuation ability, and below 60 points for the worse emergency evacuation ability.

III. METHODOLOGY

1) *Brief introduction of assessment instance of evacuation designation:* The main function of the Provincial Disaster Risk Reduction Management Office includes management of evacuation plans for the province. They also approve the disaster and contingency plan for each town in Camarines Norte. The Municipal Disaster Risk Reduction Management Office on the other hand develop municipal disaster plan and contingency for the respected towns. The contingency plan includes the number of evacuations available per hazard and the locations affected by disaster that is needed in evacuation planning.

Identification and assigning of households in their respective evacuation centers is manually done by the Barangay Disaster Risk Reduction Management Committee (BDRRMC) during the preparation of evacuation plan for each barangay. Once the BDRRMCs have already prepared an evacuation plan for their respective barangays, the MDRRMO consolidate those evacuation plans for the town contingency plan and approves the plans by the PDRRMO.

According to the MDRRMO, several factors must be considered when assigning evacuees but they are difficult to implement due to issues such as the condition of the evacuation center and absence of household information in the barangay. The BDRRMC consumes lots of time in devising evacuation

TABLE II
STATISTICAL VALUES OF CAMARINES NORTE EVACUATION DESIGNATION
ABILITY BASED ON THE ASSESSMENT INDEX SYSTEM

The values/Sites	X1	X2	X3	X4	X5	X6	X7
A. Moreno Intgd. School	0	1	1	1	1	1	0
B. Anita V. Romero ES	0	1	1	1	1	1	0
C. Gregorio Pimentel Sch.	0	1	1	1	1	1	0
D. F. Baldovino ES	0	1	1	1	1	1	0
E. Cobangbang ES	0	1	1	1	1	1	0
F. Calasgasan ES	0	1	1	1	1	1	0
G. Alawihao HS	0	1	1	1	1	1	0
H. Porfirio R. Ponayo HS	0	1	1	1	1	1	0
I. Cams. Norte Nat'l. HS	0	1	1	1	1	1	0
J. Brgy. Calasgasan Hall	0	1	1	1	1	1	0
K. Brgy. Cobangbang Hall	0	1	1	1	1	1	0
L. Brgy. Magang Hall	0	1	1	1	1	1	0
M. Brgy. Mambalite Hall	0	1	1	1	1	1	0
N. Brgy. Pamorangan Hall	0	1	1	1	1	1	0
The values/Sites	X8	X9	X10	X11	X12	X13	X14
A. Moreno Intgd. School	1	1	1	3	0	1	200
B. Anita V. Romero ES	1	0	1	0	0	1	100
C. Gregorio Pimentel Sch.	1	1	1	2	0	1	250
D. F. Baldovino ES	1	1	1	5	0	1	300
E. Cobangbang ES	1	1	1	2	0	1	300
F. Calasgasan ES	1	1	1	6	0	1	300
G. Alawihao HS	1	0	1	0	0	1	200
H. Porfirio R. Ponayo HS	1	1	1	3	0	1	200
I. Cams. Norte Nat'l. HS	1	1	1	8	0	1	500
J. Brgy. Calasgasan Hall	1	1	1	7	0	1	150
K. Brgy. Cobangbang Hall	1	1	1	4	0	1	50
L. Brgy. Magang Hall	1	1	1	2	0	1	50
M. Brgy. Mambalite Hall	1	1	1	0	0	1	50
N. Brgy. Pamorangan Hall	1	1	1	3	0	1	100

plans since every type of disaster may require a different evacuation plan for the community and if they follow proper evacuation rules, it is very difficult for them since it is manually done at present.

During the announcement of pre-emptive evacuation, the barangay officials are tasked to inform each household affected by the possible disaster and advise them to pre-emptively evacuate for their own safety and protection. The barangay officials use different early warning tools and/or devices such as big flags to give signals to the households if they need to evacuate, or a megaphone and siren to communicate and warn their constituents. These methods results in a considerable delay in the relay of information.

The assessment instance are the different designated evacuation area assigned by the Provincial Disaster Risk Reduction Management Council (PDRPMC) of the province of Camarines Norte. The evacuation centers are: Moreno Integrated School, Anita V. Romero Elementary School, Gregorio Pimentel School, F. Baldovino Elementary School, Cobangbang Elementary School, Calatagan Elementary School, Alawihao High School, Profirio R. Ponayo High School, Camarines Norte National High School, Brgy. Calasgasan Brgy. Hall, Brgy. Cobangbang Brgy. Hall, Brgy. Magang Brgy. Hall, Brgy. Mambalite Brgy. Hall, and Brgy. Pamorangan Brgy. Hall.

2) *Data Collection*: Based on neural network assessment model index system, index value and other related contents combining with Camarines Norte Evacuation designation situation, analysis and statistics are made, combining with related literatures. The assessment index system statistical results of emergency evacuation capacity of the Evacuation designation are shown in Table II.

3) *Neural network training*: (a) Data regularization processing. To facilitate processing data, the researcher suppose to do regularization with known numeric index which transfer all numeric indicators into a value between 0 and 1. Correspondingly, it is conducive to improve the emergency evacuation ability which the indicator of the best value in each evacuation designation is set to 1 and the worst value is 0 [10];

```
a=max (p');
for i=1:14
for j=1:14
ptest ( i, j )=p(i,j)/a(i);
end
end
```

(b) Training sample setting. After data regularization processing, for the training sample, this paper adopts the following corresponding rules: assume that every index of 1 for 100 points, each index of 0.8 for 80 points, 0.6 for 60 points, 0.4 for 40 points, 0.2 for 20 points, 0 for 0 points; p1=ones (1, 14); p2=0.8.*ones (1, 14); p3=0.6.*ones (1, 14); p4=0.4.*ones (1, 14); p5=0.2.*ones (1, 14); p6=0.*ones (1, 14); ptrain=[p1;p2;p3;p4;p5;p6]; t= [100,80,60,40,20,0];

(c) To bring in the known data and implement the neural network training.
net=newff (minmax(ptrain'),[59,1],'tansig','purelin','traingd');
net =init (net);
net.trainparam.epochs=100000;
net.trainparam.goal=1e-10;
[Net,tr]=train (net, ptrain', t);

(d) To assess the emergency evacuation actual ability of designated evacuation shelters and obtain emergency evacuation capability assessment results. Bringing evacuation designation statistics to assessment model to assess 14 evacuation sites to get score and existing in vector score.

```
for i=1:14
a=ptest (:,i);
score (i) =sim(net, a);
end
```

A. The Simulation results

The conduct of neural network training for the different samples takes a lot of time so that the training results can be able to achieve the stability. Each samples were repeated 10 times for each evacuation designation simulation to improve the level of accuracy of the assessment result and reduce the error of neural network training. The average was taken from the result of the 10 times simulation conducted. Results are summarized in Table III.

Based from the accumulated data in the table, it can be observed that the evacuation sites B and G are below 60, this

TABLE III
AVERAGE SCORES OF CAMARINES NORTE EVACUATION DESIGNATION
CAPABILITY ASSESSMENT RESULTS

Evacuation Designation	Average Score	Evacuation Designation Ability
A	67.86	Bad emergency evacuation ability
B	57.85	Worse emergency evacuation ability
C	67.50	Bad emergency evacuation ability
D	70.00	General emergency evacuation ability
E	67.86	Bad emergency evacuation ability
F	70.71	General emergency evacuation ability
G	58.57	Worse emergency evacuation ability
H	67.86	Bad emergency evacuation ability
I	73.57	General emergency evacuation ability
J	70.36	General emergency evacuation ability
K	67.50	Bad emergency evacuation ability
L	66.07	Bad emergency evacuation ability
M	64.64	Bad emergency evacuation ability
N	67.14	Bad emergency evacuation ability

means that the ability of emergency evacuation is poorer in the line of 14 evacuation designation, and evacuation designation I equips the strongest emergency evacuation capability.

B. Analysis of the Simulation Results

The simulation analysis provides the following results:

- 1) The average value of the emergency evacuation capability assessment in the 14 evacuation designation areas is 66.96 that means the emergency evacuation capability of the assessment is bad emergency ability level. Initial observation from the evacuation designation shows lacking in many emergency capability aspects such as on Tsunami warning ability, public response emergency education, personal protective equipments, and others. In addition, funding support from the Local Government Units and the Disaster Management Council hampers capability to promote emergency evacuation ability especially in case of Tsunami. Several emergency evacuation centers are located along coastal areas which defer its purpose for Tsunami evacuation.
- 2) Sorting the evaluation results from the highest to the lowest based on the 14 identified evacuation designation areas, it reveals that those evacuation areas located in central town area received better support attention rather than those located in strategic places situated in high areas suited for Tsunami evacuation relocation. It suggests that these weaknesses might be given attention by the PDRRMC and the provincial government to allocate budget/funds necessary to improve evacuation management operations.
- 3) The evacuation designations B and G have scores below 60 points that means the emergency evacuation ability of the two evacuation areas are poor. The main reason for this is that these areas are near coastal location

with low capacity and lack financial and physical resources to handle evacuation operations. Therefore, it is highly suggested that these areas should be removed as evacuation designation sites especially if the disaster is earthquake leading to Tsunami so that lives of the people will be spared. Also, general inspection and audit is necessary in order to ascertain certain issues surrounding evacuation areas in the province.

IV. CONCLUSION

Document analysis, interview and a thorough on-site investigation from the evacuation designation sites and PDRRMC operation management factors, combined with relevant research on Tsunami led this paper to build an index system that includes 14 indexes including Tsunami warning ability index, emergency evacuation preparedness and emergency response capacity. This provided an actual situation analysis and simulated assessment results. The BP neural network model is used to simulate and train the numerical values above. Then the assessment is made. After many times of assessment, experimental error decrease. The emergency evacuation capacity assessment results of evaluation instance of the evacuation designation sites show that the emergency evacuation ability of the PDRRMC during actual operation is good but also reveals weak areas that need improvement. Through the neural network model assessment, the evacuation sites B and G are below 60, this means that the ability of emergency evacuation is poorer in the line of 14 evacuation designation, and evacuation designation I equips the strongest emergency evacuation capability. It is clear that the emergency evacuation capacity of several evacuation designation sites is bad and this needs immediate attention.

The assessment result of this paper shows that BP network is effective in assessing the example evacuation designation emergency evacuation capability. However, there are other influencing factors that should be considered and BP network is limited to fit assessment objects. Therefore, the classic BP network should be improved and adding a fuzzy logic into the system to improve decision making process and promote smart evacuation plans is highly recommended for further exploration.

ACKNOWLEDGMENT

The author would like to thank the Provincial Disaster Risk Reduction Management Office of Daet, Camarines Norte and Mr. Santiago Mella the MDRRMO Officer for the data and significant insights on disaster management.

REFERENCES

- [1] Charnkol, T., Tanaboriboon, Y., and Hanaoka, S. (2007). *Emergency Trip Destination of Evacuation as Shelter Analysis for Tsunami Disaster: A Case Study in Phuket, Thailand*. Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 6.
- [2] Chiu, Y. (2004). "Traffic scheduling simulation and assignment for area-wide evacuation," in Proc. 7th International IEEE Conference on Intelligent Transportation Systems, pp. 537-542
- [3] Chen, C. (2012) *The Design of Smart Building Evacuation System*. International Science Press. IJCTA, 5(1).

- [4] Mitra, P., Ray, R., Chatterjee, R., Basu, R., Saha, P., Raha, S., Barman, R., Patra, S., Biswas, S., and Saha, S. (2016). *Flood forecasting using Internet of things and artificial neural networks*. 2016 IEEE 7th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), 1-5.
- [5] Qiquan, W., and Le, Z. (2009). *Application of BP Neural Network Assessment Method in the Stampede Accidents of Large-scale Activities*, China Safety Science Journal (04):127-133.
- [6] Rumelhart, D. E., Hinton, D. E., Williams, R. J. (8 October 1986), "Learning representations by back-propagating errors". *Nature*. 33 (6088): 533–536. doi:10.1038/323533a0.
- [7] Sheek-Hussein, M., Abu-Zidan, F.M. and Stip, E. (2021). *Disaster management of the psychological impact of the COVID-19 pandemic*. Int J Emerg Med 14, 19. <https://doi.org/10.1186/s12245-021-00342-z>.
- [8] Stepanov, A. and Smith, J. (2009). *Multi-objective evacuation routing in transportation networks*. European Journal of Operational Research, 198(2), 435–446.
- [9] Sun, Y., Yamori, K., and Kondo, S. (2014). *Single-person Drill for Tsunami Evacuation and Disaster Education*. Journal of Integrated Disaster Risk Management. IDRIM(2014)4(1), ISSN: 2185-8322. Available online
- [10] Wang, Q. . *Emergency Evacuation Capability Assessment of Subway Operation Based on Artificial Neural Network*. 12th International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery (ICNC-FSKD), 2016.
- [11] Xie, C. and Turnquist, M. (2011). "Lane-based evacuation network optimization: An integrated Lagrangian relaxation and tabu search approach," *Transportation Research Part C: Emerging Technologies*, vol. 19, pp. 40-63.
- [12] Xiujuan, Z., Wei, X., Yunjia, M., Fuyu, H. (2015) *Scenario-Based Multi-Objective Optimum Allocation Model for Earthquake Emergency Shelters Using a Modified Particle Swarm Optimization Algorithm: A Case Study in Chaoyang District, Beijing, China*. PLOS ONE — DOI:10.1371/journal.pone.0144455.
- [13] Yiheng, W. (2012). *Virtual assessment model on emergency evacuation capacity of Beijing subway based on BP neural network algorithm*. Journal of Safety Science and Technology, (01):5-10
- [14] Yusoff, M., Ariffin, J. and Mohamed, A. (2010). "Solving Vehicle Assignment Problem Using Evolutionary Computation," in Proc. *Advances in Swarm Intelligence*. vol 1.
- [15] Yusoff, M., Ariffin, J. and Mohamed, A. (2011). *A Modified Discrete Particle Swarm Optimization for Solving Flash Floods Evacuation Operation*. International Journal of Computers, Issue 4, Vol. 5.