International Journal on Advanced Science Engineering Information Technology

Vol.11 (2021) No. 3
ISSN: 2088-5334

Mass Evacuation Transportation Model Using Hybrid Genetic Algorithm

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***Abstract*— The process of evacuating natural disasters requires careful planning. In particular, the evacuation process needs attention in the evacuation process because it involves the safety of many people. Evacuation time itself depends on information about incomplete evacuation routes such as those concerning desired velocity and obstacle parameters. When viewed in terms of transportation planning for evacuation, it is an Auto-Based Evacuation Model problem where the community, in this case, drivers, certainly do not know the evacuation planning or the route they will go through because, in the event of a disaster, it cannot be predicted which areas will be affected. The routing problem can be viewed as a discrete problem where the traffic problem is following a user equilibrium model. It has a bi-level structure. Top-level is used to minimize evacuation time using the contraflow strategy. At the same time, traffic volume and travel time are modeled at a low level. This problem is a linear programming problem whose solution will be optimized using a Hybrid Genetic Algorithm. This model is proposed to carry out mass evacuation processes based on time-window constraints. Finally, computational results are provided to demonstrate the validity and robustness of the proposed model. Based on the test results, it can be seen that the designed model can adjust the path that the vehicle follows with the vehicle station by adjusting the available capacity. The results showed that the intended route provided by the model was the shortest route.**

***Keywords*— Transportation planning; auto-based evacuation model; linear programming; hybrid genetic algorithm.**

Manuscript received 15 Apr. 2020; revised 22 Jan. 2021; accepted 23 Feb. 2021. Date of publication 30 Jun. 2021.

I. INTRODUCTION

In particular, the evacuation process needs attention in the evacuation process because it involves the safety of many people[1]. Evacuation time depends on incomplete evacuation routes, such as those concerning desired velocity and obstacle parameters [2]. For example, in natural disasters, disasters can be felt for all levels of society who have a different understanding of the evacuation process, requiring an adequate transportation network in the evacuation process [3]. There are some methods used for the transportation network, such as the Genetic Algorithm. GA proposed by Nicklow *et al.* is used in computational processes and used for water resources engineering [4].

There are 2 (two) approaches to the evacuation route: Transit-Based Evacuation Model and the Auto-Based Evacuation Model. The Transit-Based Evacuation Model is applied if there is a fixed route for evacuation. However, if there is no fixed route, then the Auto-Based Evacuation Model will be applied [5]. When viewed in terms of transportation planning for evacuation, it is an Auto-Based Evacuation Model problem where the community, in this case, drivers certainly do not know the evacuation planning or the route they will go through because, in the event of a disaster, it cannot be predicted which areas will be affected.

The routing problem can be viewed as a discrete problem where the traffic problem is following a user equilibrium model. It has a bi-level structure. Top-level is used to minimize evacuation time using the contraflow strategy. At the same time, traffic volume and travel time are modeled at a low level.

This problem is a linear programming problem whose solution will be optimized using a Hybrid Genetic Algorithm. This model is proposed to carry out mass evacuation processes based on time-window constraints. Finally, computational results are provided to demonstrate the validity and robustness of the proposed model [6].

II. Materials and Method

A. Related Works

Several studies conducted by some researchers in transit-based evacuation planning pay less attention to time windows. Travel time from refugees from the starting point to the final point of evacuation also needs to be considered when planning the evacuation route. In general, access to resources and information will be very limited in the event of a disaster, and if it is not well planned, the routing and scheduling process will be very dangerous [7], [8]. Research over the past few decades has shown that good transportation system planning makes the evacuation process effective.

Pereira and Bish proposed several models of bus-based evacuation routes. In the proposed evacuation plan, the refugees arrive at the pre-determined pickup location at the location conditions that have been specifically stated, and there are buses available that can take all refugees to the refugee camps [9].

Goerigk *et al.*[10] has proposed an algorithm to solve two-stage bi-criteria that can solve time evacuation and the vulnerability schedule to change evacuation circumstances. Swamy *et al.* [11] has proposed an approach to evacuate refugees from the affected zone to safe areas. Qazi *et al.* [12] presenting an evacuation model based on short-notice buses, which is a dynamic approach based on the needs and flexibility of evacuation routes. The routing problem can be viewed as a discrete problem where the traffic problem follows a user equilibrium model. This approach has a bi-level structure in which the top level is used to minimize evacuation time, and the bottom level is used to manage the traffic volume of travel time[5].

Chu *et al.*[13] have used a bi-level structure that predicts congestion at the upper level and the maximum evacuation time at the lower level. Wang and Wang[14] has used the bi-level structure concept for the demand and supply of transportation systems. This problem can be solved by using the Hybrid Genetic Algorithm method [6].

B. Research Method

This research uses Bilevel Structure. The bilevel planning model is proposed using the minimum saturation of the evacuation network as the objective function for the upper-level planning model and the minimum evacuation time as the objective function for the lower-level planning model [15]. The bi-level structure in the traffic problem is a time-dependent problem with equilibrium constraints [16]. The top-level is used to minimize evacuation time using counterstrategy. At the same time, traffic volume and travel time are modeled at a low level.

C. Up-Level Model

The up-level model mainly focuses on the effect of saturation on the practical operation of traffic. The Up-Level Model can be seen in Equations 1 to 5.

$$\min Z_T = \sum_{(i,j)\in A_R} x_{ij} t_{ij} \quad (1)$$

where

$$t_{ij} = t_{ij}^0\left(1+\alpha\left(\frac{x_{ij}}{c'_{ij}}\right)^{\beta}\right), \forall(i,j)\in A_R, \quad (2)$$

$$c'_{ij} = c_{ij} - c^*_{ij} z_{ij}$$

subject to

$$y_{ij} + y_{ji} \le 1, \forall(i,j),(j,i)\in A_R \quad (3)$$

$$x_{ij} \le c'_{ij} y_{ij}, \forall(i,j)\in A_R \quad (4)$$

$$0 \le x_{ij}, \forall(i,j)\in A \quad (5)$$

Equations 1 through 5 shows contraflow strategy. Contraflow strategy is generally used to use one or several transportation routes, which are inbound lanes to be converted into outbound lanes, which are expected to increase the capacity of transportation lanes in the evacuation process.

Z_T represents regional road network available for time *t.* Whereas$x_{ij}t_{ij}$stating each unit of vehicle *x* on the evacuation route*i,j* for each time*t*. The *y* represents the capacity of the evacuation route.

D. Low-Level Model

The lower-level model mainly considers the shortest total evacuation time of all vehicles. The Low-Level Model can be seen in Equations 6 to 9.

$$\min Z_U = \sum_{(i,j)\in A_R} \int_0^{x_{ij}} t_{ij}(w)d(w) \quad (6)$$

subject to

$$d_{pq} = \sum_{r\in R_{pq}} X_r^{pq}, \forall(p,q)\in V \quad (7)$$

$$x_{ij} = \sum_{(p,q)\in V}\sum_{r\in R_{pq}} X_r^{pq}\delta_{ij,r}, \forall(i,j)\in A_R \quad (8)$$

$$x_r^{pq} \ge 0, \forall r\in R_{pq} \quad (9)$$

The optimization or approximate optimal evacuation plan of the evacuation network was obtained at the top level, while the traffic volumes and travel times in streets were derived from equilibrium traffic assignments at the bottom level.

Z_U state the total evacuation time by considering the road capacity *V* and distance *d*. Meanwhile, *X* states the total number of vehicles evacuated by considering the travel speed *A* at a distance *r*.

E. K-Means

The pseudocode of K-Means as follows.

Input: *X*: a data set containing *'n'* data objects
k: the number of clusters,
Output: Set of Centroids (μ_p)
1: Arbitrarily choose *k* objects from *X* as the initial cluster centers.
2: repeat
3: (re) assign each data object to the cluster to which the data object is the most similar, based on the mean value of the data objects in the cluster,
4: Update the cluster centers (μ_p)
//where μ_p is the cluster centers; p={1,2,...,*k*} i.e. *calculate the mean value of the data objects for each cluster//*
5: Until No. change
6: return μ_p

Based on these algorithms, it can be seen that K-Means has the following stages.

1. Determine the initial cluster center (centroid) that can be done by specifying an instance, but in general, it is done by using a random number.
2. Place each sample or instance into a cluster with the closest similarity level, in this case, based on distance calculation using euclidean distance.

3. After all samples or instances have been successfully placed, calculate the average value of the attribute values of each instance to be used as a new cluster center (centroid).
4. Update the value of the cluster center (centroid) based on the results from step 3.
5. Repeat step 2 through step 4 until the optimal state or when the performance obtained has not changed.

F. Modified K-Means

The pseudo code of Modified K-Means is as follows [17].
Input: U=$\{n_1, n_2, \ldots, n_n\}$ // Set of n Number of data points.
Output: A set of R Clusters. // Number of Desired Cluster
Step:

1: Calculate R $\cong \sqrt{\frac{n}{2}}$
2: Allocate x = 1, assign a value to f // if the value of f is not given, then it was 1 by default and f > 0
3: Find the closest pair of data point from U. Move those points to the new set N_x.
4: Find the closest point of N_x and move it to N_x from U.
5: Repeat step (4) until the number of elements of N_x reach $(\frac{n}{R} x f)$
6: When, N_x are full and the number of elements of U$\neq 0$. Increment the value of x. New x $= x + 1$. (Repeat step III).
7: The center of gravity of each N_x. Those are the initial centroids C_j and element s of N_x are the elements of R_m.
8: Find the closes centroid for each data points and allocate each data points cluster. Calculate new centroid for each R_m.
9: Calculate the D_l (D_l=largest distanced data point from each centroid of each cluster)
10: Get the data points in the interval of D_l x $\frac{4}{9}$ to D_l
11: Find the closest centroid for those points and allocate them to the closest centroid cluster
12: Find a new centroid for each R_m

G. Hybrid Genetic Algorithm

The pseudocode for the Hybrid Genetic Algorithm as follows [18], [19].

Input : A dataset *D* having *R* records and |A| attributes, where A is the set of attributes
Output: A set of Clusters C
Require:

$$P_s \leftarrow \emptyset$$
$$P_o \leftarrow \emptyset$$
$$P_m \leftarrow \emptyset$$
$$P_c \leftarrow \emptyset$$
$$D' \leftarrow \text{Normalized (D)}$$
$$CR_b \leftarrow \text{The best chromosome of each generation}$$
$$P_d \leftarrow \emptyset$$
$$P_f \leftarrow \emptyset$$

end
Step 1: /* Normalized Datasets*/
The numerical attributes of A_0= [*l*,u] where $R^0_{i,j}$ is normalized as

$$R_{ij} = \frac{R^0_{ij}}{u-1} \tag{10}$$

and D$'$ *is the normalized dataset*

Step 2:/*Modified K-Means*/
Perform calculating the distance between two records.

$$d(R_1, R_2) = \frac{\sum_{j=1}^{t}|R_{i,j} - R_{l,j}| + \sum_{j=t+1}^{m} d(R_{i,j}, R_{l,j})}{|A|} \tag{11}$$

Step 3: /*Initial Population with Probabilistic Selection*/
Set $P_s \leftarrow \emptyset; K = \langle 2, 3, 4 \ldots . (3\, x \frac{s}{10} + 1)\rangle$;
for *j* = 1 **to** 5 **do**
  for *i* = 1 **to** |*K*| **do**
    /* Produce a chromosome CR with $K_i$genes;
    K_1= 2, K_2= 3 … K_9= 10
    CR ←ProduceChromosome (*R*, K_i);
    P_d← P_f∪ *R*;
  for *i* = 1 **to** 3 x s/10 **do**
    /* Produce a random number in the range 2 to $\sqrt{|R|}$
    k = ProduceRandNumber (2, $\sqrt{|R|}$);
for *j* = 1 **to** 5 **do**
    CR ←ProduceChromosomoe (*R*, *k*);
  P_f←P_f ∪ *R*;
  Return P_f

Step 4: /*Crossover*/
P_0 ← PerformCrossover (P_s) using Enhanced Crossover and Standard Crossover

Step 5: /*Elitism*/
Insert $CR_b$to the *chromosome* of the current generation if the current generation is worse than the generation before the current generation.

Step 6: /*Mutation Operation */
Insert $CR_b$to the *chromosome* of the current generation if the current generation is worse than the generation before the current generation While P_m ← PerformMutation (P_s)

Step 7: /*Probabilistic Cloning with MK-Means */
For k = 1 **to** m **do**
P_W^K =FindWorstChromosome (P_c)
P_W^K =ReplaceWithNeighborBestChromosome (P_g)
P_B^K =FindLocalBestChromosome (P_c)
L_b ← P_b^k/*Insert P_b^k to L_b as the best chromosomes of each *k**/

Step 8: /*Chromosome Selection */
C ← FindGlobalBestChromosome (L_b)

H. Hybrid Genetic Algorithm for Mass Evacuation

The step of the Hybrid Genetic Algorithm for Mass Evacuation as follows.

Step 1: /* Normalized Datasets*/
To create a normalized dataset, this study used a structured chromosome population. Structured chromosome population was represented by the coordinate of all points of evacuation.
Step 2:/*Modified K-Means*/
Before performing a modified K-Means, the process that must be done is calculating the X and Y coordinates of all distribution points.

The X and Y coordinates are calculated as follows.

$$X_i = X_i - X_o$$
$$Y_i = Y_i - Y_o \tag{12}$$

Calculate the polar angles of distribution points.

$$\theta_i = \begin{cases} tan^{-1}\frac{y_i}{x_i}, X_i > 0, Yi > 0 \\ \pi + tan^{-1}\frac{y_i}{x_i}, X_i < 0 \\ 2\pi + tan^{-1}\frac{y_i}{x_i}, X_i > 0, Yi < 0 \end{cases} \tag{13}$$

Perform calculating the distance between two records.

$$d(R_1, R_2) = \frac{\sum_{j=1}^{t}|R_{i,j} - R_{l,j}| + \sum_{j=t+1}^{m} d(R_{i,j,}R_{l,j})}{|A|} \tag{14}$$

Step 3:/*Perform Selection for Initial Population*/
The 10% of chromosomes with superior fitness value are selected as a parent and will go to the next step.

Step 4: /*Crossover*/
The crossover method that was used in this study is enhanced crossover and standard crossover.

III. Results and Discussion

For example, there is a 12 x 10 Km^2 transportation line with 35 junctions and 57 roads, as shown in Figure 1.

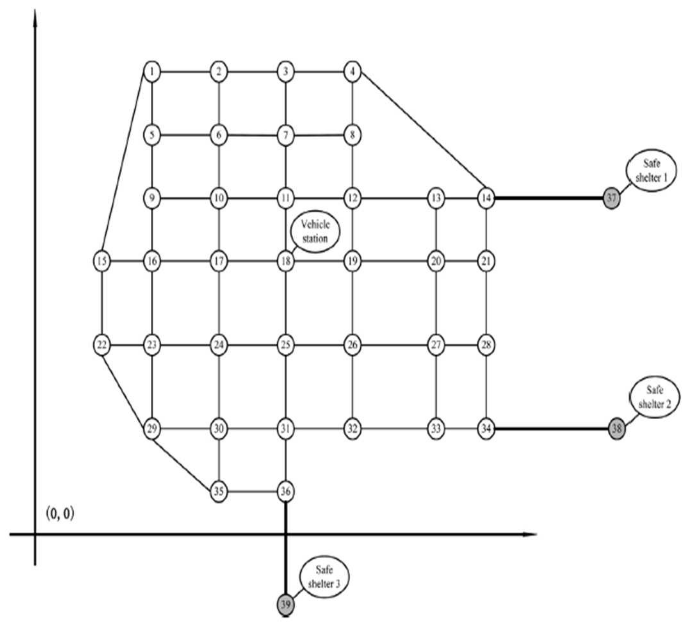

Fig. 1 Evacuation Transport Network

Figure 1 shows an evacuation route that consists of a number of vehicles and involves some vehicle stations as well as a safe shelter. Each link to the vehicle station has a distance, and each vehicle is directed to arrive as quickly as possible to the nearest safe shelter. The detailed information from Figure 1 can be seen in Table 1.

TABLE I
Detailed Information for Evacuation Transport Network

Link	Distance (Km)	Link	Distance (Km)	Link	Distance (Km)
1-2	2	12-13	2.5	23-29	2
1-5	1.5	12-19	1.5	24-25	2
1-15	4.75	13-14	1.5	24-30	2
2-3	2	13-20	1.5	25-26	2
2-6	1.5	14-21	1.5	25-31	2
3-4	2	14-37	10	26-27	2.5
3-7	1.5	15-16	1.5	26-32	2
4-8	1.5	15-22	2	27-28	1.5
4-14	5	16-17	2	27-33	2
5-6	2	16-23	2	28-34	2
5-9	1.5	17-18	2	29-30	2
6-7	2	17-24	2	29-35	2.5
6-10	1.5	18-19	2	30-31	2
7-8	2	18-25	2	30-35	1.5
7-11	1.5	19-20	2.5	31-32	2
8-12	1.5	19-26	2	31-36	1.5
9-10	2	20-21	1.5	32-33	2.5
9-16	1.5	20-27	2	33-34	1.5
10-11	2	21-28	2	34-38	10
10-17	1.5	22-23	1.5	35-36	2
11-12	2	22-29	2.5	36-39	10
11-18	1.5	23-24	2		

Based on Table 1, it can be seen the distance of each link between each vehicle station. In Table 1, it can be assumed that 39 vehicle stations can be selected to arrive at the nearest safe shelter. Based on the results of the application of the model, obtained results can be seen in Table 2.

TABLE II
Result of the Applivation of Model

Instance ID	Population Size	C^S	S	Assignments of Pick-Up Points	Assignment of Vehicles M_{PS}
1	8175	2970	S_1	p2, p4, p5, p6	3, 4, 1, 1
			S_2	p5, p6	1, 3, 5
			S_3	p1, p2, p4, p5	9, 6, 7, 5
2	19278	7510	S_1	p3, p4, p6	3, 4, 5
			S_2	p5, p6, p8	1, 2, 4
			S_3	p1, p2, p3, p4	5, 6, 8, 9
3	26780	8760	S_1	p4, p5, p7, p8	4, 6, 7, 8
			S_2	p4, p7, p3	5, 6, 7
			S_3	p1, p3, p4, p5	5, 7, 8, 9
4	31890	9156	S_1	p1, p2, p6	7, 8, 9
			S_2	p3, p4, p6	3, 5, 6
			S_3	p5, p6, p8, p9	3, 7, 8, 9

Based on Table 2, given various population sizes, which are needed to carry out the pickup process from the starting point to each refugee camp. Based on each instance, we can obtain the number of vehicles used for the evacuation process through arrangements for each existing vehicle.

IV. Conclusion

Based on the test results involving 4 (four) population size variations, namely: 8175, 19278, 26780, and 31890, it can be seen that the designed model can adjust the path that the vehicle follows with the vehicle station by adjusting the available capacity. Based on the test results, the results obtained by the model have been able to determine the transport evacuation. The amount of transportation and time needed to determine the evacuation process can be determined through the existing model. The results obtained are good enough, and future research is expected to consider the process of a microscopic evacuation plan if the available transportation lines are inadequate.

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