❒ 2204

Intelligent evacuation model in disaster mitigation

M. Safii[1], Syahril Efendi[1], Muhammad Zarlis[1], Herman Mawengkang[2]
[1]Faculty of Computer Science and Information Technology, Universitas Sumatera Utara, Medan, Indonesia
[2]Faculty of Math and Science, Universitas Sumatera Utara, Medan, Indonesia

Article Info

ABSTRACT

Mitigation is a pre-disaster action that aims to prepare for a disaster situation. One of the mitigation activities is evacuation, which aims to reduce disaster-related losses. Because disaster damage cannot be predicted, dealing with evacuation efforts requires a dynamic model. This study will utilize a dynamic model that combines the game theory model for choosing the evacuation location and the open vehicle routing problem (OVRP) model for selecting evacuation routes to create an intelligent system. The game theory model will be used to supplement the selection of alternate evacuation locations by taking into account geographical features that are very uncertain in the event of a crisis. An evacuation route equipped with an OVRP model with the goal of optimizing travel time is required to mobilize disaster-affected people. With the development of the Intelligent Evacuation System idea, combining the two models will create a new model. The simulation model is evaluated using linear, interactive, and discrete optimizer (LINDO), which may minimize the evacuation time from the evacuation route to a safe destination by 50 minutes if there is no contra-flow to allow more people to be evacuated.

Corresponding Author:

M. Safii
Faculty of Computer Science and Information Technology, Universitas Sumatera Utara
St. Dr. T. Mansur No.9, Padang Bulan, Medan, Sumatera Utara 20222, Indonesia
Email: m.safii@students.usu.ac.id

1. INTRODUCTION

The concept of an intelligent evacuation system involves information systems in affected placements in several alternative locations. This concept is a solution to dynamic evacuation activities that will be carried out in mitigation activities [1]. Several evacuation locations were competed to determine the strategy to be used as an evacuation location by considering the geographical aspect where the impact of the disaster could not be predicted. The purpose of determining the evacuation location is to maximize the number that can be saved and the disaster's effect may well be reduced. Several aspects are considered in the evacuation process, an example of this would be the amount that could be mobilized, how many people can be transported at a time, and utilized to get to an evacuation site by the quickest way possible [2], [3].

In managing evacuation, the area has a constraint function, such as transporting and concentrating those affected by the disaster to a safe area [4], [5]. The evacuation scale is an important part that is considered in evacuation activities. In general, evacuation consists of small-scale evacuation and long-distance evacuation. Small-scale evacuation is usually guided by emergency evacuation immediately and emergency conditions that are affected by a small space, for example, the occurrence of a small explosion, the collapse of a building, or the occurrence of a fire. Long-distance evacuation generally requires a vehicle as a mode of transportation and is generally instructed by disaster-related institutions or related ministries that communicate with other units [6], [7]. Evacuation activities are required to move quickly to place the

affected victims in the disaster location to a safe location by considering the absence of congestion and chaos in the traffic situation throughout the evacuation process [8].

The evacuation process requires an evacuation route that is regulated in the concept of transportation management. In the evacuation process, it is immediately possible to find the fastest route, such as the pattern of solving the traveling salesman problem (TSP) if the starting and ending nodes are the same and each node must be visited and is also called the vehicle routing problem (VRP) [9]. The selection of the fastest route can also be solved by using the open vehicle routing problem (OVRP) method. OVRP, on the other hand, does not require the vehicle to be returned to its original pool once it has visited the last customer on the route [10]. OVRP problem-solving uses heuristic or metaheuristic methods such as tabu search [11]. Previous research that has been done discusses the application of the disaster traffic management model with the heuristic open vehicle routing problem with time window (HOVRP) in a contra-flow state [12]–[14].

The disaster evacuation handle routing time model is an optimization of disaster evacuation transportation management conditions contra-flow not to occur in all route sections with the central assumption that safe areas have been determined with an optimum time of 400 minutes during the evacuation process [15]–[17]. In this study, we will discuss the dynamic model of determining the location of disaster evacuation using game theory and determining the effective evacuation route. Game theory applications can be used in various emergencies [18]. One of the game theory developments is the combinational game, which is looking for an optimal strategy in several possibilities [19].

2. PROBLEM STATEMENT

One of the techniques used to produce optimum decisions is linear programming, a mathematical method that places limited resources for optimal outcomes or results, such as maximizing profit or minimizing costs [20]–[22]. In linear programming problems, the solution can be in the form of fractions to produce the optimal value in the form of real numbers. The result of the solution may deviate from the goal because the solution is rounded to the nearest integer. Not a few problems in real life require solving decision variables in integer form and problem-solving models must be sought to obtain optimum integer solutions. In integer programming, some or all of the decision variables are integers as part of linear programming development [23], [24]. Evacuation problems can be done by using a linear program approach, which is game theory. In its implementation, it can be found in activities that are competitive in nature which allows competition or conflict to occur. The impact of this competition occurs on two people or two parties or a number of groups of people or groups [19].

The game is a form of competition between 2 people or parties or between 2 groups or teams that are close together and use rules that are known by the adjacent parties [25], [26]. On the other hand, the philosophy of game theory is a mathematical approach that defines an atmosphere of competition and conflict between various needs [27]. Using this concept, we can better understand how various competitive environments influence decision-making and how two or more requirements are interconnected.

2.1. Game theory on disaster management

The strategy used in determining the evacuation location uses a mixed strategy. In this strategy, a player or company will use a mixture of more than one strategy to get maximum results, where: x_i = Probability of player A with strategy $i(i = 1,2,3,...,m)$, y_i = The probability that player B chooses strategy $j(j = 1,2,3,...,n)$ [28], [29]. So that;

$$\sum_{i=1}^{m} x_i = \sum_{j=1}^{n} y_j = 1 \qquad (1)$$

$$x_i, y_j \geq 0, \text{ for every } i \text{ and } j \qquad (2)$$

The minimax criteria for mixed strategy are as shown in: player A has:

$$x_i \left(x_i \geq 0, \sum_{i=1}^{m} x_i = 1 \right) \qquad (3)$$

which will produce:

$$max \, x_i \left\{ \min \left(\sum_{i=1}^{m} a_{i1} x_i, \sum_{i=1}^{m} a_{i2} x_i, ..., \sum_{i=1}^{m} a_{in} x_i \right) \right\} \qquad (4)$$

Player B has;

$$y_j \left(y_j \geq 0, \sum_{j=1}^{n} y_j = 1 \right) \qquad (5)$$

which will produce:

$$min \, y_j \left\{ max \left(\sum_{j=1}^{n} a_{1j} y_j \,, \, \sum_{j=1}^{n} a_{2j} y_j \,, \, \dots \,, \, \sum_{j=1}^{n} a_{mj} y_j \right) \right\} \tag{6}$$

$$EV* = \sum_{i=1}^{m} \, \sum_{j=1}^{n} \, a_{ij} x_i^* \cdot y_j^* \tag{7}$$

The payoff value obtained from the subtraction between player 1 and player 2 is assumed to have a value as in the matrix below. The strategies used are as shown in:

EL_1 = Loc 1
EL_2 = Loc 2
EL_3 = Loc 3
EL_n = Loc n
X_a = Place elevation
X_b = Total population
X_c = Evacuation route length
X_d = Hierarchy of the roads
X_e = Type of transportation
X_f = Evacuation area

Using players and tactics, the optimum solution to the return calculation is found. In deciding where to evacuate, the tactics used throughout the evacuation may be advantageous. The computation of each player is expressed by associating Loc 1 (EL_1) with Loc 3 (EL_3), Loc 2 (EL_2) with Loc 3 (EL_3), and Loc 1 (EL_1) with Loc 2 (EL_2). At each evacuation location, a strategy can be obtained that can be used to achieve an advantage in the evacuation, which is assumed to have the value of the game player comparison as follows. It is assumed that the optimum solution is the optimum solution for the Loc 1 and Loc 3 matrix as shown in Table 1.

Table 1. Optimum solution of location 1 and location 3 matrix at location 1

X_a	X_b	X_c	X_d	X_e	X_f	Z
0	0.01	0	0	0	0.03	0.04

so:

$$V = \frac{1}{0,04} = 25$$

$$X_a = X_a * V = 0 * 25 = 0$$

$$X_b = X_b * V = 0.01 * 25 = 0.25$$

$$X_c = X_c * V = 0 * 25 = 0$$

$$X_d = X_d * V = 0 * 25 = 0$$

$$X_e = X_e * V = 0 * 25 = 0$$

$$X_f = X_f * V = 0.03 * 25 = 0.75$$

Because K=20 has been increased by the acquisition matrix components shown above, the game's worth rises to $V = 25 - 20 = 5$. As a result, the best course of action is 5. The best course of action is obtained for Loc 1, namely the strategy for population and evacuation area, with a game value of 5 as shown in Table 2.

Table 2. Optimum solution for location 1 and location 3 at location 3

Y_a	Y_b	Y_c	Y_d	Y_e	Y_f	Z
0.01	0.02	0	0	0	0.01	0.04

so:

$$V = \frac{1}{0,04} = 25$$

$$Y_a = Y_a * V = 0.01 * 25 = 0.25$$

$$Y_b = Y_b * V = 0.01 * 25 = 0.25$$

$$Y_c = Y_c * V = 0 * 25 = 0$$

$$Y_d = Y_d * V = 0.01 * 25 = 0.25$$

$$Y_e = Y_e * V = 0.01 * 25 = 0.25$$

$$Y_f = Y_f * V = 0 * 25 = 0$$

The game value is now $V = 25 - 20 = 5$ because of the addition of the acquisition matrix components to $K=20$, as a result, 5 is the optimal solution. The best course of action is achieved for Loc 3, that is the altitude of place, total population, hierarchy of the roads, and type of transportation strategies with game value 5. It is assumed that the optimum solution is the optimum solution for the Loc 1 and Loc 2 matrix as shown in Table 3.

Table 3. Optimum solution of location 1 and location 2 matrix

	Y_b	Y_c	Minimum
X_d	7	3	3
X_f	7	13	7
Maximum	7	13	

The value of 7 is seen in the table above, if a saddle point exists, then the game is in its most ideal state. The optimal strategy for location 2 is the population size strategy and the optimal strategy for Loc 1 is the evacuation area strategy. It is assumed that the optimum solution is the optimum solution for the Loc 2 and Loc 3 matrix as shown in Table 4.

Table 4. Optimum solution of location 2 and location 3 matrix at location 2

X_a	X_b	X_c	X_d	X_e	X_f	Z
0.01	0	0	0	0.01	0.02	0.04

so:

$$V = \frac{1}{0,04} = 25$$

$$X_a = X_a * V = 0.01 * 25 = 0.25$$

$$X_b = X_b * V = 0 * 25 = 0$$

$$X_c = X_c * V = 0 * 25 = 0$$

$$X_d = X_d * V = 0 * 25 = 0$$

$$X_e = X_e * V = 0.01 * 25 = 0.25$$

$$X_f = X_f * V = 0.03 * 25 = 0.75$$

Because of the addition of the acquisition matrix components $K=40$, the game's value is $V = 25 - 40 = -15$. As a result, -15 is the best course of action. The best course of action for Loc 2 is

achieved, that is the strategy of place height, type of transportation and area of evacuation place with a game value of -15 as shown in Table 5.

Table 5. Optimum solution of location 2 and location 3 matrix at location 3

X_a	X_b	X_c	X_d	X_e	X_f	Z
0.03	0	0	0	0.01	0	0.04

so:

$$V = \frac{1}{0,04} = 25$$

$$Y_a = Y_a * V = 0.03 * 25 = 0.75$$

$$Y_b = Y_b * V = 0 * 25 = 0$$

$$Y_c = Y_c * V = 0 * 25 = 0$$

$$Y_d = Y_d * V = 0 * 25 = 0$$

$$Y_e = Y_e * V = 0.01 * 25 = 0.25$$

$$Y_f = Y_f * V = 0 * 25 = 0$$

The game value is now $V = 25 - 40 = -15$ because of the addition of the acquisition matrix entries to K=40, as a result -15 is the optimal solution. The best course of action for Loc 3 is achieved such as altitude of place and type strategy of transport with a game value of -15. Accomplishing the goals of the evacuation procedure is dependent on the evacuation site. In determining the evacuation location, one must provide alternative locations due to the impact of unpredictable damage. Game theory, a combinational game to find the optimal strategy in several possibilities, can be used to determine alternative evacuation locations. The determination of this evacuation location is given a set of N_2 which will then be optimised in selecting an evacuation route as a set of final spots or safe destinations $N_2 = \{v_{n_1}, v_{n_2}, ..., v_{n_s}\}$. In solving the problem of choosing an evacuation location, it is assumed that it has more than 1 location or is given a set of L_n with influencing variables such as altitude (X_a), population (X_b), length of evacuation route (X_c), road hierarchy (X_d), type of transportation (X_e), and the area of the evacuation site (X_f). The simulation of determining the evacuation location can be seen in the following Figure 1.
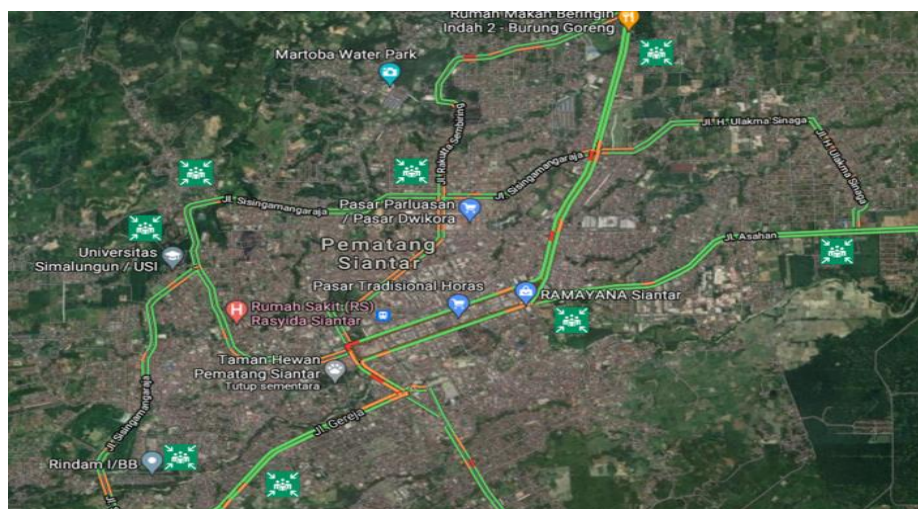

Figure 1. Simulation of alternative evacuation locations

2.2. Optimisation of evacuation routes

After the evacuation location is determined, the evacuation route will be determined. Evacuation route selection is part of transportation management. In determining the evacuation route, a mathematical model is made to minimize the time in the evacuation process. The flow of vehicular traffic at the time of a natural disaster can be expressed in a directed graph $G = (V, E)$ with $V = \{v_0, v_1, \ldots, v_n\}$ is the set of evacuation point spots. Node v_0 is the starting point for evacuation, with a record of the number of nodes v_0 get more than one. It is assumed that at these M nodes, the vehicle fleet is located. Then $E = \{(v_i, v_j): v_i, v_j \in V, i \neq j, j \neq 0\}$ is the set of vehicle paths. In the VRP, all vehicles must depart from the central node and return to that node. Whereas in OVRP the vehicle does not return to the central node. This is reasonable because the flow of the route starts from the evacuation center v_0 and goes to the safe area node v_n.

The model that will be generated follows the VRP model pattern. The type of vehicle used for evacuation is heterogeneous. So, the current model pattern is heterogeneous VRP. For evacuation it is necessary to have time windows. Therefore, in the realm of VRP, this condition refers to the heuristic open vehicle routing problem with time window (HOVRPTW) model pattern.

A route is used to symbolize every arc in E (i, j), linking nodes i and j through a route. This kind of network is known as a static network since every arc in the network only connects part of the nodes in the network to each other. A parameter is attached to each route and node. As a network, each node k represents a place with an initial population p_k and capacity q_k. Given a capacity of c_{ij} for every path (i, j), where $(i, j) \in E$. A path's capacity is the amount of flows it can handle in a given period of time, provided there is no congestion. It is the total of vehicles per hour on each lane that determines capacity on a lane-based roadway network. For each trajectory, it defined travel time t_{ij} where $(i, j) \in E$. If the road is clear of evacuation, it is considered that the t_{ij} constant represents the average speed of travelling over the arc (i, j). It is commonly known to as the free flow rate or grace time (lead) for the bow by this particular characteristic (i, j).

When it comes to how many people can be evacuated at a given moment, the line capacity is always considered to remain constant. Unfortunately, in reality, the capacity of the track is not always the same. It is the total of entities present in an arc that determines the capacity of that arc at any moment. Flow-dependent capacity reduces the number of network flow issues, and adds new limitations, by incorporating it into the system. The objective to be achieved from this problem model is planning to regulate the flow of vehicles from the initial location of the disaster to a safe location so that the vehicle's travel time is minimal. The notation used is as shown in:

Set:
N : Set of nodes
K : Vehicle set
N_0 : Evacuation starting node set, $N_0 = \{v_{01}, v_{02}, \ldots, v_{0d}\}$
N_1 : Transfer node set $N \backslash \{v_0\}, \{v_n\}$
N_2 : Set of end nodes (safe destination), $N_2 = \{v_{n1}, v_{n2}, \ldots, v_{ns}\}$
T : Travel time set

Parameter:
Q_k : Vehicle capacity $k \in K$
t_{ij} : Travel time from node $i \in N_0$ to node $j \in N_1$
$[a_i, b_i]$: The earliest and the last time on the node $i \in N_1$
c_{ij} : The path capacity of the node $i \in N_0 \cup N_1$ to node $j \in N_1 \cup N_2$
st_i : Service time at node $i \in N_0 \cup N_1$
td_i : Slowest time to arrive at node $i \in N_1$

3.   METHOD

The research was conducted using descriptive research methods. This research was conducted to determine the value of the independent variable, both 1 or more independent variables and no comparison was made between several variables [15]. The data collection technique used in this research is a literature study that collects data by studying various literature books and related documents to find solutions to problems in determining several alternative evacuation locations and optimal routes or routes for evacuation. The model development carried out is a dynamic model determining the location of evacuation in disaster mitigation which is generally seen in the following Figure 2.

The research starts from formulating a description of the problem, namely, how to determine an evacuation location based on the geographical conditions of an area. Next, describe the model for determining the evacuation location and determine the variables and parameters of the problem. Next, the game theory model will be used to solve the issue of locating the evacuation site, and once the findings are

obtained, the development of the model for locating is discussed. The next stage is the determination of model variables and parameters to complete the evacuation route or transportation route and followed by making an optimization model of the evacuation route/path and validation by testing the data using linear, interactive, and discrete optimizer (LINDO) software and after being valid it becomes a new model for determining evacuation locations in disaster mitigation.
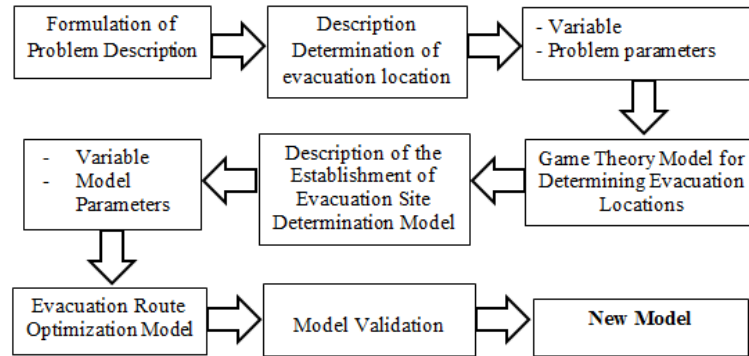

Figure 2. Research methodology

4. RESULTS AND DISCUSSION

Intermediate nodes signify where evacuation flows are converging (merging) or crossing. Minimizing the amount of time needed to evacuate in order to salvage as much material as possible is the primary objective. The objective function is expressed in the following expression.

$$Min = \sum_{i \in N_0} \sum_{j \in N_1} t_{ij} \sum_{k \in K} x_{ij}^k + \sum_{i \in N_1} \sum_{j \in N_2, i \neq j} t_{ij} \sum_{k \in K} x_{ij}^k + \sum_{i \in N_0} \sum_{j \in N_1} t_{ij} \sum_{k \in K} y_{ij}^k + \sum_{i \in N_1} \sum_{j \in N_2, i \neq j} t_{ij} \sum_{k \in K} y_{ij}^k \ (8)$$

4.1. Mathematical model formula

With obstacles or requirements that need to be met:

$$\sum_{k \in K} \sum_{i \in N_0} \quad x_{ij}^k \ = \ d, \forall j \in N_1 \cup N_2 \tag{9}$$

This equation ensures that the vehicle for each type departs from the l node of the initial disaster location to the next j node in the E path.

$$\sum_{j \in N_1} x_{ij}^k = K \quad \forall k \in K, \forall i \cup N_0 \tag{10}$$

This equation is to ensure that the number of vehicle trips departing from the initial disaster location is at most K paths.

$$\sum_{d \in N_0} \sum_{k \in K} y_{di}^k + \sum_{j \in N_1; i \neq j} \sum_{k \in K} x_{ji}^k = 1 \quad \forall i \in N_1 \tag{11}$$

This obstacle requires that a path cannot be traversed unless it starts from the initial location of the disaster.

$$\sum_{j \in N_1} x_{ij}^{tk} \ = \sum_{j \in N_2} x_{ij}^{tk} , \forall k \in K, \forall i \in N_0, \forall t \in T \tag{12}$$

This expression is to force that the vehicle will visit and leave a node at the time of travel t.

$$\sum_{j \cup N_1} x_{ij}^k = 1 \quad \forall k \in K, \forall i \in N_0 \tag{13}$$

This equation is to ensure that for each vehicle there is only one path from the selected initial disaster location.

$$\sum_{i\in N_0} x^{tk}_{ij+1} \leq 1, \forall j \in N_1 \cup N_2, \forall k \in K, \forall t \in T \tag{14}$$

There are artificial nodes (artificial).

$$\sum_{k\in K} \sum_{i\in N_0} x^{tk}_{(j+1)i} = 0, \forall j \in N_1, \forall t \in T \tag{15}$$

It is not allowed to start service from artificial nodes.

$$\sum_{k\in K} \sum_{j\in N_1 \cup N_2} x^{tk}_{ij} = 0, \forall i \in N_0, \forall t \in T \tag{16}$$

Vehicles that have left the initial location of the disaster are not allowed to return to the initial location.

$$\sum_{(i,j)\in N, i\neq j} x^{tk}_{ij} \leq ST - 1, \ \forall k \in K, \forall t \in T \tag{17}$$

Sub-tour elimination process (ST).

$$\sum_{(i,j)\in N, i<j} x^{k}_{ij} - \sum_{(i,j)\in N, j<i} x^{k}_{ij} = 0 \quad \forall k \in K \tag{18}$$

This equation is to maintain the flow of vehicle flow to continue.

$$\sum_{k\in K} \sum_{i\in N_0} x^{k}_{ii} = 0, \tag{19}$$

To prevent loops.

$$y_{ij} \leq c_{ij} x^{k}_{ij} \quad \forall i \in N_0, \forall j \in N_1 \cup N_2, i \neq j, \forall k \in K \tag{20}$$

The equation to state that the number of path currents does not exceed the path capacity.

$$l^{k}_{i} \leq a_i \sum_{j\in N_1} x^{k}_{ij}, \quad \forall i \in N_o, \forall k \in K \tag{21}$$

$$a_i \sum_{j\in N_1} x^{k}_{ij} \leq l^{k}_{i} + t_{ij} \leq b_i \sum_{j\in N_1} x^{k}_{ij}, \forall i \in N_0, \forall k \in K \tag{22}$$

It should be noted the time of arrival at a node and the time of departure.

$$x^{k}_{ij}, y^{k}_{ij} \in \{0,1\} \qquad \forall (i,j) \in N, \forall k \in K \tag{23}$$

$$l^{k}_{i} \geq 0 \quad \forall i \in N, \forall k \in K \tag{24}$$

Requirements for decision variables.

4.2. Model trial

Trial of optimization models to determine evacuation routes or paths using LINDO software with the input means of transportation used is heterogeneous. It can function as a means of transportation that moves in the same direction and does not return to the starting point/node as the starting point of the moving vehicle with the following input. Based on the calculations, the minimum travel time of vehicle in matix X and Y are shown in Table 6 and Table 7, respectively.

Table 6. Minimum vehicle travel time matrix X

Ji	X0	X1	X2	X3	X4	X5
i=1	5	0	0	0	0	0
i=2	8	9	0	0	0	0
i=3	4	10	6	0	0	0
i=4	7	8	9	12	0	0
i=5	6	12	11	10	8	0
i=6	4	6	8	9	12	7

Table 7. Matrix of minimum vehicle travel time Y

Ji	y0	y1	y2	y3	y4	y5
i=1	5	0	0	0	0	0
i=2	8	9	0	0	0	0
i=3	4	10	6	0	0	0
i=4	7	8	9	12	0	0
i=5	6	12	11	10	8	0
i=6	4	6	8	9	12	7

Minimize

5 X011 + 8 X021 + 4 X031 + 7 X041 + 6 X051 + 4 X061 + 9 X121 + 10 X131 + 8 X141 + 12 X151 + 6 X161 + 6 X231 + 9 X241 + 11 X251 + 8 X261 + 12 X341 + 10 X351 + 9 X361 + 8 X451 + 12 X461 + 7 X561 + …

Minimize

5 Y011 + 8 Y021 + 4 Y031 + 7 Y041 + 6 Y051 + 4 Y061 + 9 Y121 + 10 Y131 + 8 Y141 + 12 Y151 + 6 Y161 + 6 Y231 + 9 Y241 + 11 Y251 + 8 Y261 + 12 Y341 + 10 Y351 + 9 Y361 + 8 Y451 + 12 Y461 + 7 Y561

With the constraint function is as shown in: subject to

X011 + X211 + X311 + X411 + X511 + X611 = 1
X022 + X122 + X322 + X422 + X522 + X622 = 1
X033 + X133 + X233 + X433 + X533 + X633 = 1
X044 + X144 + X244 + X344 + X344 + X644 = 1
X055 + X155 + X255 + X355 + X455 + X655 = 1

The results of the input above are as shown in:

LP OPTIMUM FOUND AT STEP 23
OBJECTIVE FUNCTION VALUE
−   50.00000

From LINDO's calculation results, the maximum time to evacuate is 50 minutes with variable values and costs as shown in Table 8. In slack or surplus, it can be observed whether the resistance is active or not. If slack or surplus equal to 0 it means the constraint is active. Moreover, if slack or surplus not equal to 0 means the constraint is not active. For example, row 12 is an active constraint whose dual price is negative (-) i.e., 4, 000000 as can be seen in Table 9. This figure indicates that the accumulation of each part of the right-hand side of the obstacle will decrease the value of 4,000000. The output of the sensitivity analysis is as shown in Table 10. No. Iterations= 23. Ranges in which the basis is unchanged: obj. coefficient ranges.

Table 8. Value of optimal decision variables

Variable	Value	Reduced Cost
X011	0.000000	1.000000
X021	0.000000	4.000000
X031	1.000000	0.000000
X041	0.000000	3.000000
X051	0.000000	2.000000
X061	0.000000	0.000000

Table 9. Slack or surplus

Row	Slack Or Surplus	Dual Prices
2)	0.000000	0.000000
3)	0.000000	0.000000
4)	0.000000	0.000000
5)	0.000000	-2.000000
6)	0.000000	0.000000
7)	6.000000	0.000000
8)	6.000000	0.000000
9)	6.000000	0.000000
10)	6.000000	0.000000
11)	6.000000	0.000000
12)	0.000000	-4.000000
13)	0.000000	-6.000000
14)	0.000000	0.000000

Table 10. Sensitivity analysis

Variable	Current Coef	Allowable Increase	Allowable Decrease
X011	5.000000	INFINITY	1.000000
X021	8.000000	INFINITY	4.000000
X031	4.000000	0.000000	INFINITY
X041	7.000000	INFINITY	3.000000
X051	6.000000	INFINITY	2.000000
X061	4.000000	INFINITY	0.000000

     Based on the sensitivity analysis results above, it is explained that the variable column is the decision variable, and the current column current coef is the coefficient of the objective function. In the column, allowable increase on the variable X011 is the limit of the increase in value so as not to change the optimum value of the decision variable. In the allowable decrease column, the value is unlimited, which is the limit for the decrease, so that it does not affect the optimum value of the decision variable.

5. CONCLUSION

     This research produces a dynamic model of determining evacuation locations in disaster mitigation, integrated with optimization of transportation routes related to the intelligent evacuation system. To determine the evacuation location with game theory algorithm and the determination of evacuation routes using the OVRP model can produce a new open dynamic model. The simulation model is tested using LINDO, which can minimize the evacuation time of 50 minutes from the evacuation route to a safe destination location with the assumption that there is no contra-flow to increase the population that can be evacuated.

REFERENCES

[1] A. M. Ibrahim, I. Venkat, K. G. Subramanian, A. T. Khader, and P. De Wilde, "Intelligent evacuation management systems: A review," *ACM Transactions on Intelligent Systems and Technology (TIST)*, vol. 7, no. 3, pp. 1–27, Apr. 2016, doi: 10.1145/2842630

[2] H. Lyonnais, "Graph Shortest Path Search Method for Disaster Evacuation, (In Indonesia: Metode Pencarian Lintasan Terpendek Graf untuk Evakuasi Bencana)," *Sekolah Teknik Elektro dan Informatika Institut Teknologi Bandung*, pp. 1–5, 2012.

[3] A. E. Amideo, M. P. Scaparra, and K. Kotiadis, "Optimising shelter location and evacuation routing operations: The critical issues," *European Journal of Operational Research*, vol. 279, no. 2, pp. 279–295, Dec. 2019, doi: 10.1016/j.ejor.2018.12.009.

[4] Y. Zhang and X. D. Chen, "An optimization model for the vehicle routing problem in multiproduct frozen food delivery," *Journal of applied research and technology*, vol. 12, no. 2, pp. 239–250, 2014.

[5] J. Kendra, J. Rozdilsky, and D. A. McEntire, "Evacuating Large Urban Areas: Challenges for Emergency Management Policies and Concepts," *Journal of Homeland Security and Emergency Management*, vol. 5, no. 1, 2008, doi: 10.2202/1547-7355.1365.

[6] G. Li, L. Zhang, and Z. Wang, "Optimization and planning of emergency evacuation routes considering traffic control," *The Scientific World Journal*, vol. 2014, 2014, doi: 10.1155/2014/164031.

[7] X. Zhang, *Development of a mixed-flow optimization system for emergency evacuation in urban networks*. University of Maryland, College Park, 2012.

[8] M. H. Othman and A. A. Hamid, "Impact of Flooding on Traffic Route Choices," *SHS Web Conf.*, vol. 11, p. 01002, 2014, doi: /10.1051/shsconf/20141101002.

[9] T. Caric and H. Gold, *Vehicle routing problem*, 2008.

[10] C. Ren, "Research on single and mixed fleet strategy for open vehicle routing problem," *Journal of Software*, vol. 6, no. 10, pp. 2076–2081, Oct. 2011, doi: 10.4304/jsw.6.10.2076-2081.

[11] A. R. Hedar and M. Abdallah, "Applying Tabu Search in Finding an Efficient Solution for the OVRP," *International Journal of Open Problems in Computer Science and Mathematics*, vol. 7, no. 4, pp. 36–51, Dec. 2014.

[12] T. Pichpibul and R. Kawtummachai, "A heuristic approach based on clarke-wright algorithm for open vehicle routing problem," *The scientific world journal*, vol. 2013, 2013, doi: 10.1155/2013/874349.

[13] S. A. Bagloee, K. H. Johansson, and M. Asadi, "A hybrid machine-learning and optimization method for contraflow design in post-disaster cases and traffic management scenarios," *Expert Systems with Applications*, vol. 124, pp. 67–81, Jun. 2019, doi: 10.1016/j.eswa.2019.01.042.

[14] H. Tuydes and A. Ziliaskopoulos, "Tabu-based heuristic approach for optimization of network evacuation contraflow," *Transportation Research Record*, vol. 1964, no. 1, pp. 157–168, Jan. 2006, doi: 10.1177/0361198106196400117.

[15] D. Hartama, H. Mawengkang, M. Zarlis, and R. W. Sembiring, "Model of emergence evacuation route planning with contra flow and zone scheduling in disaster evacuation," *Computer Science and Information Technologies*, vol. 2, no. 1, pp. 1–10, Mar. 2021, doi: 10.11591/csit.v2i1.p1-10.

[16] S. Shekhar *et al.*, "Experiences with evacuation route planning algorithms," *International Journal of Geographical Information Science*, vol. 26, no. 12, pp. 2253–2265, Nov. 2012, doi: 10.1080/13658816.2012.719624.

[17] V. Campos, R. Bandeira, and A. Bandeira, "A Method for Evacuation Route Planning in Disaster Situations," *Procedia - Social and Behavioral Sciences*, vol. 54, pp. 503–512, Oct. 2012, doi: 10.1016/j.sbspro.2012.09.768.

[18] J. Fuka, J. Volek, and I. Obršálová, "Game theory as a tool of crisis management in a company," *WSEAS Transactions on Business and Economics*, vol. 11, no. 1, pp. 250–261, 2014.

[19] A. D. Farooqui and M. A. Niazi, "Game theory models for communication between agents: a review," *Complex Adaptive Systems Modeling*, vol. 4, no. 1, pp. 1–31, Jul. 2016, doi: 10.1186/s40294-016-0026-7.

[20] A. K. Jain, H. Saxena, R. Bhardwaj, G. V. V. J. Rao, and C. S. Nanda, "Application of linear programming for profit maximization of a Pharma Company," *Journal of Critical Reviews*, vol. 7, no. 12, pp. 1118–1123, 2020.

[21] I. S. Kanu, B. A. Ozurumba, and I. C. Emerole, "Application of Linear Programming Techniques to Practical Decision Making," *Mathematical Theory and Modeling*, vol. 4, no. 9, pp. 100–112, 2014.

[22] S. Bouajaja and N. Dridi, "A survey on human resource allocation problem and its applications," *Operational Research*, vol. 17, no. 2, pp. 339–369, 2017, doi: 10.1007/s12351-016-0247-8.

[23] F. B. S da Silva, "Linear and Integer Programming: With Excel Examples," pp. 1–159, May 2015.

[24] E. E. Ammar and A. A. Emsimir, "A mathematical model for solving integer linear programming problems," *African J. Math. Comput. Sci. Res.*, vol. 13, no. 1, pp. 39–50, Feb. 2020, doi: 10.5897/AJMCSR2019.0804.

[25] U. F. Khattak, A. Mustapha, M. Yaseen, M. A. Shah, and A. Shahzad, "Enhancing Integrity Technique Using Distributed Query Operation," in *Recent Trends and Advances in Wireless and IoT-enabled Networks*, Jan. 2019, pp. 139–146, doi: 10.1007/978-3-319-99966-1_13.

[26] A. Debnath, A. Bandyopadhyay, J. Roy, and S. Kar, "Game theory based multi criteria decision making problem under uncertainty: A case study on Indian tea industry," *Journal of Business Economics and Management*, vol. 19, no. 1, pp. 154–175, 2018, doi: 10.3846/16111699.2017.1401553.

[27] B. A. Bhuiyan, "An overview of game theory and some applications," *Philosophy and Progress*, vol. 59, no. 1–2, pp. 111–128, 2018, doi: 10.3329/pp.v59i1-2.36683.

[28] J. Coles and J. Zhuang, "Decisions in disaster recovery operations: a game theoretic perspective on organization cooperation," *J. Homel. Secur. Emerg. Manag.*, vol. 8, no. 1, p. 0000102202154773551772, Jul. 2011, doi: 10.2202/1547-7355.1772.

[29] O. Raoof and H. Al-Raweshidy, "Theory of Games: an Introduction," *Game Theory*, vol. 1, 2010.

BIOGRAPHIES OF AUTHORS

M. Safii ⓘ 🔾 ᔆᶜ Ⓟ born in Pematangsiantar, North Sumatra, Indonesia in 1980. Completed his Bachelor of Information Systems Study Program at the Multimedia Prima Informatics Management College, Medan in 2005, completed his Masters in Computer Science (M.Kom) in the Informatics Engineering Study Program at Universitas Sumatera Utara, Medan, Indonesia in 2011. He is currently pursuing a Doctorate in Computer Science at Universitas Sumatera Utara, Medan, Indonesia. Research interest in intelligent system and data mining. He can be contacted at email: m.safii@students.usu.ac.id.

Syahril Efendi ⓘ 🔾 ᔆᶜ Ⓟ is an author who completed his undergraduate education at the Faculty of Mathematics, Universitas Sumatera Utara, Medan. Completed Master of Computer education in computer science study program at Universiti Kebangsaan Malaysia (UKM), and completed Doctorate Program education at Faculty of Mathematics, Universitas Sumatera Utara, Medan. Research interest in the fields of operation research and information science. He can be contacted at email: syahnyata1@gmail.com.

Muhammad Zarlis ⓘ 🔾 ᔆᶜ Ⓟ is a Professor at the Faculty of Computer Science and Information Technology at Universitas Sumatera Utara, Medan, Indonesia. Completed his Bachelor of Physics education at the Faculty of Mathematics, Universitas Sumatera Utara, Medan. Completed his master's in computer science in the Computer Science study program at the Faculty of Computer Science, Universitas Indonesia, Jakarta, and completed his Doctorate program in Computer Science at Universiti Sains Malaysia (USM), Penang. Current research interests are in the fields of intelligent systems, computer security and computation. He can be contacted at email: m.zarlis@usu.ac.id.

Herman Mawengkang ⓘ 🔾 ᔆᶜ Ⓟ is a Professor at the Faculty of Mathematics, Universitas Sumatera Utara, Medan, Indonesia. Completed his Bachelor of Mathematics education at the Faculty of Mathematics, Universitas Sumatera Utara, Medan in 1974. Completed his Doctorate Program in Mathematics education at the University of New South Wales, Sydney, Australia. Current research is conducted in the fields of computer science and applied mathematics. He can be contacted at email: hmawengkang@yahoo.com.