Intelligent evacuation model in disaster mitigation

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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.

Keywords: Disaster management, Evacuation, Game theory, Intelligent system, Mitigation

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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 \( i (i = 1,2,3,\ldots,m) \), \( y_j = \) The probability that player B chooses strategy \( j (j = 1,2,3,\ldots,n) \) [28], [29]. So that:

\[
\sum_{i=1}^{m} x_i = \sum_{j=1}^{n} y_j = 1
\]

\( x_i, y_j \geq 0 \), for every \( i \) and \( j \) \hfill (2)

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

\( x_i (x_i \geq 0, \sum_{i=1}^{m} x_i = 1) \) \hfill (3)

which will produce:

\[
\max x_i \{ \min (\sum_{i=1}^{m} a_{i1}x_i, \sum_{i=1}^{m} a_{i2}x_i, \ldots, \sum_{i=1}^{m} a_{in}x_i) \}
\]

Player B has:

\( y_j (y_j \geq 0, \sum_{j=1}^{n} y_j = 1) \) \hfill (5)
which will produce:

\[
\min y_j \left\{ \max \left( \sum_{j=1}^{n} a_{ij} y_j, \sum_{j=1}^{n} a_{2j} y_j, \ldots, \sum_{j=1}^{n} a_{mj} y_j \right) \right\}
\]

\[ EV^* = \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} x^*_i \cdot y^*_j \]

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

<table>
<thead>
<tr>
<th>( X_a )</th>
<th>( X_b )</th>
<th>( X_c )</th>
<th>( X_d )</th>
<th>( X_e )</th>
<th>( X_f )</th>
<th>( Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.01</td>
<td>0</td>
<td>0</td>
<td>0.03</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>

so:

\[ V = \frac{1}{0.04} = 25 \]

\[ X_a = X_a \cdot V = 0 \cdot 25 = 0 \]

\[ X_b = X_b \cdot V = 0.01 \cdot 25 = 0.25 \]

\[ X_c = X_c \cdot V = 0 \cdot 25 = 0 \]

\[ X_d = X_d \cdot V = 0 \cdot 25 = 0 \]

\[ X_e = X_e \cdot V = 0 \cdot 25 = 0 \]

\[ X_f = X_f \cdot V = 0.03 \cdot 25 = 0.75 \]

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

<table>
<thead>
<tr>
<th>( Y_a )</th>
<th>( Y_b )</th>
<th>( Y_c )</th>
<th>( Y_d )</th>
<th>( Y_e )</th>
<th>( Y_f )</th>
<th>( Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.02</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>
Intelligent evacuation model in disaster mitigation (M. Safii)

so:

\[ V = \frac{1}{0.04} = 25 \]

\[ Y_a = Y_a \times V = 0.01 \times 25 = 0.25 \]

\[ Y_b = Y_b \times V = 0.01 \times 25 = 0.25 \]

\[ Y_c = Y_c \times V = 0 \times 25 = 0 \]

\[ Y_d = Y_d \times V = 0.01 \times 25 = 0.25 \]

\[ Y_e = Y_e \times V = 0.01 \times 25 = 0.25 \]

\[ Y_f = Y_f \times V = 0 \times 25 = 0 \]

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

<table>
<thead>
<tr>
<th>( X_a )</th>
<th>( Y_a )</th>
<th>( Y_c )</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>( X_f )</td>
<td>7</td>
<td>13</td>
<td>7</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>( X_a )</th>
<th>( X_b )</th>
<th>( X_c )</th>
<th>( X_d )</th>
<th>( X_e )</th>
<th>( X_f )</th>
<th>( Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0.02</td>
<td>0.04</td>
</tr>
</tbody>
</table>

so:

\[ V = \frac{1}{0.04} = 25 \]

\[ X_a = X_a \times V = 0.01 \times 25 = 0.25 \]

\[ X_b = X_b \times V = 0 \times 25 = 0 \]

\[ X_c = X_c \times V = 0 \times 25 = 0 \]

\[ X_d = X_d \times V = 0 \times 25 = 0 \]

\[ X_e = X_e \times V = 0.01 \times 25 = 0.25 \]

\[ X_f = X_f \times V = 0.03 \times 25 = 0.75 \]

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

<table>
<thead>
<tr>
<th></th>
<th>X_a</th>
<th>X_b</th>
<th>X_c</th>
<th>X_d</th>
<th>X_e</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.03</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0</td>
<td>0.04</td>
</tr>
</tbody>
</table>

so:

\[ V = \frac{1}{0.04} = 25 \]

\[ Y_a = Y_a \times V = 0.03 \times 25 = 0.75 \]

\[ Y_b = Y_b \times V = 0 \times 25 = 0 \]

\[ Y_c = Y_c \times V = 0 \times 25 = 0 \]

\[ Y_d = Y_d \times V = 0 \times 25 = 0 \]

\[ Y_e = Y_e \times V = 0.01 \times 25 = 0.25 \]

\[ Y_f = Y_f \times V = 0 \times 25 = 0 \]

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 \( V = \{v_0, v_1, ..., v_n\} \) is the set of evacuation point spots. Node \( v_0 \) is the starting point for evacuation, with a record of the number of nodes \( n \) 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 arc through the network. 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, \( N_0 = \{v_{01}, v_{02}, ..., v_{0d}\} \)
- \( N_1 \) : Transfer node set \( N \setminus \{v_0\}, \{v_n\} \)
- \( N_2 \) : Set of end nodes (safe destination), \( N_2 = \{v_{n1}, v_{n2}, ..., v_{n3}\} \)
- \( T \) : Travel time set

Parameter:
- \( Q_k \) : Vehicle capacity \( k \in K \)
- \( t_{ij} \) : Travel time from node \( i \in N_0 \) to node \( j \in N_1 \)
- \( [a_t, b_t] \) : 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 \( j \in N_1 \cup N_2 \)
- \( s_{ti} \) : 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.

$$\text{Min} = \sum_{i\in N_0} \sum_{j\in N_1} x_{ij}^k + \sum_{i\in N_0} \sum_{i\neq j} t_{ij} \sum_{k\in K} x_{ij}^k + \sum_{i\in N_0} \sum_{i\neq j} t_{ij} \sum_{k\in K} y_{ij}^k + \sum_{i\in N_0} \sum_{i\neq j} t_{ij} \sum_{k\in K} x_{ij}^k$$

(8)

4.1. Mathematical model formula

With obstacles or requirements that need to be met:

$$\sum_{k\in K} x_{ij}^k = d_i, \forall j \in N_1 \cup N_2$$

(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.

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

(10)

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

$$\sum_{d\in N_1} \sum_{k\in K} y_{di}^k + \sum_{j\in N_1 \cup i \neq j} \sum_{k\in K} x_{ij}^k = 1, \forall i \in N_1$$

(11)

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

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

(12)

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

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

(13)

This equation is to ensure that for each vehicle there is only one path from the selected initial disaster location.
\[ \sum_{i \in N_0} x_{ij}^{tk} \leq 1, \forall j \in N_1 \cup N_2, \forall k \in K, \forall t \in T \]  

(14)

There are artificial nodes (artificial).

\[ \sum_{k \in K} \sum_{i \in N_0} x_{(j+1)i}^{tk} = 0, \forall j \in N_1, \forall t \in T \]  

(15)

It is not allowed to start service from artificial nodes.

\[ \sum_{k \in K} \sum_{i \in N_0 \cup N_2} x_{ij}^{tk} = 0, \forall i \in N_0, \forall t \in T \]  

(16)

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

\[ \sum_{(i,j) \in N, i \neq j} x_{ij}^{tk} \leq ST - 1, \forall k \in K, \forall t \in T \]  

(17)

Sub-tour elimination process (ST).

\[ \sum_{(i,j) \in N, i < j} x_{ij}^k - \sum_{(i,j) \in N, j < i} x_{ij}^k = 0 \quad \forall k \in K \]  

(18)

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

\[ \sum_{k \in K} \sum_{i \in N_0} x_{ii}^k = 0, \]  

(19)

To prevent loops.

\[ y_{ij} \leq c_{ij} x_{ij}^k \quad \forall i \in N_0, \forall j \in N_1 \cup N_2, i \neq j, \forall k \in K \]  

(20)

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

\[ l_{ij}^k \leq a_i \sum_{j \in N_1} x_{ij}^k, \quad \forall i \in N_0, \forall k \in K \]  

(21)

\[ a_i \sum_{j \in N_1} x_{ij}^k \leq l_{ij}^k + t_{ij} \leq b_i \sum_{j \in N_1} x_{ij}^k, \forall i \in N_0, \forall k \in K \]  

(22)

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

\[ x_{ij}^k, y_{ij}^k \in \{0,1\} \quad \forall (i,j) \in N, \forall k \in K \]  

(23)

\[ l_{ij}^k \geq 0 \quad \forall i \in N, \forall k \in K \]  

(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 matrix X and Y are shown in Table 6 and Table 7, respectively.

<table>
<thead>
<tr>
<th>Table 6. Minimum vehicle travel time matrix X</th>
<th>Table 7. Matrix of minimum vehicle travel time Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>X0</td>
</tr>
<tr>
<td>i=1</td>
<td>5</td>
</tr>
<tr>
<td>i=2</td>
<td>8</td>
</tr>
<tr>
<td>i=3</td>
<td>4</td>
</tr>
<tr>
<td>i=4</td>
<td>7</td>
</tr>
<tr>
<td>i=5</td>
<td>6</td>
</tr>
<tr>
<td>i=6</td>
<td>4</td>
</tr>
</tbody>
</table>

Intelligent evacuation model in disaster mitigation (M. Safii)
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 + X444 + 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
  - 50.0000

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>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Reduced Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>X011</td>
<td>0.000000</td>
<td>1.000000</td>
</tr>
<tr>
<td>X021</td>
<td>0.000000</td>
<td>4.000000</td>
</tr>
<tr>
<td>X031</td>
<td>1.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>X041</td>
<td>0.000000</td>
<td>3.000000</td>
</tr>
<tr>
<td>X051</td>
<td>0.000000</td>
<td>2.000000</td>
</tr>
<tr>
<td>X061</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Row</th>
<th>Slack Or Surplus</th>
<th>Dual Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>2)</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>3)</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>4)</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>5)</td>
<td>0.000000</td>
<td>-2.000000</td>
</tr>
<tr>
<td>6)</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>7)</td>
<td>6.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>8)</td>
<td>6.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>9)</td>
<td>6.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>10)</td>
<td>6.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>11)</td>
<td>6.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>12)</td>
<td>0.000000</td>
<td>-4.000000</td>
</tr>
<tr>
<td>13)</td>
<td>0.000000</td>
<td>-6.000000</td>
</tr>
<tr>
<td>14)</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Current Coef</th>
<th>Allowable Increase</th>
<th>Allowable Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>X011</td>
<td>5.000000</td>
<td>INFINITY</td>
<td>1.000000</td>
</tr>
<tr>
<td>X021</td>
<td>8.000000</td>
<td>INFINITY</td>
<td>4.000000</td>
</tr>
<tr>
<td>X031</td>
<td>4.000000</td>
<td>0.000000</td>
<td>INFINITY</td>
</tr>
<tr>
<td>X041</td>
<td>7.000000</td>
<td>INFINITY</td>
<td>3.000000</td>
</tr>
<tr>
<td>X051</td>
<td>6.000000</td>
<td>INFINITY</td>
<td>2.000000</td>
</tr>
<tr>
<td>X061</td>
<td>4.000000</td>
<td>INFINITY</td>
<td>0.000000</td>
</tr>
</tbody>
</table>
Based on the sensitivity analysis results above, it is explained that the variable column is the decision variable, and the current column current coeff is the coefficient of the objective function. In the column, allowable increase on the variable XO11 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


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