Determination of Tsunami Evacuation Route using Dijkstra's Algorithm: Case Study of Batukaras, Indonesia

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Abstract. During a tsunami, the choice of evacuation route is vital for safety. Dijkstra's algorithm is used to plan the shortest route for evacuation. The optimal shortest route is obtained from various nodes to the evacuation zone by identifying the distance, determining the speed and density of pedestrians, and shelter availability. The puspose of this study is to identify the shortest route to the evacuation zone by determining the speed and density of pedestrians, and shelter availability in Batu Karas, Indonesia. The method used is Dijkstra Algorithm, python as programming languange, and data retrieval conducted in Batu Karas. The farthest distance from a node to the evacuation zone is 1850 m. It takes 34 minutes to evacuate, with an Estimated Time Arrival of tsunami (ETA) is 20 minutes. Based on these results, it is necessary to have an additional evacuation zone to minimize the distance to the evacuation zone. This study can be used to determine tsunami evacuation route for tsunami risk area in Indonesia.

Keywords: Evacuation route, Dijkstra's algorithm, Tsunami

1 Introduction

Natural disasters are a global phenomenon that must be considered, as they can cause enormous economic, social, and environmental damage in metropolitan areas. Earthquakes and tsunami are natural disasters affecting coastal regions. Japan, Chile, Indonesia, and other countries with active subduction zones have experienced earthquakes and tsunamis [1].

A tsunami is one of the natural disasters that frequently have a significant impact on people's life. The tsunami waves caused casualties and substantial property damage. Earthquakes can cause tsunamis with a depth of fewer than 30 kilometers and a magnitude of more than 6.5 Mw in the middle of the ocean. In open places, tsunamis move quickly, but as they reach the coast, their speed slows, and their wave height increases as the sea depth decreases [2]. Within tens of minutes of an earthquake, nearby coastlines can be destroyed by local tsunamis. It is common in subduction zones, such as the Pacific plate. Residents of low-lying coastal locations can execute a vertical tsunami

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evacuation (TVE) by evacuating between buildings or mounds that serve as temporary evacuation zones [3].

A temporary Evacuation Zone (TEZ), as defined by the National Agency of Disaster Countermeasures of Indonesia (Indonesian: BNPB), is one of the measures used to reduce the danger of casualties during a tsunami. The provision of TEZ in tsunami-prone areas as evacuation and shelter areas might take the form of existing structures, newly constructed facilities created particularly for temporary evacuation sites, or hills, both natural and artificial hills designated as TEZ [4]. Time planning is one of the things to examine and plan for TEZ development. The time planning covers the Time for Early Warning (TEW), the Estimated Time of Arrival (ETA), and the Estimated Time of Evacuation (ETE) for evacuating all exposed residents. In addition, evacuation capacity is required for the planning and developing of a Tsunami TEZ. Evacuation capacity is the capability of existing infrastructure in a tsunami-prone area to safely evacuate all residents exposed to the tsunami from that area. The evacuation capacity factor is dependent on the health of the road infrastructure in a region, the total population vulnerable to a tsunami, and the ability of people to walk quickly, which is represented by the speed and area required to travel [5]. An analysis is necessary to find the shortest vertical escape path from an exposed location point to the TEZ.

Pangandaran is included in the tsunami risk zone. One of the tsunamis that occurred in 2006 had a magnitude of 7.7 Mw[6]. Tsunami occurrences that have occurred in one location have the potential to reoccur in the future, needing research to determine the shortest evacuation path to lessen the danger of a tsunami catastrophe. Batukaras is one of those in the Pangandaran region with a moderate tsunami danger category damaged in 2006, which is a worry for this study [7]. Several nodes in the Batukaras are identified using Dijkstra's algorithm to calculate the shortest evacuation route.

2 Methods

2.1 Data preparation

This study aims to determine the shortest route from a given location to a catastrophe evacuation destination. This research consists of various phases. The initial step involved data collection via a survey conducted in Batukaras. The data collected in Batu Karas are population data, tourist visits, business actors, and evacuation places. In addition, a survey of the evacuation site was conducted to establish the location's condition, size, and capacity [8].

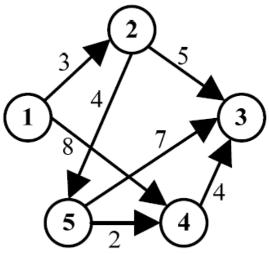
Once the number of people who can be evacuated is known, it is possible to estimate how long it will take to get everyone out of a tsunami-affected area. This time is also known as the Estimated Time for Evacuation (ETE), which may be calculated using the following formula:

$$ETE = \frac{Population \cdot d}{W \cdot v}$$

W represents road width (m), d represents pedestrian density (m2/person), and v represents pedestrian velocity (m/s). After collecting the necessary data, an analysis is conducted to pick a strategy for determining the shortest evacuation route to facilitate the most effective evacuation of residents. The selected methodology is the Dijkstra method.

2.2 Dijkstra Algorithm

Dijkstra's algorithm is an algorithm that may also be used to calculate the shortest distance between two locations or if a location is represented as a point, the smallest distance between two points. A weighted graph consists of a set of points or so-called nodes connected by a distance on each edge [9]. As shown in Fig. 1, the components of Dijkstra's algorithm are graphs and adjacency matrices.



	1	2	3	4	5
1	0,	3,	∞,	8,	∞
2	3,	0,	5,	∞,	4
3	∞,	5 ,	0,	4,	7
4	8,	∞ ,	4,	0,	2
5	∞,	4,	7,	2,	0

Fig. 1. Representation of map (a) weighted graph, and (b) adjacency matrix[10]

When an edge directly connects two vertices in a graph, they are considered adjacent. The neighborhood matrix for directed graph a=(aij) is denoted as [10],

$$a_{ij} = \begin{cases} W_{ij}, (V_i, V_j) \in E \\ \infty, (V_i, V_j) \notin E \end{cases} , i, j = 1,2, \cdots n$$

where W_{ij} indicates the edge weight (V_i, V_j). If it turns out that V_i and V_j have no relationship, W_{ij} is modified to denote that there is no edge between V_i and V_j.

To compute the Dijkstra algorithm, points and the weights of the lines connecting these points are required. The determined node sites are high-traffic areas, intersections, and evacuation zones. In comparison, weight is the distance between nodes that are connected. Python is then used to simulate the data to discover the shortest route.

This method works by comparing the distance between the beginning location and the destination point, accumulating numerous different paths, and deciding on the shortest path that may be the best option before showing the chosen route.

3 Result and Discussion

The first step in calculating the shortest route is identifying the node as the vertex and the weight as the edge in the study location. Nodes are determined based on a particular area's human population and evacuation zone. Once the nodes are established, their links will be weighted according to their distances. Fig. 2 is an illustration map of Batukaras and their respective nodes and weights.

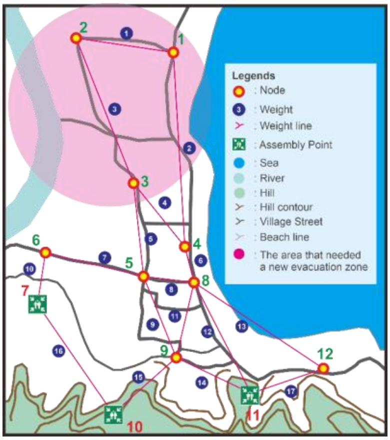


Fig. 2. Illustration map of Batukaras with node plots.

Furthermore, the nodes displayed on the map determine the initial node and final node for the evacuation route. The initial nodes consist of intersections, residential areas, and tourism destinations. The last node defined is the evacuation zone, which is the location where evacuees will assemble in the event of a tsunami. The beginning and ending nodes are listed in Table 1.

Table 1. Startng and ending vertexes of nodes

Code	Location name	Vertexes
1	TPI 2	Starting vertex
2	Sanghiangkalang	Starting vertex
3	Sanghiangkalang 2	Starting vertex
4	TPI 1	Starting vertex
5	Simpang 4	Starting vertex
6	Simpang 3a	Starting vertex
7	Evacuatione Zone 2	End vertex
8	Simpang 3c	Starting vertex
9	Simpang 3b	Starting vertex
10	Evacuation Zone 1	End vertex
11	Evacuation Zone 3	End vertex
12	Vacation zone	Starting vertex

After identifying the nodes and weights, we must determine the shortest route from a node to an evacuation zone. Dijkstra's method is utilized to determine the quickest route. This work uses Dijkstra's algorithm to calculate the shortest evacuation path analytically and numerically. Actual distances that are not connected or do not have access are then weighted using the notation ∞. So that the representation of Figure 2 can be expressed as follows in Table 2.

Table 2. Adjacency matrix with nodes and weights

Nodes	1	2	3	4	5	6	7	8	9	10	11	12
1	0	450	∞	850	∞	∞	∞	∞	∞	∞	∞	∞
2	450	0	550	∞	∞	∞	∞	∞	∞	∞	∞	∞
3	∞	550	0	600	550	∞	∞	∞	∞	∞	∞	∞
4	850	∞	600	0	∞	∞	∞	100	∞	∞	∞	∞
5	∞	∞	550	∞	0	450	∞	200	450	∞	∞	∞
6	∞	∞	∞	∞	450	0	250	∞	∞	∞	∞	∞
7	∞	∞	∞	∞	∞	250	0	∞	∞	750	∞	∞
8	∞	∞	∞	100	250	∞	∞	0	400	∞	600	∞
9	∞	∞	∞	∞	450	∞	∞	400	0	500	500	∞
10	∞	∞	∞	∞	∞	∞	750	∞	500	0	∞	∞
11	∞	∞	∞	∞	∞	∞	∞	600	500	∞	0	400
12	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	400	0

Table 2 is an adjacency matrix table used to determine the shortest evacuation route with Dijkstra's algorithm. The yellow boxes represent the evacuation zone, and the orange boxes represent the distance between two nodes. After identifying the nodes and weights, the shortest route from a node to a predefined evacuation zone must be found. Dijkstra's method is utilized to identify the quickest route. Using Dijkstra's algorithm to calculate the shortest evacuation path, human and numerical analyses were conducted in this work. Real-world distances that are not connected or do not have access are then weighted using the notation. So that the representation of Figure 2 can be expressed as follows in Table 2: aij = side weights (i,j) in the matrix above, where aij contains numbers for nodes that are connected, aij=0 for values of nodes that are identical (with itself), and aij = ∞ for nodes that are not connected elsewhere. The matrix's weight values will be used to develop a program that compares the shortest distance between two nodes. Filling in the value on the connected portion signifies that the node has a weight equal to the value input, which will then be used to determine the shortest value. This can be done manually if only a few points are used, but as the number of nodes increases, manual analysis becomes increasingly time-consuming. This will also influence the correctness of the data as the nodes continue to grow, and it will only be possible to add nodes with a specific weight mid-process. Therefore, a numerical approach is required to identify the quickest evacuation path.

As a numerical tool for locating the shortest evacuation route with Dijkstra's algorithm, Python can help accelerate the analytical procedure. Both analytical and numerical results were consistent in finding the shortest path based on Fig. 2. From the numerical results, Table 3 shows the quickest evacuation route from the nodes to the evacuation zone. The acquired results include connected nodes and travel distance to the evacuation zone.

Table 3. The distance from nodes to evacuation zone with the shortest route

Code	Location name	Evacuation zone 1 (10)		Evacuation zone 2 (7)		Evacuation zone 3 (11)	
		Distance (m)	Shortest route	Distance (m)	Shortest route	Distance (m)	Shortest route
1	TPI 2	1850	1-4-8-9-10	1850	1-4-8-5-6-7	1550	1-4-8-11
2	Sanghiangkalang	2050	2-3-5-9-10	1750	2-3-6-7	1850	2-3-4-8-11
3	Sanghiangkalang 2	1500	3-5-9-10	1200	3-6-7	1300	3-4-8-11
4	TPI 1	1000	4-8-9-10	1000	4-8-5-6-7	700	4-8-11
5	Simpang 4	1100	5-8-9-10	700	5-6-7	800	5-8-11
6	Simpang 3a	1000	6-7-10	250	6-7	1250	6-5-8-11
8	Simpang 3c	900	8-9-10	900	8-5-6-7	600	8-11
9	Simpang 3b	500	9-10	1150	9-5-6-7	500	9-11
12	Vacation zone	1200	12-11-10	1700	12-8-5-6-7	400	12-11

After identifying the shortest evacuation path, the time it would take residents to reach the evacuation zone as the tsunami approached would be calculated. Based on Equation 1, it is first decided whether an evacuation zone is required. With the provisions that are the number of residents, business actors, and visitors at the busiest time obtained from the survey results, the density of people and the width of the road, which is a reference from BNPB, respectively 1 m2/person and 5 m, the speed of the person walking, ETE 28-32 minutes were calculated. Based on the ETA that has occurred in Pangandaran [11], of which Batukaras is a part, it has been determined that ETE>ETA. According to these results, a BNPB evacuation zone standard-compliant evacuation zone is required. The evacuation capacity to accommodate evacuees is also determined by the ratio of the evacuation zone's area to its population density. The applied ratio was determined that the three evacuation zones could safely house evacuees in the event of a tsunami. The time required for an individual to reach the evacuation zone must then be determined. Fig. 3 shows the time required to reach the evacuation zone from various nodes.

The pedestrian velocity is derived from FEMA [12] and Zhu et al. [13]. Distance from each node to the evacuation point is plotted against the speed of FEMA [12] and Zhu et al. [13] to produce the distance versus time graph. The obtained time is used as a benchmark to determine if all determined nodes are estimated times shorter than the ETA. According to Figure 3, a person in good health has a sufficient estimated time to reach the evacuation zone. However, there are disadvantages to the actual scenario on sites, such as one's physical condition, age, and health. If this parameter is entered, it is determined, based on the walking speed of FEMA [12] for these conditions and Zhu et al. [13], that the projected time for some nodes to reach the evacuation zone is insufficient since the evacuation time exceeds the ETA. According to the results of this analysis, more evacuation zones are required for nodes with the most significant distance to the evacuation zone, such as TPI 2, Sanghiangkalang, and Sanghiangkalang 2. It can be seen the area that needs a new evacuation zone from Fig. 1 marked by magenta color.

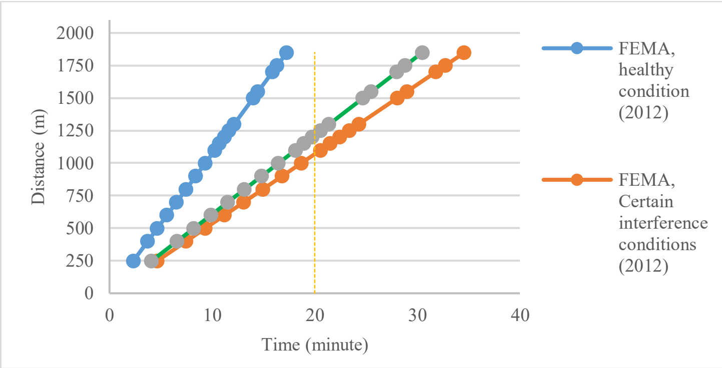


Fig. 3. Graph of distance vs time with various of pedestrian speeds

4 Conclusion

The studied results show that the time it takes to evacuate the farthest nodes to the evacuation zone is longer than the ETA, meaning that the tsunami will arrive sooner than it takes to evacuate. Hence, a new evacuation zone is required to reduce evacuation time. Using Dijkstra's algorithm, the greatest distance between a node and one of the evacuation zones is determined to be 1,850 meters. The shortest evacuation path obtained yields the same results whether calculated analytically or numerically.

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