An Evacuation Route In Bengkulu City Based On Fuzzy Dijkstra Algorithm

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Abstract. Bengkulu City is one area that has the potential to be hit by the tsunami disaster. Therefore an evacuation route is needed that can be used when a disaster strikes. In this study, a weighted graph is made by considering the node as a road intersection, the edge as the road connecting it, and weight as a fuzzy output obtained based on the length and width of the road. Furthermore, the evacuation route is obtained by calculating the smallest number of weights from each intersection to the cluster point using Dijkstra Algorithm. The result is an evacuation route that consider the length and width of the roads.

1. Introduction

Bengkulu Province is an area that is close to the meeting area of 2 (two) tectonic plates of the world, namely the Indo-Australian plate and the Eurasian plate. This caused a syringe earthquake to occur in Bengkulu Province. In Bengkulu province there have been earthquakes with large magnitude at least twice in a short time, namely 2000 and 2007. The earthquakes that occurred in Bengkulu on 4 June 2000 with a magnitude of 7.3 on the Richter Scale (SR) and 12 September 2007 with a magnitude of 7.9 SR caused the death toll of more than 100 people. The worst damage was in Enggano Island, Ngalam Market, Suharaja, South Bengkulu and Bengkulu City. The team's survey report from the Meteorology and Geophysics Agency (BMG) describes the level of damage using the Modified Mercally Intensity (MMI) scale that the worst level of damage occurred on Enggano Island.

Based on the location of the occurrence, the earthquakes that occurred around the Bengkulu area were mostly centered offshore [2]. This fact provides evidence that the city of Bengkulu has great potential to be hit by sea waves, tsunami, which occur due to earthquakes on the seabed. Seeing these conditions, of course, it is necessary to prepare for the earthquake and tsunami that can occur at any time. Careful planning is needed to deal with disasters in order to reduce the risks that can occur. One of the efforts that can be done is to create an evacuation route.

Determining the evacuation route is one of the shortest path problems. The distance from the starting point to the evacuation point should be the minimum distance as possible. Related research can be found in [4] which determines the shortest evacuation route for earthquake and tsunami prone areas in Padang City.

Dijkstra's Algorithm is one of the popular algorithms in the shortest path problem. This algorithm was introduced by EW Dijkstra in 1959 [8]. The study of determining the shortest path using this algorithm can be found in [7] which determines the shortest tsunami evacuation route in Palu city. In addition, in [5] also found the use of the Dijkstra algorithm in the shortest path problem by considering...
several types of vehicles used. The use of Dijkstra's Algorithm to determine the shortest path can also be combined with the fuzzy logic which can be found in [1] and [6].

Determination of evacuation routes in the city of Bengkulu has been carried out and can be found in [9] which determines the evacuation route based on travel time using the Floyd Warshall Algorithm. In [9] the travel time is obtained based on several variables such as road length and road capacity. In this study, the evacuation route is determined based on evacuation speed, and the variables that determine the travel time are length and width of the road. The relationship between the travel time and length and width of the road will be determined using fuzzy logic. Meanwhile, the determination of the evacuation route will be carried out based on the Dijkstra algorithm.

2. Research Method

In this study, to obtain an evacuation route is carried out in several steps. The steps in this study are as follows:
1. Forming a road graph with assuming the intersection of the road as a vertex and a road segment as an edge.
2. Determine the weight, which is the fuzzy output obtained based on the length and width of the road. This step starts with determining the membership function, creating fuzzy rules, and obtaining fuzzy output.
3. Determine the shortest path based on the weight given using Dijkstra's Algorithm. Dijkstra algorithm steps as follows: set $v_i$ as an initial point and set $v$ as an end point. First, start point label is $(v_i, 0)$, adjacent point label is $(v_i, L(v_i, v))$, and the other points label is $(v_i, \infty)$. In addition, set as $V = V - \{v_i\}$. Second, If $V = \emptyset$, so end the algorithm. Third, use $v_k \in V$, it has the smallest label of the $L(v_k) = \min\{L(v_j) : v_j \in V\}$. If $v_k = v_n$, end the algorithm, and else make $v_k$ for a permanent label and set is $V = V - \{v_k\}$. Fourth, check the adjacent point $v_k$, if $L(v_j) = L(v_k) + L(v_k + v_j)$, set label $v_j$ as $(v_k, L(v_k) + L(v_k + v_j))$, so given label and return the second step.

3. Result and Discussion

3.1. Data
This study examines the evacuation routes used when a disaster occurs. The problem in this research is how to solve the application of Dijkstra's algorithm in determining the evacuation route to the gathering point. To create an evacuation route, a weighted graph is made with the combined weight of the road length and road width parameters which results in a fuzzy output in the form of the evacuation speed level. Here is a graph formed by considering vertices as intersections and edges as roads.
Figure 1. Road Graph in Bengkulu City, Teluk Segara District

where:

\begin{align*}
\text{\(e_p_1\)} & : \text{Evacuation Point at Kampung Kelawi} \\
\text{\(e_p_2\)} & : \text{Evacuation Point at Alun-alun Kota Bengkulu} \\
\text{\(e_p_3\)} & : \text{Evacuation Point at Masjid At-taqwa} \\
\text{\(v_1\)} & : \text{Simpang 1 Bencoolen} \\
\text{\(v_2\)} & : \text{Simpang 2 Bencoolen} \\
\text{\(v_3\)} & : \text{Simpang Musirwan Zainul} \\
\text{\(v_4\)} & : \text{Simpang Bali} \\
\text{\(v_5\)} & : \text{Simpang 1 TP Kasim Nasir} \\
\text{\(v_6\)} & : \text{Simpang 2 TP Kasim Nasir} \\
\text{\(v_7\)} & : \text{Simpang 2 Sentot Alibasyah} \\
\text{\(v_8\)} & : \text{Simpang 3 Letkol Iskandar} \\
\text{\(v_9\)} & : \text{Simpang 1 Lettu Zulkifli} \\
\text{\(v_{10}\)} & : \text{Simpang 2 Lettu Zulkifli} \\
\text{\(v_{11}\)} & : \text{Simpang 1 Sentot Alibasyah} \\
\text{\(v_{12}\)} & : \text{Simpang Panjaitan} \\
\text{\(v_{13}\)} & : \text{Simpang 1 Ahmad Yani} \\
\text{\(v_{14}\)} & : \text{Simpang 2 Ahmad Yani} \\
\text{\(v_{15}\)} & : \text{Simpang 1 Panjaitan} \\
\text{\(v_{16}\)} & : \text{Simpang 2 Panjaitan} \\
\text{\(v_{17}\)} & : \text{Simpang Arraw} \\
\text{\(v_{18}\)} & : \text{Simpang Pasar Ikan} \\
\text{\(v_{19}\)} & : \text{Simpang 3 Ahmad yani} \\
\text{\(v_{20}\)} & : \text{Monumen Kota Bengkulu} \\
\text{\(v_{21}\)} & : \text{Simpang Polres} \\
\text{\(v_{22}\)} & : \text{Simpang 1 Belato} \\
\text{\(v_{23}\)} & : \text{Simpang 2 Belato} \\
\text{\(v_{24}\)} & : \text{Simpang Veteran} \\
\text{\(v_{25}\)} & : \text{Simpang Vand Iskandar baksir} \\
\text{\(v_{26}\)} & : \text{Simpang 1 Letkol Santoso} \\
\text{\(v_{27}\)} & : \text{Simpang Moh Hasan}
\end{align*}
The following is the length and width of the roads. The data will be used as parameters to form a fuzzy output in the form of evacuation speed.

| Edge | Street | Length | Width | Edge | Street | Length | Width |
|------|--------|--------|-------|------|--------|--------|-------|
| $v_{13}$ | Simpang 1 Jamik | Enggano St. | 244 | 3 | $v_{23}v_{24}$ | Ahmad Yani St. | 165 | 10 |
| $v_{14}$ | Simpang 1 Letkol Iskandar | Bencoolen St. | 338 | 5,5 | $v_{23}v_{25}$ | Panjaitan St. | 218 | 4 |
| $v_{15}$ | Simpang 2 Letkol Iskandar | Ibnu Hajar St. | 332 | 3 | $v_{24}v_{25}$ | Ahmad Yani St. | 150 | 10 |
| $v_{16}$ | Simpang Unihaz | TP Kasim Nasir St. | 138 | 4 | $v_{26}v_{27}$ | Panjaitan St. | 287 | 4 |
| $v_{17}$ | Simpang KH Ahmad Dahlan | Bencoolen St. | 1068 | 5,3 | $v_{26}v_{28}$ | Pendakian St. | 163 | 4 |
| $v_{18}$ | Simpang 1 Khadijah | Nusirwan Zainul St. | 187 | 6 | $v_{26}v_{27}$ | Pasar Ikan St. | 262 | 4 |
| $v_{19}$ | Simpang 2 Khadijah | Pratu Aidit St. | 475 | 4 | $v_{26}v_{28}$ | Arraw St. | 258 | 4 |
| $v_{20}$ | Simpang Benteng | Enggano St. | 362 | 3 | $v_{26}v_{28}$ | Kol Berlian St. | 226 | 5 |
| $v_{21}$ | Simpang 3 Bencoolen | Bali St. | 618 | 13,5 | $v_{27}v_{32}$ | Arraw St. | 317 | 4 |
| $v_{22}$ | Tugu Pers Bencoolen | Sumatera St. | 537 | 13,1 | $v_{28}v_{32}$ | Prof Dr Hazairin St. | 150 | 6 |
| $v_{38}$ | Simpang 1 Kerapu | TP Kasim Nasir St. | 365 | 4 | $v_{29}v_{32}$ | Ahmad Yani St. | 200 | 10 |
| $v_{39}$ | Simpang 2 Letkol Santoso | Sentot Alibasyah St. | 284 | 4 | $v_{29}v_{30}$ | Ahmad Yani St. | 154 | 10 |
| $v_{40}$ | Robert Hamilton Monument | Letkol Iskandar St. | 245 | 4 | $v_{29}v_{31}$ | Veteran St. | 302 | 5 |
| $v_{41}$ | Simpang Kerapu | Letda Abu Hanifah St. | 520 | 6 | $v_{30}v_{31}$ | Ahmad Yani St. | 250 | 10 |
| $v_{42}$ | Simpang 2 Jamik | H. Moh Zahab St. | 203 | 3 | $v_{31}v_{34}$ | Veteran St. | 237 | 5 |
| $v_{43}$ | Simpang Kebun Geran | Sentot Alibasyah St. | 288 | 4 | $v_{31}v_{36}$ | Letkol Santoso St. | 340 | 4 |
| $v_{44}$ | Simpang Lima Ratu Samban | Iskandar 11 St. | 260 | 3 | $v_{31}v_{42}$ | Ahmad Yani St. | 733 | 10 |
| $v_{45}$ | Simpang Jam | Letkol Iskandar St. | 260 | 4 | $v_{32}v_{33}$ | Ahmad Yani St. | 264 | 4 |
| $v_{46}$ | Simpang Jawa | Lettu Zulkifli St. | 231 | 3 | $v_{32}v_{33}$ | Belato St. | 598 | 4 |
| $v_{47}$ | Simpang Sukamerindu | Lettu Zulkifli St. | 115 | 3 | $v_{33}v_{34}$ | Pari St. | 390 | 6 |
| $v_{11}$ | Simpang 2 Jawa | Lettu Zulkifli St. | 231 | 3 | $v_{33}v_{34}$ | Rejamat St. | 281 | 5 |
| $v_{12}$ | Simpang 3 Jamak | Sentot Alibasyah St. | 188 | 4 | $v_{33}v_{37}$ | Prof Dr Hazairin St. | 199 | 6 |
| $v_{13}$ | Simpang 3 Jawa | MT Haryono, St. | 370 | 13,5 | $v_{34}v_{35}$ | Ikandar Baksir St. | 212 | 4 |
| $v_{14}$ | Simpang 4 Jawa | Jawa St. | 264 | 13 | $v_{35}v_{37}$ | M Hasan 1 St. | 295 | 5 |
| $v_{15}$ | Simpang 4 Jamak | Letkol Iskandar St. | 194 | 4 | $v_{35}v_{39}$ | Ikandar Baksir St. | 380 | 4 |
| $v_{16}$ | Simpang 4 Jawa | Jendral Sudirman St | 485 | 10 | $v_{36}v_{39}$ | Letkol Santoso St. | 292 | 4 |
| $v_{17}$ | Simpang 4 Jamak | Jendral Sudirman St | 100 | 10 | $v_{36}v_{43}$ | Cendrawash St. | 758 | 4 |

**Table 1.** Road Length and Width Data in Teluk Segara District, Bengkulu City
3.2. Membership function

The first step is to form a fuzzy set of road lengths and widths. In this research, the length of the road is divided into three, namely short, middle and long. Meanwhile, the fuzzy sets for road width are low, middle and high. Membership function of the length of the road are given by

\[
\mu_{L,short}(x) = \begin{cases} 
1 & x \leq 100 \\
\frac{500 - x}{500 - 100} & 100 < x < 500 \\
0 & x \geq 500 
\end{cases}
\]

\[
\mu_{L,middle}(x) = \begin{cases} 
1 & x \geq 1000 \\
\frac{x - 100}{500 - 100} & 100 < x < 1000 \\
\frac{1000 - x}{1000 - 500} & 500 < x < 1000 \\
0 & x \leq 1000 
\end{cases}
\]

\[
\mu_{L,long}(x) = \begin{cases} 
1 & x \geq 1000 \\
\frac{x - 500}{1000 - 500} & 500 < x < 1000 \\
0 & x \leq 500 
\end{cases}
\]

and membership function of the width of the road are given by

\[
\mu_{W,low}(x) = \begin{cases} 
1 & x \leq 3 \\
\frac{5 - x}{5 - 3} & 3 < x < 5 \\
0 & x \geq 5 
\end{cases}
\]

\[
\mu_{W,middle}(x) = \begin{cases} 
\frac{x - 3}{500 - 100} & 3 < x \leq 5 \\
\frac{13 - x}{13 - 5} & 5 < x < 13 \\
0 & x \geq 13 
\end{cases}
\]
In this research, the determination of fuzzy output is based on the following rules:

- IF Length is short AND width is high THEN the speed is very fast
- IF Length is middle AND width is high THEN the speed is fast
- IF Length is short AND width is middle THEN the speed is normal
- IF Length is middle AND width is middle THEN the speed is normal
- IF Length is long AND width is middle THEN the speed is slow
- IF Length is short AND width is low THEN speed is slow
- IF Length is long AND width is low THEN speed is very slow
- IF Length is long AND width is high THEN speed is normal

And the speed level values used are as follows:

Very fast : 0.1
Quick : 0.25
Normal : 0.5
Slow : 0.75
Very Slow : 1

The following is a fuzzy output table for each road section. The fuzzy outputs are obtained based on the road length and width parameters.

![Table](image-url)
3.4 Shortest Path

The fuzzy output obtained in Table 2 is used as the weight of the graph in Figure 1. The route of the evacuation route is determined using Dijkstra’s Algorithm. The following is a picture of the evacuation route determined using Dijkstra’s Algorithm.

![Figure 2. Evacuation Route for Teluk Segara District, Bengkulu City](image)

Based on Figure 2, there are 21 routes for evacuation routes. The routes is divided into three group with the following details:

a) 4 routes to the evacuation point at Kampung kelawi:
   - \(v_5 - v_2 - v_1 - ep_1\)
   - \(v_8 - v_9 - v_7 - v_3 - v_4 - ep_1\)
   - \(v_{10} - v_{11} - v_{12} - v_4 - ep_1\)
   - \(v_{46} - v_{47} - v_4 - ep_1\)
b) 14 routes to the evacuation point at Alun-alun Kota Bengkulu,

\[
\begin{align*}
    v_6 &- v_{19} - v_{20} - v_{24} - e p_2 \\
    v_{14} &- v_{13} - v_{42} - v_{31} - v_{29} - e p_2 \\
    v_{15} &- v_{17} - v_{18} - v_{30} - v_{29} - e p_2 \\
    v_{16} &- v_{17} - v_{18} - v_{30} - v_{29} - e p_2 \\
    v_{21} &- v_{22} - v_{23} - v_{24} - e p_2 \\
    v_{25} &- v_{24} - e p_2 \\
    v_{26} &- v_{28} - e p_2 \\
    v_{27} &- v_{28} - e p_2 \\
    v_{32} &- v_{33} - e p_2 \\
    v_{34} &- v_{33} - e p_2 \\
    v_{35} &- v_{37} - v_{33} - e p_2 \\
    v_{36} &- v_{31} - v_{29} - e p_2 \\
    v_{38} &- v_{37} - v_{33} - e p_2 \\
    v_{43} &- v_{42} - v_{31} - v_{29} - e p_2
\end{align*}
\]

c) routes to the evacuation point at Masjid At Taqwa

\[
\begin{align*}
    v_{39} &- v_{40} - e p_3 \\
    v_{41} &- v_{40} - e p_3 \\
    v_{45} &- v_{44} - e p_3
\end{align*}
\]

4. Conclusion

An Evacuation routes have been obtained in this study. This route considers the evacuation speed obtained based on the length and width of the road. For further research, other variables can be added such as congestion so that the evacuation route will be better.

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