Application of the clarke-wright algorithm in determining tsunami disaster evacuation route in Purworejo district

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Abstract. The potentials for tsunami in Indonesia are spread over many areas, one of which is Purworejo. Purworejo has a high tsunami potential because it is located on the Indo-Australian plate. In Central Java, Purworejo occupies the 3rd position in the tsunami-prone area. Therefore, a route is needed to evacuate the population to mitigate the tsunami. This research focuses on two sub-districts, namely Ngombol and Purwodadi. The problems in this paper are: (1) Which points can be used as evacuation sites (2) How to model tsunami evacuation routes with graphs (3) What are the optimal evacuation routes. The method used to find the evacuation route is the VRP with time window. The algorithm used is Clarke Wright algorithm. The optimal evacuation route is obtained if all points are evacuated with minimal time and distance. From nine final evacuation points, only 4 points that fulfill criteria for the shortest distance and can be accessed by vehicles. There are eight final routes with minimum time of 42 minutes. Each of depots B3 and C2 has 3 routes. Whereas each of depots C4 and C5 has 1 route.

1. Introduction
Indonesia is an archipelagic country that is located between the world's major plates, namely the Eurasian plate, the Pacific plate, and the Indo-Australian plate. This causes Indonesia to become a prone area to natural disasters such as earthquakes[1]. Most of Indonesia's territory is territorial waters so that an earthquake with an epicenter at sea can cause a tsunami. The areas that are potential for tsunamis are spread in various parts of Indonesia, one of which is the Purworejo District. Purworejo District is in the southern part of Central Java, bordering the district of Magelang and Wonosobo in the North, Kebumen in the West, Yogyakarta in the East, and Samudera Indonesia in the South. Several areas in Purworejo are tsunami-prone areas, including Ngombol and Purwodadi. Purworejo has a high tsunami potential because it is located on the Indo-Australian plate which moves 5-7 cm every year. The vulnerability of Purworejo District is in third position after Cilacap and Kebumen based on identification of the Badan Nasional Penanggulangan Bencana (BNPB) of Indonesia[2]. Therefore, there is a need for investigating the problem to reduce the impact of the tsunami or tsunami mitigation in Purworejo District. Tsunamis that often occur in Indonesia are short-range/local tsunamis, i.e., tsunamis that are about 200 km from the epicenter. The tsunami arrival time is between 10 until 60 minutes, so it is needed a fast and accurate early warning[3]. A vehicle routing problem (VRP) is needed to determine the tsunami evacuation route. Evacuation route planning is an important component of civil authorities' efforts to identify the safest and most efficient routes to prepare for natural and man-made disasters [4]. The VRP is a problem in determining transportation routes to carry out all (or some) requests with a given fleet of vehicles in certain capacities or limitations [5]. Conventional methods and heuristics for defining evacuation routes generally are based mainly on geographic proximity and seek for the shortest
travelling time [6]. There are three methods to solve the VRP, that are exact method, heuristics, and meta-heuristics [7].

The exact method, also known as the approximation method, is done by calculating all possible solutions. Heuristic methods are criteria, methods, or principles to determine the choice of a number of alternatives in order to achieve some goals effectively[8]. Agrawal et al., [9] said that the metaheuristic algorithm is an optimization method that can get the optimal solution (near-optimal) of the optimization problem. The metaheuristic method is designed to solve combinatorial optimization problems if the heuristic method cannot find an effective and efficient solution. One of metaheuristic method is Evolutionary Planning (EP) algorithm which discussed in Tang et al., [10].

Various solutions for determining the route using heuristic methods include the Clarke-Wright algorithm[11], the A* algorithm[12], etc. Various solutions to the problem of determining routes using metaheuristic methods include the Ant Colony Optimization (ACO) algorithm[13], the genetic algorithm [14], the fuzzy algorithm [15], etc. The Clarke-Wright Algorithm is suitable for route finding where there is no previous route/solution (initial route). In addition, because the Clarke-Wright algorithm is included in the heuristic method, the resulting solution has good quality with a relatively fast completion time. This makes the Clarke-Wright Algorithm suitable to be used to solve the problem of finding a tsunami evacuation route[16].

The problems in this paper are as follows: (1) Which points that can be used as evacuation sites in Ngombol and Purwodadi sub-districts; (2) How are the graph models of tsunami evacuation routes in Ngombol and Purwodadi sub-districts; (3) What are the optimal evacuation routes. We use the Matlab program to find tsunami evacuation routes in Purworejo District because Matlab is a mathematical and graphic software package with reliable programming capabilities. Matlab has built-in functions to perform many operations and there is a toolbox that can be added [17].

2. Method

The algorithm used in this study is the Clarke-Wright algorithm. The calculation in the algorithm is done by combining two points into one route[18]. For example, two vertices \(i\) and \(j\) have their own routes as shown in Figure 1(a), if one route is used to travel through two vertices \(i\) and \(j\), then savings (\(S_{ij}\)) will be obtained as shown in Figure 1(b).

![Figure 1](image)

Figure 1. Early Route Forms and Savings

The steps of Clarke-Wright algorithm are as follows [19]:

1. Initialize the algorithm with a given set of vertices and distances between them.
2. Create an empty set of routes.
3. For each route in the set, add a vertex to the route if the savings are positive.
4. Repeat step 3 until all vertices are included in a route.
5. Calculate the total cost of each route.
6. Select the route with the minimum cost as the optimal route.
7. If the optimal route is not found, go back to step 2.

The Clarke-Wright Algorithm is suitable for route finding where there is no previous route/solution (initial route). In addition, because the Clarke-Wright algorithm is included in the heuristic method, the resulting solution has good quality with a relatively fast completion time. This makes the Clarke-Wright Algorithm suitable to be used to solve the problem of finding a tsunami evacuation route[16].
3. Result and Discussion

3.1. Final Evacuation Points
Final evacuation points are places used to evacuate disaster victims and there are in a safe zone according to the mapping from Badan Penanggulan Bencana Daerah (BPBD) of Purworejo District. The final evacuation points based on the results of BPBD mapping in Purworejo District are as follows.

| Code | Name (Description of Location) |
|------|--------------------------------|
| B1   | Susuk, Ngombol                 |
| B2   | Briyan, Ngombol                |
| B3   | Ngombol, Ngombol               |
| B4   | Candi, Ngombol                 |
| C1   | Bongkot, Purwodadi             |
| C2   | Guyangan, Purwodadi            |
| C3   | Sidoharjo, Purwpdadi           |
| C4   | Banjarsari, Purwodadi          |
Based on the availability of road access to each final evacuation point, there are several final evacuation points where do not meet the road criteria that can be passed by large vehicles (trucks). The final evacuation points that meet the criteria are B3, C2, C4, and C5.

3.2. Temporary Evacuation Points
A temporary evacuation point is a place that functions as a temporary gathering point for disaster victims until they get directions from related parties to the final evacuation point. In this study, there are 24 temporary evacuation points, 13 points in sector B (Ngombol) and 11 points in sector C (Purwodadi).

Table 2. Temporary Evacuation Points

| Code | Name (Description of Location)                        |
|------|-------------------------------------------------------|
| 6    | TK Permata Hati, Awu – Awu                           |
| 7    | Balaidesa Awu – Awu                                  |
| 8    | Pelataran Toko Indo Jaya                             |
| 9    | Balaidesa Keburuhan                                  |
| 10   | Pasar Tradisonal Desa Wonoroto                       |
| 11   | Balaidesa Malang                                     |
| 12   | Rumah Bapak Sutarno, Pagak                           |
| 13   | Pelataraan Scell Konter                              |
| 14   | SDN Pagak                                            |
| 15   | JKB Purworejo                                        |
| 16   | Masjid Wero                                          |
| 17   | SDN Girirejo                                         |
| 18   | Pos Polisi Kentengrejo                               |
| 19   | Pelataran Sugeng Bibit                               |
| 20   | Balai Desa Ngentak                                   |
| 21   | Masjid Jami Al Khasanah Jatimalang                   |
| 22   | Sub Terminal Nampurejo                               |
| 23   | Lapangan Geparang                                    |
| 24   | Perengan Barat, Jatikontal                           |
| 25   | Bejojo, Jogoresan, Purwodadi                         |
| 26   | Pelataraan Noris Cell                                |
| 27   | Masjid Al Kalim, Karanganyar                         |
| 28   | Pelataraan Kelompok Tani Gemah Ripah                 |
| 29   | Balaidesa Jogobooyo                                  |

3.3. Graph Model
Evacuation points that have been selected will become points on the graph and the access roads between evacuation points will become edges on the graph. To obtain a graph model, the data of the distance between evacuation points is needed (see Tables 3, 4, 5, and 6).
Table 3. Distance Between Evacuation Points Connected to B3 (km)

|       | B3  | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|
| B3    | 0   | 10,2| 9,9 | 8,7 | 9,3 | 6,3 | 7,9 | 9,1 |
| 6     | 0   | 0,3 | -   | -   | -   | -   | -   | -   |
| 7     | 0   | 1,4 | -   | 3,6 | 5,7 | -   | -   | -   |
| 8     | 0   | 0,6 | 2,5 | 4,5 | -   | -   | -   | -   |
| 9     | 0   | -   | -   | -   | -   | -   | -   | -   |
| 10    | 0   | 3,5 | -   | -   | -   | -   | -   | -   |
| 11    | 0   | 1,2 | -   | -   | -   | -   | -   | -   |
| 12    |    | 0   | -   | -   | -   | -   | -   | -   |

Table 4. Distance Between Evacuation Points Connected to C2 (km)

|       | C2  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21  | 22  | 23  | 24  | 26  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| C2    | 0   | 7,7 | 8,2 | 7,1 | 7,2 | 6,5 | 5,9 | 4,8 | 5,4 | 4,1 | 3,3 | 4,2 | 5,3 | 7,1 |
| 13    | 0   | -   | 0,6 | -   | -   | 1,8 | 2,9 | -   | -   | -   | -   | -   | -   | -   |
| 14    | 0   | -   | 1,1 | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 15    | 0   | -   | -   | 1,2 | 2,3 | -   | -   | 3,8 | -   | -   | 7,6 | -   | -   | -   |
| 16    | 0   | 0,8 | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 17    | 0   | -   | -   | 1,1 | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 18    | 0   | 1,1 | -   | -   | 2,6 | -   | -   | -   | 6,5 | -   | -   | -   | -   | -   |
| 19    | 0   | 0,8 | 2,4 | 1,7 | -   | 3,5 | 5,4 | -   | -   | -   | -   | -   | -   | -   |
| 20    | 0   | 3,1 | 2,5 | -   | 4,3 | 6,1 | -   | -   | -   | -   | -   | -   | -   | -   |
| 21    | 0   | 0,9 | 2,4 | 2,2 | 4,7 | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 22    | 0   | 1,7 | 2   | 4   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 23    | 0   | 3,5 | 5,3 | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 24    | 0   | 5,8 | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 26    |    | 0   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |

Table 5. Distance Between Evacuation Points Connected to C4 (km)

|       | C4  | 25  | 27  |
|-------|-----|-----|-----|
| C4    | 0   | 3,8 | 7,9 |
| 25    | 0   | 9,8 |
| 27    | 0   | -   |

Table 6. Distance Between Evacuation Points Connected to C5 (km)

|       | C5  | 28  | 29  |
|-------|-----|-----|-----|
| C5    | 0   | 5,5 | 5,1 |
| 28    | 0   | 3,6 |
| 29    | 0   | -   |

From the data in tables above, the problems in this study can be modeled as the graphs in Figure 4.
Figure 4. The Graph Models for visualizing evacuation points and the access roads between them

3.4. Optimal Evacuation Routes
To get a solution to the problem, it is necessary to have time data between evacuation points and depot time data with each evacuation point (see Tables 7, 8, 9 and 10).

Table 7. Time Between Evacuation Points Connected to B3 (minutes)

|     | B3  | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| B3  | 0   | 19  | 18  | 14  | 15  | 11  | 18  | 21  |
| 6   | 0   | 1   | -   | -   | -   | -   | -   | -   |
| 7   | 0   | 4   | 8   | 13  | -   | -   | -   | -   |
| 8   | 0   | 1   | 5   | 10  | -   | -   | -   | -   |
| 9   | 0   | -   | -   | -   | -   | -   | -   | -   |
| 10  | 0   | 11  | -   | -   | -   | -   | -   | -   |
| 11  | 0   | 3   | -   | -   | -   | -   | -   | -   |
| 12  | 0   | -   | -   | -   | -   | -   | -   | -   |

Table 8. Time Between Evacuation Points Connected to C2 (minutes)

|     | C2  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21  | 22  | 23  | 24  | 26  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| C2  | 0   | 10  | 18  | 9   | 14  | 12  | 8   | 7   | 10  | 7   | 6   | 7   | 11  | 9   |
| 13  | 0   | -   | 1   | -   | -   | 2   | 3   | -   | -   | 5   | -   | -   | -   | 8   |
| 14  | 0   | -   | 3   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 15  | 0   | -   | -   | 1   | 2   | -   | -   | 4   | -   | -   | 7   | -   | -   | -   |
| 16  | 0   | 2   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 17  | 0   | -   | -   | 3   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 18  | 0   | 1   | -   | -   | 3   | -   | -   | -   | -   | -   | -   | -   | -   | 6   |
| 19  | 0   | 3   | 3   | 2   | -   | 7   | 5   | -   | -   | -   | -   | -   | -   | -   |
| 20  | 0   | 7   | 6   | -   | 10  | 9   | -   | -   | -   | -   | -   | -   | -   | -   |
| 21  | 0   | 2   | 5   | 6   | 6   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 22  | 0   | 4   | 6   | 4   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 23  | 0   | 9   | 7   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 24  | 0   | 9   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 26  | 0   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
Table 9. Time Between Evacuation Points Connected to C4 (minutes)

|     | C4 | 25 | 27 |
|-----|----|----|----|
| C4  | 0  | 6  | 12 |
| 25  | 0  | 15 |    |
| 27  |    |    | 0  |

Table 10. Time Between Evacuation Points Connected to C5 (minutes)

|     | C5 | 28 | 29 |
|-----|----|----|----|
| C5  | 0  | 7  | 6  |
| 28  | 0  | 6  |    |
| 29  |    | 0  |    |

Time data is obtained from calculations based on google maps by entering the origin and destination points. Then a choice of routes will appear, the selected route by selecting the existing road access so that the selected route can be traversed by medium to large vehicles. Google street view is used to see the availability of road access.

Within a period of 15 minutes, none of the points in B3 depots could be evacuated. The iteration results show that all routes obtained exceed the time limit. Following are the routes for temporary evacuation points that can be evacuated within 15 minutes from depots C2, C4, and C5.

Figure 5. GUI for a Period of 15 minutes

Based on Figure 5, there are 17 temporary evacuation points that do not meet the requirements due to exceeding the time limit. These points are points with codes 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 24, 26, and 27. For points that can be evacuated are points with codes 19, 21, 22, 23, 25, 28, and 29.
Within a period of 30 minutes, there were 5 temporary evacuation points that did not meet the requirements because they had exceeded the time limit. These points are points with codes 6, 7, 11, 12, and 14. The routes for temporary evacuation points that can be evacuated within 30 minutes from depots B3, C2, C4, and C5 are depicted in Figure 6.

Within 45 minutes, all temporary evacuation points are included in the evacuation route. The routes for temporary evacuation points that can be evacuated within 45 minutes from depots B3, C2, C4, and C5 are depicted in Figure 7.
Within 60 minutes, all temporary evacuation points are included in the evacuation route. The routes for temporary evacuation points that can be evacuated within 60 minutes from depots B3, C2, C4, and C5 are depicted in Figure 8.

The evacuation route is said to be optimal if all points are evacuated with minimal time and number of routes. Based on the calculation results using Matlab programming, the optimal evacuation route is obtained as depicted in Figure 9, with a period of 42 minutes and has 8 evacuation routes.

### 4. Conclusion

The selected points as final evacuation points are B3, C2, C4, and C5. The graph models for the tsunami evacuation route in Purworejo District is depicted in Figure 4. The optimal evacuation route means that a route in which all points can be selected with the minimum time and distance. The minimum travel time of the optimal route using the Clarke-Wright algorithm in determining a tsunami evacuation route in Purworejo District is 42 minutes. The following are the optimal routes for the solution of the problem.
This research can be developed for areas other than Purworejo by adding other variables, such as the volume and density. In addition, further research is needed on the advantages, effectiveness, and accuracy of the Clarke-Wright algorithm for research on tsunami mitigation. For example, by using another algorithm to compare it with the Clarke-Wright algorithm.

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