Journal of Physics: Conference Series

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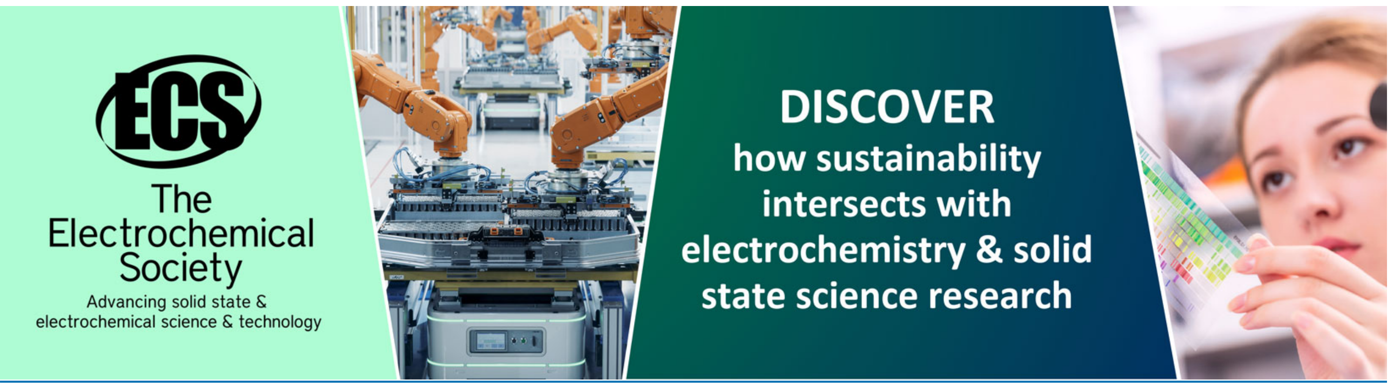
To cite this article: Z M Mayasari *et al* 2019 *J. Phys.: Conf. Ser.* **1188** 012094



IOP Conf. Series: Journal of Physics: Conf. Series **1188** (2019) 012094 doi:10.1088/1742-6596/1188/1/012094

Mathematical modeling approach of an evacuation model for tsunami risk reduction in bengkulu

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Abstract. In tsunami mitigation plan, evacuation plays a crucial measure for saving human lives, especially for communities who are living in coastal areas. The main problem of evacuation system is to minimize the time to evacuate the vulnerable population. This can be done by determining the effective evacuation route. The effective evacuation route from a cluster (center of population) to an assembly point (safety area) should consider the minimum travel time. In calculating travel time between cluster and assembly point we have to consider the speed of walking of evacuees. The speed of walking of evacuees is influenced by several factor i.e width of the road, road density, number of evacuees in a group, etc. This research develop a mathematical modeling to choose the most effective evacuation route in coastal areas of Bengkulu city, Indonesia. The used method in determined minimun travel time is Flyod Warshall algorithm and the tsunami evacuation system software is made using mathlab programming. Indonesian Tsunami Early Warning System (InaTEWS), takes about 15 minutes after an early warning tsunami to evacuate. The result of the evacuation modeling shows there are 5 clusters of 48 clusters need more than 15 minutes to reach safety area.

1. Introduction
Tsunami is a wave or series of ocean waves created by sudden, large disturbances of the deep ocean-water mass [1]. There are many factors which cause tsunami such as: earthquakes, volcanic eruption, landslides, slumps, and meteor impact. The destruction due to tsunami impact is various depending on the source the distance from the epicentre and also the intensity of the trigger factors which cause tsunami. Mostly, the coastal areas which are densely populated will have severely damages because high concentration of population, buildings, infrastructure, and sosio-economic facilities. Furthermore, tsunami can cause death. The most recent tsunami which hit Palu, Indonesia on September 28^{th}, 2018. More than 1500 people died, and caused hundreds of houses were completely damage.

Bengkulu is a city in Sumatera Island, Indonesia. Some parts of its city are directly facing the Indian Ocean. Bengkulu city located in a tsunami prone area. In the period 2000 – 2010, Bengkulu had experienced two earthquakes with a large magnitude, on June 4^{th}, 2000 with a magnitude of 7,3 Mw, the epicenter was 100 Km offshore southwest of the city of Bengkulu in a depth of 0 – 60 Km under sea level, and on September 12^{th}, 2007 with a magnitude of 7,9 Mw, the epicenter was 160 Km offshore southwest of the city of Bengkulu in a depth of 30 Km. Both of these earthquakes have the potential to cause a tsunami [2].

In a tsunami mitigation plan, evacuation plays a very important role in before, during, and after disaster strikes for saving human lives. It is very important to prepare the city and its community with

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a disaster mitigation in order to reduce the damage and losses. There are two methods to evacuate people in case of tsunami, horizontal evacuation and vertical evacuation. In horizontal evacuation, people move to safer areas in a distant location or higher ground such as a hill. In vertical evacuation people are evacuated to the higher floors of a tsunami-resistant building nearby [3].

The evacuation route planning will find out routes to minimize the time to evacuate the vulnerable population [4]. The effective evacuation route from a given point should consider the minimum travel time. Travel time is influenced by the speed of walking of evacuees. The speed of walking of evacuees is influenced by several factor i.e width of the road, road density, number of evacuees in a group, etc.

Some researchers have conducted a study of tsunami mitigation plan. A study about a tsunami evacuation system model bases shortest path and minimum evacuation time which calculating shortest path using Dijkstra algorithm in Palu City [5]. A study about a vertical evacuation planning which effective evacuation route are obtained by Find Closest Facility on Network Analyst in Bali Province [6]. A study about a mathematical model to tsunami evacuation problem using macroscopic model approach in Bengkulu [7]. A study about an evacuation model for vertical evacuation using GIS tools in a tsunami-prone area [3].

The main issue of this research is tsunami evacuation planning with the focus to choose the most effective evacuation routes by consider the minimum travel time using Flyod Warshall Algorithm and the tsunami evacuation system software is made using mathlab programming.

2. Basic theory

2.1. Bengkulu city

Bengkulu is a city in Sumatera Island, Indonesia. Some areas in Bengkulu are coastal and tsunami-prone area because directly facing the Indian Ocean. In the period 2000 – 2010, Bengkulu had experienced two earthquakes with a large magnitude and both of these earthquakes have the potential to cause a tsunami. Since 2006, the government have anticipated to tsunami by determining many safety area as an assembly point for community as can be seen in the Table 1.

Table 1. Assemby point in Bengkulu city

Assembly point	Height (m)	Coverage of evacuation areas (subdistrict)	Evacuation route
Kampus Universitas Bengkulu	15 – 20	Rawa Makmur Permai Rawa Makmur Beringin Jaya	Jl. UNIB Raya Jl. Kandang Limun Jl. Bandar Raya
Kampung Kelawi	14	Pasar Bengkulu Kampung Bali Kampung Kelawi Tanjung Agung Tanjung Jaya	Jl. Pasar Bengkulu-Jl. Kalimantan-Jl. Enggano
Lapangan Merdeka	15	Pondok Besi Malabero Sumur Meleleh Berkas Kebon Keling Tengah Padang	Jl. Pendakian-Jl. Depan Benteng Jl. Depan Lapas-Jl. SMP Carolus Jl. Pasar Barau-Jl. Dalam Pasar Baru Koto II
Mesjid At-Taqwa	14	Penurunan Anggut Bawah	Jl. Pasar Baru-Jl. Nala Jl. Putri Gading Cempaka
Simpang Empat Pantai	12,5	Penurunan Kebun Beler	Jl. Sedap Malam Jl. Kebun Beler
STM Negeri	13	Lempuing	Jl. Batanghari Jl. Kampar

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Lapangan Sepakbola Kemuning	10,5	Lempuing Lingkar Barat	Jl. Pembangunan Jl. Pariwisata Jl. Ciliwung Jl. Serayur
Balai Buntar	19	Lempuing Padang Harapan	Jl. Cimanuk Jl. Kap. Tendean Jl. Natadirja
Lapangan Pagar Dewa	15	Muara Dua Kandang Mas Bumi Ayu Kandang	Jl. Ir. Rustandi Sugiarto
Lapangan Pesantren Pancasila	20	Jembatan Kecil Sawah Lebar Kebun Tebeng	Jl. Jembatan Kecil Jl. Gunung Bungkuk Jl. Merapi Jl. Danau
Terminal Betungan	20	Padang Serai Sumber Jaya Bumi Ayu Teluk Sepang	Jl. Raya Betungan Jl. Dua Jalur Simpang Kandis
Simpang Empat Nakau	21	Tanjung Agung Tanjung Jaya Semarang Surabaya	Jl. Irian Jl. Halmahera Jl. Danau

Source : City Planning and City Building Supervision in [8]

2.2. Graph

A graph is an ordered pair $G = (V, E)$ consisting of a nonempty set V (called the vertices/nodes) and a set E (called edges) of two element subsets of V. The symbols $|V(G)|$ dan $|E(G)|$ denote the numbers of vertices and edges in a graph G. If $V(G) = \{v_1, v_2, v_3, \dots, v_n\}$ and $E(G) = \{e_1, e_2, e_3, \dots, e_m\}$ then $|V(G)| = n$ and $|E(G)| = m$.

2.3. Directed graph, undirected graph and weighted graph

A directed graph is a set of object (called vertices or nodes) that are connected together, where all the edges are directed from one node to another. A graph where the edges are bidirectional is called an undirected graph. In directed graph $(v_i, v_j) \neq (v_j, v_i)$. A weighted graph is a graph in which each branch is given a numeric weight.

2.4. The shortest path

The shortest path is minimum path needed to reach a place (node) from another place (node). In a path, there are source node and sink node. Other nodes that connect the source node and sink node are called intermediate nodes. Some of the shortest path problem are: a pair shortest path, all pair shortest path, single-pair shortest path, and intermediate pair shortest path. In this research, the problem shortest path is single-pair shortest path.

2.5. Flyod Warshall

Flyod Warshall algorithm is an algorithm for finding shortest path in a weighted graph with positive or negative edgeweights (but no negative cycle) [9]. This algorithm compares all possible paths through the graph between each pair of vertices. The accuracy of this algorithm always shows a value 100% [10]. The Flyod Warshall algorithm mechanism is done in several steps.

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Steps of Flyod Warshall algorithm are:

1. Represent a weighted graph as a matrix. The weight for each is:
   $w_{ij} = 0, \quad if\ i = j$
   $= w(i,j), \quad if\ i \neq j\ and\ (i,j) \in E$
   $= \infty \quad if\ i \neq j\ and\ (i,j) \notin E$
   The output format is a matrix $n \times n$ with distance/travel time $D = [d_{ij}]$, d_{ij} is a distance/travel time from vertex i to vertex j.
2. Decompose the Flyod Warshall.
   i. $d_{ij}(k)$ is the shortest path length from *i* to *j* so that all intermediate vertices on the path (if any) are collected at $\{1, 2, \ldots, k\}$.
   ii. $d_{ij}(0)$ is collected at w_{ij}, there is no intermediate vertex
   iii. $D(k)$ becomes matrix $n\ x\ n$ $[d_{ij}(k)]$
   iv. Determine $d_{ij}(n)$ as distance/travel time from i to j then calculate $D(n)$.
   v. Calculate $D(k)$ for $k = 0, 1, \ldots, n$.
3. Determine the shortest path structure
   At this step, make the observations.
   i. A shortest path does not contain a cycle.
   ii. For a shortest path from vertex *i* to *j* with several intermediate vertices on the path, select from $\{1, 2, \ldots, k\}$, with 2 possibilities:
      i. *k* is not a *vertex* on the path, the shortest path has a length ${d_{ij}}^{k-1}$
      ii. *k* is a *vertex* on the path, the shortest path has a length ${d_{ik}}^{k-1} + {d_{kj}}^{k-1}$
   iii. Determine the shortest path from vertex *i* to *j* that contains vertex *k*
   iv. The shortest path contains a subpath from vertex *i* to *k* and a subpath from vertex *k* to *j*
   v. Every sub path only contains intermediate vertex at $\{1, 2, \ldots, k-1\}$ and as much as possible has a minimum value, named ${d_{ik}}^{k-1}$ and ${d_{kj}}^{k-1}$ so that the path has a length ${d_{ik}}^{k-1} + {d_{kj}}^{k-1}$
4. Iterate, starting from 0-iteration to n^{th} iteration
   i. Determine $D(0)$ (0-iteration)= $[w_{ij}]$, is a weighted matix
   ii. Determine *D(k)*, ${d_{ij}}^{(k)}$ = min{ ${d_{ij}}^{(k-1)}, {d_{ik}}^{(k-1)} + {d_{kj}}^{(k-1)}$ for $k = 1, \ldots, n$, where n is number of vertex.
5. The final result is a matrix for the n^{th} iteration. This matrix shows the shortest path for each vertex in the graph.

2.6. Evacuation time

Evacuation time is the available time for evacuate. It is defined by knowing the remaining time after the issuance of tsunami warning to the arrival of tsunami waves [11]. Indonesian Tsunami Early Warning System – InaTEWS, takes about 15 minutes after an early warning tsunami to evacuate [5]. In 15 minutes evacuees must have reached safe area (an assembly point). The length time to reach the assembly poits is affected by speed of walking. Many research related to the speed of walking was conducted in disaster approach gave different results. One of them gave an overview of the speed of walking in disaster evacuation as can be seen in the Table 2.

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Table 2. Evacuee walking speed

Walking condition	Average walking speed (m/sec)
A person pushing a perambulator	1,070
A person with a child	1,020
An independent walking elderly person	0,948
A group of walking elderly people	0,751

Source: Institute of Fire Safety & Disaster Preparedness (1987) after Sugimoto *et al*, (2003) in [11].

Based on this data, in this research assumed the speed of walking is 0,751(m/sec) because if the evacuees with the slowest speed can reach an assembly point, other evacuees that move faster can reach an assembly point consequently.

3. Results and discussion

3.1. Data availability and research location

Data used for this research are primary data obtained through direct measurements and secondary data obtained from relevant agencies or previous studies. Research location in the coastal area Bengkulu City, Teluk Segara District. Teluk Segara district is prone to tsunami disaster [12].

3.2. Research procedure

Steps of this research procedure are:
First, observation and data collection. The data used are network map Bengkulu City, assembly point, width of the road, length of the road, road density and number of evacuees in a group,
Second, cluster research area. In this step, research area are divided into 48 clusters and there are 3 the nearest assembly point,
Third, make a road network graph. The road network graph is created based on the clusters and assembly points,
Fourth, make a tsunami evacuation system software. Tsunami evacuation system software to choose the most effective evacuation route is made using mathlab programming. The method used in determined minimun travel time is Flyod Warshall algorithm,
Fifth, analize program performance. Software in step 4 was tested to verify the validating of the resulting model. Tested are carried out using available data and validated with real conditions in the research area,
Sixth, determination an effective evacuation routes. Based on step 1 – step 5, an effective evacuation routes are determined.

3.3. Road network graph

For this research, the road network graph contains 48 clusters and 3 the assembly point determined by government (Figure 1).

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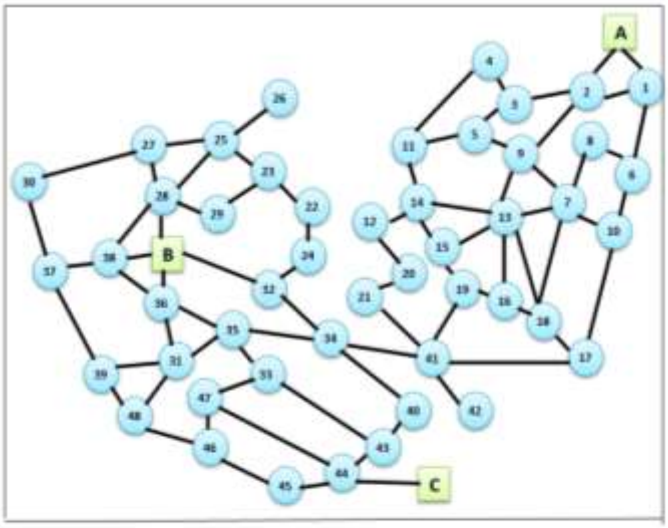

Figure 1. Road network graph teluk segara district Bengkulu city

Information:

A : Assembly point Kampung Kelawi
B : Assembly point Lapangan Merdeka
C : Assembly point Mesjid At-Taqwa
1 : Simpang Jl. Ibnu Hajar, Jl. Bali, Jl. Enggano
2 : Simpang 4 Jl. Ibnu Hajar
3 : Simpang 1 Jl. Ibnu Hajar, Jl. TP. Kasim Nasir
4 : Simpang Jl. Bencolen , Jl. Ibnu Hajar
5 : Simpang Jl TP. Kasim Nasir, Jl. Sentot Alibasyah
6 : Simpang Jl. Bali, Jl. Bali 1
7 : Simpang (1) Jl. Sentot Alibasyah
8 : Ujung dalam Jl. Bali 1
9 : Simpang Jl. Moh. Zahab, Jl. Sentot Alibasyah
10 : Simpang Jl. MT. Haryono, Jl. Sentot Alibasyah
11 : Simpang Jl. Letda Abu Hanifah, Jl. Letkol Iskandar, Jl. Tp Kasim Nasir
12 : Simpang 4 Jl. Iskandar 10
13 : Simpang 4 Jl. H. Moh. Zahab, Jl. Lettu Zulkifli, Gg. Iskandar 11
14 : Simpang Jl. Letkol Iskandar, Gg. Iskandar 11
15 : Simpang 4 Jl. Mayor Salim Batubara, Jl. Letkol Iskandar
16 : Simpang Jl. Letkol Iskandar, Jl. Iskandar 6A
17 : Simpang Jl. MT. Haryono, Jl. Letkol Iskandar
18 : Simpang (2) Jl. Letkol Iskandar
19 : Simpang (3) Jl.Letkol Iskandar
20 : Simpang (1) Jl. Mayor Salim Batubara
21 : Simpang Jl. Sudirman, Jl. Mayor Salim Batubara
22 : Simpang (l) Khadijah, Jl. KH. Ahmad Dahlan
23 : Simpang 3 Jl. Letda Abu Hanifah, Jl. Khadijah
24 : Simpang Jl. Khadijah, Jl. Burniat
25 : Simpang (1) Belakang Benteng Marlborough
26 : Ujung pantai Tapak Paderi
27 : Bundaran Benteng Marlborough
28 : Simpang JL. DI. Panjaitan, Jl. Ahmad Yani

29 : Simpang Jl. Benteng, Jl. Siti Khadijah
30 : Simpang Jl. Arrow, Jl. Bawal
31 : Simpang Jl. Belato, Jl. Rejamat
32 : Simpang Jl. Khadijah, Jl. A. Yani
33 : Simpang Jl. M. Hasan 1, Jl. Van Iskandar Bakar
34 : Simpang RS. Bahayangkara, Jl. A. Yani
35 : Simpang Jl. Rejamat, Kuburan Inggris
36 : Simpang Jl. Todak, Jl. Moh. Hasan
37 : Simpang Jl. Kol. Barlian, Jl. Arrow
38 : Ujung Jl. Kol. Barlian
39 : Simpang Jl. Belato, Jl. Arraw
40 : Simpang Jl. Letkol Santosa, Jl. Cendrawasih
41 : Simpang Jl. Jendral Sudirman, Samping Unihaz
42 : Ujung Simpang 4 Jl. Sudirman III
43 : Simpang Jl. Letkol Santoso, Jl. Van Iskandar Bakar
44 : Simpang 3 Jl. Soekarno Hatta, Jl. Letkol Santoso, Jl. Moh. Hasan
45 : Simpang 4 Jl. Kerapu Ujung
46 : Simpang Jl. Pari, Jl. Kerapu
47 : Simpang Jl. Moh. Hasan, Jl. M. Hasan 1
48 : Simpang Jl. Pari
(A,1) : Jl. Enggano
(A,2) : Simp. Jl. Ibnu Hajar (Kantor Polsek Teluk Segara) – Simp. (1) Jl. Enggano
(1,2) : Jl. Enggano
(1,6) : Jl. Bali
(2,3) : Jl. Ibnu Hajar
(2,9) : Jl. Pratu Aidit
(3,4) : Simp. Jl. TP. Kasim Nasir, Jl. Ibnu Hajar - Simpang Jl. Bencoolen
(3,5 : Jl. TP. Kasim Nasir
(5,9) : Jl. Sentot Alibasyah
(5,11 : Jl. TP. Kasim Nasir
(6,8) : Jl. Bali 1
(6,10) : Jl. Bali
(7,10) : Jl. Sentot Alibasyah
(7,8) : Gg. (1) Jl. Sentot Alibasyah – Ujung Jl. Bali 1
(7,9) : Jl. Sentot Alibasyah
(7,18) : Jl. Lettu Zulkifli
(8,9) : Ujung Jl. Bali 1- Simp. Jl. Moh. Zahab, Jl. Sentot Alibasyah
(9,13) : Jl. Moh. Zahab
(10,17) : Jl. MT. Haryono
(11,14) : Jl. Letkol Iskandar
(12,14) : Jl. Iskandar 10
(12,20) : Simp. Jl. Iskandar 10 – Simp. Jl. Mayor Salim Batubara
(13,14) : Gg. Iskandar 11
(13,15) : Simp. Jl. Moh. Zahab, Jl. Lettu Zulkifli, Jl. Gg. Iskandar 11 – Simp. Jl. Mayor Salim Batubara
(13,16) : Simp. Jl. Moh. Zahab, Jl. Lettu Zulkifli, Jl. Gg. Iskandar 11 – Simp. Jl. Letkol Iskandar, Jl. Iskandar 6A
(13,18) : Simp. Jl. Moh. Zahab, Jl. Lettu Zulkifli, Jl. Gg. Iskandar 11 – Simp. Jl. Letkol Iskandar, Jl. Lettu Zulkifli
(14,15) : Simp. Jl. Letkol Iskandar, Jl. Iskandar 10 –Simp. Jl. May Salim, Jl. Iskandar 8
(15,19) : Simp. Jl. May Salim, Jl. Iskandar 8 – Simp. Jl. Letkol Iskandar, Jl. Bukit Barisan

(16,18) : Simp. Jl. Letkol Iskandar, Jl. Iskandar 6A - Simp. Jl. Letkol Iskandar, Jl. Lettu Zulkifli
(16,19) : Simp. Jl. Letkol Iskandar, Jl. Iskandar 6A - Simp. Jl. Bukit Barisan
(17,18) : Simp. Jl. Letkol Iskandar, Jl. MT. Haryono - Simp. Jl. Iskanadar 5
(17,41) : Simp. Jl. Letkol Iskandar, Jl. MT. Haryono – Jl. Jend. Sudirman
(19,41) : Jl. Bukit Barisan
(20,21) : Simp. (3) Jl. May Salim Batubara - Simp. Jl. May Salim Batubara, Jl. KH. Ahmad Dahlan
(21,41) : Simp. Jl. May Salim Batubara, Jl. KH. Ahmad Dahlan – Jl. Jend. Sudirman
(22,23) : Simp. Jl. Khadijah. Gg. Khadijah – Simp. Jl. Khadihah, Jl. Letda Abu Hanifah
(22,24) : Simp. Jl. Khadijah. Gg. Khadijah - Simp. Jl. Khadihah, Jl. Burniat
(23,25) : Simp. Jl. Khadihah, Jl. Letda Abu Hanifah – Simp. Tapak Paderi
(23,29) : Simpang 3 Jl. Letda Abu Hanifah, Jl. Khadijah - Simpang Jl. Benteng, Jl. Siti Khadijah
(24,32) : Simp. Jl. Khadihah, Jl. Burniat – Simp. Jl. A. Yani, Jl. Khadijah
(25,26) : Simp. Tapak Paderi – Ujung Pantai tapak paderi
(25,27) : Simp. Tapak Paderi – Bundaran Tugu Pers
(25,28) : Simp. Tapak Paderi – Simp. Jl. Benteng, Jl. A. Yani
(27,28) : Bundaran Tugu Pers – Simp. Jl. Benteng, Jl. A. Yani
(27,30) : Bundaran Tugu Pers – Simp. Jl. Arrow, Jl. Panjaitan
(28,29) : Simp. Jl. Benteng, Jl. A. Yani – Simp. Jl. Benteng, Jl. Siti Khadijah
(28,B) : Simp. Jl. Benteng, Jl. A. Yani – Lapangan Merdeka
(28,38) : Simp. Jl. Benteng, Jl. A. Yani – Simp. Jl. Pasar Ikan, Jl. Kol Berlian, Jl. Prof. Dr. Hazairin
(30,37) : Simp. Jl. Arrow, Jl. Panjaitan – Simp. Jl. Arrow, Jl. Kol Berlian
(31,35) : Jl. Rejamat
(31,36) : Simp. Jl. Rejamat, Jl. Moh. Hasan – Simp. Jl.Todak, Jl. Moh. Hasan
(31,39) : Simp. Jl. Belato, Jl. Rejamat – Simp. Jl. Belato, Jl. Arrow
(31,47) : Simp. Jl. Rejamat, Jl. Moh. Hasan - Simp. Jl. M. Hasan 1, Jl. Moh. Hasan
(32,34) : Simp. Jl. A. Yani, Jl. Khadijah – RS. Bhayangkara
(32,B) : Simp. Jl. A. Yani, Jl. Khadijah – Lapangan Merdeka
(33,35) : Simp. Jl. M. Hasan 1, Jl. Van Iskandar Bakar – Simp. Jl. Rejamat, kuburan Inggris
(33,43) : Simp. Jl. M. Hasan 1, Jl. Van Iskandar Bakar – Simp. Jl. Letkol Santoso, Jl. Van Iskandar Bakar
(33,47) : Simp. Jl. M. Hasan 1, Jl. Van Iskandar Bakar - Simp. Jl. M. Hasan 1, Jl. Moh. Hasan
(34,35) : RS. Bhayangkara – Ujung Jl. Rejamat
(34,40) : RS. Bhayangkara - Simpang Jl. Letkol Santosa, Jl. Cendrawasih
(34,41) : RS. Bhayangkara - Simpang Jl. Jendral Sudirman, Samping Unihaz
(35,36) : Ujung Jl. Rejamat - Simpang Jl. Todak, Jl. Moh. Hasan
(36,38) : Simpang Jl. Todak, Jl. Moh. Hasan - Ujung Jl. Kol. Barlian
(36,B) : Simpang Jl. Todak, Jl. Moh. Hasan – Lapangan Merdeka
(37,38) : Jl. Kol. Barlian
(37,39) : Simp. Jl. Kol. Barlian, Jl. Arrow – Simp. Jl. Belato, Jl. Arrow
(38,B) : Ujung Jl. Kol. Barlian – Lapangan Merdeka
(39,48) : Simp. Jl. Belato, Jl. Arrow - Simp. Jl. Pari, Jl. Arrow
(40,43) : Simp. Jl. Letkol Santoso, Jl. Cendrawasih – Simp. Jl. Letkol Santoso, Jl. Van Iskandar Bakar
(41,42) : Simp. Jl. Jendral Sudirman, Samping Unihaz - Ujung Simp. 4 Jl. Sudirman III
(43,44) : Simp. Jl. Letkol Santoso, Jl. Van Iskandar Bakar – Simp. 3 Jl. Soekarno Hatta, Jl. Letkol Santoso, Jl. Moh. Hasan
(44,45) : Simp. 3 Jl. Soekarno Hatta, Jl. Letkol Santoso, Jl. Moh. Hasan – Simp. 4 Jl. Kerapu Ujung
(44,47) : Simp. 3 Jl. Soekarno Hatta, Jl. Letkol Santoso, Jl. Moh. Hasan – Simpang Jl. Moh. Hasan, Jl. M. Hasan 1
(44,C) : Simp. 3 Jl. Soekarno Hatta, Jl. Letkol Santoso, Jl. Moh. Hasan – Mesjid At-Taqwa
(45,46) : Jl. Kerapu (Simp. 4 Jl. Kerapu Ujung – Simp. Jl. Pari, Jl. Kerapu)
(46,47) : Simp. Jl. Pari, Jl. Kerapu – Simp. Jl. Moh. Hasan, Jl. M. Hasan 1

(46,48) : Jl. Pari (Simp. Jl. Pari, Jl. Kerapu – Simp. Jl. Pari)

3.4. Speed of walking of evacuees

The speed of walking of evacuees is calculated based on equation (1).

$$V = (C_0/C_1)\ x\ Vs \quad (1)$$

$$C_0 = W/S \text{ (round-in value)} \quad (2)$$

$$C_1 = W/S \text{ (round-up value)} \quad (3)$$

Information:
C_0 = Base capacity of the road
C_1 = Actual capacity of the road during disaster
V = Actual speed of walking during disaster (m/sec)
Vs = Speed of walking during disaster by a group of elderly person (0,751 m/sec)
W = Width of the road (m)
S = Space requirement of person (0,625 m^2)

The speed of walking of evacuees can be seen in the Table 3.

Table 3. Speed of walking of evacuees

Width of the road (m)	Base capacity (C_0)	Actual capacity (C_1)	Speed (m/sec)
2	3	4	0,563
2,5	4	4	0,751
3	4	5	0,601
3,5	5	6	0,626
4	6	7	0,644
4,5	7	7	0,657
5	8	8	0,751
5,5	8	9	0,667
6	9	10	0,676
7	11	12	0,688
8	12	13	0,693
9	14	15	0,701
10	16	16	0,751
12	19	20	0,713
13	20	21	0,715
13,5	21	22	0,717

3.5. Travel time

Travel time is a time needed to travel from a cluster to a cluster or from a cluster to an assemby point. In this research, travel time can be seen in the Table 4.

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Tabel 4. Travel time

C (AP)	*Edges*	Travel time *(sec)*	C (AP)	*Edges*	Travel time *(sec)*	C (AP)	*Edges*	Travel time *(sec)*
1	(A,1)	206,3	27	(15,19)	41,2	52	(31,47)	143,1
2	(A,2)	164,0	28	(16,18)	51,9	53	(32,34)	104,2
3	(1,2)	119,3	29	(16,19)	76,8	54	(33,35)	134,9
4	(1,6)	399,0	30	(17,18)	121,9	55	(32,B)	213,7
5	(2,3)	177,9	31	(17,41)	564,9	56	(33,43)	285,9
6	(2,9)	304,4	32	(19,41)	247,5	57	(33,47)	113,3
7	(3,4)	21,5	33	(20,21)	91,5	58	(34,35)	166,8
8	(3,5)	88,6	34	(21,41)	206,6	59	(34,40)	255,6
9	(5,9)	182,3	35	(22,23)	127,3	60	(34,41)	326,5
10	(5,11)	315,4	36	(22,24)	73,8	61	(35,36)	198,9
11	(6,8)	152,1	37	(23,25)	86,2	62	(36.38)	177,2
12	(6,10)	76,2	38	(23,29)	103,9	63	(36,B)	32,0
13	(7,10)	123,8	39	(24,32)	85,9	64	(37,38)	155,3
14	(7,9)	179,1	40	(25,26)	153,4	65	(37,39)	278,3
15	(7,18)	233,1	41	(25,27)	121,7	66	(38,B)	59,5
16	(7,8)	219,2	42	(25,28)	139,9	67	(39,48)	112,0
17	(9,13)	137,0	43	(27,28)	94,0	68	(40,43)	583,1
18	(10,17)	256,7	44	(27,30)	352,3	69	(41,42)	187,2
19	(11,14)	159,8	45	(28,29)	80,0	70	(43,44)	112,4
20	(12,14)	121,0	46	(28,B)	173,9	71	(44,45)	144,3
21	(12,20)	172,4	47	(28,38)	370,3	72	(44,47)	381,1
22	(13,14)	151,7	48	(30,37)	201,9	73	(44,C)	285,3
23	(13,15)	145,9	49	(31,35)	152,2	74	(45,46)	217,7
24	(13,16)	228,3	50	(31,36)	173,1	75	46,47)	63,2
25	(13,18)	292,1	51	(31,39)	183,3	76	(46,48)	196,9
26	(14,15)	149,1						

3.6. Design tsunami evacuation system software

Tsunami evacuation system is a software to determine an effective evacuation route based on minimum travel time from every cluster to every assembly point. In determining minimum travel time using Flyod Warshall algorithm and the tsunami evacuation system software is made using matlab programming.
Program algorithm

1. Input a matrix $A_{51\times51}$. The matrix $A_{51\times51}$ which the entries are travel time, i.e :

$$\begin{aligned} w_{ij} &= 0, && if\ i = j \\ &= w(i,j), && if\ i \neq j\ and\ (i,j) \in E \\ &= \infty && if\ i \neq j\ dan\ (i,j) \notin E \end{aligned}$$

2. Do Flyod Warshall algorithm. Find the minimum travel time from every clusters to all assembly points.
3. Based on step 2 and matrix at every iteration, find the nearest assembly point from every clusters and the effective evacuation route.
4. Finish

In this research, a tsunami evacuation system software have been produced which can be used to determine the evacuation route with minimum travel time from each cluster to all assembly point in Bengkulu City.

Table 5. Evacuation route with minimum travel time

C	Assembly Point	Evacuation route	Travel time (minute)	C	Assembly point	Evacuation route	Travel time (minute)
1	A	1 → A	3,44	25	B	25 → 28 → B	5,23
2	A	2→ A	2,73	26	B	26 → 25 → 28 → B	7,79
3	A	3→ 2 → A	5,69	27	B	27 → 28 → B	4,47
4	A	4→ 3 → 2 → A	6,01	28	B	28 → B	2,90
5	A	5→3→2→A	7,18	29	B	29 → 28 → B	4,23
6	A	6→1→ A	12,15	30	B	30 → 37 → 38 → B	6,95
7	A	7→ 10 → 6 → 1 → A	12,62	31	B	31 → 36 → B	3,42
8	A	8→6→ 1 → A	12,6	32	B	32 → B	3,56
9	A	9→ 2 → A	7,80	33	B	33 → 35 → 36 → B	6,10
10	A	10 → 6 → 1 → A	11,36	34	B	34 → 32 → B	5,30
11	A	11→ 5 → 3 → 2 → A	12,43	35	B	35 → 36 → B	3,85
12	A	12→ 14 → 13 → 9 → 2 → A	17,04	36	B	36 → B	0,53
13	A	13→ 9 → 2 → A	10,10	37	B	37 → 38 → B	3,58
14	A	14→13→ 9 → 2 → A	12,63	38	B	38 → B	0,99
15	A	15→14→13→ 9 → 2 → A	14,93	39	B	39 → 31 → 36 → B	6,47
16	B	16→ 19 → 41 → 34 → 32 → B	16,15	40	B	40 → 34 → 32 → B	9,56
17	A	17→ 10 → 6 → 1 → A	15,64	41	B	41 → 34 → 32 → B	10,74
18	B	18→16→ 19 → 41 → 34 → 32 → B	17,01	42	B	42 → 41 → 34 → 32 → B	13,86
19	B	19→41→34→32→B	14,87	43	C	43 → 44 → C	6,63
20	B	20→21→41→34→32 →B	15,71	44	C	44 → C	4,76
21	B	21→41→34→32 →B	14,17	45	C	45 → 44 → C	7,16
22	B	22→24 →32→B	6,22	46	B	46 → 47 → 33 → 35 → 36 → B	6,86
23	B	23 →29→28→B	5,96	47	B	47 → 33 → 35 → 36 → B	5,80
24	B	24 →32→B	4,99	48	B	48 → 39 → 31 → 36 → B	8,34

According to Table 5, an effective evacuation route can be seen in Figure 2.

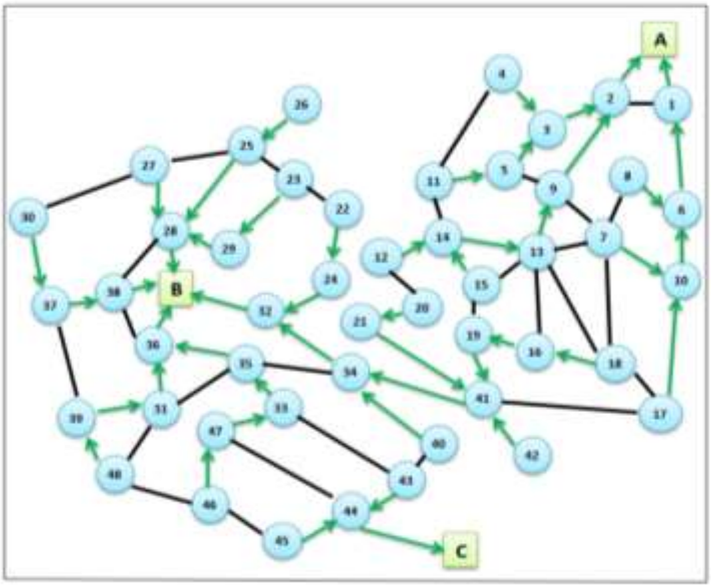

Figure 2. An effective evacuation route

4. Conclusion

A tsunami evacuation system software has been produced which can be used in determining an effective evacuation route from each cluster to the nearest assembly point. Determination of the minimum evacuation time using Flyod Warshall algorithm. The results show that for this research area, there were 5 clusters that took more than 15 minutes (InaTEWS, takes about 15 minutes after an early warning tsunami to evacuate) to get the nearest assembly points.

5. Acknowledgement

This research supported by Universitas Bengkulu under grant Penelitian Unggulan Universitas Bengkulu 2018 with No. SP DIPA-042.01.2.400977/2018.

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