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# A quantitative analysis of the level of congestion that occurred on the tsunami evacuation route during the tsunami disaster

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**Abstract.** This paper presents a quantitative analysis of the level of congestion that might occur on the tsunami evacuation route during the tsunami disaster. This evacuation route was defined using ArcGIS software based on the estimated evacuation distance. The area was extracted in several grids. The selected distance was the shortest one between each center point of the grid to the TES location point. The walking speed during the evacuation was estimated equal to the average walking speed of adults, children, and the oldster. This study found that congestion might occur in several points of the evacuation routes, and the level of service of the route would vary from A to D.

## 1 Introduction

A tsunami is a terrible sea wave that occurs due to earthquakes or volcanic eruptions on the seabed. West coastal of Sumatera Island has been hit four times by earthquakes and tsunami (fig.1) in the last 15 years. According to Latief [1], the city of Padang is a city with a very high level of danger. The estimated height of the tsunami is 9 meters, and the time it takes for these waves to reach the land is about 35-37 minutes.

An evacuation that can be done during earthquake and tsunami disasters are horizontal and vertical evacuations. In the horizontal evacuation, the evacuees move away from the tsunami-prone area. The time that evacuees have after valid information from the Disaster Mitigation Agency (or Badan Penanggulangan Bencana Daerah - BPBD) to evacuate is 17 minutes [4]. The average pedestrian speed is 1.33 m / sec [2]. The estimated distance that can be traveled by evacuees on foot is as far as 1.37 km while vertical evacuation is evacuation by utilizing buildings that are still surviving after the earthquake and has a height exceeding the estimated height of the tsunami.

TES (Temporary Evacuation Shelter) or also referred to as TEB (Tsunami Evacuation or Escape Building), is a building that is close to the center of the crowd or a residence that can be accessed by foot or vehicle [8]. Buildings that can be used as TES are partly owned by the government, which can be used at certain times or buildings that were deliberately made for the purpose of tsunami evacuation itself. In the city of Padang, there are 4 TES that have been built, and 58 buildings that have the potential as TES [3].


**Fig. 1.** History of the Earthquake and Tsunami on the West Coast of Sumatera

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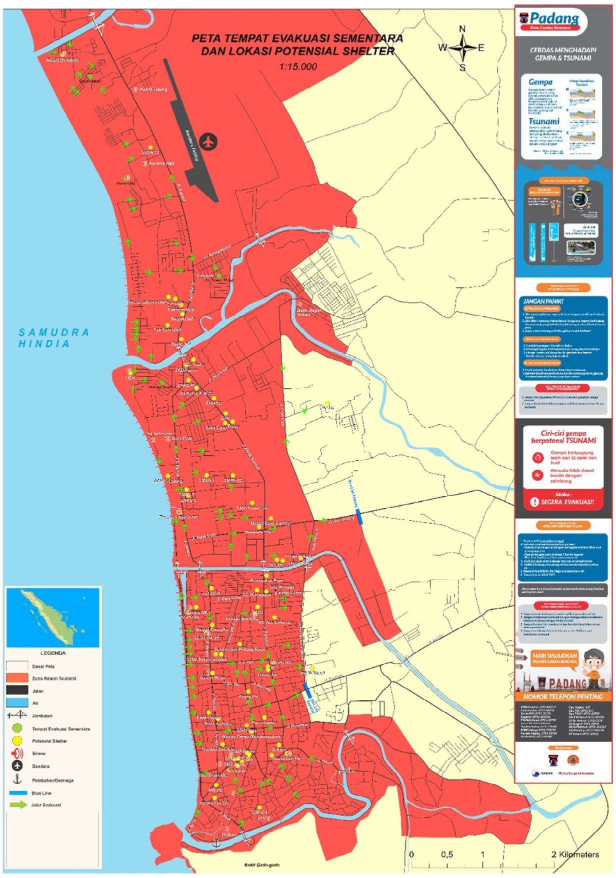


**Fig. 2.** TES and Potential Building TES Location.

TES buildings and buildings that have the potential to be a TES are spread in every district that has the potential to be exposed to a tsunami (fig. 2). In this study, the target TES is located in the West Sumatra governor's office complex with the surrounding area as its service area.

# 2 Literature Review

## 2.1 Estimated Number of Populations Affected by the Tsunami

Based on data from the Padang City Disaster Management Agency, residents who are exposed to the tsunami hazard are located along the coast of Padang. In the 2017 Padang city tsunami contingency planning document, it is stated that there are 50 villages affected by the tsunami, with a total population of 273,755 people. However, in this study, the affected area was limited to the surrounding area of the Governor Office's TES. As this study takes a small part of Padang, the number of people exposed was estimated to be 7971 people spread in 6 villages and divided into 91 grids. The population will be divided equally for each grid. The contingency planning document does not show detailed age groupings for populations exposed to the tsunami hazard.

**Table 1.** Predicted village and population that might be affected by the tsunami

| No | District | Exposed Population | Population / grid |
|---|---|---|---|
| 1 | Rimbo Kaluang | 2186 | 121 |
| 2 | Ujung Gurun | 607 | 61 |
| 3 | Purus | 1563 | 130 |
| 4 | Padang Pasir | 1304 | 93 |
| 5 | Olo | 1139 | 104 |
| 6 | Kampung Jao | 1172 | 65 |

## 2.2 TES Coverage Area, Evacuation Time, Walking Speed.

An earthquake event, it takes 5 minutes by Meteorology, Climatology and Geophysics Agency (or Badan Meteorologi, Klimatologi, and Geofisika – BMKG) to determine that an earthquake has a potential to trigger a tsunami or not. If it has a potential for tsunami, then it would take approximately 3 minutes to disseminate the information. The community would take 10-12 minutes to prepare themselves to evacuate. If the tsunami wave propagation time from the tsunami center to land is 37.1 minutes, then the community only has 17.1 minutes to evacuate [2] (fig. 3).

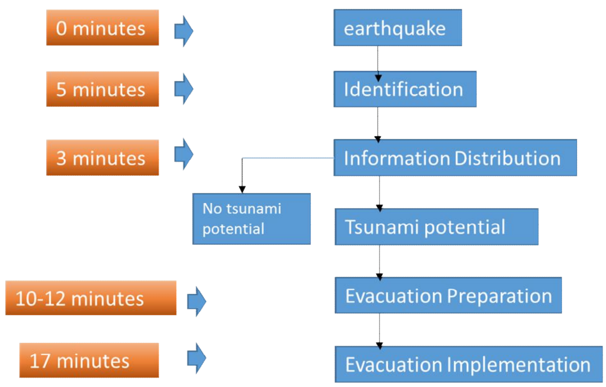


**Fig. 3.** Evacuation timeline

The TES coverage area is the farthest limit from the TES that allows evacuees to reach the TES safely. Generally, the TES coverage area will be circular with the TES building as its center. If the effective tsunami evacuation time is 17.1 minutes [2], and the average speed when walking is 1.33 m / sec [2]. So, the distance that can be reached in 17.1 minutes is 1.37 km. This number is used as the radius of the circle in making the TES coverage area (fig. 4). If the TES position is between evacuees and the sea, it is unlikely that people will go to TES [9].

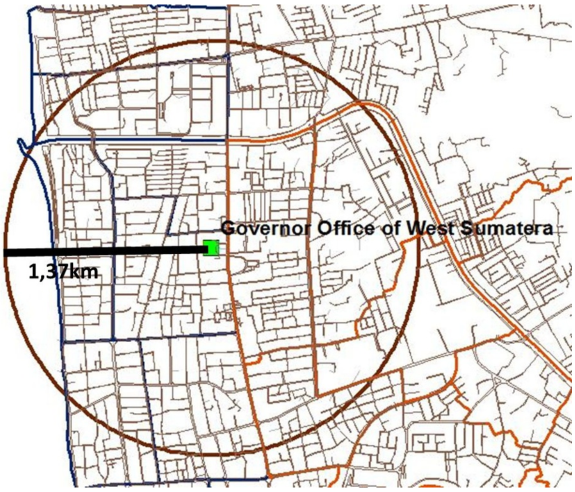


**Fig. 4.** Coverage Area of TES

### 2.3 Level of Service

The measurement used in the calculation of this LOS is pedestrian space, whilst pedestrian speed and flow are used as the second calculation [7].

• LOS A. Pedestrian Space > 5.6 m2/p Flow Rate ≤ 16p/min/m. In this condition, pedestrians can walk freely without fear of conflict with other pedestrians (fig. 5).

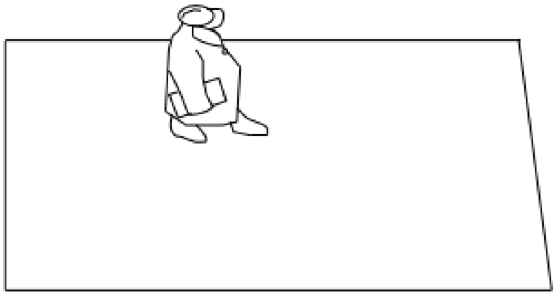

**Fig. 5.** LOS A

• LOS B. Pedestrian Space >3.7−5.6m2/p, Flow Rate > 16−23p/min/m. The conditions in LOS B provide enough space for pedestrians to move at will, but there is already the possibility of conflict with other pedestrians (fig. 6).

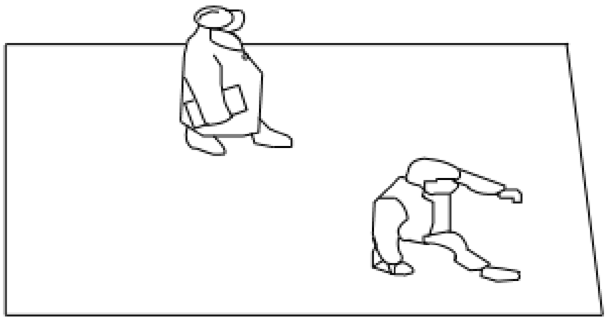

**Fig. 6.** LOS B

• LOS C. Pedestrian Space > 2.2−3.7m2/p, Flow Rate > 23−33 p/min/m. In this condition, there is enough space to move at normal walking speeds and pass in the same direction (fig. 7).

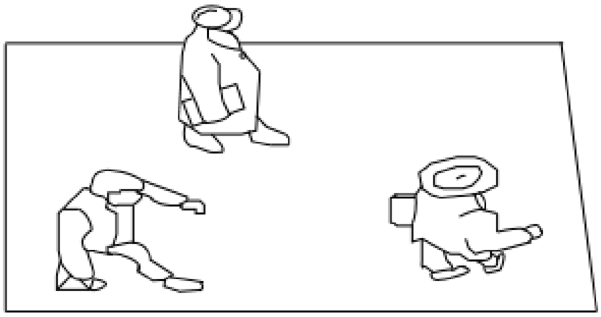

**Fig. 7.** LOS C

• LOS D. Pedestrian Space > 1.4−2.2m2/p, Flow Rate > 33−49p/min/m. In LOS D space for walking is still enough but can no longer walk past other pedestrians in the same direction (fig. 8).

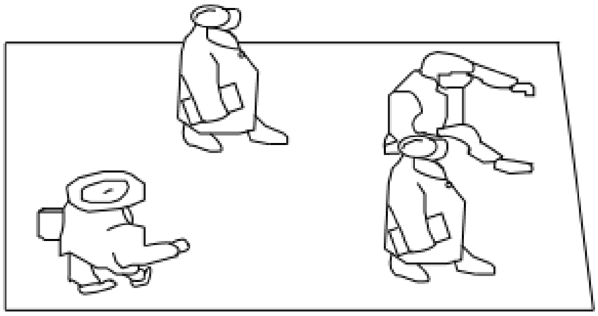

**Fig. 8.** LOS D

• LOS E. Pedestrian Space > 0.75-1.4m2/p, Flow Rate > 49-75p/min m. At this level, pedestrians have no choices except for certain walking speeds (fig. 9).

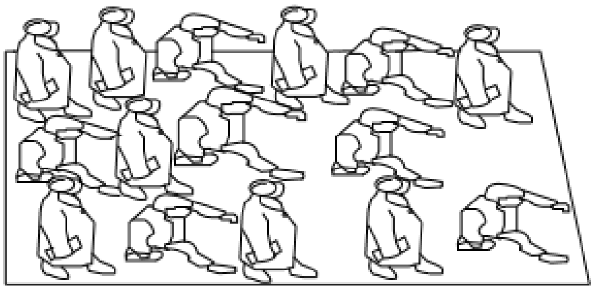

**Fig. 9.** LOS E

• LOS F. Pedestrian Space ≤ 0.75m2/p, Flow Rate varies p/min/m. LOS F is the worst level where normal running speed is no longer possible (fig. 10).

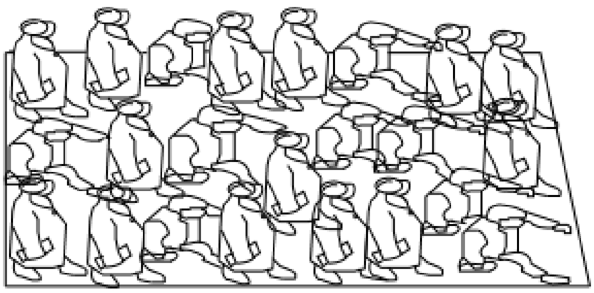

**Fig. 10.** LOS F

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# 3 Methodology

## 3.1. Determination of Location and Object of Research.

The chosen location as TES in this study was the Escape Building within the Governor's Office of West Sumatra. The TES building is located in the District of Padang Barat, Padang Pasir Village. This building was chosen because it has been verified by BPBD as a TES that can be accessed by the public.

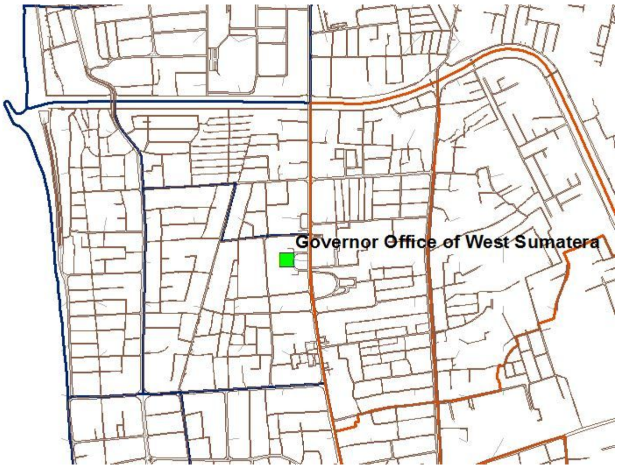


**Fig. 11.** Determining TES Location

## 3.2. Determination of TES Coverage Area Boundary.

The location chosen as TES is the Escape Building within the Governor's Office of West Sumatra. The TES building is located in the District of Padang Barat, Padang Pasir. Village. This building was chosen because it has been verified by BPBD as a TES that can be accessed by the public.

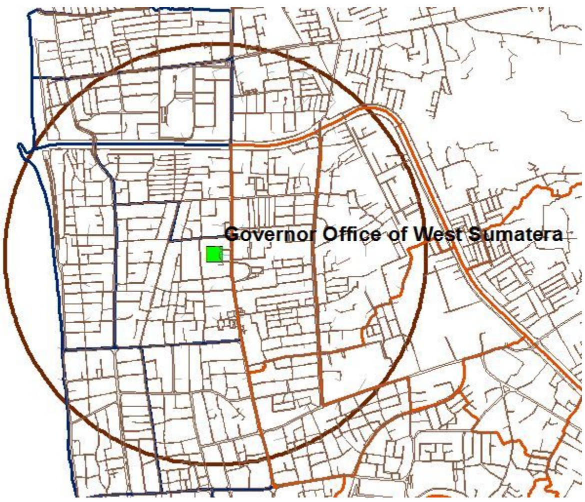


**Fig. 12.** Determining TES Boundary

Determination of this boundary is needed in determining the calculation of the number of populations exposed by the tsunami. Besides making the TES boundary line, the coverage area also makes it easy to determine the capacity and demand for the TES.

## 3.3. Grid Creation on the Map.

Grid making (fig. 13) will help to make it easier to mark locations, determine the number of residents in each location, and determine the population movements that are carried out in groups.

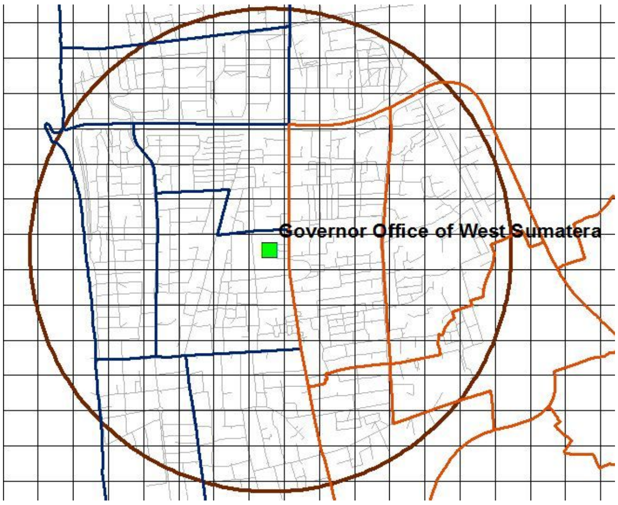


**Fig. 13.** Grid Creation

On each grid there is a midpoint of the grid that will be named by number so that it can be used as the identity of the grid. In addition, at the midpoint of the grid will also be given attributes that contain information on the number of residents at that location (fig. 14).

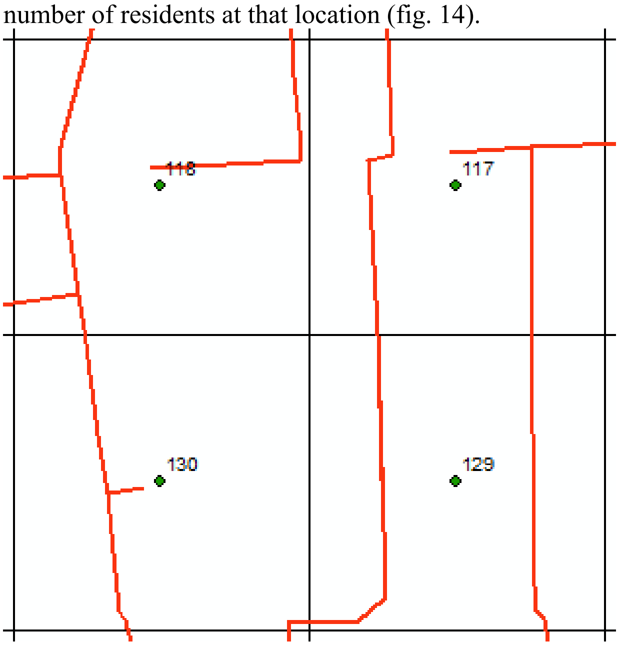


**Fig. 14.** Grid Details

## 3.4. Determining the Shortest Path.

The determination of the shortest path is calculated by using the ArcGIS application. Each center point of the grid will have the shortest path to the Governor's Office

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TES. When determining the shortest pathway, it can be seen that several roads will be passed by many evacuees, so that it can be used as a reference as a congestion-prone location. This can be seen in fig. 15.

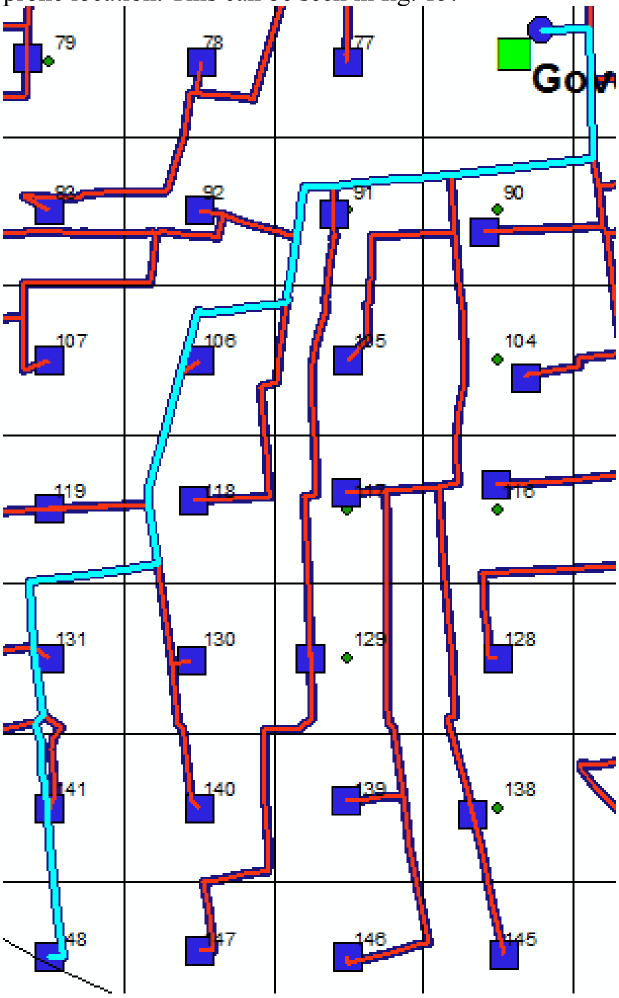


**Fig. 15.** Shortest Path Result

Each path used by each grid during the movement to the TES can be seen and displayed so that there is no error in determining the route even though there is a build-up of paths. Fig. 15 shows the shortest evacuation route that can be traveled from grid 148 to the Governor's Office TES.

### 3.5. Evacuation Movement Flow.

In this study, the evacuation movement was simulated to be carried out at 25 minutes, 30 minutes, and 35 minutes after the earthquake occurred and proved to cause a tsunami. If calculated from the initial movement when the evacuation begins, the evacuation process is carried out at minute 5 (fig. 16), minute 10 (fig. 17), and minute 15 (fig. 18).

In the 5th minute after the evacuation begins, the movement of evacuees is still spread over many grids, but there have been several piles of pedestrians on certain grids (fig. 16). The 10th minute after the evacuation is carried out, the movement of evacuees is increasingly conical and makes some points look crowded (fig. 17). In the 15th minute, there were still evacuees who were still far from the TES, but the piles of evacuees that occurred at the TES location and the road around the TES was getting bigger (fig. 18).

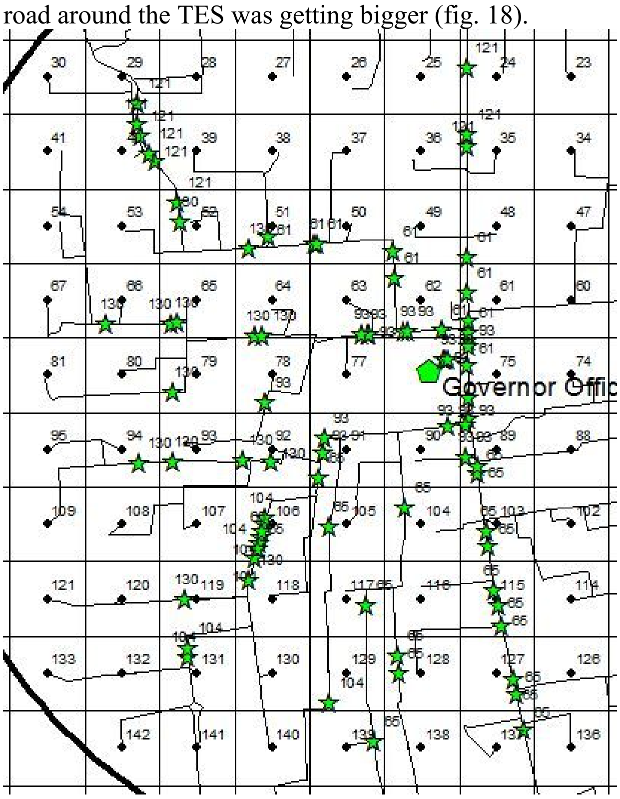


**Fig. 16.** 5 Minutes After Evacuation Begin.

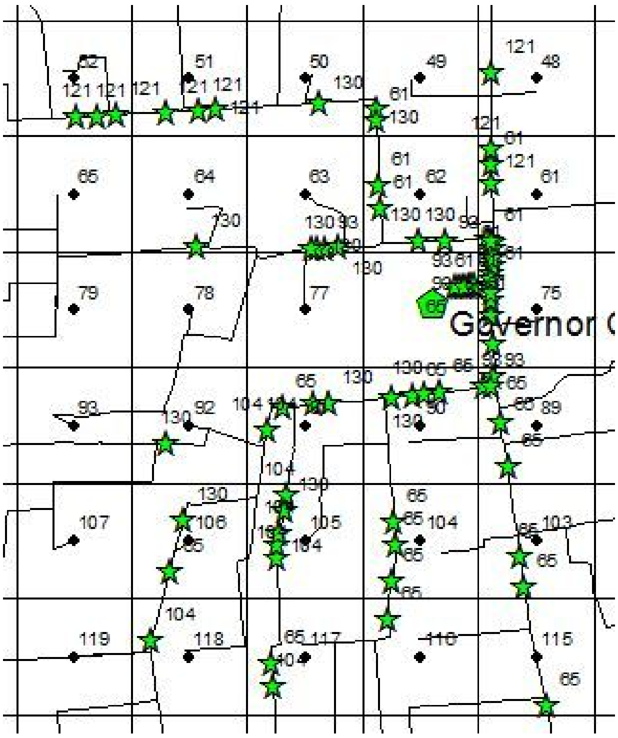


**Fig. 17.** 10 Minutes After Evacuation Begin

### 3.6. Pedestrian Space

Pedestrian space is used as a reference for determining LOS. Calculations for pedestrian space can use the following formula:

*Pedestrian Space = Area Width /Pedestrian Volume* (1)

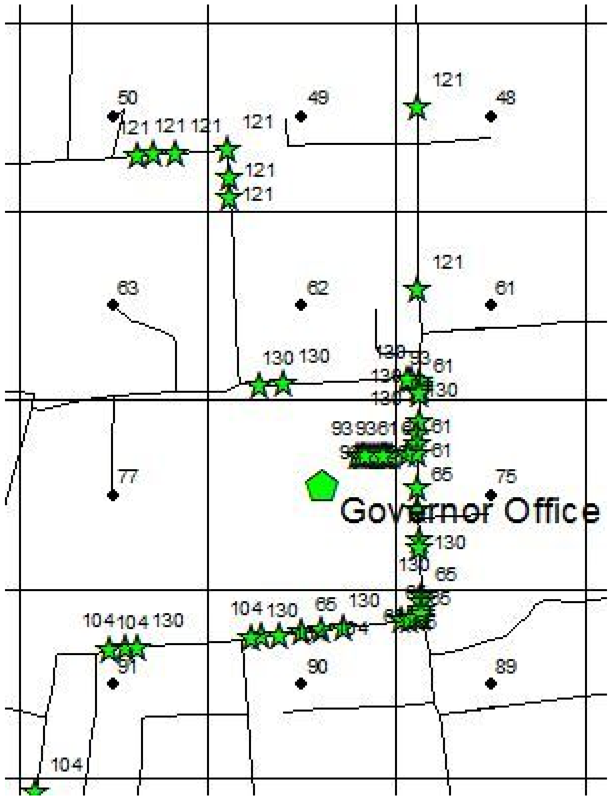


**Fig. 18.** 15 Minutes After Evacuation Begin

## 4 Result

The results of this study would be several maps showing the level of service for each road section used for evacuation. Each map will provide info that contains level of service for each route.

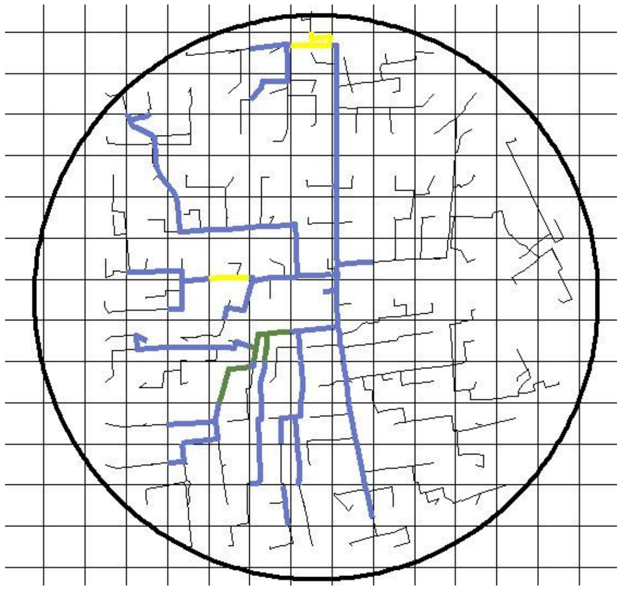

**Fig. 19.** 5 Minutes After Evacuation Begin

The first map (fig. 19) shows that 5 minutes after the information was disseminated by the government, there was a movement of evacuees, but there was no visible congestion yet. Few evacuees have reached the TES due to closer distance, can be identified from 44 grids that have evacuees pile. There are two grids that have LOS B, and two other grids have LOS C, and the rest are in LOS A.

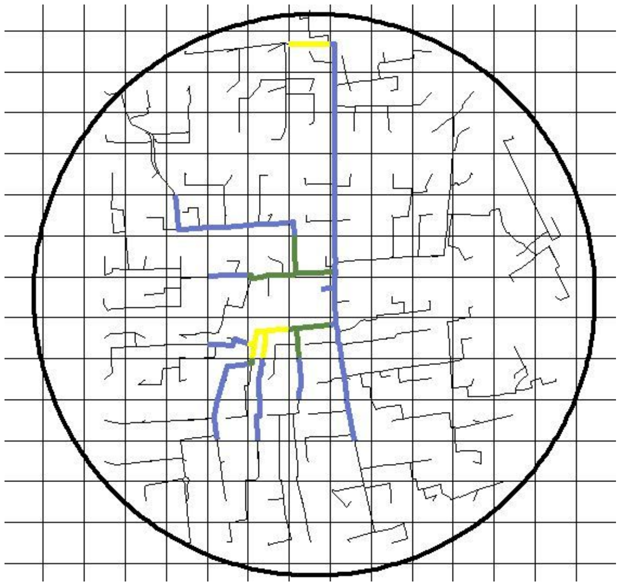

**Fig. 20.** 10 Minutes After Evacuation Begin

The second map is the situation during the evacuation at 10 minutes. The movement of evacuees looks increasingly closer to TES. In the 10th minute, 27 grids that have experienced refugee pile appears, four grids get LOS B, and two grids in LOS C.

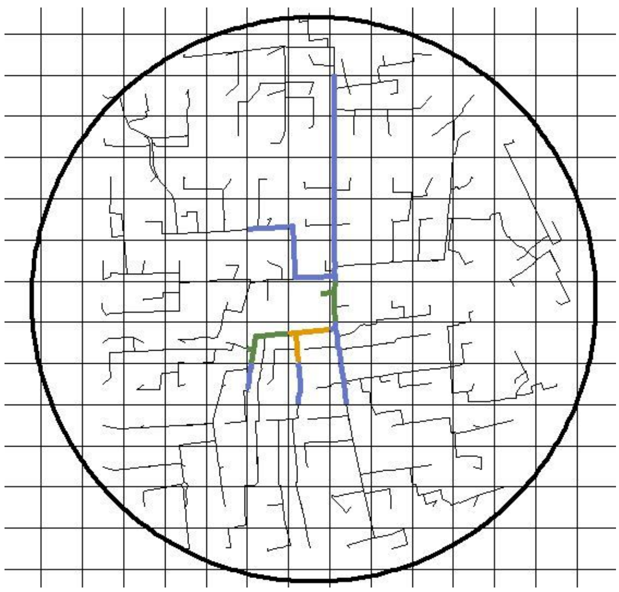

**Fig. 21.** 15 Minutes After Evacuation Begin

The 3rd map shows the movement of evacuees that are getting closer to TES, from 16 grids that have three grids in LOS B, and one grid on LOS D.

## 5 Conclusion

This research was conducted to determine the condition of the traffic of pedestrians on the evacuation road when an earthquake followed by a tsunami hit Padang and plotted to a map. In the map, the condition of this road is equipped with information on the level of service where we can find out the condition of the particular road density. This information can be utilized by the government in anticipating road congestion when an earthquake is followed by a tsunami. Further, simulating the different evacuation starting time and also the evacuation speed by age would be our next research.

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