https://doi.org/10.1051/e3sconf/202133106005

Assessment of tsunami evacuation road performance

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Abstract. A series of disasters, from the 2004 Aceh Tsunami to the 2009 Padang Earthquake, has changed the paradigm of urban development in coastal areas in Indonesia. District or City Regional Regulations concerning Regional Spatial Planning finally oblige disaster mitigation by constructing evacuation roads. The attraction of the Tsunami Evacuation Road (TES) which was built with a relatively wide size in the city, makes the road a favourite route for motorists. The increased vehicular traffic also triggered the addition of the number of new commercial buildings along the road. The Indonesian Road Capacity Manual 1997 for urban roads is used as a reference in the analysis of the service performance of these road sections. The relatively rapid increase in traffic volume and side-road disturbances have resulted in a relative decline in road performance in a short period. The active role of the government in minimizing body side disturbances, by maximizing the implementation of traffic management and control of land-use changes are options.

1 Introduction

Since a series of disasters from the Aceh Tsunami disaster in 2004 to the West Sumatra earthquake in 2009, it has changed the paradigm of urban infrastructure development in many cities on the west coast of Sumatra, Indonesia. Municipal / Regency Regional Regulations on Regional Spatial Planning have made it mandatory to mitigate the Tsunami disaster, by constructing several evacuation roads in the city. The attractiveness of the Tsunami disaster evacuation road, which was built wide in the city, makes it the favourite route choice for motorists and drivers in fast-growing traffic activities. And in turn, triggered a sporadic increase in the number of houses and commercial buildings along the road. The Indonesian Road Capacity Manual (IRCM) 1997 in the section of urban roads is used as a reference for analysing road performance indicators.

There are several cities with a large population on the west coast of Sumatra. Many municipal and district governments along the regions understand that there is a high risk of a tsunami disaster. The government continues to make mitigation efforts, through regulation and provision of disaster-responsive and safe urban infrastructure. There are two types of evacuation options, horizontal and vertical evacuation. Vertical evacuation, by providing shelter buildings that are friendly to earthquake and tsunami disasters. And options for horizontal evacuation, by providing TES. The urban road network must be built to provide security and safety guarantees and could accommodate as much as needed when people evacuate. People can go to escape to higher locations, as a relatively safe place.

The understanding of the municipal and regency governments in mitigating the tsunami disaster is shown in the form of public policies (regional regulations), and the realization of the construction of TESs in its urban road network. The form of the policy is stated in the Regional Regulation on Regional Spatial Planning (RTRW) of each of the Municipality and Regency. Traffic growth that occurs in the evacuation route is believed to reduce the performance of the evacuation road, which is marked by frequent traffic jams, the lower travel time.

This article will provide an overview of the performance of the TES. Quantitative and qualitative methods are used in analysing.

2 Road Capacity and Tsunami Evacuation Road

2.1 Road Capacity and Degree of Saturation

Road capacity is the maximum current that passes through a point on the road per unit hour under certain conditions. The IRCM-1997 used four parameters to determine the capacity of the road, namely correction factors for road width, road lane separation, roadside disturbance, and city size [1]. The basic equation for determining capacity on urban roads is as follows:

$$C = C0 \times FCW \times FCSP \times FCSF \times FCCS \quad (1)$$

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Where: C = Capacity (emp / hour), C_0 = Basic capacity (emp / hour), F_{CW} = Road width adjustment factor, F_{CSP} = Directional separation adjustment factor (only for undivided roads), F_{CSF} = Adjustment factor of side and shoulder, F_{CCS} = City size adjustment factor.

$$DS = Q / C \quad (2)$$

Where: DS = Degree of Saturation, Q = maximum traffic volume (flow) (emp / hour), C = Capacity (emp / hour).

2.2 Traffic Growth

Traffic growth predictions have been discussed in detail [2], where five types cause traffic growth. Traffic growth is likely to vary from the normal traffic growth; future traffic volumes shall be predicted by taking into account: Normal growth, Diverted Traffic, Generated/ Induced Traffic, Intermittent traffic, and Suppressed traffic. Had discussed that trade integration, and global trade, in general, has increased more than three times faster than global aggregate output .[3]. Trade gives rise to traffic. Traffic growth from the economic performance are as follows: fair cost structures e.g., a full allocation of external costs; improving efficiency using modern logistics; consensual settlement development planning; and support for regional marketing.

2.3 Tsunami Evacuation Road

Many researchers have researched TES, both on how to determine and choose evacuation routes in a city. Many considerations were taken in determining the TES [4]. The Indonesian government issued a National Standard, to determine the TES. TESs are designed practically and simply so that they are easily followed by decision-makers and stakeholders, but they are still based on scientific principles [5].

The Indonesian Standards Agency requires that in the design of TESs several things become practical considerations, namely: TESs are designed through a road alignment from the coastline; should not cross rivers or bridges; to avoid the build-up of refugees, made several parallel evacuation routes that move away from the coast; in densely populated areas, an evacuation route is designed in the form of a block system; for very low and sloping areas, which are far from high places, a safe area system in the form of buildings or artificial hills is made, which is recommended as a temporary vertical evacuation; every evacuation route needs signs to guide refugees; the direction of daily traffic is directed towards the direction of evacuation; the activities in designing the evacuation cycle need to be phased, starting with data collection, studio work, provisional design, field review, final design, printing and outreach [5].

Previous studies, such as those carried out on the Last-mile Evacuation project by the UN and the German government. The project produced a map of the travel time when tsunami evacuations hit the municipality of Padang. The project shows how much time is needed to escape from a location in the tsunami hazard zone to a safe altitude area. The project also predicts the time needed for evacuation for different periods, in the morning, afternoon, and evening [6,7].

3 Method

Many studies have been conducted to review the effectiveness of TESs, including in designing. However, of all the articles and books written about TESs, there is no writing that clearly and thoroughly states what parameters were calculated or used in designing TESs and how to evaluate the performance of existing TESs in various cities.

The main method used in this study is to review existing TESs in urban areas. Evacuation roads that have been determined by the municipality or district government are used as a sample of the assessed road, while the steps taken are:

- Reviewing several textbooks or journal articles on TESs,
- Conduct a road performance assessment by calculating the current volume and capacity of the road,

4 Analysis and Results

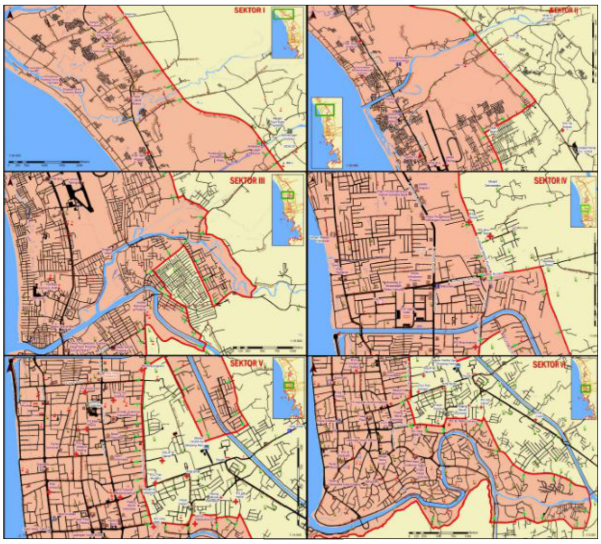
4.1 Road Geometric

In 2012, the Padang municipal government approved Regional Regulation number 4 of 2012, concerning the 2010-2030 Padang Municipal Spatial Plan (RTRW). The RTRW has listed six zones of the city road (Fig 1 (a)), as a TES [8]. This regulation becomes a reference in urban space development. In this study, Alai-By-pass Road, Padang was selected. This road is one of the roads that have been determined by Padang Municipality as a TES. This road is very important as a TES because it connects the western area (coastal area) from downtown Padang to the east of the city (the higher area, as a tsunami safe zone).

The technical data for the Alai-By-pass Road are as follows, are urban roads, Primary Arterial roads, road length = 4.1km, lane width (j) = 4 x 3.5 m, shoulder-width (b) = 1 m, width pavement = 14 m, raised median width (m) = 0.3 m, and pedestrian path width (t) = 1 m [9]. There are road signs and road-marks that are posted as signs indicating the road section as a TES (Fig 1. (b)). There are two types of cross-sectional sections of the TES, from the Alai-By-pass Road, one with an elevated median and the other without a road median (Fig 1. (c)).

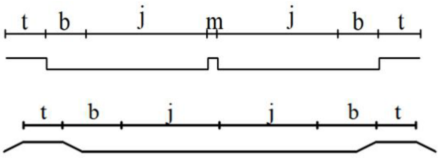
4.2 Land Used and Building Function

Changes in land use along the TES are reviewed, aerial photographs of 2010, 2013, 2016, and 2019, respectively observed (Fig 2.). The number of buildings for the year of observation is calculated. Visually in the field visible changes in the number of buildings along with the TES of Alai-By-pass Road. Table 1. shows that for almost 10 years there has been a significant increase in the number of buildings on both sides of the road (north and south side of the road). During that period, there was more than a hundred percent increase.



(a)

(b)



(c)

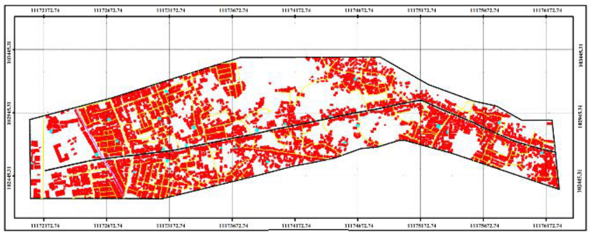
Fig. 1. (a) Map of six horizontal evacuation route sectors in Padang City [8], (b) Tsunami safety zone boundary road-mark, (c) Types of a cross-section of TES of Alai-By-pass Road.

Table 1. Number of buildings and area of vacant lots on Alai-By-pass Road, in the years 2010, 2013, 2016, 2019

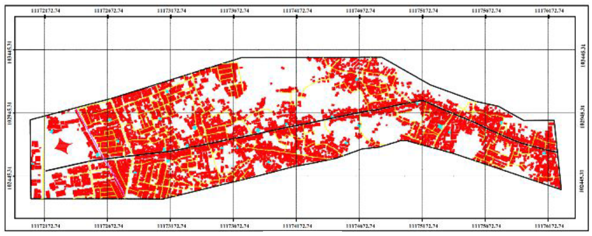
Road Side	**Number of the building (unit)**			
	Year			
	2010	**2013**	**2016**	**2019**
North side	278	490	494	520
South side	161	475	491	510
Total number	439	965	985	1030
Percentage Growth		39.94%	0.69%	1.52%
	Area of vacant lots in the observation (Ha)			
Area of vacant lots	174	167.3	165.8	163.7
Reduction of Vacant Land		2.23	0.50	0.70

Based on the analysis in the GIS software, it is also obtained a change in the total area of land use from each year of observation, which is as presented in Table 1.

In terms of building function, many buildings have changed their function, such as houses that have changed into shops, restaurants, minimart, shop houses, workshops or gas stations, or vacant lots become shop houses. The main reason for changing is the high land value for the business.



(a)



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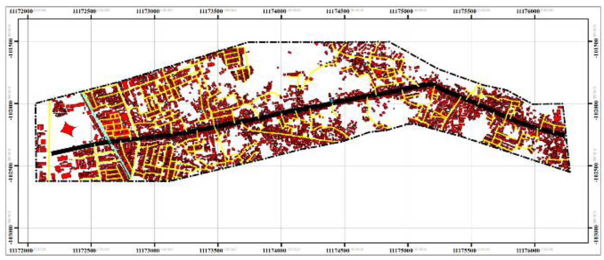

(d)

Fig. 2. Map of the area on TES of Alai-By-pass Road (a) digitizing the map in the year 2010, (b) digitizing the map in the year 2016), (c) Aerial photographs in the year 2019, (d) digitizing maps in the year 2019.

4.3 Traffic Volume

Three sets of daily traffic volume data for 2016, 2017 and 2018, on Alai-By-pass Road were obtained from previous studies [10, 11, 12]. And for 2019 data, a survey was conducted to obtain daily traffic volume. The four data sets are then compared to obtain the number of changes in traffic volume that have occurred.

Fig 3 shows the comparison of hourly daily traffic volume for the year 2016 to 2019. A collection of daily traffic data in 2016, different from other data sets in the year, because the 2016 data are only collected three morning, afternoon, and evening rush hour periods (which are taken for two continuous hours each period). It shows (1) hours and peak traffic volume in 2016 is 07.30-08.30WIB, 1612emp/hr, (2) hours and peak traffic volume in 2017, 06.45-07.45WIB, 2715emp/hr, (3) hours and peak traffic volume in 2018, 06.45-07.45WIB, 2740emp/hr, (4) hours and peak traffic volume in 2019, 07.00-08.00WIB, volume 2845emp/hr. The total peak traffic volume in both directions passing the Alai-By-pass Road has increased during the period.

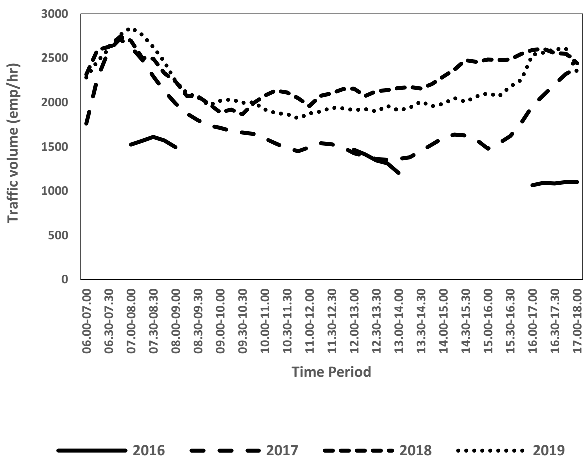

Fig. 3. Hours and peak traffic volume for year 2016 to 2019

4.4 Road Capacity and Performance

Before 2012 the Alai-By-pass Road was a road with a width of less than 5m. Over time, a major earthquake occurred on 30 September 2009, resulting in the Padang municipal government reorienting development for all sectors, including the road sector. Where several roads were widened and designated as evacuation roads. So that through central government funds, by 2012 the Alai-By-pass Road has become 12m wide. Due to a very significant road widening, this road is the first choice of drivers and motorists on their way from the west to the east (vice versa) in the city of Padang. Initially, there were relatively few houses and shops along both sides of the road. However, over time, activities along this road become congested and tend to disrupt road performance, due to vehicles parked on the road, long queues at several locations, pedestrian crossings, and school-safe zones, etc.

Using equation (1), the capacity of the Alai-By-pass Road is calculated. The road capacity is calculated based on field conditions from the four correction factors in equation (2). Then, the four correction factors were compared during the period 2016 to 2019. During that period, from the results of a review of the map and land use along the road as well as side obstacles that occurred due to activities on the constructed land. Table 2 shows the four correction factors for calculating road capacity. In 2019 there was a reduction in the value of the correction factor for the adjustment of obstacles and direction separation (some segments of the road became separated). This decrease was caused by the increasingly crowded land activities along the evacuation road (shops and minimarkets) and the increasing number of traffic disturbances on the road, resulting in a reduced road capacity value.

Table 2 . Road Capacity of Alai-By-pass Road in the year 2016-2019.

Year	**Factor**					**Road Capacity (emp/hr)**
	C_O	**F_{CW}**	**F_{CSP}**	**F_{CSF}**	**F_{CCS}**	
2016	6000	1	1	0.91	0.94	5132.40
2017	6000	1	1	0.91	0.94	5132.40
2018	6000	1	1	0.86	0.94	4850.40
2019	6000	1	0.985	0.86	0.94	4777.64

Table 3 . Degree of Saturation (DS) and Performance Index of TES for year 2016 to 2019.

Year	**Peak hour**	**Volume Total (emp/ hour)**	**Road Cap. (emp/ hour)**	**DS**	**Perform. Level Index**
2016	07.30-08.30	1612.2	4850.40	0.33	B
2017	06.45-07.45	2714.75	4850.40	0.56	C
2018	06.45-07.45	2740.30	4850.40	0.56	C
2019	07.00-08.00	2845	4777.64	0.60	C

Table 3 shows the performance level index of the TES reviewed during the study period, which is decreasing (from level B to C). The assessment that has been carried out on TES in Padang, shows that there are two reasons for the decline in the performance of TES, the first is an increase in traffic volume, and the second is an increase in traffic disturbances on the side of the road caused by an increase in land-use activities.

Maintaining the TES function as an escape route using vehicles from the Tsunami disaster in areas along the coast must be the main concern of the government. Supervision and prohibition of increased interference during TES is a priority, for TES to function.

5 Summary and Recommendation

The capacity and performance of TES have decreased over a 4-year period from 2016 to 2019.Some of the reasons for the decrease in capacity is that the level of side interference on TES has increased every year, it is seen from changes in the number and activity of buildings, as well as the level of compliance of road users who park on-street with irregular parking.

Along the Tsunami evacuation road, it is very necessary:

- o Monitoring of land-use change and enforcement of land use regulations.
- o Law enforcement against offenses by drivers and motorists who do not comply with parking rules.

The author thanks the Directorate of Research and Community Service (DRPM) of the Ministry of Research, Technology, and https://doi.org/10.1051/e3sconf/202133106005

Higher Education (Kemenristekdikti RI) for providing research funding through the Master Thesis Research (PTM) scheme with contract number 051/SP2H/LT/DRPM/2019. A thank you also goes to the Research and Community Service Institute (LPPM), Universitas Andalas, for helping with the administration of research and disbursing research funds, with contract #T/31/UN.16.17/PT.01.03/PKR-Kebencanaan/ 2019.

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