ADIBs: A Low-Cost Early Tsunami Warning System for Malaysia

Muhammad Zaidi bin Mohtar and Norli binti Umar

Techno Brozek Enterprise, Melaka, Malaysia

E-mail: technobrozek@gmail.com
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Abstract. Tsunami Warning System (TWS) consist detection and notification system that mostly operated by countries affected by Tsunami. For Malaysia, it is not cost effective to use cutting edge TWS. The reason is it free from big earthquakes where its location far from tectonic plate boundaries. Besides, it's surrounded by neighbouring countries which act like natural wall to prevent natural disaster reach to Malaysia territory. Fatal Tsunami happened on 2004 has changed this fact and Malaysia is exposed to secondary effect of natural disaster happened at neighbouring countries. An earthquake with magnitude nine (9) occurred at Banda Aceh was generate Tsunami wave that propagate from Indonesia to Malaysia coastline killed 68 people. As an immediate action, Malaysian government introduce Malaysia Tsunami Early Warning System (SAATNM) which the technology behind the system is from imported equipment. Unfortunately, this sophisticated equipment is costly to maintain and it's exposed to vandalise. Thus, ADIBs is acronyms for Aware Tsunami Detection Interconnected Built-In System is a TWS propose by authors to help Malaysian government agencies to develop a low cost and reliable TWS suitable for Malaysia usage. The authors also propose a novel method to calculate Tsunami risk which considers severity of Tsunami, occurrence of Tsunami and detection of Tsunami. Tsunami Failure Mode Effect Analysis (TFMEA) has successful informs Malaysia should focus on prevention works rather than using expensive TWS.

Keywords: ADIBs , Tsunami Warning System , Tsunami Failure Mode Effect Analysis

1. Introduction

1.1 Malaysia Tsunami History

On 26-December-2004, an undersea earthquake with magnitude 9.0 happened near Sumatra, Indonesia killed over 200,000 people at six (6) countries (Indonesia, Sri Lanka, India, Thailand, Somalia and Malaysia). The remembrance tragedy was followed by deadliest tsunami struck the states located northern of Malaysia which sacrificed 68 people [1]. Malaysia is a Southeast Asia country where its location is geo-strategic that's safe from earthquakes, tsunami, volcanoes eruption and tornados. After the tragedy, there is no guarantee the safe condition will lasting forever. Malaysia are exposed to secondary effect of natural disaster happened at neighboring countries.

Figure 1 to Figure 6 shows the destruction at affected location after hit by Tsunami. Within short time, the victims losses their houses, valuable belongings and more sad were losing their family members in front of their eyes. Malaysian is mooted with long time history without any big natural disaster occurred except bad flooding. They were surprised and not expect that Tsunami waves can reach to their coastline. Inside Figure 7 shows an indicator that Malaysia is a "protected country" which free from active volcanoes and far away from tectonic plates boundaries as in Figure 8. It's also located at center of Southeast Asia that's surrounded by neighboring countries like Indonesia, Philippine and Cambodia. Their function is like "natural walls" that reduce or eliminate outside threats from reach to Malaysia. Despite of this believe, the Sunda Arc is major active plate boundary where Indo-Australia Plate is subducted at 70mm/year under the Eurasian plate caused earthquakes and potential to generate Tsunami [11]. Thus, the Tsunami happened on 2004 was triggered the Malaysian government to get ready for future threats and they must to make sure the sad tragedy will not repeated. As a result, Malaysia National Tsunami Early Warning System (SAATNM) was established on 2005 by Malaysian Meteorological Department (MET Malaysia) [12].

Figure 1 Tsunami at Acheh, Indonesia [2]

Figure 2 Tsunami at Ampara, Sri Lanka [3]

Figure 3 Tsunami at Madras, India [4]

Figure 4 Tsunami at Phuket, Thailand [5]

Figure 5 Tsunami at Puntland,Somalia [6]

Figure 6 Tsunami at Kuala Muda, Malaysia [7]

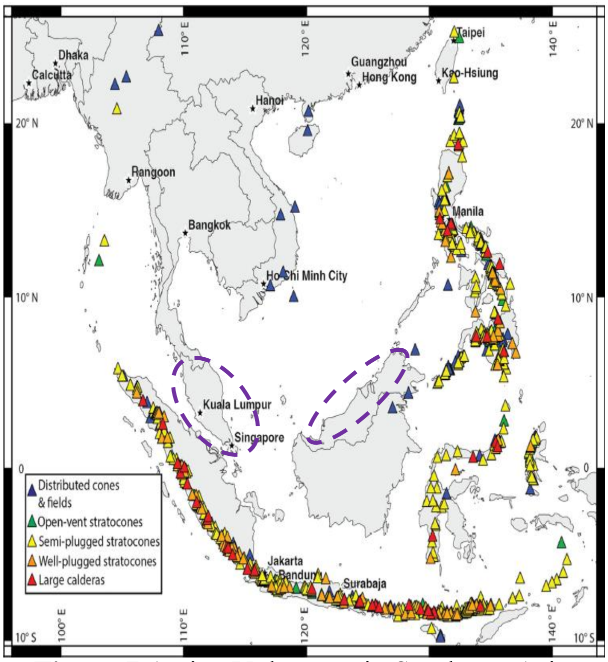

Figure 7 Active Volcanoes in Southeast Asia (Malaysia Inside Purple Circle is free from volcanoes) [8]

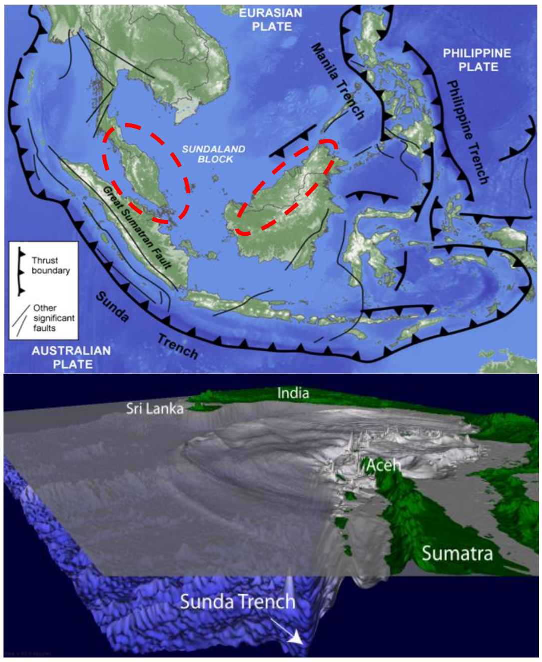

Figure 8 Tectonic Plates in Southeast Asia. Malaysia Inside Red Circles (Above) and Subduction at Sunda Trench caused Earthquake (Below) [9][10]

1.2Malaysia Tsunami Risk Analysis

Based Figure 9 and Figure 10, there have potential Tsunami can occur at West and East of Malaysia according to historical data of earthquakes. Risk assessment of Tsunami can be calculated by using Tsunami Failure Mode Effect Analysis (TFMEA) method. This method is first ever in the world proposed by authors to determine Severity of Tsunami (ST), Occurrence of Tsunami (OT) and Detection of Tsunami (DT).

The severity of Tsunami (ST) is determined according to research conducted by International Research Institute of Disaster Science (IRIDeS), Tohoku University. The data of 100 world historical tsunami was selected based on earthquake larger than 7.5 magnitude and the seismic events after years 1600*AD* [15]. Then, the data is filtered by authors according to 2 criteria and tabulated in Table 1. The first criterion is the tsunami was occurred in Southeast Asia and the second criterion is it's happened at neighbouring countries near to Malaysia coastline.

The authors classified the Severity Rank based on how big the Severity of Effect to numbers of Deaths, Damage and House Destroyed. The numbers of Deaths is the first factor followed by value of Damage in million dollar and numbers of house destroyed. The numbers or values are benchmarked to historical Tsunami data in Table 1. Table 2 shows the Severity of Tsunami (ST) proposed by authors with Severity Rank from one (1) to ten (10). Severity Rank is added inside Table 1 at last column to determine the severity of Tsunami happened at South East Asia.

As summary, Malaysia is exposed with severe Tsunami happen at neighbouring country especially West Malaysia which near to Sunda Trench was recorded highest Tsunami severity rank compared to East Malaysia has lower Tsunami severity rank. This claim is same as a conclusion made by a research conducted by geologist at University of Malaya [16].

Table 1 Summary of Tsunami Filtered by Authors

No.	Year	Location	Maximum Water Height (m)	Deaths (ppl)	Damage ($Mill.)	House Destroyed	Severity Rank
1	1897	Sulu Sea	7.0	13	No data	33	7
2	1975	Philippine Trench	3.0	0	No data	30	5
3	1977	Solomon Island	0.04	0	0	0	1
4	1996	Sulawesi	7.7	9	1	400	7
5	2004	Sumatra	50.9	227,899	10,000	No data	10

Table 2 Severity of Tsunami (ST)

Effect	Severity of Effect	Severity Rank
SMALL EARTHQUAKE	No tsunami	1
BIG EARTHQUAKE	No tsunami	2
SMALL TSUNAMI	No destruction. Maximum water height less than 1 meter	3
BIG TSUNAMI	No destruction. Maximum water height more than 1 meter	4
DAMAGE	Low number of damage (<1$Mill.) or house destroyed (<100) or both	5
FATAL	Low number of deaths (<100ppl) but no damage and house destroyed	6
FATAL & DAMAGE	Low number of deaths (<100ppl) and damage (<1$Mill.) or house destroyed (<100) or both	7
SMALL DESTRUCTION	Massive number of damage (>1$Mill.) or house destroyed (>100) or both	8
BIG DESTRUCTION	Massive number of deaths (>100ppl), but no damage and house destroyed	9
TOTAL DESTRUCTION	Massive number of deaths (>100ppl) and damage (>1$Mill.) or house destroyed (>100) or both	10

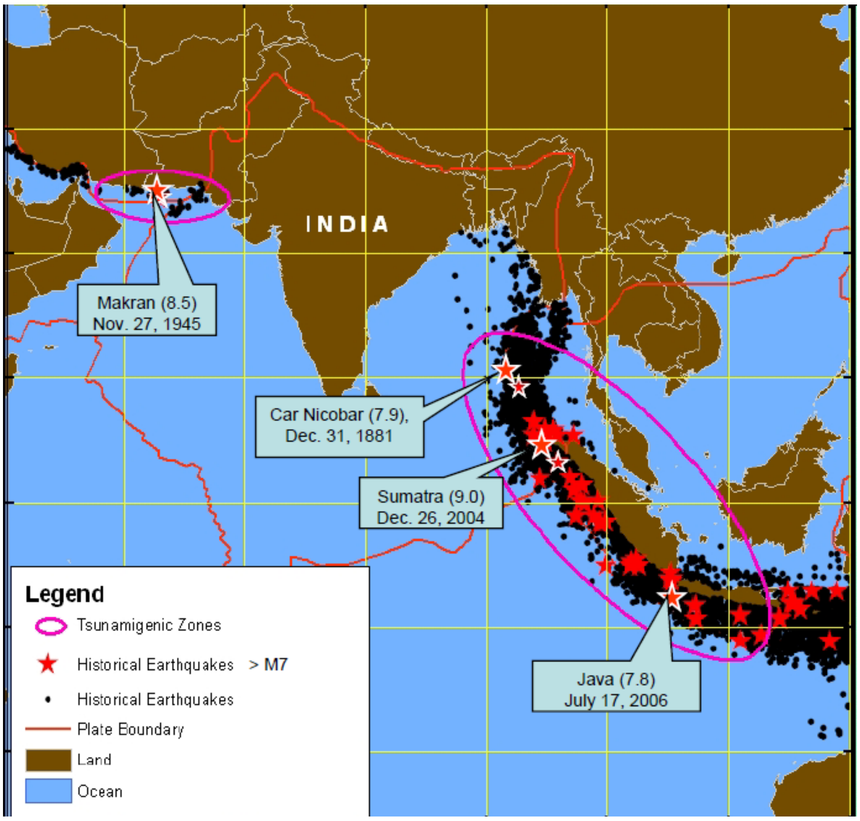

Figure 9 Potential Tsunamigenic Zoned based on Historical Earthquakes Near to West Malaysia [13]

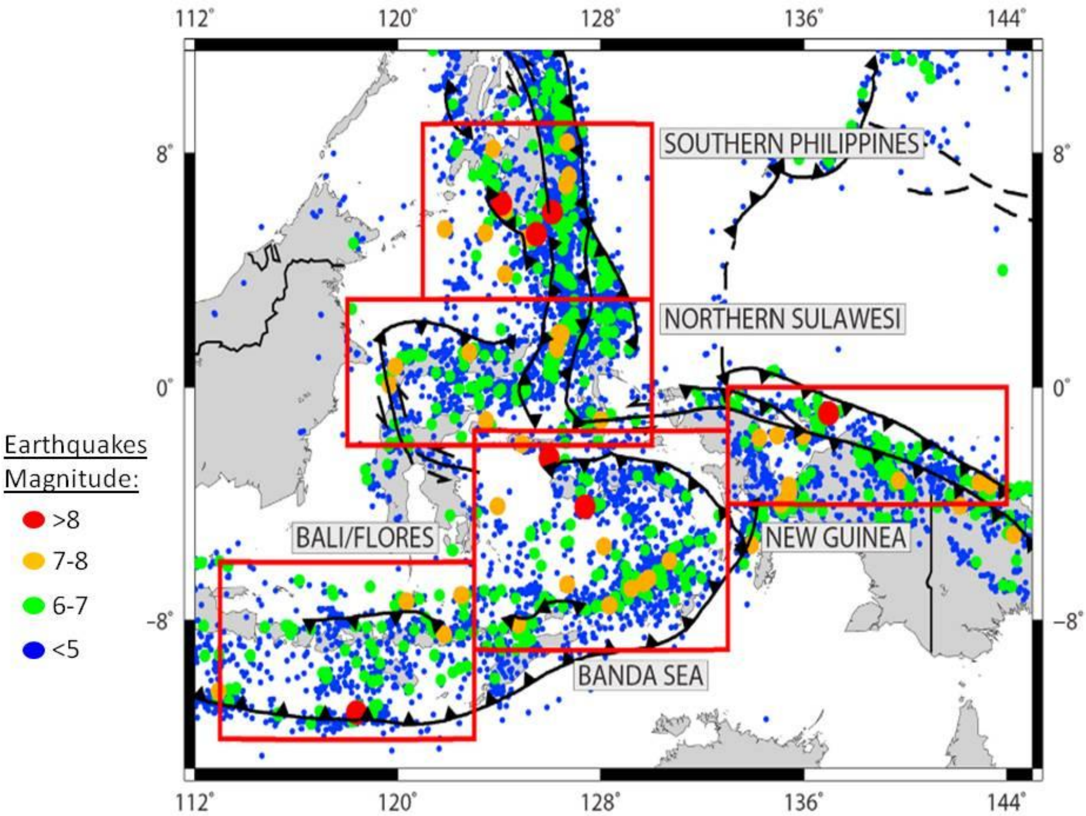

Figure 10 Potential Tsunamigenic Zoned based on Historical Earthquakes Near to East Malaysia [14]

Occurrence of Tsunami (OT) is frequency of earthquakes occur at one place that are able to generate Tsunami. It's shows as an indicator of regional instability. Data recorded in Figure 12 shows that earthquakes with high magnitude are seldom to happen compared to earthquakes with low magnitude are frequently happen. In Figure 11, only Zone A, B, C, D, E and H are selected as subject of study because these zones are near to Malaysia Coastline. From earthquakes return period data, the authors propose OT as in Table 3. Higher Occurrence Rank of Tsunami has higher probability for Tsunami to generate.

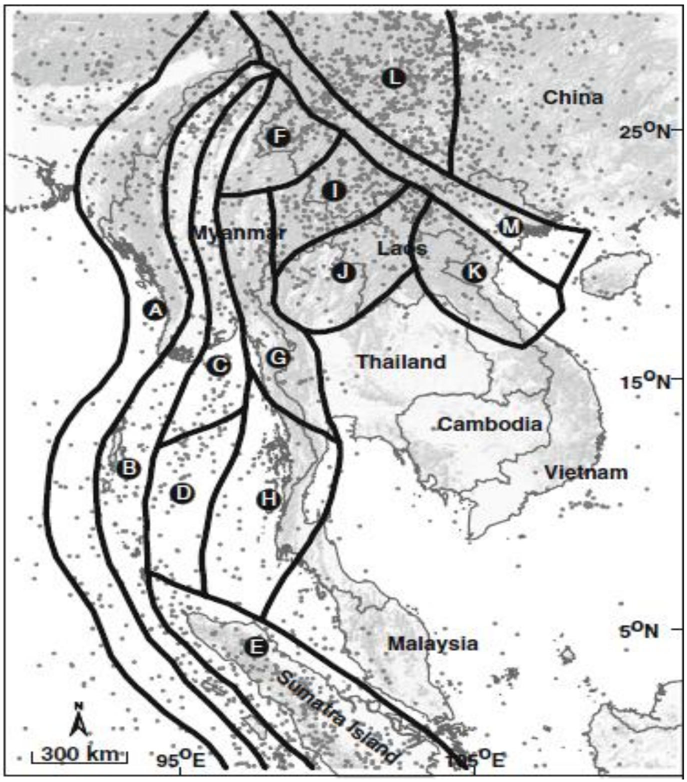

Figure 11 Map of South East Asia with Divided by Zone as Source of Earthquakes [17]

Mw	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F	Zone G	Zone H	Zone I	Zone J	Zone K	Zone L	Zone M
3	2.5 dys	3.9 dys	4.8 dys	86.2 dys	3.6 dys	12.4 dys	25.9 dys	26.7 dys	12.9 dys	4.3 dys	19.4 dys	6.4 dys	5.8 dys
3.5	5.1 dys	8.6 dys	10.9 dys	135.1 dys	8.4 dys	27.7 dys	49.7 dys	56.9 dys	25.9 dys	10.7 dys	45.2 dys	12.8 dys	15.3 dys
4	10.5 dys	18.7 dys	25.ldys	212.Odys	20.Odys	62.Odys	96 6 dys	120.9 dys	52.3 dys	26.7 dys	105.3 dys	25.7 dys	40.4 dys
45	21.7 dys	41.Odys	57.7 dys	332.5 dys	47.2 dys	138.5 dys	183.6 dys	256.9 dys	1O5.4 dys	66.7 dys	245.4 dys	51.7 dys	106.4 dys
5	449 dys	89.6 dys	132.5 dys	1.4 yrs	I11.5 dys	310.7 dys	1.Oyrs	1.5 yrs	212.5 dys	166.8 dys	1.6 yrs	104.1 dys	280.1 dys
5.5	92.7 dys	196.Odys	304.3 dys	2.2 yrs	263.5 dys	1.9 yrs	1.9 yrs	3.2 yrs	1.2 yrs	1.lyzs	3.7 yrs	209.3 dys	2.Oyrs
6	191.6 dys	1.2 yrs	1.9 yrs	35 yrs	1.7 yrs	43 yrs	3.6 yrs	6.8 yrs	2.4 yrs	2.9 yrs	5.5 yrs	1.2 yrs	5.3 yrs
65	l.lyrs	2.6 yrs	4.4 yrs	5.5 yrs	4.Oyrs	9.5 yrs	6.8 yrs	14.4 yrs	4.8 yrs	7.lyrs	19.8 yrs	2.3 yrs	l4.Oyrs
7	2.2 yrs	5.6 yrs	10.1 yrs	5.6 yrs	9.5 yrs	21.4 yrc	13.2 yrs	30.5 yrs	9.6 yrs	17.9 yrs	46.2 yrs	4.7 yrs	36.9 yrs
7.5	4.6 yrs	12.3 yrs	23lyrs	13.6 yrs	22.5 yrs	47.9 yrs	25.3 yrs	64.9 yrs	19.4 yrs	44.7 yrs	107.8 yrs	9.4 yrs	97.2 yrs
8	9.5 yrs	26.9 yrs	53.2 yrs	21.3 yrs	53.2 yrs	107.2 yrs	48.5 yrs	138.Oyrs	39.lyrs	ll17yrs	251.2 yrs	18.9 yrs	255.9 yrs
8.5	19.7 yrs	58.9 yrs	122.2 yrs	33.4 yrs	125.7 yrs	239.9 yrs	93.2 yrs	293.4 yrs	78.5 yrs	279.3 yrs	585.5 yrs	38.Oyrs	673.5 yrs
9	40.7 yrs	128.8 yrs	280.5 yrs	52.4 yrs	297.2 yrs	537.Oyrs	179.lyrs	623.7 yrs	158.9 yrs	698.2 yrs	1364.6 yrs	76.4 yrs	l774.2 yrs

dys days, *yrs* years

Figure 12 Estimated Return Period of Earthquakes at South East Asia [17]

Table 3 Occurrence of Tsunami (OT)

Probability of Occurrence Tsunami	Occurrence Reason	Probability Period	Occurrence Rank
VERY LOW	Very low earthquake magnitude 3 to 3.5	Every couple of days	1
LOW	Low earthquake magnitude 3.5 to 4	Every week or couple of weeks	2
	Low earthquake magnitude 4 to 4.5	Every couple of weeks or every month	3
MODERATE	Moderate earthquake magnitude 4.5 to 5	Every month or couple of months	4
	Moderate earthquake magnitude 5 to 5.5	Every couple of months or every year	5
	Moderate earthquake magnitude 5.5 to 6.5	Every year or couple of years	6
HIGH	High earthquake magnitude 6.5 to 7	Every couple of years	7
	High earthquake magnitude 7.5 to 8	Every 10 to 30 years	8
	High earthquake magnitude 8 to 8.5	Every 30 to 50 years	9
VERY HIGH	Very high earthquake magnitude 8.5 to 9	Every 50 years or more	10

Lastly, Detection of Tsunami (DT) is measurement degree of tsunami detection. The possibility of detections are divided into five (5); VERY FAST DETECTION, FAST DETECTION, SLOW DETECTION and TOO SLOW DETECTION. Table 5 shows the Detection of Tsunami (DT) according to Tsunami Bulletin Issue (TBI). Tsunami Bulletin Issue is period taken after seismic event to inform public to start mitigation or precaution. This is based on data of Tsunami Warning System (TWS) developed by several countries as tabulated in Table 4 below. Some countries are taking longer time to release TBI because they allocate extra time to conduct details analysis. Thus, they can avoid false TBI. For example is India TWS required 30 minutes to release TBI. Based on past earthquakes database, the epicentre centre was happened far away from their country. Thus, the tsunami wave was taking more than 30 minutes to reach to their coastline.

Table 4 Tsunami Warning System (TWS) for Asia Countries

Tsunami Warning System (TWS)	Tsunami Bulletin Issue (TBI)
Japan	After 3 minutes [18]
Iran	After 4 minutes [19]
Indonesia	After 4.5 minutes [11]
Oman	After 5 Minutes [19]
Malaysia	After 12 minutes [20]
India	After 30 minutes [13]

Table 5 Detection of Tsunami (DT)

Possibility of Detection	Tsunami Warning System (TWS) Readiness	Tsunami Bulletin Issue (TBI)	Detection Rank
VERY FAST DETECTION	VERY FAST	After 1 minute of earthquake	1
	VERY FAST	After 2 minutes of earthquake	2
FAST DETECTION	FAST	After 3 minutes of earthquake	3
	FAST	After 4 minutes of earthquake	4
	FAST	After 5 minutes of earthquake	5
SLOW DETECTION	OK	After 6 to 7 minutes of earthquake	6
	OK	After 8 to 9 minutes of earthquake	7
	OK	After 9 to 10 minutes of earthquake	8
	OK	After 10 to 11 minutes of earthquake	9
TOO SLOW DETECTION	NOT OK	After 12 minute of earthquake	10

Tsunami Risk Priority Number (TRPN) is a total number of multiplications ST, OT and DT. The TRPN number can be used to prioritise the list of risk. The highest number of TRPN will be put as first priority of risk to be evaluated and propose a counter-measure. When a counter measure is taken, the TRPN number must reduce compare to initial TRPN without any countermeasure.

Fatality is more severe compared to losses of others thing. Therefore, the authors make a conclusion that a risk with ST equal or more than six (6) MUST assign a counter-measure. Figure 13 shows all 13 states in Malaysia are evaluated by using TRPN. An analyse is conducted to evaluate how serious the risk of Tsunami to their coastline. In Table 6, the Priority of Tsunami Risk is divided into three (3); HIGH RISK, MEDIUM RISK and LOW RISK based on TRPN.

Perlis, Kedah, Pulau Pinang, Perak and Selangor are list of state (No.1 to 5) that exposed to MEDIUM RISK of Tsunami. Their ST is six (6) because in 2004 they had experienced fatal Tsunami. While other states, not having any single Tsunami happened. Thus, their ST is one (1). For OT, the same states and also Sabah have highest number which is eight (8). The reason is their locations are near to neighbouring countries like Indonesia and Philippines that frequently exposed to high magnitude of earthquakes. The rest of states have OT equal to one (1). However, all states have same DT. Refer to Table 7 for details.

As summary, Tsunami Failure Mode Effect Analysis (TFMEA) proposes by authors is a novel method to help related government agencies to evaluate Tsunami risk at their country. For Malaysia, result of analysis shows five (5) from 13 states is in MEDIUM RISK and the rest is in LOW RISK. Counter measures must be taken either by prevention or detection to reduce the risk from MEDIUM RISK to LOW RISK. Then, safety of public can be ensured. This analysis must conduct before implementation of Tsunami Warning System (TWS). Therefore, by this risk assessment can identify which locations need government to put as high priority.

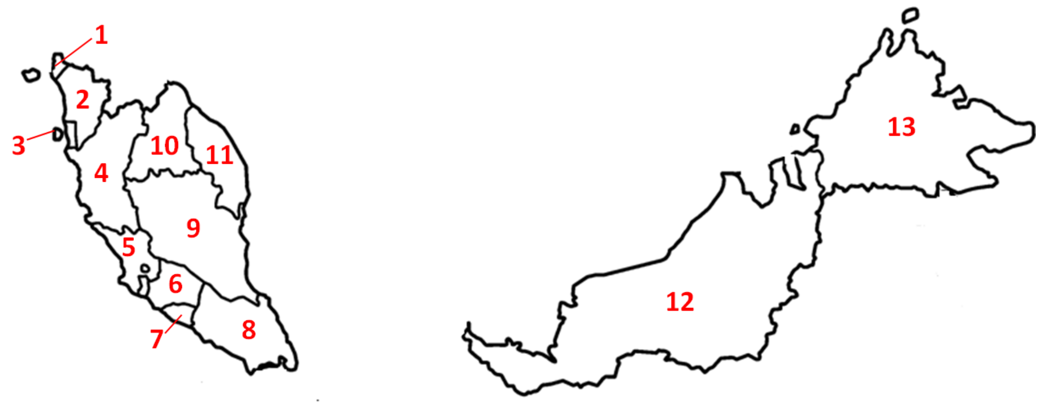

Figure 13 TRPN Evaluation based on States in Malaysia

Table 6 Priority of risk based on TRPN

Tsunami Risk Priority Number (TRPN)	Priority of Tsunami Risk
729-1000	HIGH RISK
210 - 728	MEDIUM RISK
1 - 209	LOW RISK

Table 7 TFMEA for Malaysia without TWS

State	Tsunami Failure Mode Effect Analysis (TFMEA)				Priority of Tsunami Risk
	Severity of Tsunami (ST)	Occurrence of Tsunami (OT)	Detection of Tsunami (DT)	Tsunami Risk Priority Number (TRPN)	
1-Perlis	6	8	10	480	MEDIUM RISK
2-Kedah	6	8	10	480	MEDIUM RISK
3-Pulau Pinang	6	8	10	480	MEDIUM RISK
4-Perak	6	8	10	480	MEDIUM RISK
5-Selangor	6	8	10	480	MEDIUM RISK
6-Negeri Sembilan	1	1	10	10	VERY LOW RISK
7-Melaka	1	1	10	10	VERY LOW RISK
8-Johor	1	1	10	10	VERY LOW RISK
9-Pahang	1	1	10	10	VERY LOW RISK
10-Kelantan	1	1	10	10	VERY LOW RISK
11-Terengganu	1	1	10	10	VERY LOW RISK
12-Sarawak	1	1	10	10	VERY LOW RISK
13-Sabah	1	8	10	80	VERY LOW RISK

2. Methodology

ADIBs is acronym for **A**ware Tsunami **D**etection **I**nterconnected **B**uilt-In **S**ystem. It's a low-cost Tsunami Warning System (TWS) that currently develop by authors. ADIBs consist existing sub-system and it using more than 80% local made components as stated inside Table 8. The technology of components inside sub-system is commercially available and made by local original equipment manufacturer (OEM). Figure 14 below shows ADIBs conceptual image.

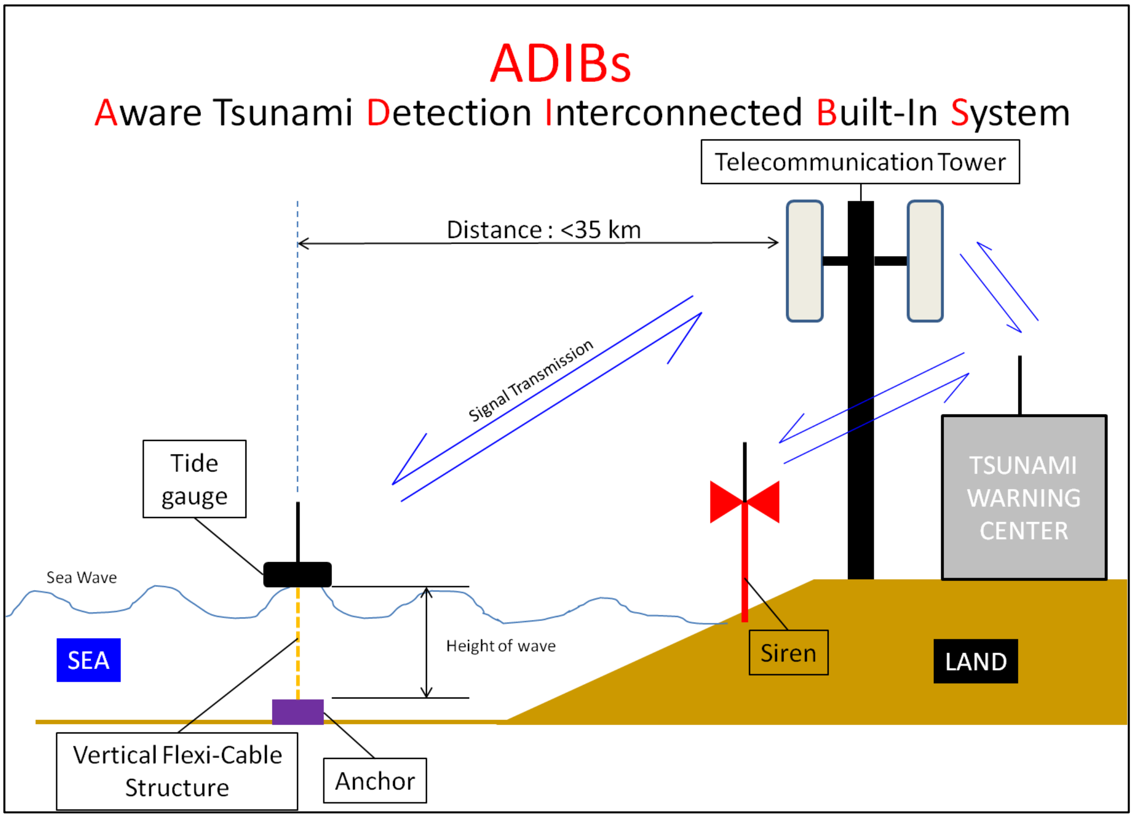

Figure 14 ADIBs Conceptual

Table 8 ADIBs Sub-system

ADIBs Sub-system	Classification of Sub-system	
	New or Existing	Local or Import or Mix
Tide Gauge (Power devices, Controller devices, Measurement devices, Transmitter devices, Protection devices)	New	Local
Anchor	New	Local
Vertical Flexi-Cable Structure	New	Local
Telecommunication Tower	Existing	Mix
Siren	New	Local
SCADA (Software, Hardware)	New	Local
Data storage	New	Local
Summary	86% New 14% Existing	86% Local 14% Mix

The distance of tide gauge at sea is below than 35km from coastline where it's depend on maximum distance signal can transmit from tide gauge to telecommunication tower. Roughly check through Google Map in Figure 15 shows that distance between Banda Aceh to Langkawi is circa 471km. On 2004, Tsunami hit Malaysia at Pantai Cenang, Langkawi on 12:45pm after tsunami wave travel 3 hours from Banda Aceh [21]. Based on this fact, the Tsunami wave moving speed is circa 157km/hour. Worse comes to worst, the tsunami warning must announce within 3 hours from earthquake occur. It's also depending on location of epicenter. More near the epicenter to Malaysia territory, less time required to release Tsunami Warning.

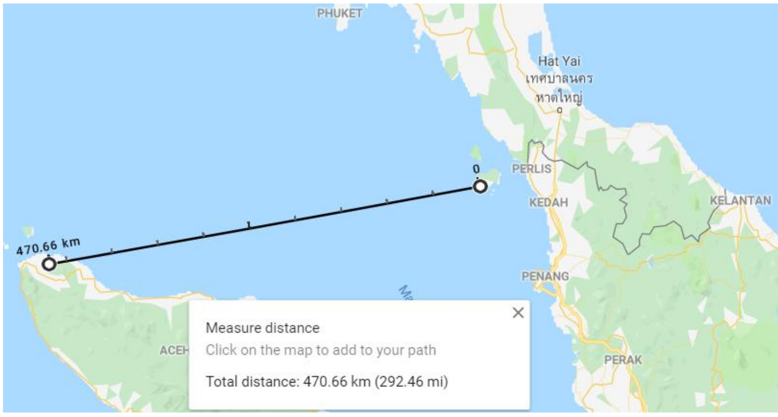

Figure 15 Distance between Banda Acheh to Langkawi (Google Map)

Therefore, ADIBs offering cost effective solution for Malaysian government to replace buoys system that already obsolete caused by vandalism and not functioning [22]. The expensive cost to replace with new one and for conduct regular maintenance is the main factor why Malaysian government stop from using buoys type TWS and only fully depend on tide gauges and tsunami information from neighbouring countries. Estimation cost for replace a new buoy is about RM 3 million and maintenance cost is about RM 0.5 million [23].

Unfortunately, these tides gauges are normally installed near to coastline not at open sea. Consequently, late detection of tsunami wave usually happen because they only able to observe sudden change of tide wave reading when tsunami wave is very near to coastline. In Figure 16 shows the tide gauges were installed at port and light house.

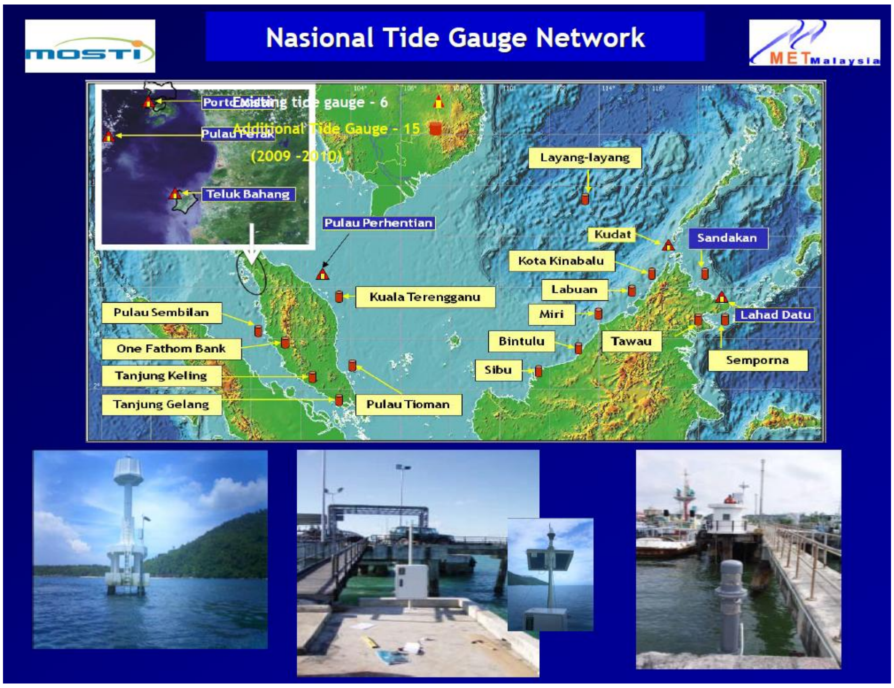

Figure 16 Malaysia Tide Gauges near to coastline [20]

Moreover, data recorded from Tsunami on 2004 in Figure 17 proven that tide gauge at Langkawi only can detect anomaly reading on 12:00PM which is 45 minutes before Tsunami hit Pantai Cenang on 12:45PM. From this finding, there is potential high fatality caused by time-lapse for Tsunami warning reach to people and insufficient evacuation time because of traffic conjunction and crowded people. Thus, highly suggest installing ADIBs as frontline Tsunami detection that help to increase detection time and give more time for evacuation process.

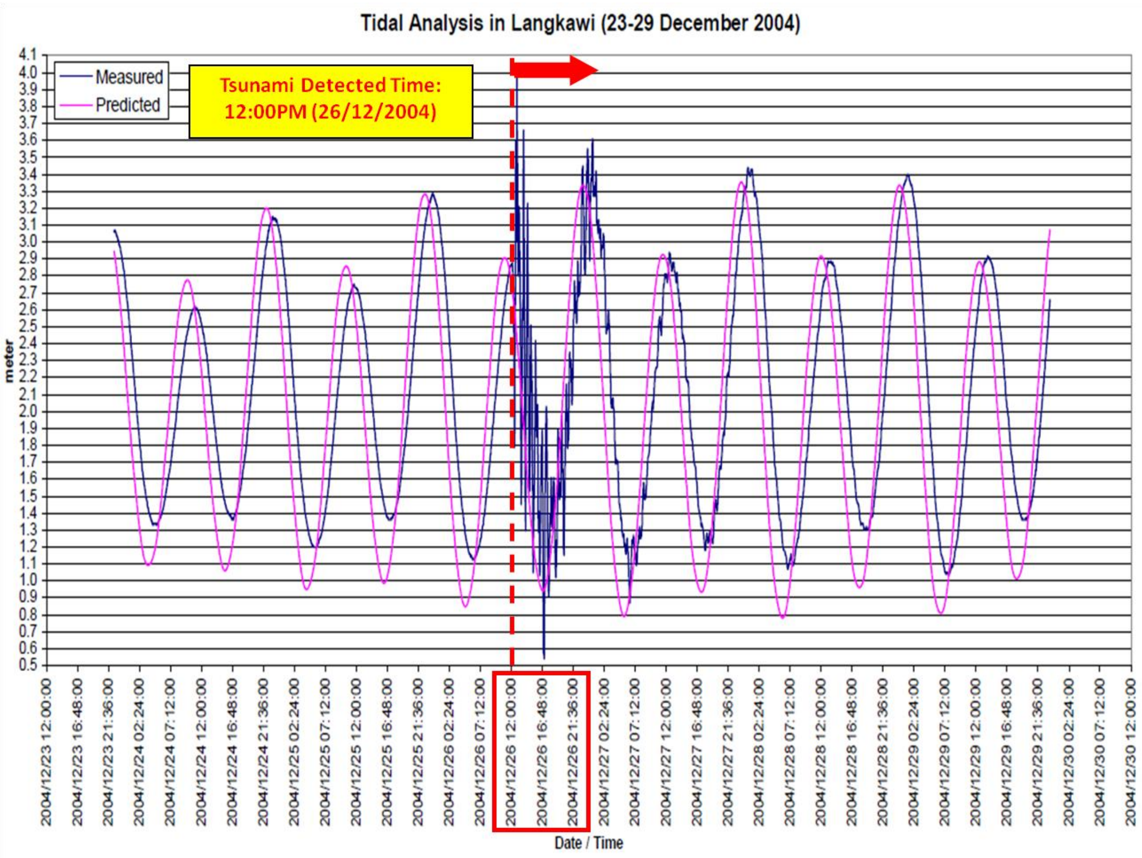

Figure 17 Tidal records from Langkawi indicating sea levels during the tsunami (Dept. of Survey & Mapping Malaysia) [21]

According to risk analysis result in Table 7, Malaysia' states at northern region are exposing to MEDIUM RISK of Tsunami. Then, in Figure 18, 19 and 20 are suggesting locations to install ADIBs. By install ADIBs, priority risk of TRPN can be lowered and increase detection time.

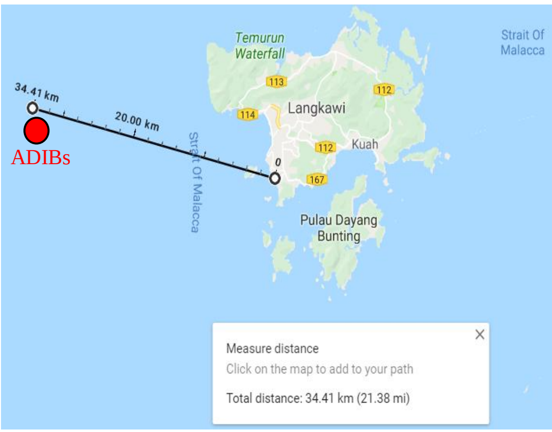

Figure 18 ADIBs at Langkawi, Kedah

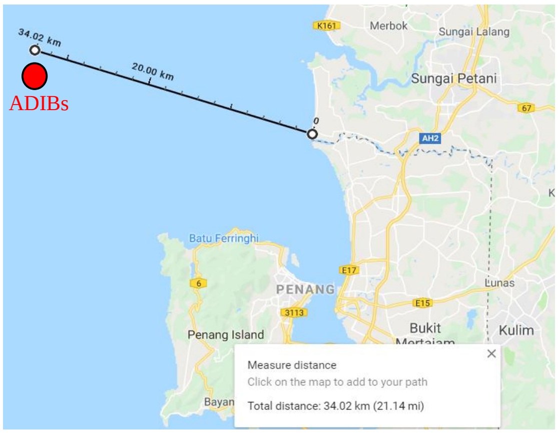

Figure 19 ADIBs at Kuala Kedah, Kedah

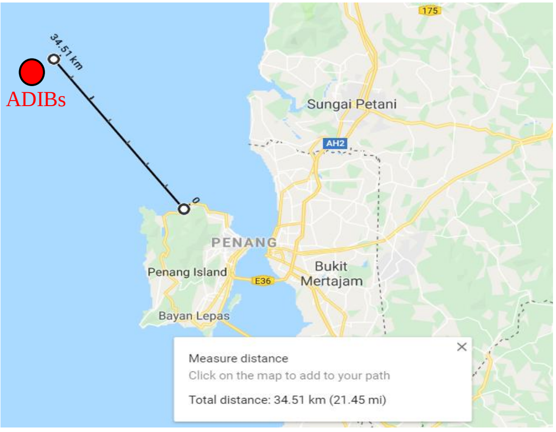

Figure 20 ADIBs at Batu Feringgi, Pulau Pinang

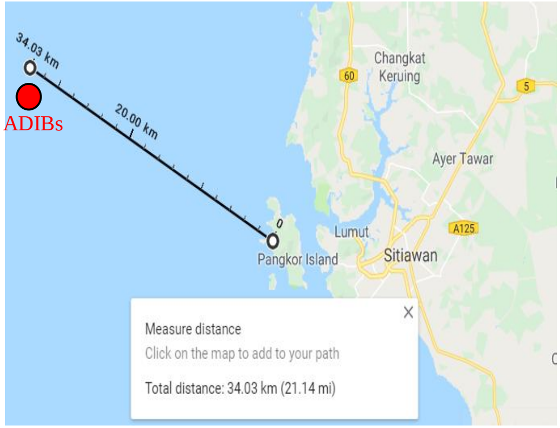

Figure 21 ADIBs at Pulau Pangkor, Perak

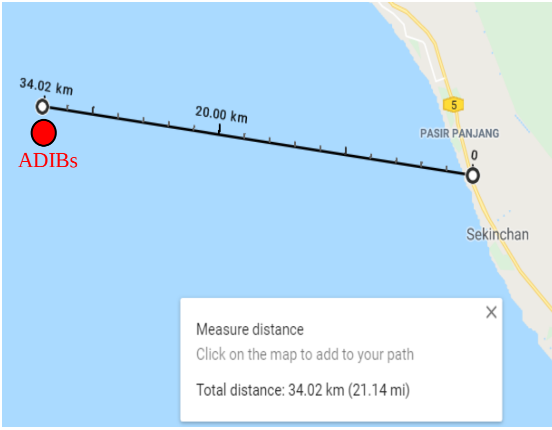

Figure 22 ADIBs at Sekinchan, Selangor

3. Results & Discussions

Malaysia TWS with ADIBs can help to reduce ST from six (6) to five (5) as highlighted by green colour inside Table 9. That means, only fatal can be eliminated with early Tsunami detection system. Destruction caused by Tsunami can't be avoided if there still have buildings or any human made structures near to coastline. Even though the TWS is equipping with advance and expensive Tsunami detection system, it's only improve the detection time but not prevent the destruction. Thus, Malaysian government should focus on prevention works such as coastal protection and rehabilitation and shoreline management. While for TWS is highly advisable to use low-cost system that is cheaper to be replace if damage or vandalise and easy to maintain.

ADIBs also can help to improve current tsunami detection time. TWS with coastal tide gauges only can detect tsunami early 45 minutes meanwhile TWS with ADIBs where it's located maximum 35km from coastline can detect early 1 to 3 hours (Still under investigation for exact time).

Table 9 TFMEA for Malaysia with ADIBs

State	Tsunami Failure Mode Effect Analysis (TFMEA)				Priority of Tsunami Risk
	Severity of Tsunami (ST)	Occurrence of Tsunami (OT)	Detection of Tsunami (DT)	Tsunami Risk Priority Number (TRPN)	
1-Perlis	5	8	10	400	MEDIUM RISK
2-Kedah	5	8	10	400	MEDIUM RISK
3-Pulau Pinang	5	8	10	400	MEDIUM RISK

4-Perak	5	8	10	400	MEDIUM RISK
5-Selangor	5	8	10	400	MEDIUM RISK
6-Negeri Sembilan	1	1	10	10	VERY LOW RISK
7-Melaka	1	1	10	10	VERY LOW RISK
8-Johor	1	1	10	10	VERY LOW RISK
9-Pahang	1	1	10	10	VERY LOW RISK
10-Kelantan	1	1	10	10	VERY LOW RISK
11-Terengganu	1	1	10	10	VERY LOW RISK
12-Sarawak	1	1	10	10	VERY LOW RISK
13-Sabah	1	8	10	80	VERY LOW RISK

4. Conclusion

As summary, Techno Brozek Enterprise is Malaysian company that currently develop a local Tsunami Warning System (TWS) called ADIBs. This low cost TWS is using available technology which more than 80% of sub-system components made by local OEM. They also introduce Tsunami Failure Mode Effect Analysis (TFMEA) as a novel approach to calculate Tsunami risk. TFMEA result informs that Malaysia should implement low cost TWS like ADIBs and focus on prevention works to eliminate destruction caused by Tsunami.

Acknowledgments

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