RANK OF TRIGGER FOR EVACUATION BASED ON REGIONAL CHARACTERISTIC AND TSUNAMI TYPE IN INDONESIA

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From 1600 to 2007, Indonesia has experienced several tsunamis, with approximately 172 tsunamis occurring. For the past 20 years, especially after the great Indian ocean tsunami 2004, there have been developments of science, technology and law for disaster reduction in Indonesia. However, the high number of victims makes the well organized and rapid evacuation become crucial. This result provides result on personal characteristic of Indonesia people concluded from past-event analysis of human behavior. The first rank of factor to trigger people start evacuating is message from the authorities, second rank is seeing other people behavior and third rank is feeling ground motion. This information is valuable as an input parameter in the evacuation modelling to determine timing in evacuation not just based on assumption that all agent evacuate at the same time, but to considered individual timing of each agent. We also found the possible danger of the future evacuation in Indonesia. After the tsunami early warning established in 2008 and tsunami drill conducted in several location in Indonesia since 2005, people tend to delay the evacuation because they are waiting for an evacuation order from the authorities. This situation is very dangerous because some past tsunami event in Indonesia categorized as near-field tsunami and some triggered by non-seismic activity. Apart from equipment and technology development, building capacity and resiliency in people to recognize the danger and enough knowledge of tsunami evacuation should be undertaken continuously

Key Words : *tsunami evacuation, human behavior, tsunami early warning*

1. INTRODUCTION

Indonesia is surrounded by large tectonic plate, the collision of the Indo-Australian tectonic plates in the south, the Eurasian Plate in the North and the Pacific Plate in the Northeast to the southwest and considered as one of the most tectonic active areas in the world. From 1600 to 2007, Indonesia has experienced several tsunamis, with approximately 172 tsunamis occurring. Realizing the high threat and vulnerability to tsunamis, the government undertakes disaster management. However, the challenges faced are vast administrative areas, large population and inequality in infrastructure. Studies of tsunami incidents in Indonesia show a lack of knowledge and awareness, early warning and communication failure, which resulted in the high number of victims of the tsunami disaster. The research results highlight that well organized and rapid evacuation is crucial to save lives in a rapid onset disaster.

Research by Kubish et al., 2020 used previous studies to identified factor which influence the fatality rate in tsunami events, and which are important for evacuation research into four categories;

1. Characteristics of the tsunami (e.g. arrival time and inundation depth),
2. Characteristics of the terrain (e.g. slope and land elevation),
3. Characteristics of tsunami mitigation measures (e.g. evacuation routes and zones, and DRM),
4. Personal characteristics (e.g. awareness of tsunami and knowledge of evacuation routes and zones, mental and physical ability).

These characteristics tend to be site-specific, which causes us to specifically analyze how these characteristics are in Indonesia. The characteristic of tsunami in Indonesia is available from the Indonesia Meteorological, Climatological, And Geophysical Agency (https://inatews.bmkg.go.id/) and also gave real time

Table 1. Information of past-event disaster used for evacuation behavior analysis.

Location	Date & Time	EQ Magnitude (Mw)	Tsunami Type
Pangandaran	17 July 2006, 15:20	7.7	Tsunamigenic earthquake
Mentawai	25 Oct 2010, 21:42	7.8	Tsunamigenic earthquake, Near-field
	02 Mar 2016, 15:38	8.3	(no tsunami happened)
Padang	12 Sept 2007, 18:10	7.9	(no tsunami happened)
	02 Mar 2016, 15:38	8.3	(no tsunami happened)
Aceh	11 April 2012, 15:38	8.6	(no tsunami happened)
Palu	28 Sept 2018, 18:02	7.7	Earthquake & Landslide Non-seismic tsunami
Krakatau	22 Dec 2018, 21:03	-	Volcano eruption Non-seismic tsunami

warning when disaster happened. Characteristic of the terrain also already provided by Indonesia Geospatial Information Agency and can be accessed in this website (https://tanahair.indonesia.go.id/). The third is characteristic of tsunami mitigation measures are provided by Indonesian National Board for Disaster Management in the form of hazard and risk maps, tsunami safe zone can be seen in the map but the evacuation route is not complete yet (https://inarisk.bnpb.go.id/). Of the four factors, the data that are still scattered and have not been summarized is the personal characteristics.

There only a few evacuation researches in Indonesia and mostly did not consider the personal characteristic. Muhari et al., 2012 created an evacuation planning step in Pacitan based on the tsunami mitigation planning plan, however the output such as evacuation time, zone, shelter and routes map were not provided. The next researches are tsunami evacuation in Padang by Muhammad et. al, 2017 and Ashar et. al, 2017 both using GIS-based evacuation research for evacuation time simulation and simulations of the shortest path to the nearest evacuation zones. One research by Mas et al., 2015 implemented agent-based modelling approaches which considered individual departure times of evacuee.

Seeing this fact, it can be concluded that there is too little research on tsunami evacuation, let alone those that have considered personal characteristics. However, recent natural disasters have shown the importance of integrating engineering, social, phycological and educational sciences to create a holistic picture of evacuation research (Kubisch et al., 2020, Mas et al., 2015).

The purpose of this research is to determine one of the personal characteristics for tsunami evacuation in Indonesia, namely what factors have the most influence on triggering people to evacuate. The results of this research can show whether there is a dynamical relation between people behavior with the science and technology of earthquake, tsunami and disaster risk reduction development. In addition, this ranking can be used as a guide to determine the input parameters to be used for Agent-Based Modelling which estimation about evacuation behavior

2. METHODOLOGY

The disaster event used for this analysis has been done not only for the tsunami that occurred but also the potential tsunami (**Table 1**). The main data used for this analysis were the published results of post-disaster field surveys that were conducted by different international survey teams and government agency. It should be noted that the data were obtained from different types of surveys, some of which were derived from extensive questionnaire surveys, while others conducted only interviews with a limited number of people, thus there is the issue of whether the data really illustrates and represents the characteristics and responses of local populations. Although there are potential problems with using such heterogeneous source materials, there is no other data available and thus the results of the analysis can give at least a general and qualitative view of the characteristics, backgrounds, and responses of the population in each area.

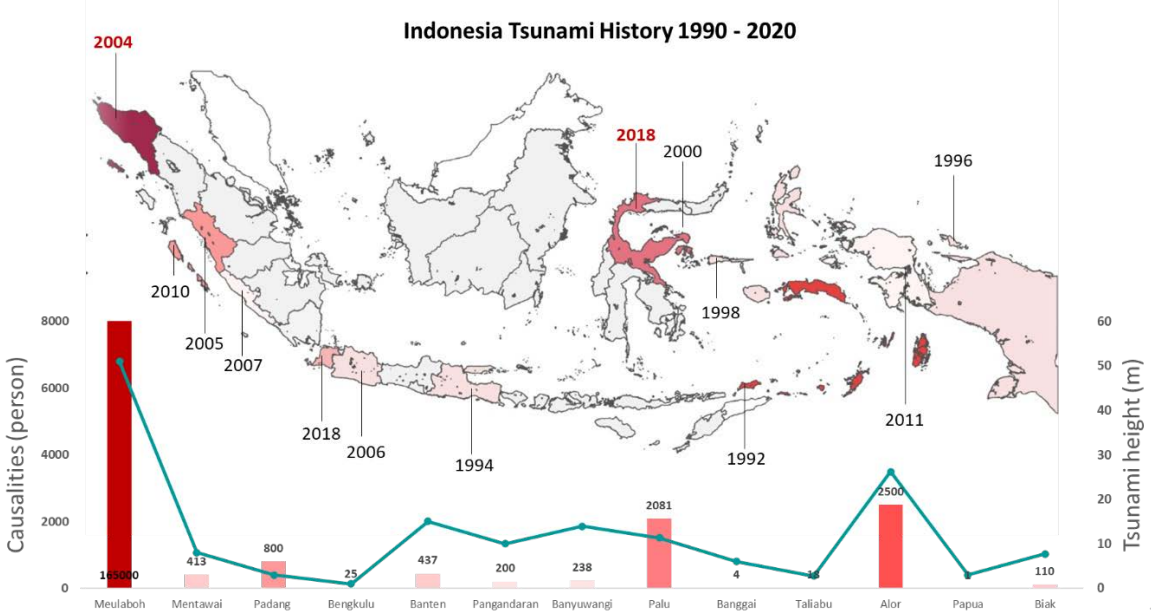

Fig.1 Tsunami events in Indonesia over the past 20 years. The worst causalities happened in 2004 Indian Ocean Tsunami.

First, the actual triggers of tsunami evacuation, as recorded by interviews and questionnaire surveys, will be collected from field survey reports and classified into categories. Then, the triggers will be ranked, for questionnaire by sorted highest to lowest percentage while for the interview deducted from survivor story. The varied rank result then correlating with disaster characteristic, event situation and local people background, to find the similarity rank of trigger to start evacuating.

(1) Tsunami events in Indonesia over the past 20 years.

Tsunami is a rapid-onset disaster, categorize as near-field if propagate with less than 30 minutes and far-field if propagate more than 30 minutes (Okal and Synolakis, 2008). Different sources caused different tsunami characteristic, however differentiation maybe subtle if it is a multi-hazard disaster. For evacuation analysis it is important to acknowledge tsunami type before analyzing human behavior. Latief and Puspito, 2000 created a statistical tsunami in Indonesia and it is known that 90% have been caused by earthquakes, 8 % by volcanic eruption and 1% by landslides. During 1990 – 2020, there were 13 tsunamis happened in Indonesia. Tsunami cause by earthquake 11 events, by landslides 1 event, and by volcanic eruption 1 event. Tsunami event and casualties in Indonesia can be seen in **Fig. 1**.

(2) Development of technology, science and law for disaster risk reduction in Indonesia

After the devastating of 2004 Indian Ocean Tsunami, German-Indonesia Tsunami Early Warning System (GITEWS) had been developed. In 2008, this system fully operated only by Indonesia government and changed its name as Indonesia Tsunami Early Warning System (Ina-TEWS). Despite advanced numerical performance the TEWS still rely on precomputed databases based on seismic sources. The Ina-TEWS hasn't been covered for tsunami caused by landslide and volcanic eruption. Continual improvement always been done, especially after the event occurred. However, when the expected tsunami is a near field or generated by landslide and volcano, this system not functioning properly. This was proven when tsunami Mentawai 2010, tsunami Sulawesi 2018 and tsunami Sunda Strait 2018 happened. Large casualties occurred as a result of this failed warning and poorly prepared community. The timeline of technology, science and law development can be seen on **Table 2.**

As the available time span between a warning and the impact of a tsunami wave in Indonesia generally is very short, all necessary preparations should have been made in advance. Aside from TEWS development, an official evacuation plan is essential to provide the community with the necessary reference, guidance and information. Every country has different cultural background, social background dan geographical feature. Those will contribute to society action and perception about the tsunami risk and their level sense of danger. There are number of studies about evacuation behavior at the specific locations and events. This study focusing in Indonesia and compare multiple events to find the similarity of evacuation behavior despite all the differences. The result is identifying the rank of evacuation trigger that make Indonesian people start to evacuate.

Table 2. Development of technology, science and law of disaster risk reduction in Indonesia.

year	Month	Event	Location
2004	Dec	Indian Ocean Tsunami	Aceh
2005		Establishment of Indonesia Tsunami Early Warning System	
	Dec	Tsunami Drill 1	Padang
2006	July	Pangandaran Tsunami	West Java
	Sept	Ministerial Decree of The Coordinating Minister for People Welfare no. 21/2006	
	Dec	Tsunami Drill 2	Bali
2007	April	Indonesia Law 24/2007 - Disaster Management Law	
	Dec	Tsunami Drill 3	Banten
2008	Nov	Indonesia Tsunami Early Warning System (InaTEWS) launched	
2009		Improvement of tsunami warning dissemination, 10 - 5 minutes	
2010	Oct	Mentawai Tsunami	
2018	Sept	Palu Tsunami	Central Sulawesi
	Dec	Krakatau Tsunami	Sunda Strait,
2019	January	Formulated Presidential regulation on the strengthening of the national multi-hazard early warning system.	

3. RESULT

(1) Impact and exposure of trigger factor

Evacuation decision is triggered by one or several factors. Those factors can separate by the source such as natural cause, warning, and behavior cause; by the exposure, impact and time. Ranking of evacuation start trigger rank affected by exposure and impact of the trigger. Impact is a marked effect that makes people recognize their level of danger. While, exposure is the spatial distribution of those factors. Some factor can reach a wide area and still have relatively same impact level while others factor can only reach small area (**Fig. 2).** Exposure are time dependent in the short-term period, from the start of the disaster until evacuation. For example, ground motion makes a big impact and wide exposure for couple of minutes (1-5 minutes) after the earthquake however that will stop after that period of time. On the other hand, seeing other people's behavior can only create impact within radius of limited human visibility, but this factor will continue triggered people to start evacuate from the disaster start until people finish evacuated. As impact and exposure are dependent to time and space therefore it is possible to one person expose to many factors which cause their level of danger increase.

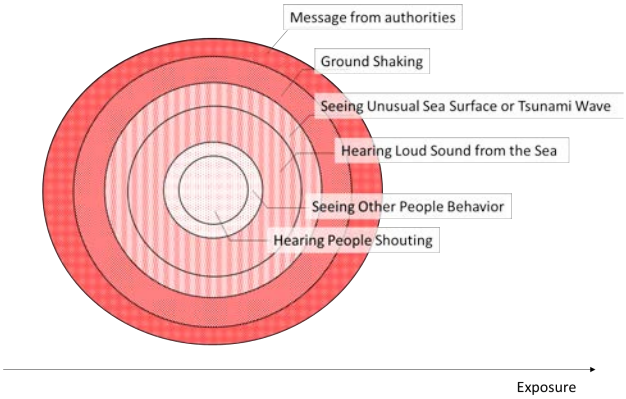

Fig. 2. Impact and exposure level of trigger factor to start evacuation

(2) Factor that triggered people to start evacuating

After tsunami events, researcher conduct a survey to understand people behavior during tsunami. Many surveys try to cover the framework of response phase and evacuation movement phase. This framework points out about the continuous psychological and physical process in tsunami evacuation and the dynamical transition of notifications during tsunamis.

The results of these surveys provide a basic understanding of the actual behavior and response of coastal residents during tsunamis, as well as other

scientific and engineering aspects of the events. In order to formulate appropriate mitigation strategies, it is necessary to learn some lessons from these events.

Regarding of different types of survey these triggers can be classified into the following six categories: feeling the ground motion, seeing other people's behavior/hearing other people's warning, seeing an unusual behavior of the sea, hearing a loud sound, seeing/feeling a tsunami wave, and receiving a message from the authorities. Timeline of the disaster started when earthquake took place creating a ground motion. The shaking could also be followed by landslide or volcanic eruption. With the time varied from 3-30 minutes the first tsunami wave will hit coastal area. Summary explained in **Table 3**.

Pangandaran Tsunami, 2006

When tsunami in Pangandaran happened in 2006, Indonesia tsunami early warning system just in the development process. Buoy system of deep-ocean assessment and reporting of tsunami hasn't been deployed. While, 160 seismograph and tide gauge networks along Indonesia water still on the processed. Survey conducted by Muhari et.al., 2007 found local people felt no significant shock and some people felt a strong earthquake. Tsunami awareness and information found to be not evenly distributed, in the 2 of 5 village it was more than 90% people never been given information about tsunami. Generally, most of the respondent start to evacuate when they see tsunami wave and seeing other's people evacuated.

Padang, 2007 and 2016

For Padang, the results of observations only based on earthquakes that potentially can cause a tsunami. Because, Padang is one of the tsunami-prone area but until today there has never been hit by a tsunami. On September 2007 a series of heavy earthquake originated on the west coast of Sumatra struck Padang. GTZ, a partner for Indonesia tsunami early warning system development conducted questionnaire survey with 200 random citizen of Padang city. They wanted to explore tsunami preparedness and the tsunami early warning dissemination to local people. The result were 15% people immediately evacuate while around 75 % people wouldn't start evacuated directly after strong ground shaking and just stay on alert when received tsunami warning (GTZ, 2007). In November 2016, team consist of Indonesia government agency, researcher and university conducted survey to see effectivity of tsunami early warning system. In Padang they found number of people who immediately evacuated was 23% even though the ground shaking felt weak (II MMI). This result is higher than number of people who immediately evacuated on 2006. The reason why they started to evacuate because of the tsunami early warning (26%), seeing other people behavior (20%) and feeling ground shaking (16%). While, 22% people didn't evacuate because of weak ground shaking and not receiving message from authorities (11%).

Mentawai 2010 and 2016

In 2010, Indonesia tsunami early warning already launched and can give warning from 10 to 5 minutes. Tsunami drill also been carried out in several places for 4 times (**Table 2**). Unfortunately, when tsunami Mentawai happened in 2010, some people didn't evacuate immediately after the earthquake. Hill et al., 2012, Satake et.al.,2012 and Mikami et.al., 2014 found that because of the slow ground shaking people thought tsunami wouldn't hit the island. People evacuated after hearing the sound of incoming wave or seeing tsunami inundation. After the tsunami event in 2010, central and local government tried to improve infrastructure, tsunami early warning system and conduct tsunami drill. Those improvements were showed in the survey after earthquake in 2016, survey team found out that 73% people got message from the authorities and 53% immediately evacuate. However, some people didn't evacuate because they only felt the weak ground shaking

Aceh 2012

People of Aceh experience the great Indian ocean tsunami in 2004. The scale of the disaster is one of the biggest in history and became the monumental event for the government to develop disaster management in Indonesia. Research by Goto and Affan, 2012 reported that 67% of people immediately evacuate after feeling the ground motion. Many people received message from authorities while they were evacuating. The fast response team by government agency, researcher and university in 2012 also gave similar report.

Palu 2018

A strike-slip and landslide-induced tsunami that happened in Palu on September 2018 was a rare event. This event showed the weakness and failure of the current Indonesia tsunami early warning system. The current system only based on tectonic earthquake and the tsunami arrival time in Palu was faster than the early warning capacity to detect and issues warning (less than 5 minutes). The message was failed to receive by local communities due to power outage and telecommunication failure. Survey conducted by Harnantyari et al., 2020, found out that 50% of people evacuated after feeling the ground motion and seeing other's people behavior. Only a small percentage of people who evacuated after seeing tsunami wave, that probably people who delayed evacuating after feeling the ground motion already failed to save their live. People behavior who delayed evacuating and lost direction can be seen on the several personal videos uploaded to the internet.

Krakatau 2018

Only 3 months after the Palu tsunami, another tsunami hit Indonesia. The tsunami in Sunda strait triggered by volcanic eruption of Krakatau. Similar with what happened in Palu, Indonesia tsunami early warning system was failed to detect and issues warning. Not only the local people around sunda strait (Banten, Cilegon, and Lampung) didn't received the warning but also central government clueless of what happened on the time of the tsunami hit the area. Questionaire survey conducted by Takabate et. al., 2020, found out that due to no ground shaking, most people (61,4%) evacuated after seeing the tsunami wave and hearing the loud sound from the sea (44,6%).

(3) Basic model of evacuation triggered rank

Human behavior in the evacuation process at the first glance looks random and inconsistent. A pattern can be seen by identifying the natural process, warning availability, and past disaster experience (**Table 3**). The basic model (**Fig. 3**) shows the rank of factor that trigger people to start evacuate which include the impact and exposure of those factor. Basic model is a simplification to understand and explain what makes people in Indonesia start to evacuate. The first factor that triggered people to start evacuating is receiving message from authorities. This clearly indicated from survey result in Padang 2007 and 2016 and Mentawai 2016. While implicitly can be inferred from the interview result in Pangandaran 2006, Mentawai 2010 and Palu 2018. After the ground shaking people delayed evacuation because they were waiting for the evacuation instruction. Second rank is seeing other people behavior, we divide this factor into two categories, first the early evacuation is when people start evacuating when seeing other people evacuate before the tsunami coming and second is the late evacuation is when people start evacuating when the tsunami coming. The exposure radius of this factor is very small because it depends on the human field of view however the impact will continuously affect until people stop evacuate. This factor always follows the main factor, either it is natural phenomena or authorities warning. The third rank is ground motion, this factor has a very powerful impact to elevate people sense of danger, however if the ground shaking relatively slow and gentle people failed to notice that the tsunami will come. That's what happened in Pangandaran 2006, Mentawai 2010

Table 3. Rank factor of people to start evacuate based on report and journal paper

	Pangandaran 2006	Padang 2007	Mentawai 2010	Aceh 2012	Padang 2016	Mentawai 2016	Palu 2018	Krakatau 2018
Ground motion	○	○	○	○	○	○	○	×
Tsunami	○	x	○	x	x	x	○	○
Message from the authorities	x	○	**Δ**	○	○	○	**Δ**	×
1		**b**		**a**	**b**	**b**	**c**	
2		**c**		**c**	**c**	**a**	**a**	
3		**a**			**a**			
4	**d**		**e**				**d**	
5	**g**		**g**					**f**
6							**e**	**e**
7				**g**		**g**		**g**

O : existing, X : none, △ : not completely. 1-3 factor before tsunami coming, 4-7 factor when tsunami coming

a) feeling the ground motion, b) receiving message from the authorities, c) seeing others people behavior (early evacuation-before tsunami coming), d) seeing tsunami wave, e) hearing loud sound from the sea, f) hearing tsunami sirens, and g) seeing others people behavior (late evacuation – when tsunami coming).

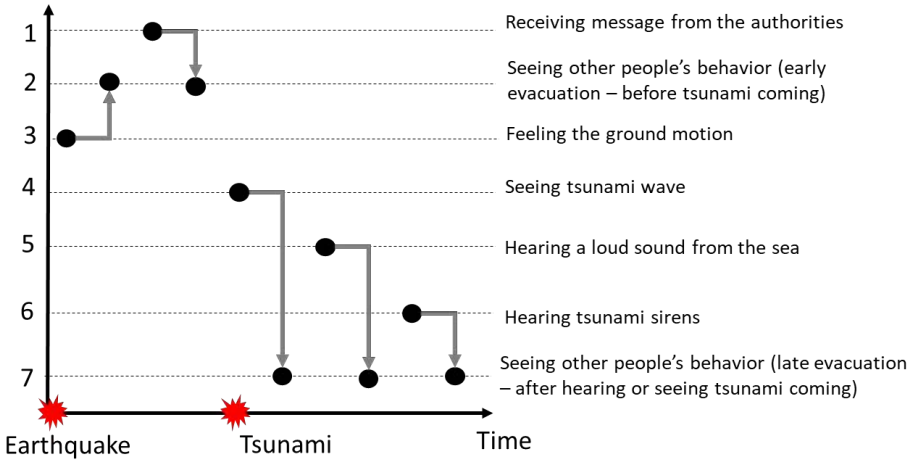

Fig. 3. Basic model of evacuation triggered rank in Indonesia

and Palu 2018, they believe strong ground shaking are the sign of tsunami coming. Unfortunately, in those events the ground shaking was not enough to exceed people level of danger to start evacuating.

When tsunami coming, we categorize rank as late evacuation because the available time for people to start evacuating become shorter. Especially, if we consider that most of tsunami in Indonesia are categorized as near-field tsunami. This is what happened in Pangandaran 2006, Mentawai 2010 and Krakatau 2018. Due to relatively gentle to none existent ground motion and also with no message from authorities' people start evacuating when they hear or see tsunami coming. As a result, many people couldn't save their live.

(3) Past disaster experience factor

Disaster experience contribute to people level of danger. We notice this condition on Aceh 2012 event. People tend to be more sensitive to nature sign and decide to evacuate earlier before they receive message from the authorities. This situation explained in **Fig. 4** that show the trigger ranking model in Aceh 2012. People in Aceh had terrible experience caused by great Indian ocean tsunami in 2004. Therefore, people choose to immediately evacuate when they felt the ground motion.

(4) Hidden danger of evacuation delayed

In Indonesia, message from the authorities consist tsunami warning notification that disseminated using various media (radios, TVs, and social media). When the message received some people immediately evacuate while others local people continue to deliver using traditional equipment (knocking on the wood or bamboo) or mosque loudspeaker. Tsunami warning system in Indonesia develop after the great Indian ocean tsunami earthquake, therefore before 2007 message from authorities is non-existent.

There is a possible danger with the message from authorities became the number one ranking for Indonesia people to start evacuating. Report from UNDRR and UNESCO-IOC, 2019 explained that the development of tsunami early warning system is technocratic and follow a top-down approach which ignores the social complexity downstream. This is

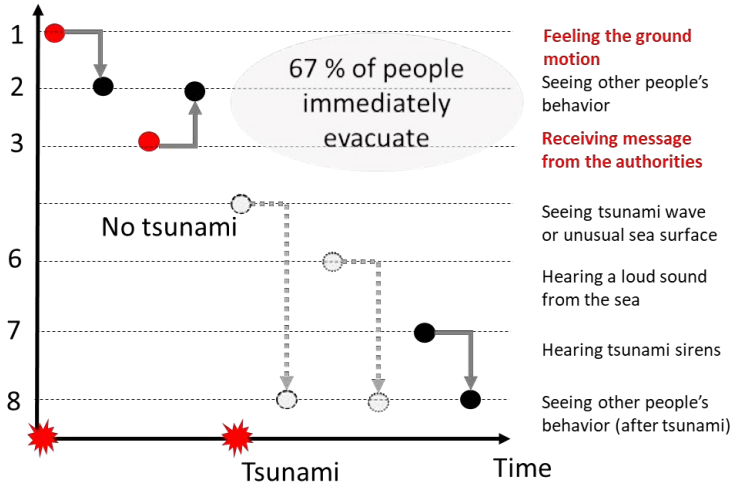

Fig. 4. Modified basic model for group of people with past tsunami experience

similar with the result of study about early warning system in the world failure to give warning to the downstream level by Collins, 2009. Considering characteristic of tsunami from the past disaster event and failure of early warning systems, further approach should be to understand more about personal characteristic of Indonesia people. If people have capacity to recognize the danger and enough knowledge of tsunami evacuation, they will immediately evacuate without waiting for authorities order and direction.

4. CONCLUSION

For the past 20 years, there have been developments of science, technology and law for disaster reduction in Indonesia. This created a new dynamic with social and cultural relation in the society. Our study showed the behavior change have been affected by the development of tsunami early warning system, past disaster experience and capacity building. The first rank of factor to trigger people start evacuating is message from the authorities, second rank is seeing other people behavior and third rank is feeling ground motion. The gentle and slow ground motion make people failed to notice the possibility of tsunami coming, caused people to do a late evacuation when seeing or hearing tsunami coming.

This result provides result on personal characteristic of Indonesia people concluded from past-event analysis of human behavior. Integrating this factor as an input parameter in the evacuation modelling to determine timing in evacuation not just based on assumption that all agent evacuate at the same time, but every agent considered individually.

After summarizing, we found the possible danger of the future evacuation in Indonesia. Before the tsunami early warning system launched in 2008, people delayed the evacuation because they didn't have enough information to understand that tsunami will come as in Aceh 2004 and Pangandaran 2006. After the tsunami early warning established and tsunami drill conducted in several location in Indonesia, people delayed the evacuation because they are waiting for an evacuation order from the authorities. This situation is very dangerous because some past tsunami event in Indonesia categorized as near-field tsunami and some triggered by non-seismic activity. Apart from equipment and technology development, building capacity and resiliency in people to recognize the danger and enough knowledge of tsunami evacuation should be undertaken continuously.

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