CHAPTER 4
CONCLUSIONS

This chapter provides a summary of what has been accomplished (Section 4.1) and suggests future avenues for prospective research (Section 4.2).

4.1 Summary of Results

The objective of this study is to develop a pragmatic tool for evaluating the performance of a tsunami evacuation plan of Patong municipality, Phuket, Thailand. To achieve this objective, the following three tasks were accomplished:

1. Developed a dynamic model for calculating tsunami travel times in the Andaman Sea region.
2. Developed a spreadsheet model to determine the probability that evacuees, if following the evacuation plan, could reach safty before the leading tsunami wave strikes.
3. Used both models to examine the implications of some measures for safer evacuation.

The remaining part of this section elaborates further on the above three research accomplishments.

4.1.1 Tsunami Speed Model

The development of the tsunami speed model, called Method of Nearfield Tsunami Exploring (MONTE), constitutes the following set of accomplishments:

1. The model provides a powerful tool for tsunami evacuation planning in the Andaman Sea region, because it predicts the tsunami travel times to considered targets (tsunameter/target community) with satisfactory accuracy (time difference < 2 min/h).
2. The model is robust under a plausible range of all parameters, making it reliable even when the exact values of the parameters are not known. For reliable prediction, the model requires nearshore bathymetry be accurate to at least 57% of actual water depth, provided that the 2 minute data set (ETOPO2v2) is

accurate in deep water (> 200 m). A more detailed bathymetry data set (<2') is not needed, to keep the time difference under the acceptable limit.

3. The model suggests that ETOPO5 should not be used for travel time predictions to Patong Beach, because the data set contains a large bathymetry error in the nearshore region, causing calculation error above 2 min/h.

4. By incorporating the upper limit of wave height and the velocity correction term, the modeling process led to the modification of Green's law and solitary wave theory, providing a more accurate calculation of tsunami travel times in the nearshore region.

5. The causal relationships among the model components are explicit and simple, allowing the user to evaluate the validity of the model with ease.

4.1.2 Tsunami Evacuation Model

The development of the tsunami evacuation model, called Simplified Evacuation Drill (SPEED), provides the following set of accomplishments:

1. The model makes it easy to evaluating the performance of the tsunami evacuation plan for Soi Bangla in Patong municipality.

2. The model provides several insights into the plan performance. It suggests that the full-scale tsunami evacuation drill on 25 July 2007 represents merely an optimistic case where successful evacuation is readily achieved. By contrast, under a worst-case scenario, local inhabitants could be exposed to tsunami inundation, although the probability of the event is low, $\Pr(\{HQ > 1\}) = 0.13$.

4.1.3. Implications of Measures for Tsunami Hazard Mitigation

Three mitigating measures have been found to be potentially effective. The models suggest that the use of siren warning, vertical evacuation, and fast movement could protect people in Soi Bangla from exposure to tsunami inundation. Here, the public at risk must adopt at least one of the following three measures: starting evacuation immediately after the siren sounds, heading to an evacuation shelter building located no more than 150 m away from the beach, and moving at the speed greater than 105 m/min.

Some more advanced measures, including the use of real-time tsunami forecasting system and the improvement of DART buoy technology, are unlikely to increase the evacuation performance as much as expected, because these measures can reduce just five or six minutes of evacuation delay. Therefore, the impact of these measures is similar to that of the *status quo*.

In sum, the model results support a conventional rule of thumb for safe tsunami evacuation: "Right after the siren is sounded, run for higher ground."

4.2 Suggestions for Future Research

The models developed in this study should be viewed as initial─never final. Based on the results of our validity testing, both models can be useful for building confidence in the evacuation plan for Soi Bangla. But there are several areas requiring more intensive research to make the models also useful for other evacuation zones. Below is a brief description of major challenges facing the application of the models:

1. The MONTE model rests on the assumption that the leading tsunami wave crest does not break until reaching the shoreline. If ones are sure that the wave will break in the nearshore region of their communities, the model boundary should be extended to incorporate the effect of wave breaking.

2. The MONTE model also ignores the effect of wave refraction. Therefore, model enhancement to incorporate the reflection process is needed if large oceanic obstacles (*e.g.* islands) are present somewhere along the ray trajectory.

3. The MONTE model considers the tsunami source as a single point, not as a line of sources. Should scientists be interested in the effect of the multiple sources on tsunami travel times, they can use this model by changing the parameter values to represent each tsunami source (*i.e.* initial wave height, initial water depth, source location, and bathymetry profile along the ray trajectory). But this is still a time consuming process.

4. The behavioral validity of the MONTE model can be criticized for being questionable because the model was validated using the observed data for the 2004 Sumatra earthquake tsunami alone. Greater confidence in the model is to be gained when another tsunami occurs in this region, provided that the observed tsunami travel times for that event are found to be consistent with the calculated travel times.

5. Further research should determine the location of a tsunami source that posts the greatest risk to each vulnerable community in the Andaman Sea region. That source is the point from which tsunamis propagate using the shortest travel time, which can be examined within the framework of the MONTE model.

6. The conclusions of the SPEED model are most sensitive to the preparation time; it is wise to design strategies to minimize this delay. Such strategies, if effective, would reduce the total evacuation delay by as much as 35 minutes.

7. The value of the delay due to traffic friction was only roughly estimated in this study. Further research should provide more accurate estimates for this parameter if the actual delay is likely to be longer than 10 minutes.

8. The safety criterion used in this study was defined using a risk assessor's perspective, and is rather conservative: a tsunami evacuation is judged safe only if all evacuees are capable of reaching the designated safe destination before the leading tsunami strikes. Further research should examine the safety criterion as accepted by the local public, because the policy recommendations (Section 4.1.3) are sensitive to such a criterion.