CHAPTER 2
RESEARCH METHODOLOGY

1. Theoretical Formulation

Prior to this step, the author's mind was prepared by consulting available literature on theory and model development (Forrester, 1961, 1968, 1969, 1971, 1973, 1985, 1989, 1990, 1994, 2003; Gere, 1984, 2004; Whetten, 1989; Beveridge, 1990; Fitzer, 1993; Varian, 1994; Kelly, 1998; Popper, 2002). Free full-time for two years was then spent to develop hypotheses about tsunami travel times and evacuation times under tsunami emergencies. Relevant data were gathered from various information sources: textbooks, journal articles, webpages, newspapers, magazines, official documents, and E-mails. These data were organized into 16 folders, named Great Circle, Eyewithness Accounts, Tide Guage Records, Propagation, Generation, Warning, Evacuation, Gravity, Linear Interpolation, Monte Carlo Simulation, Bathymetry, Evacuation, Shoaling, Solitary Wave, Oceanography, and Validation. Grounded theory (Luna-Reyes and Andersen, 2003) was used to identify key concepts contained in the database. Such concepts were marked as problems, causes, solutions, and desirable conditions, using red, blue, green, and violet wax-crayons, respectively. Personal intuition, developed through this reading, was used to answer two questions: i) What major factors determine the successs of a tsunami evacuation?, and ii) How such factors are causally related? This effort led to theories of tsunami wave speed and of tsunami evacuation time (see Chapter 3) which explain why a given tsunami evacuation plan is likely (or unlikely) to be effective.

2. Model development

The descriptive theories formulated in the previous step were translated to two computer models: one was intended to calculate tsunami travel times in the Andaman Sea region; the other was used to determine whether a given tsunami evacuation plan could protect inhabitants from tsunami hazards. Each of the models has its purposes, conceptualization, formulation, and validation procedures as described below.

2.1 Development of a Tsunami Travel Time Model

2.1.1 Model Purposes

A model of tsunami wave speed, called Method of Nearfield Tsunami Exploring (MONTE), was developed to more accurately calculate tsunami travel times to tsunameters in the Andaman Sea and to Patong Beach, a community in Thailand that was hit by the tsunami of 26 December 2004. The model was also used to determine the required degree of bathymetry accuracy to ensure accurate calculation of tsunami travel times. The model focuses on the leading crest of a nearfield tsunami generated by an earthquake in the Sunda Subduction Zone and propagating along the shortest path (minor great cicle arc) to the populous Patong Beach on the west coast of Phuket. Other targets were included for model validation (Figure 3).

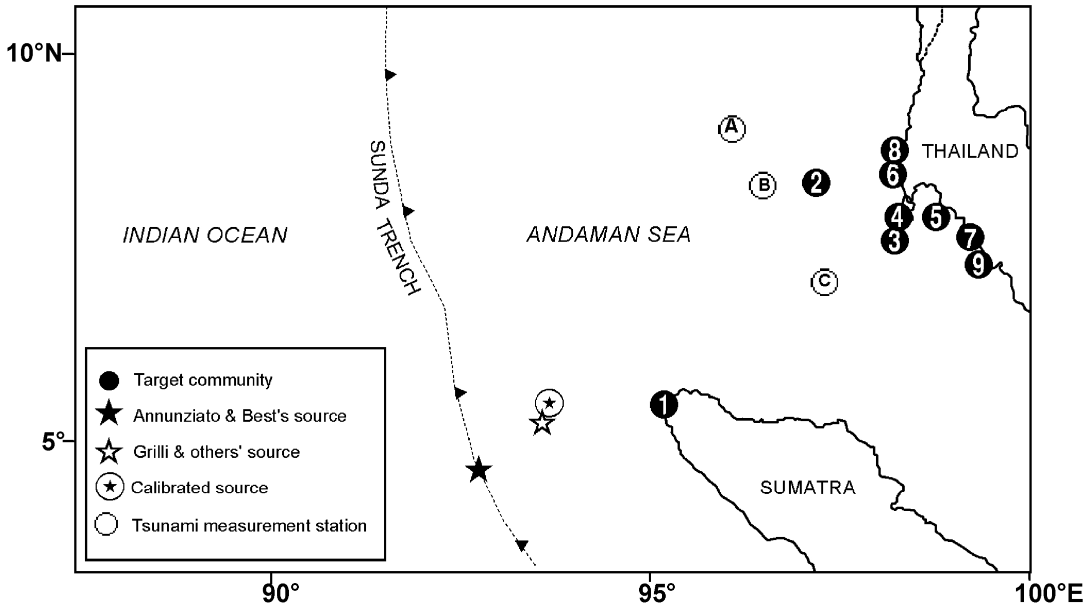

Figure 3. Map of tsunami sources and some targets in the Andaman Sea region. Nembered locations are identified in Table 6

2.1.2 Model Conceptualization

The first step in building the model was to express the theoretical concepts as a level-rate diagram, so that a system dynamics modeling technique can be used to solve the function of $s(t)$ over the interval $[0, T]$. Guided by the principles of systems (Forrester, 1990), key theoretical concepts, consisting of parameters and variables that govern the dynamics of wave celerity along the ray trajectory, were selected as model components. The variables were further classified into level, rate, and auxiliary variables. Level variables represent where the accumulation takes place in the system. Rate variables represent what causes levels to change. Auxiliary variables represent what affects rates and can change immediately in response to changes in levels. A flow diagram clarifies how these model components are causally related (Figure 4).

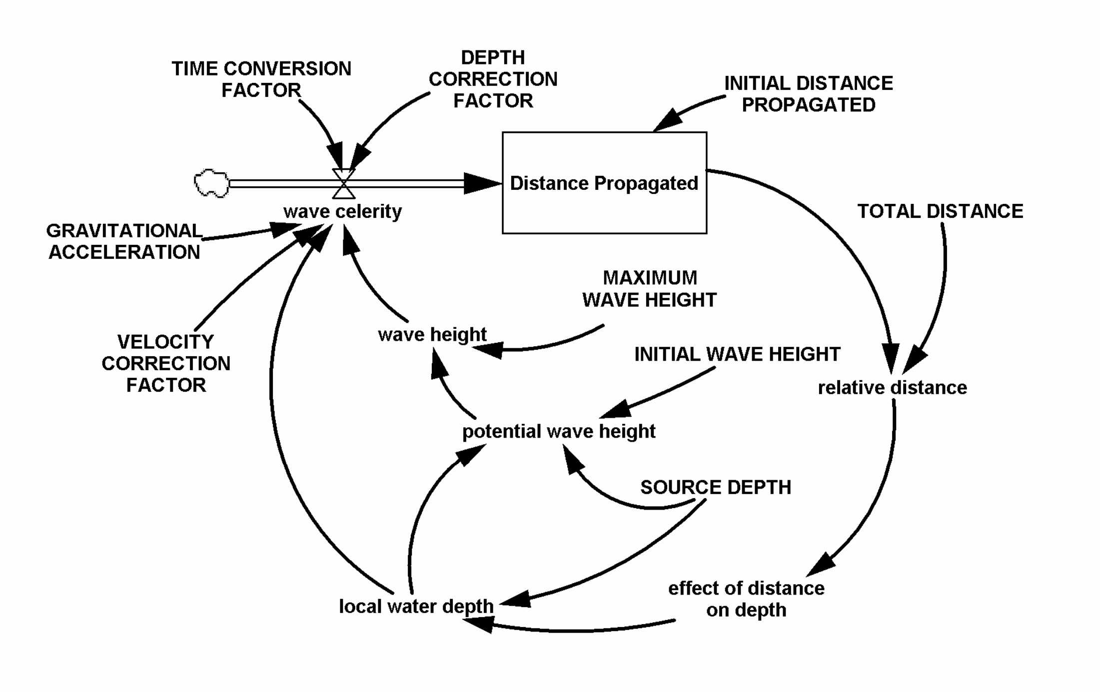

Figure 4. Flow diagram of a tsunami travel time model used in this study

Wave celerity is the rate that increases distance propagated, which in turn increases relative distance of the leading crest, which alters local water depth and wave height, both of which influence the wave celerity, which affects the level of distance propagated. This feedback relationship was considered a minimal structure necessary for calculating the travel time of a nearfield-tsunami.

2.1.3 Model Formulation

To build the MONTE model, the flow diagram shown in Figure 4 was entered in the Sketch Drawing Area of modeling software, Vensim (Ventana Systems, 2007), and the Equation Editor tool was used to type in the equations and units of measurement (Appendix A).

Most of the parameter values used in the model were taken from reports on the 26 December 2004 tsunami. The model's tsunami source (5.458°N, 94.000°E) is a calibrated source near to the eastern border of the southern rupture zone (Fine *et al.* 2005; Grilli *et al.* 2007), far from the fault epicenter that was noted in Annunziato and Best (2005) as the tsunami source (Figure 3). The model's target is the shoreline of Patong Beach (7.9°N, 98.276°E). The model was run on an IBM laptop computer (Pentium M, 1.5 GHz, and 248 MB RAM). The fourth-order Runge-Kutta (RK4) integrations were made with a 0.03125 minute step. With the selected parameters, the model reproduced the tsunami travel time to Patong Beach with calculation error less than 2 min/h, which is the maximum acceptable error used in Shokin *et al*. (1987).

2.1.4 Model Validation

The structural soundness and accuracy of the MONTE model in generating accurate predictions of tsunami travel times to both tsunameters and shorelines in the Andaman Sea region was validated using three types of tests: i) structural tests, ii) structurally-oriented behavior tests, and iii) point prediction test (Forrester and Senge, 1980; Sterman, 2000).

2.2 Development of a tsunami evacuation model

2.2.1 Model Purpose

A model of tsunami evacuation demonstraton, **s**im**p**lifi**e**d **e**vacuation **d**rill (SPEED), was developed to more objectively evaluate the effectiveness of a tsunami evacuation plan for Soi Bangla─the most populous area in Patong Beach, Phuket, Thailand (PMO, 2007a). The model was also used to identify effective measures to enhance the ability of local inhabitants to escape tsunami disaster. The model focuses on the evacuation plan of the Patong Municipality Office (PMO, 2005, 2007a, b), and the national tsunami warning system with three tsunami measurement stations located in the Andaman Sea (Figure 3), as proposed by the Thai Meteorology Department (TMD, 2006).

2.2.2 Model Formulation

A computer model was developed to provide automated conclusions on the plan effectiveness. Eqs. (32)─(34) and the data in Table 2 were translated to a static model in Microsoft® Excel spreadsheet (Appendix B). Parameter values were then specified in the white cells (Figure 5) to generate a conclusion on the levels of public safety provided in the community. With the assigned parameters, the base model concluded that the effectiveness of the evacuation plan for Soi Bangla was debatable, with 67% safety level.

Table 2. Criteria and benchmarks for effectiveness of a tsunami evacuation plan

Model Conclusion*			Effectiveness Benchmark†		
Best	**Normal**	**Worst**	**Qualitative Label**	**Risk Symbol**	**Satisfaction (%)**
1	1	1	Alright	□	100
1	1	0	Debatable	⊡	67
1	0	0	Critical	▣	33
0	0	0	Super-critical	■	0

*1 = All evacuees can reach safety before the first tsunami wave arrives (HQ $\leq$ 1); 0 = Some evacuees fail to do so (HQ> 1) †Modified from Macgill and Siu (2006)

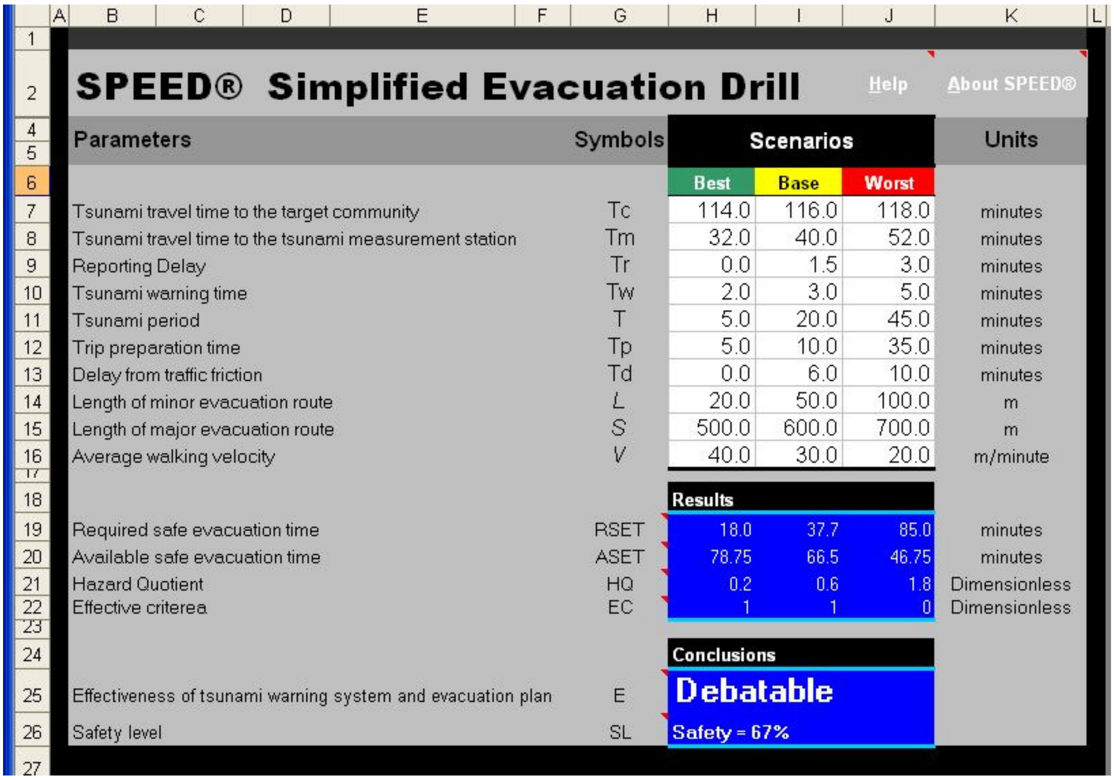

Figure 5. Interface of the SPEED model used in this study

2.2.3 Model Validation

The structural soundness and accuracy of the SPEED model in generating plausible conclusions on the effectiveness of the tsunami evacuation plan for Soi Bangla was validated using three types of tests: (i) structural tests, (ii) structurally-oriented behavior tests, and (iii) point prediction test (Forrester and Senge, 1980; Sterman, 2000).

3. An Example of Application

The usefulness of the models was demonstrated with an example showing how to evaluate the effectiveness of a tsunami evacuation plan for Soi Bangla, Patong municipality, Phuket. The plan was obtained from the Patong Municipality Office on July 25, 2007.

4. Materials and Equipment

This study required materials, both softwares and hardwares, and some important equipment as shown in Table 3.

Table 3. Materials and equipment for evaluating the performance of the warning system and evacuation plan for the Patong Municipality, Phuket.

Item	Description	Intended Use
Software	Adobe Acrobat Reader 6.0	PDF documents openning
	ArcView GIS 3.2a for Windows	Figure preparation
	GODAS, Version 4.1.23	Bathymetry data extraction
	Internet Explorer	Tsunami data searching
	Lumenaut Monte Carlo Simulator	Monte Carlo simulation
	Math Type 5	Equation typing
	Microsoft Office Excel 2003	Model development
	Microsoft Office Word 2003	Document preparation
	Microsoft Office PowerPoint 2003	Diagram preparation
	Microsoft Notepad, Version 5.1	ETOPO5 data preparation
	Photoshop CS	Figure preparation
	Vensim Professional, Version 5.6a	Model development
Hardware	Digital computer, IBM ThinkPad R51	Model running and documentation
	Printer, HP LaserJet 6L	Production of technical document

Others	A4 papers	Data recording
	Stopwatch, NOKIA 6300	Evacuation time measurement
	Pens, 045 REYNOLDS	Data recording
	50-m measuring tape, TOPLON 4050	Measurement of route length