A GENERALIZABLE TSUNAMI EVACUATION PLANNING MODEL

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This proposal summary describes a two phase program to develop and test a computer model and other analytic tools that can then be used by coastal communities to create an optimal Set of Tsunami Evacuation Plans [STEPs]. The plans would be keyed to "minimizing loss of life" from Tsunami waves based on "time-of-day" and other circumstance-based parameters. An important project hypothesis is that local communities should not have a "one-size-fits-all" Tsunami Evacuation Plan, but rather a "Set of Tsunami Evacuation Plans" [STEPs] that use pre-computed templates and pre-tested evacuation strategies based on Tsunami warning parameters coming from NOAA's Tsunami Warning Centers.

Timeline

We will first show the feasibility and usefulness of our approaches with test cases for the cities of Capitola and Santa Cruz including the Santa Cruz Yacht Harbor. We believe that insights gained from these test cases, will help us generalize our models/algorithms to other coastal cities and harbors worldwide. In Phase 1, STEPs will be created for [each of] the targeted geographies. In Phase 2 one or more of these STEPs would be "dry run" tested. After testing a "Best Practices Guide" and generalizable analytic computer models, algorithms and protocols will be made available to coastal communities worldwide to use in creating local community STEPs that would minimize loss of life.

Description of the Tsunami Evacuation Model

Tsunami wave flow modeling and forecasting has been an active research area for the past few years, and the ability to predict and warn local coastal municipalities of 1) the expected inundation zone [map] and 2) timing of impending Tsunami waves has become possible. Based on the specifics of alerts from the Tsunami Warning Center [TWC], this study proposes to use combinatorial and stochastic evacuation traffic models to predict fatalities in the inundation areas for a variety of evacuation variables. That evacuation variables may lead to different "circumstance based" Tsunami Evacuation Plans is shown in the [hypothetical] Table 1 below. The model will also consist of dividing local inundation maps into sub-maps [based on the logical partitioning of evacuee populations] to construct optimal evacuation routes.

Table 1 - Hypothetical "Set of Tsunami Evacuation Plans" [STEPs] for the City of Capitola

Inundation Zone Population	Distant Source [2-3 hrs warning]	Local Source[15 mins Warning]
Heavy population	Mix of Vehicular Evacuation and Pedestrian evacuation	Pedestrian Evacuation Only, Law enforcement constrained
Medium population	Vehicular Evacuation	Pedestrian Evacuation Only, Law enforcement constrained.
Light population	Vehicular Evacuation	Vehicular Evacuation

"Time-of-day and Circumstance-based" Fatality Variables to be Modeled

We anticipate the following non-exhaustive list of variables to be considered in our modeling effort:

- Degree of fault tolerance in TWC alerts
- Communications delays in TWC alerts
- Population density at time of warning,
- Near vs. distant source,
- Planned vs. unplanned pedestrian and automobile traffic flow,
- Reversed vs. non-reversed traffic flow [for vehicular evacuation scenarios],
- Planned vs. unplanned reverse 911 calls,
- A city-specific [street map] model of traffic flow and bottleneck analysis
- Active vs. passive law enforcement traffic management,
- Piling height, wireless notification of "dock captains" and other generic harbor variables.

Comparison with Existing Tsunami Modeling Approaches

While recent research efforts have looked into the problem of emergency evacuation for hurricanes and earthquakes, coastal community evacuation in case of a Tsunami is less investigated. Our observation is that designing tsunami evacuation strategies is significantly harder. This is primarily because [depending on time of day and inundation area variables] large populations of evacuees may be required to be transported to a safe area within a short span of time, under law enforcement and resource constraints.

Aim of the Project

Hence, the aim of this project is to design useful analytical models, algorithms and processes to carry out optimal tsunami evacuation AND to develop state-of-the-art local community tsunami evacuation plans. Saving lives in the face of such natural catastrophe is our main objective instead of merely coming up with a cost-effective evacuation strategy where some evacuees strive to save property [vehicles] that may risk other evacuees' lives. Here, we briefly outline major components of our project:

(1) Evaluation of state-of-the-art evacuation system: We will assess the performance (e.g., response time from initial alert to local spots), availability (fraction of time different components as well as the entire system being up), performability (when there are failures in the system, what is the response time distribution, or average time for an alert to the local area (people), and survivability/resilience (transient behavior of the system when changes outside of design envelope of the system are enforced) of the evacuation system. Different failure modes such as sensors failures, physical/wireless link failures, central alert system component failure and their recovery modes will be investigated. Various evacuation strategies (e.g., on foot, car and vertical evacuation) and their measures (mean time to deliver evacuation alert, delay to spread out the alert from central office to local spots, etc) will also be modeled carefully.

2) Types of models to be used. Under independence assumptions, we have solved such problems using combinatorial models such as product-form queuing networks, reliability graphs, fault trees or a combination of these. If there are dependences between components, we have used state-space models such as continuous time Markov chain, semi-Markov process, Markov regenerative process etc. For very large systems we can use hierarchical models. The most likely model type that we anticipate using in the present context is the fluid stochastic Petri net that allows modeling of jointly continuous and discrete state space systems. Model analysis will also include sensitivity analysis for different model parameters to understand the bottlenecks. Initial models will be solved by means of analytic numeric methods. As the models get more complex simulation or a hybrid method of solution will be utilized. Our considerable experience with solution methods, modeling or real systems and software packages that we have developed should be very useful in this project.

(3) Designing efficient algorithms and protocols for saving lives: We plan to design better evacuation "route construction algorithms" under law enforcement constraints as opposed to currently deployed unconstrained algorithms. We will also exploit a number of non-traditional but feasible methods to speed up the evacuation process. Example of such methods includes pre-targeted reverse 911 robo-calling.

(4) Optimization of developed evacuation methods: Our main objective is to select optimal evacuation strategy through proper traffic flow assignments, which will maximize the number of lives saved. Different design alternatives like foot vs. vehicular evacuation will be examined to understand their benefits and trade-offs. Factors influencing evacuation strategies such as distance of tsunami source, population density, time of the day as well as the other variables listed above will be carefully modeled.

For all these models, input parameters such as tsunami occurrence rate, alert delivery rate from sensors to central system will be collected from existing studies (tsunami forecasting system). The developed analytic models will be connected to the geographical information of the area such as building, local road, and highway information. When analytic models become intractable, we will use large scale simulation.