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SIMULATION OF A TSUNAMI WARNING SYSTEM WITH A DIGITAL COMPUTER

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Abstract

In this paper, the initial considerations appropriate to beginning the modelling of a tsunami-warning system, or any warning system for a natural hazard, are developed. The oldest warning system of a natural hazard, the flood-warning system for the Nile River, is used to illustrate some of the general considerations.

A flow chart for the Pacific Tsunami Warning System is presented and briefly explained. (Computer programs and listings are available but not presented.) The resulting model indicates areas appropriate for research, and also provides guidance for decision-makers evaluating changes proposed for the warning system.

1. Qualitative Considerations

The actual modelling in detail of a warning system for a natural hazard can rapidly become so complicated by details that interesting general relationships may be difficult to perceive. Therefore, we provide here a qualitative discussion of a simple early warning system for a natural hazard. This will be the oldest natural-hazard warning system that the author has encountered—the flood warning system

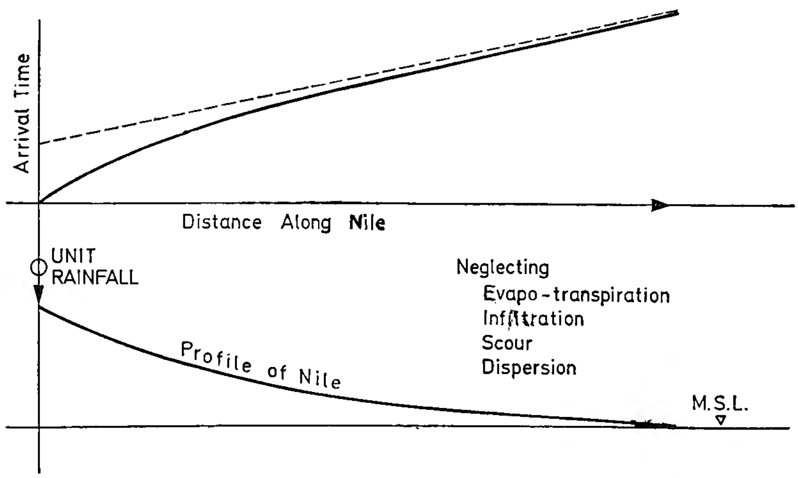

Fig. 1. Null Model (Environment) of Flood-Warning System.

developed by the early Egyptians. Mention is made of it by Biswas (*1970*).

The flooding of the Nile is an annual event with poignant significance in Egypt. The water level of the Nile is measured on a "Nilometer", with records traceable back to over *3000 B. C.* Since the flooding occurred annually, the Egyptians were prompted to evolve a flood-warning system. Diodorus states that the Nilometer at Memphis was the primary measuring point. If the water level of the Nile at Memphis attained a level which had previously resulted in severe inundation to the downstream population, then warnings were issued.

Consider how the flood-warning system have evolved. Prior to the existence of the system, or even the civilization, was the environment. This is schematically depicted in Figure 1 which shows the behavior of a unit rainfall upon an idealized profile of the Nile. All effects other than gravity are ignored. There is no hazard because there are no inhabitants in this "environment model".

Addition of an inhabitant induces the element of hazard, as shown in Figure 2, where the "problem model" is schematically described. The rainfall has resulted in the flood topping the levees of the flood plain and inundating our inhabitant.

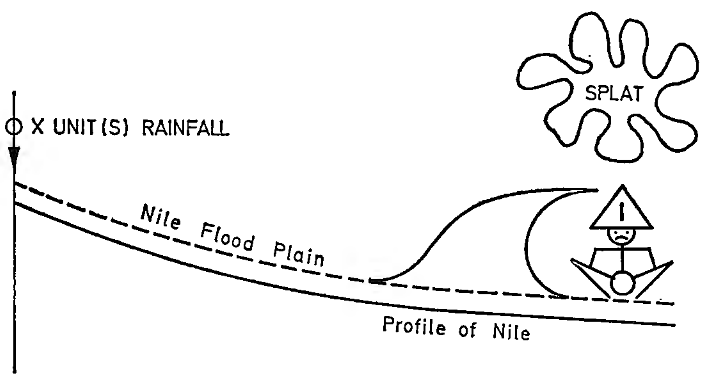

Fig. 2. First Model (Problem) of Flood-Warning System.

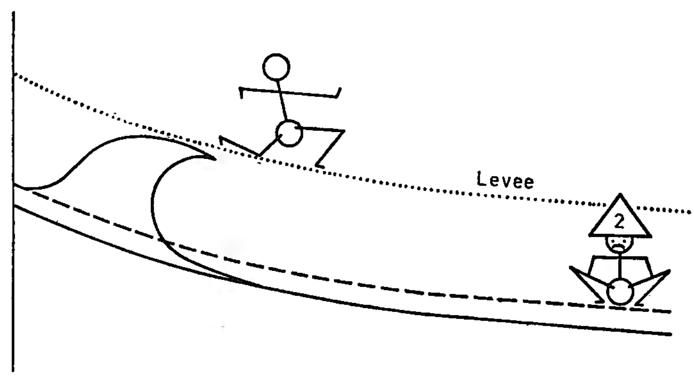

Fig. 3. Second Model (System) of Flood Warning System.

With this inundation, the inhabitant recognizes the existence of a problem, that is, a natural hazard.

If the occurrence of the natural hazard is sufficiently frequent, annually in the case of the Nile flood, the inhabitants will recognize that information about the forthcoming flood would be convenient.

The system which might have initially evolved for providing warning to downstream inhabitants of the Nile is shown in Figure 3. This is the level of modelling at which a warning system has been initiated: cal this the "warning-system model". The idealized behavior conceived for this system is that the runner, atop the levee, will race from the Memphis Nilometer to the downstream inhabitant and inform him of the forthcoming flood. This system does not work because the runner initially hired cannot run faster than the river flood.

Having conceived and created a warning system, the inhabitants are unlikely to immediately abandon their system, even when it fails due to the inadequacy of the runners. One possible behavior is to change a parameter of the system. Thus the inhabitants will conduct foot races and select only the fleetest for the privilege of carrying the information. Unfortunately, no human being can long run at a speed exceeding the river flood, so the parametric variation approach to system improvement proves inadequate, and the downstream inhabitants are again liquidated. See Figure 4.

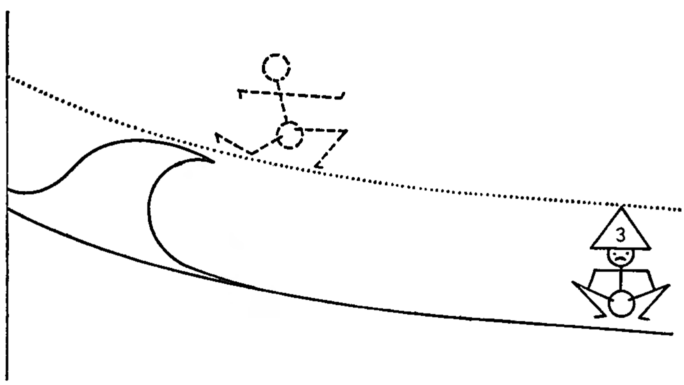

Fig. 4. Third Model (Parameter) of Flood-Warning System.

Failure of parametric variation to yield a useful system prompts the downstream inhabitants to consider more drastic variations of the system, so a structural change is made. Such a structural change is depicted in Figure 5, where the runner has been replaced by a rower. That a runner may do a mile in about four minutes whereas a rower requires slightly more than five minutes may have caused the initial preference for the runners. However, the rowers have the capability of taking advantage of the current in the Nile River. This system of rowers on the Nile communicating to downstream inhabitants the rise of the water level at the Memphis Nilometer

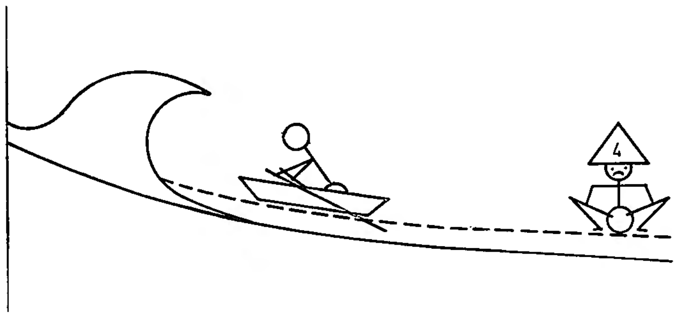

Fig. 5. Fourth Model (Structural) of Flood-Warning System.

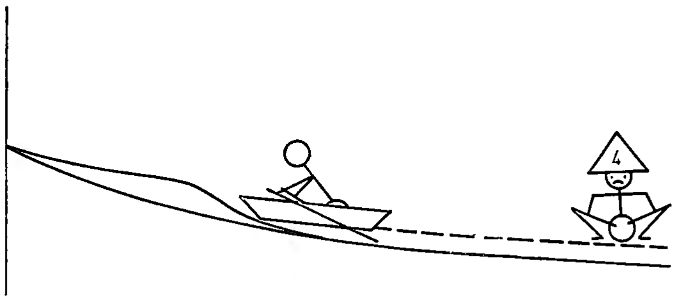

Fig. 6. Fifth Model (Environmental) of Flood-Warning System.

above a previously experienced threshold is that actually used by the Egyptians. The process by which the system evolved to this mode is completely hypothetical, but this discussion has served to indicate qualitatively the possible significant stages and changes in the development of a natural-hazard warning-system. These have been the environment model, the problem model, the warning system model, the parametric variation model, and the structural variation. The models have all assumed that the response of the inhabitants to the information is deterministic and controllable. In fact, studies now tentatively indicate that inhabitants living under the threat of a natural hazard tend to be less responsive to a system warning the longer the experience they have survived (Havighurst, *1967*). Yet another tage of the model requires the consideration of the steady-state response of the inhabitants to the system. In Figure 6 is depicted the inhabitant who may choose to decide that the warning is based on an unnecessarily high threshold. The inhabitant may consider such an unnecessary warning to be a false warning or false alert. A "feedback model" will describe this condition of the response of the inhabitants being evolved by previous experience with the warning system.

2. Digital Computer Model of Tsunami Warning System

A model will now be developed to emphasize the long-term features of the

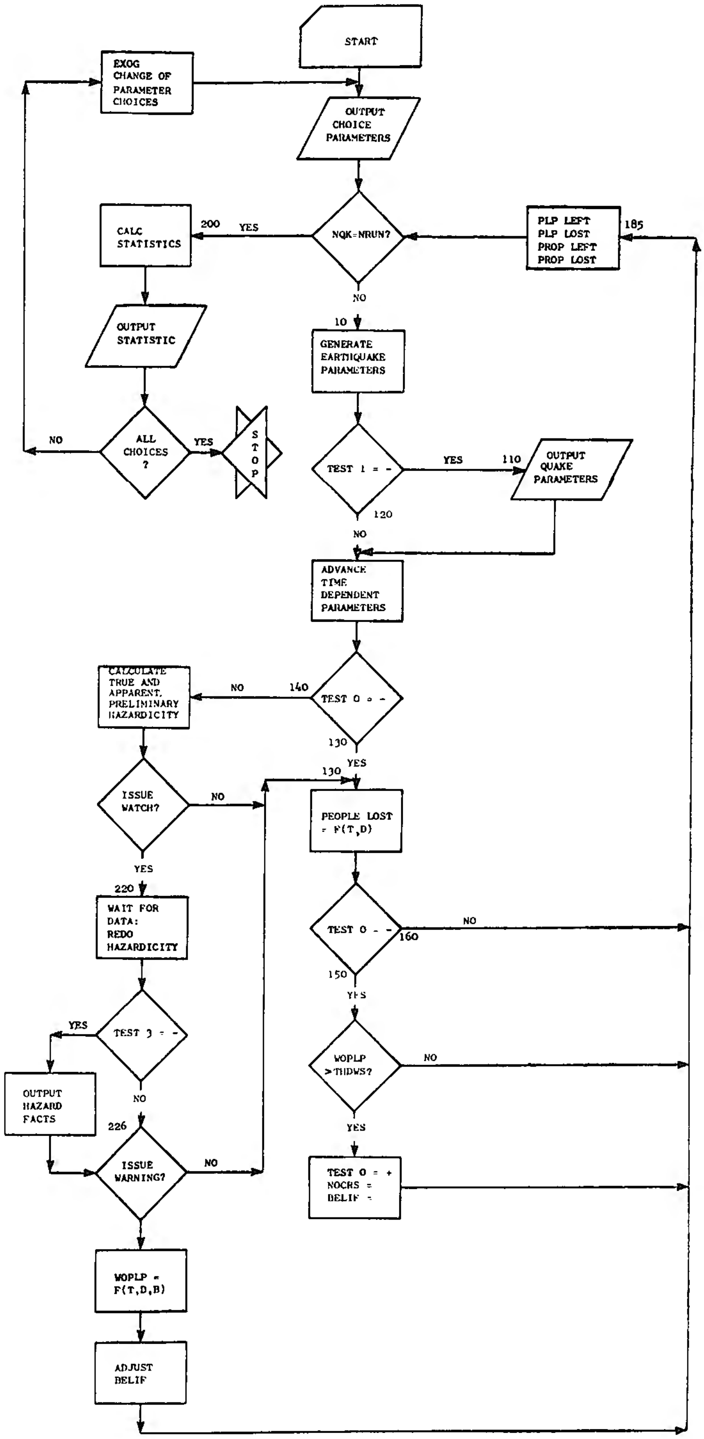

Fig. 7. Flowchart for Model of Tsunami Warning System.

Pacific Tsunami Warning System. This model has stochastic generation of earthquake parameters and tsunami parameters and is a development of the work reported by Adams [*1967*].

The tsunami warning system need not exist in the model at the time of beginning the simulation. If no system is deemed to exist, then a threshold of the number of people which must be lost to prompt creation of a system is an input parameter. When this value is exceeded, the simulation model creates a model system and future model earthquakes are monitored for their tsunamicity.

Both watches and warnings are included in this model. The system behavior is dependent upon input threshold, with the watch threshold being lower, presumably, than the warning threshold. The value of the parameter which is monitored and compared to the threshold is the sum of the disutilities corresponding to each of the stochastically generated earthquake and tsunami parameters. The water-wave observation is not assumed to be available for the watch decision. An observation of the water wave is assumed to be available in time for the warning decision.

The population density and property density along the coastline are allowed to grow with time. The population density is increased by the population growth-rate, LAMDA, decreased by population emigration, EMGRT. The population change due to birth and death are in units of percent change per-day per-unit coastline per-unit fall line. The immigration and emigration, however, are in units of individuals per day per unit coastline per unit fall line.

The property density is measured in dollars per foot of coastline per-foot fall line. The property density changes upward with time due to inflation and investment (assumed positive and lumped with inflation) and downward due to depreciation.

A pertinent feature of this program for the purposes of modelling is the distinction made between the true hazardicity of the situation and the perceived hazardicity, called the apparent hazardicity. The apparent hazardicity is assumed to be a linear function of the true hazardicity. Also, the number of people lost is made a function of belief of the people in the performance of the system. If the system is created in the course of the modelling, this value of belief is initialized at *0.5*. Otherwise, it may be initialized by an input data card to any value between *0* and *1*.

This simulation program is in the Simscript language. The technique followed is to define permanent entities with stochastic attributes. Separate random number seeds are used for each position in the program needing a random number.

In Figure 7 is given the flowchart for the model. The first action of the program is to list the parameters which have been inputted on data cards as choices. This not only includes the initialization, but also policy parameters. Input must include, of course, the number of earthquakes desired to be run in the particular simulation.

The number of quakes modeled is compared to the number desired to run. If less, then the earthquake parameters for a new earthquake are stochastically generated. The value of the stochastic quake parameters will be listed, providing the value of

TEST 1 on the input data card has been set equal to a negative value. If not, then the parameters which are dependent on the time interval between earthquakes, such as the growth of population and depreciation, are immediately computed and the pertinent parameters adjusted.

The next test determines whether the model presently includes a warning system. This is determined by the value of TEST 0. If the simulation is desired to start without a warning system existing, then TEST 0 is set equal to a negative value. In describing the flowchart, we will assume the warning system does not yet exist and proceed down the central vertical column of the flowchart.

The people lost depends upon the runup of the tsunami and the density of the people. If the WOPLE (Wiped-Out PeopLE) is greater than the THDWS (THreshold for creation of the Warning System), then the model system is created by setting TEST 0 to a positive number, noting the number of events needed for creation of events needed for creation of the system, (NOCRS) and setting the value of belief to BELFS, also a value inputted on a data card. If the number of people lost is less than the threshold, then the people density and property density are adjusted to account for the losses due to the tsunami, and the next event awaited.

If, after the time dependent parameters are adjusted, the model does include a warning system, then the system calculates the apparent disutility of the various parameters likely to be known within a couple of hours after a large earthquake about the Pacific Ocean. An apparent preliminary hazardicity is computed as a linear function of the true hazardicity. This relationship is introduced to represent possible psychology, choices, or preferences of personnel operating the system.

If the apparent preliminary hazardicity is greater than the warning threshold value (inputted on a data card), then a watch is issued. If no watch is issued, then the number of people lost is identical to that which would be lost if the system did not exist.

(The cost of operating the system is not recognized as a social cost in this model).

If a watch is issued, then additional data — an observation of the water wave — is awaited. An observation of the water wave is assumed to be received and incorporated into a revised estimate of apparent hazardicity. The values for the disutilities, true and apparent hazardicities will be output if TEST 3, a value inputted on a data card, has been set equal to a negative number.

If the revised apparent hazardicity is greater than the threshold value inputted for issuing a warning, then a warning will be issued. If no warning is issued, the number of people lost is identical to the number lost if there were no warning system. If a warning is issued, then the number of people lost depends not only on the runup and the population density but also the level of belief which the populace holds in the reliability and merit of the warning system. The value of the belief is adjusted. In the present model, this depends only on the ratio of the apparent hazardicity to the true hazardicity, called RATSU.

After the number of people lost has been determined, then the population density and property density are adjusted and the next event awaited. If the number of events desired has been executed, then appropriate statistics are computed and outputted. If no other exogenous event exists in the event list, then the model stops. If additional exogenous events are scheduled in the event list, then these will be initiated and the appropriate data cards read in the exogenous file. The time for the exogenous events is made after *9900* days. To permit a number of earthquakes to occur between exogenous resetting of policy parameters, the time is immediately adjusted to unit value upon completion of read in of initialization values.

The random parameters are generated. The amount of slip is made dependent on the magnitude, determined stochastically. The vertical component of the slip is then dependent on the stochastic values of the plunge angle and the dip angle. The component of the vertical displacement which occurs on the ocean side of the fault is then determined randomly. For ease in programming, the time at which the faulting (and concomitant earthquake and tsunami) occurs is not at the time when it is created and "caused".

The runup is made dependent on the ocean-side component of the vertical displacement. The area affected depends upon the slope of the land, LANDSL, and the minimum runup, RNUM, below which effect sare considered negligible. The parameters of the quake are listed if appropriately requested during preparation of input data cards. An alternating feedback relationship exists between the people living before the tsunami, PLPDT, and the people living after the tsunami, PLATS. The simulation is begun by inputting a value for PLATS. Similarly, alternations occur between property before the tsunami, PRBDT, and the property density at the time of the tsunami, PRATS. The value of PRATS is inputted on a data card.

After the various logical choices, assuming the system exists, the disutilities are computed. Various functional forms have been taken to relate the disutilities with the various stochastic parameters and policy parameters. The potential user of the model may have a very strong feeling for the functional form of one or more of these disutility relationships. Inspection of several listings from this model may convenience anyone that the functional form is not highly important. This is attributed to the cumulative effect of the numerous stochastic parameters involved.

Various logical decisions are made until the adjustment of BELIEF is made.

A report is always needed to provide the output when the entire sequence of faults has been generated. This is provided by a report STAT. An example of the output of STAT is given in the following table:

NO. RUN	NO. TO CREATE	NO. WATCHES	NO. WARNINGS
10	*11*	*10*	*10*
PEOPLE LOST	PROPERTY LOST		
TOTAL	TOTAL		
5.	*2571.*		

3. Conclusions

A complete description of this model, based on Simscript *1.5* and including complete listing of the computer programs, together with sample listings, is available (Adams, [*1971*]). Adaptation of the model to any warning system for a natural hazard, other than tsunamis, should be rather straightforward. While useful for educational and training purposes, such a model is also of use to administrators in evaluating the potential effects of any modifications that may be contemplated for the warning system.

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References

Adams, W. M., *1967*, Analysis of a Tsunami Warning System as a Decision-Making Process, "IX Pacific Science Congress, Tokyo, Japan, August, *1966*, Proceedings of Symposium on Tsunamis and Storm Surges.

Adams, W. M., *1971*, Evaluation by Simulation of Proposed Policies for Improving Natural-Hazard Warning-Systems", Joint Tsunami Research Effort: NOAA-HIG, University of Hawaii, Honolulu, Hawaii, *152* pages.

Biswas, Asit K., *1970*, *History of Hydrology*, North-Holland Publishing Co., Amsterdam, The Netherlands, about *250* pages.

Havighurst, J., *1967*, Perception of Tsunami Hazard, M. S. Thesis, Dept. of Geography, Univ. of Hawaii.