THE USE OF SIMULATION MODELS AND HUMAN ADVICE TO BUILD AN EXPERT SYSTEM FOR THE DEFENSE AND CONTROL OF RIVER FLOODS

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ABSTRACT

This paper presents an outline on the design of an expert system aimed at helping decision makers to operate flood control dams and to plan civil defense in flood prone.

The problem is first described and the need for an expert system is justified by the complexity of land use in the area as well as the dificulty to use simulation models on time for prediction of damages and for the analysis of the best control decisions. The expert system can synthesize the results of previous analysis with the models and the criteria of experts and it can be used on real time linked with an information system including rain intensity data and water levels at control points.

The contents of the data base of the information system, and the general specification of the different types of rules are presented.

Finally, the general methodology for the definition of the rules based on the artificial experience created by a program of runs of the differents models for representation of hydraulic behavior is discussed.

The project is now under study by the Spanish Ministry of Public Works.

1. Introduction

One practical application of Artificial Intelligence that has awakened the most interest over the last years is that of expert systems.

The development of technologies for the systematic treatment of inexact reasoning (Shortliffe (1), Duda, Hart and Nilsson (2) Shafer (3), Lowrance (4) and Zadeh (5), among others) as well as the construction of systems (Dendral (6), Mycin (1), Prospector (7) and RI (8)) applied to the world, has contributed to this. However, on developing an application on these lines, although having tools available (Teiresias (9), Ops (10), Rosie (11), etc.), the critical problem is the shaping of knowledge on an issue in a set of rules in such a way that the answers to the different questions are coherent enough and adjusted to the actual knowledge of the problems.

The personal experience of the author of this paper in some still unfinished attempts of application (12) shows that the design of this set of rules is not a simple process and does not necessarily lead to success, not so much be cause of the inadequacy of the concept of expert systems, but because of the difficulty shown by the persons consulted, of shaping their understanding of an area of knowledge into a structured aggregate of conjectures.

It is therefore considered, that the construction of expert susterns may be simpler in areas of knowledge where important theoretical support can be counted on, by building the inference rules integrating elements of the different theoretical supports or as a synthesis of results obtained through the application of models.

The present paper describes the conceptual framework on which the design of an expert system is based now under study at the Ministry of Public Works, which supports the decisions during a rise of water in a floodable region. Attention is focused in the definition of rules based on a set of mathematical simulation models of the different aspects of behavior, as an element of previous support.

2. The Problem

In autumn of 1982, important floods took place in the Spanish coastal Mediterranean regions, pointing up the needs of technical instrumentation designed to yield real time answers to a series of questions which arise during the event. In effect, in the Mediterranean area, the intensive explotation of land by tourism along the coast brings about the existence of substructures and buildings that block drainage as well as agricultural explotations giving rise to towns near the river courses. Furthermore, the climatological conditions bring little precipitation very concentrated in time which produces important flood peaks.

Therefore, the characteristics of the problem demand a rapid taking of decisions, given the important concentration in time and, furthermore, the complexity of land use and the system of hydraulic substructures, provided that any decision may influence the general behavior of the system, which does away with improvisation since actions which might appear acceptable locally might be un acceptable overall due to the intera£ tion of factors.

3. The System

In accordance with the preceeding considera tions, the construction is required of a system that gives support to the people responsible for control and civil defense during the flood period in order help them to assess the situation at any moment in the places of interest.

Taking into account the spatial structure of the area under study, its present situation and recent evolution, the clasical answer to this demand would be:

- A data base
- A knowledge base "able to understand" the va lues of the variables of the data base in ti me and space and able to give on time answers to the problematical aspects of the actual situation, and in the intervals of time in which it is desired to make forecasts.

4. The Data Base

For the purpose of information in the flood area, two subsystems may be distinguished:

- The hydrographic subsystem, made up of:
  . A catching watershed with large slopes that receives the rain, and can be described by:
    . a set of catchment areas
    . a tree-like network of rapid drainage
    . a low zone, whose axis is the river producing the floods, which can be described as the axis of the river together with a series of floodable pockets connected to the river through the temporary courses created during the flooding.

  The whole is represented in the figure 1.

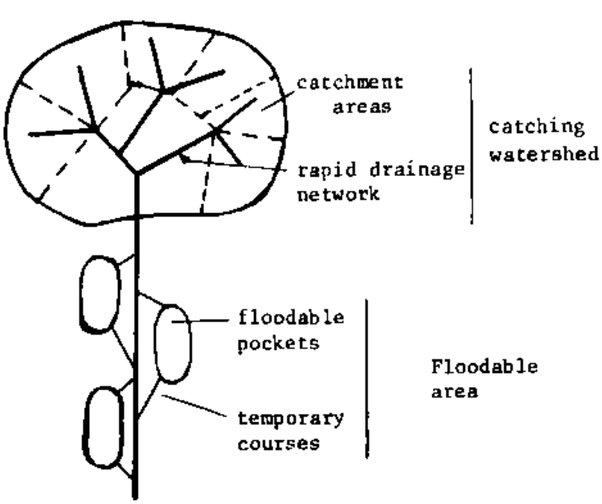

FIGURE 1

- The social-territorial subsystem made up of the system of towns, agricultural explotations and road/rail networks connecting it.

  Both subsystems occupy the region so that during a flood event the state of the first produces effects on the second (flooding of agricultural explotations, towns, blocking roads and railways, etc).

  The information system should present a picture of both subsystems so that questions can be answered on the effects on the social-territorial system. Accordingly, the information system should be:

  A simplified geographical information system spatially bounded by the contours of the agricultural explotations, urban areas and catchment areas in the watershed and with the spatial definition of the transport network (railways and highways) and the hydraulic network (steep high watershed network and main river in the low zone).

- A real time information system with:
  . Rain intensity in reception areas
  . Water levels at control points

5. The Knowledge Base

This is made up of the set of inference rules that, utilize the values of the data base and allow us to make pertinent assertions in order to evaluate the present and predictable situa tions.

In principle, these assertions would be:

- Pertinent to technical control:
  . Recommendable actions on how to operate flood gates in reservoirs, by-pass channels, etc, including blasting of barriers (roads producing backwaters).
- Pertinent to Civil Defense:
  . Water levels at different critical points
  . Alternative paths to the interrupted communi cations
  . Evacuation of urban Communities

The knowledge base must permit inferences on this type of declarations:

. In different spatial locations
. In different intervals of future time

Due to the need of quick answers it is not possible to use a set of complex simulation models, on line during the flood, but it is possible to build an inference engine that synthesize the knowledge obtained from previous model runs. This inference engine will have three main lines of reasoning:

. Reasoning on the state in every moment T
. Reasoning about the possible future states
. Reasoning about advices of control (proposals of decisions)

- There are two types of rules for reasoning about the state in a time instant:
  . Situation rules (SR). They allow the deduction of possible water levels in significant points of the flooded area based on data from control points furnished by the information system.
  . Impact rules (IR) , for estimating the level of impact in the urban and agricultural areas. They are based on the levels at the significant and control points and on their relationships with the socioeconomic system.
- There are three types for reasoning about the future:
  . Rain rules (RR) in orden to estimate rain intensity in the near future based on pluviographs shapes and their observed evolution.
  . Inflow rules (IFR) to compute the flows at every watershed outlet, from the present state of levels in the reception area and the estimated rain intensities.
  . Flood level rules (FLR) to deduce the expected water levels at the control points based in the actual state in these points and the possible future evolution in the inflow from the watershed areas.

  All these rules will be defined for fixed future time intervals (i.e. rules of 1 hr, 2 hr 6 hr——)

Once estimated the water levels at the control points, with different degrees of certainty the expected future levels and impacts at significant points, can be infered using the rules SR and IR, defined for the state at time T.

- There are two types of control rules:
  . Operation rules (OR) in order to propose variations in the control policy of dams, the blasting of obstacles that close the flows in some areas, etc.
  . Civil defense rules (CDR) to propose alternative travel paths in transport networks,. .etc.

The general structure is summarized in fig. 2.

6. System Operation

The system operates in the following way:

. A real time information system furnishes the basic data at specified time intervals. From these data the system produces the basic predicates that represent the premises for the inference engine.

. Based on these premises, real time inferences can be made on the situation of areas uncontrolled by the information system.

. It is also possible to make inferences on the future situation at the controlled and uncontrolled areas. The time intervals for inference may be chosen among those fixed in the rules (i.e. one couls use 30 min, 1 hr, etc... inference rules). The fact of updating the premises at every instant, doesn't imply to repeat all the inferential process. It will be posible to design a truth maintenance system to modify only those conclusions affected by the modified premises.

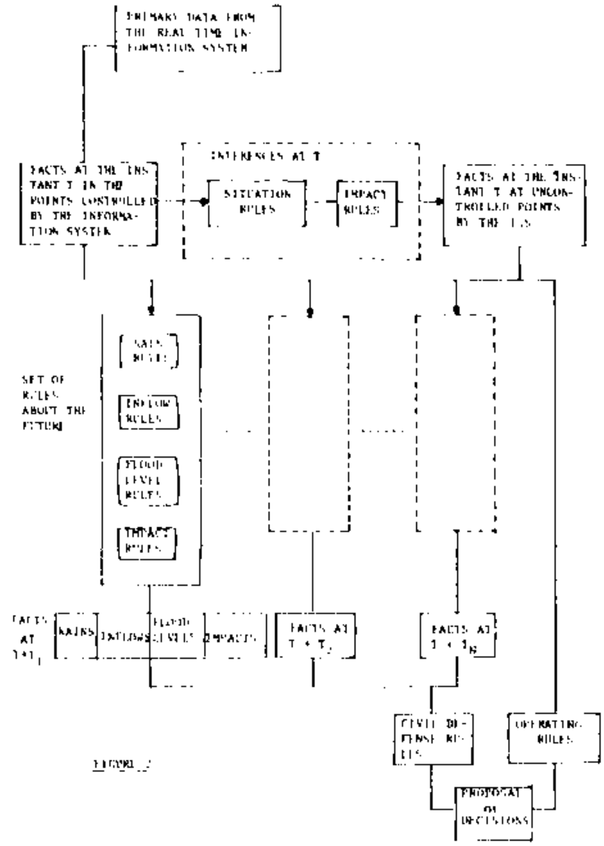

FIGURE 2

7. Building the knowledge base

The facts related by every set of rules are complex enough to define the rules only by the criteria of the experts.

Hydraulic engineering offers a set of mathematical methods for modelling the behaviour of water levels at both areas: reception and floodable. The general methodology to define the rules is :

. Use the existing data to calibrate:
  . Statistical models of pluviogram structure
  . An analogical model of the catching watershed areas
  . A numerical integration model of the unsteady flow equations for the floodable area

. Development with the advice of the experts, of a plan of model runs oriented to define the rules

. Definition of the rules based on:
  . The results of the artificial experience created by the model runs
  . The criteria of the experts evaluating the reliability.of the theory of the mo-

dels and the quality of the calibration
. The inclusion of complementary rules, by the experts, on impacts, dams operation and civil defense.

For the definition of rules based on Simulation results:

. A frame of discernement with predicates representing the basic facts must be defined

. Each rule must be described in terms of formulae composed of the basic facts specified for the different objects (rain levels in watershed areas, water levels in control and significant points, points of significant impacts...)

. The grid of simulated cases of every model must enable to establish the possibility of inference of some basic facts from a composition of facts. For that, the inspection of the number of simulated cases in which both the antecedent and consequent are satisfied compared with the total cases where some of them is satisfied, will allow to take the decision to include the rule and the estimation of its strength.

The rules to forecast the rain intensities can be built up by the analysis of a sample of storms time series registered in the data base.

For the representation of the behavior of the watershed area one of two classic simulation systems will be used: Stanford Watershed Simulation Model IV (13) or SWMM (Storm Water Management Model) (14).

The inflow rules (IFR) and the operation rules (OR) for the dams in the watershed can be built by analysis of the results of runs with the watershed simulation model.

For the simulation of the unsteady flow in the floodable area, an implicit Scheme (15) will be used for the numerical integration of the Saint Venant equations. This numerical model is able to compute the levels in the river and flood areas at every time instant, based on these results is possible to build the situation rules (SR) and, by analysis of the relationships between the increments of flows from the watershed and the increments of water levels, it is possible to build the flood level rules (FLR) for prediction.

Finally by expert analysis of the evolution of water levels and the knowledge of the situation of the social-territorial system, the impact rules (IR) and the Civil defense rules (CDR) can be defined.

8. Conclusions

The specifications and some basic aspects on the design of an expert system have been presented. The building of the system based on a set of simulation models runs permits the definition or rules with an important level of insight in the system behavior, and allows the experts to work in real expert tasks (Advising on the definition of the set of models runs to elucidate the key aspect of behavior adiusting the computed results based on reliability criteria of models formulation and calibration ,and including final rules on dam operations and civil defense)

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