# EXPLORING "IDEAS", A MULTIDIMENSIONAL DYNAMIC SIMULATION APPROACH

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## ABSTRACT

There are three types of variables and relationships: numerical, linguistic and pictorial. Traditional system dynamics models are defined by a set of numerical equations which are defined from causal diagrams. Expert systems modeling has shown that one could also develop and use linguistic dynamic models. IDEAS is an integrated simulation approach that considers state of the art numerical and linguistic formulations and introduces pictorial models.

Pictorial models consider pictographs, symbols and signs defined by their color, shape, size and position. Operations in these models include reproduction, mutation and fertile and sterile encounters, following a biological analogy.

IDEAS may be applied to variety of problems. Two simple natural resource management models are presented to illustrate its potential applications.

## INTRODUCTION

Numerical entities are easily interpreted, written and manipulated and have a compact notation (Nickerson, 1988). Thus, most models are numerical although reality is usually described by pictures and words.

Expert system modeling has shown that one could also develop and use linguistic dynamic models (Câmara, et al., 1987). Models using pictures and pictorial operations, in addition to state of the art numerical and linguistic dynamic simulation methods, were recently proposed by Câmara et al., 1990.

This integrated simulation approach named IDEAS is based, as the traditional system dynamics paradigm on casual diagrams and feedback loop concepts. The difference is that variables and operations may be linguistic, numerical and pictorial.

In this paper, pictorial models and the operations between numerical, linguistic or pictorial variables are discussed in detail. Methods inspired on biology, set theory, logic and vector calculus are proposed to implement such models and operations. Simple fire propagation and oil dispersion models are presented to illustrate IDEAS potential applications.

## MULTIDIMENSIONAL DYNAMIC SIMULATION

The basic structure of IDEAS models is defined by their entities and relationships, which are assumed to be simple 0—1 relationships. This structure can be translated into a casual diagram. Numerical, linguistic and pictorial entities are identified in IDEAS diagrams. From these diagrams one can define two classes of relationships; strictly numerical, linguistic or pictorial relationships and operations describing the interaction between numerical, linguistic and pictorial entities.

Strictly numerical modelling may follow traditional system dynamics methods. The manipulation of linguistic entities may use simple logic rules as proposed in Câmara et al. 1987. Pictorial methods to deal with pictorial entities and approaches to deal with numerical, linguistic and pictorial entities are less common.

### Pictorial Simulation

Pictorial simulation is usually considered as the algorithmic animation of pictorial objects. The growth of animation in simulation has been justified because pictorial simulation may be seen as aiding debugging, communication and decision (Luehrmann and Byrkett, 1989).

The pictorial simulation methods developed in IDEAS follow this tradition but rely only on pictorial entities and operators. In IDEAS, pictorial entities may be pictographs (representing real objects), symbols (abstract representations of objects or processes) and signs (arbitrary signs) (Arnheim, 1969; Lodding, 1983). These pictorial entities may assume combinations of four independent variables; size, position, shape and color.

To define the pictorial operators, let us consider that a set of pictorial entities describing a system state is considered to be a frame. Thus, the goal of pictorial dynamic simulation is to obtain a set of frames describing the evolution of the system through discrete time step advances.

Each pictorial entity is treated as a living organism which may reproduce itself, mutate or encounter other entities, producing offsprings (resulting from the combination of two or more entities) from a fertile encounter or not producing offsprings due to a sterile encounter.

Reproduction of an entity involves the copy of its own set of properties except position (that is, color, shape and size) and can be established as a function of time and space. Mutations may be activated internally by an entity and expressed again as a temporal function or activated externally by other entities. Pictorial operations in this case include change in size and shape (expansion, retraction), change in position (rotation and translation) or change in color.

Mutations in two or more pictorial entities may result in an encounter at a given point time. Fertile enconters produce offsprings which naturally will inherit properties from their parents. An offspring will generally have a position, shape and size that will be dictated by the intersection of the parent pictures, although it may also result from the reunion of those pictures implying the death of the parents, if one assumes so. The color of the offspring may be the color of one of the parents, may result from the combination of their parents colors (blending) or may be some newly assigned color.

Sterile encounters produce further mutations in one or more pictorial entities. These mutations may be represented by operators such as absorption.

A sample of the icons selected to represent these pictorial operations in the next version of IDEAS is shown in Fig. 1.. These icons will be used to code the pictorial simulation effert "once and for all" or to change the simulation interactively. The pictorial operations may be scaled by an angle (rotation), a distance (reproduction, translation) or a magnitude of relationship (intersection, absorption). A scaling menu will also be included in the coding table.

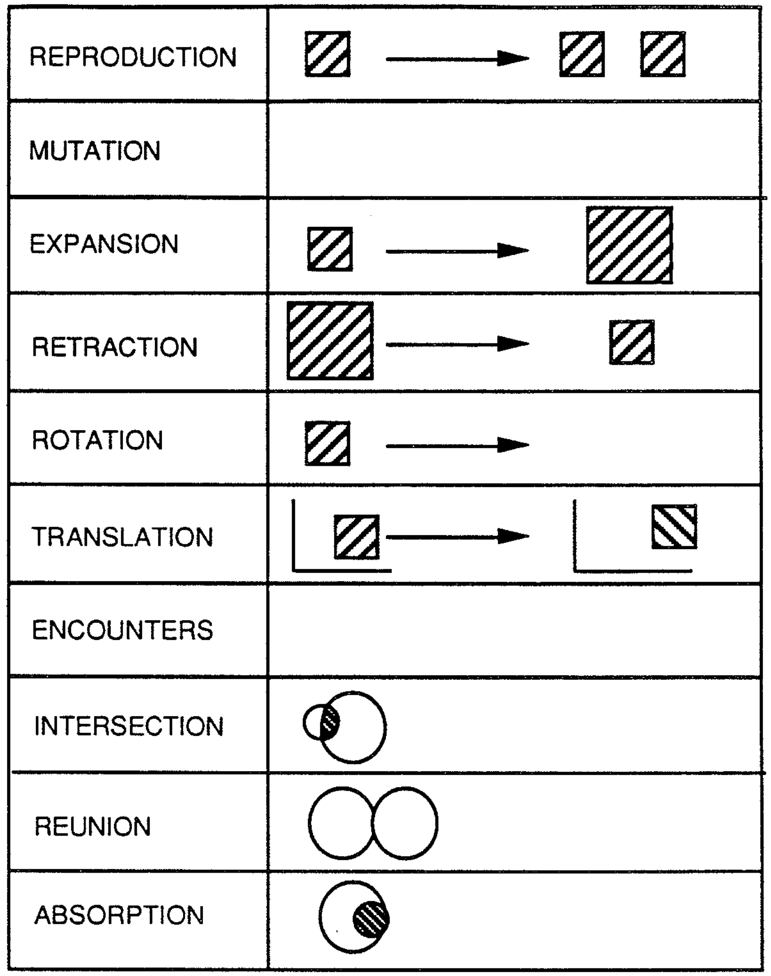


Fig. 1 - Iconic definition of pictorial operators included in IDEAS

**Interaction between Numerical, Linguistic and Pictorial Entities**

The interaction between numerical, linguistic and pictorial entities may be represented by one—to—one or several—to—one mappings. These several—to—one mappings may include interactions between a pictorial entity depending on another pictorial entity, a linguistic entity and a numerical entity. Conversely, one—to—one mappings may include interactions between a numerical entity depending on a linguistic entity or a pictorial entity depending on a numerical entity.

Whenever the dependent entity in a given mapping (one—to—one or several—to—one) is of the categorical (pictorial or linguistic) type (categorical entities reflect conventions sometimes well established such as the type of an agricultural soil) or numerical, logical rules have to be defined enumerating all possible valuations for the independent entities and resulting valuations for the dependent entity. These rules may be expressed in tree form. This tree defines the mapping for the subsequent simulation efferts.

If the dependent entity is of the ordinal (pictorial or linguistic) type (values for ordinal entities are defined by comparison with a standard or neutral value), and the effects of the independent entities on the dependent entity are truly independent and additive, then one can represent the contribution of a given independent entity on the value (or values, in the case of pictorial entities) of the dependent entity by a discrete increase or decrease on that value. This change can be represented by one or more arrows: one arrow meaning that the linguistic entity value would change one degree (i.e., low to medium); two arrows representing a change of a linguistic entity value of two degress (i.e., low to high) and so on. These contributions of the several independent entities can then be obtained by adding the arrows which makes the coding of these operations rather simple. Fig. 2. illustrates these concepts with a simple oil spill example.

## APPLICATIONS

Two simple natural resource management models were developed to illustrate IDEAS potential applications: a fire propagation model and a oil dispersion model.

### Fire Propagation Model

The spread of a fire in a forest depends on a number of factors such as the wind, humidity, type of trees, barriers and firemen intervention. A simple fire propagation model was developed using IDEAS concepts. Three main entities were considered: "Fire"; "Forest"; and "Burned Forest".

Following IDEAS terminology the "fire" *reproduced* itself following the main wind directions and as a result encounters the "forest". An offspring "burned forest" was then produced from the *intersection* of both parents.

This simple model may incorporate a control variable such as "firemen intervention" expressed as the number of firemen units avaible. While the "fire", "forest" and "burned forest" may be seen as mainly pictorial variables that can be decoded in numerical variables (i.e., areas), the variable "firemen intervention" is strictly numerical, althought it may be represented pictorially (i.e., using one icon to represent each unit).

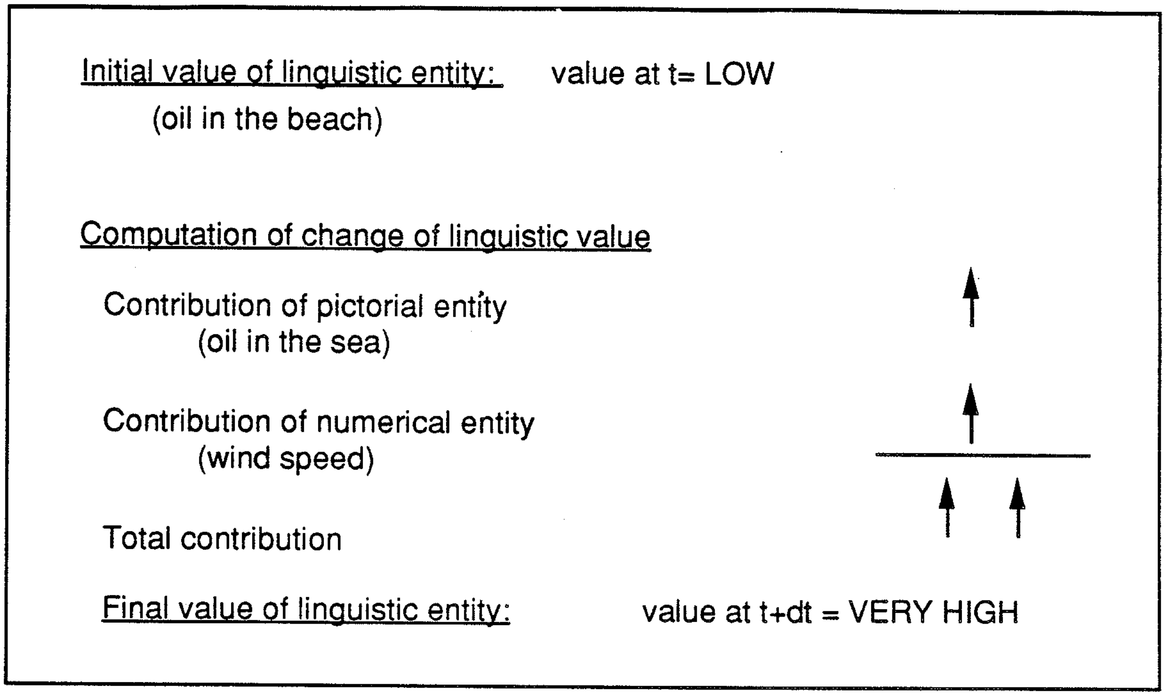


Fig. 2 — Example of a formulation for the interaction with an ordinal entity (Câmara et al., 1990)

Fig. 3 shows the simplified causal diagram for this model. Fig. 4 includes a sample output of the model implemented using IDEAS methodology.

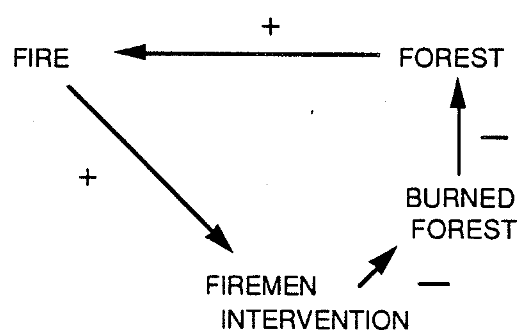


Fig. 3 - Simplified causal diagram for fire propagation model

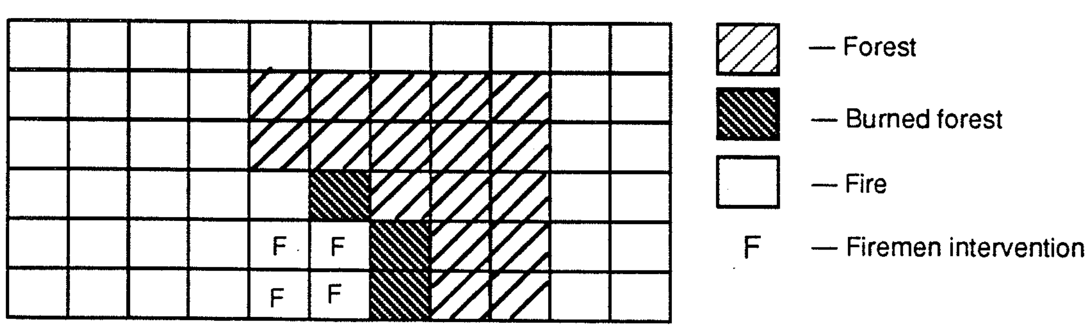


Fig. 4 - Sample output of fire propagation model

## Oil Dispersion Model

The assessment of an oil spill fate and effects in the sea is a complex process. Typically, the oil spilled is dispersed immediately after discharge due to advection and spreading. The area and thickeness of the oil is then affected by evaporation, sedimentation and decay phenomena.

Advection is influenced by dominant winds and currents. Spreading results from a dynamic equilibrium between the forces of gravity, inertia, friction, viscosity and surface tension (Steering Committee, NRC, 1985).

Evaporation is accountable for the loss of one to two thirds of the oil mass in a period of few hours after the spillage (Steering Committee, NRC, 1985). Oil may be transported to the bottom sediments though hydrodynamic processes. Oil consumed by the zooplankton also reaches the sediments in the form of fecal pellets (Steering Committee, NRC, 1985).

Photochemical oxidation and microbial action are the two most important decay processes, depending on the amount of light and temperature in the area, respectively. Cold water with reduced light, can slow decay. Warm water with plenty of light can accelerate it.

Oil spills have direct impacts on the marine fauna (fish, sea birds, mammals). Indirect effects result from the accumulation of oil in the sediments, bringing shifts in species composition that may have an adverse impact on fish.

Sandy beaches are usually more sensitive to oil than a rocky shoreline. In both cases, oil accumulation has an additional impact on the fauna and flora of the area and is a matter of social and economic concern.

Fig. 5 shows the casual diagram extracted from this problem description. Strictly linguistic operations and those involving numerical, pictorial and linguistic entities were coded using trees enumerating all possible valuations for the independent entity and the resulting value for the dependent entity. A strictly pictorial operation involved the intersection of "oil in the sea" and "beach" resulting into "oil in the beach" (Câmara et al., 1990).

A sample of the model outputs, for a generic case, using a monochromatic monitor is presented in Fig. 6. This figure illustrates the wealth and complementarity of information produced by models using IDEAS methodology.

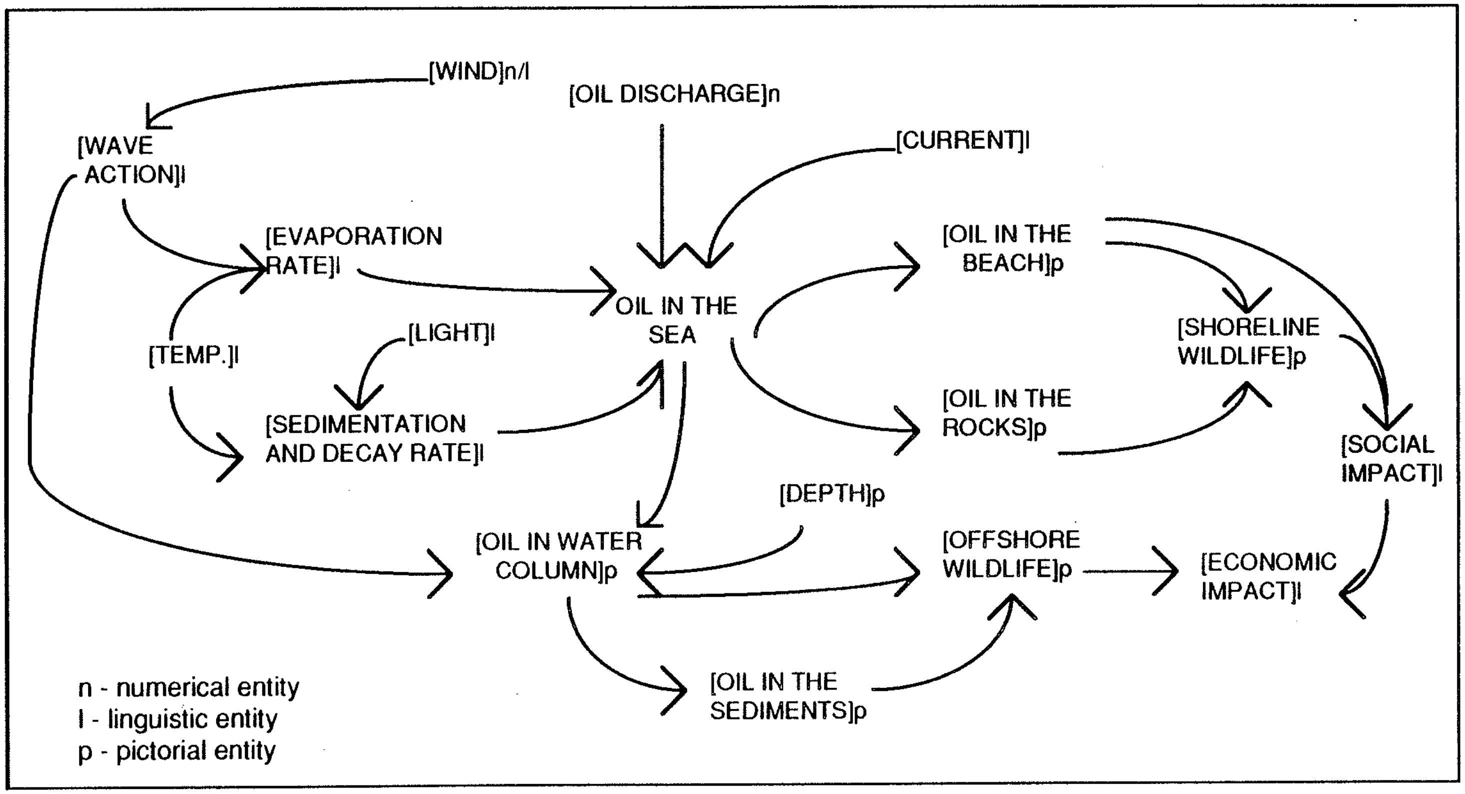


Fig. 5 - Causal diagram of oil dispersion model (Câmara et al., 1990)

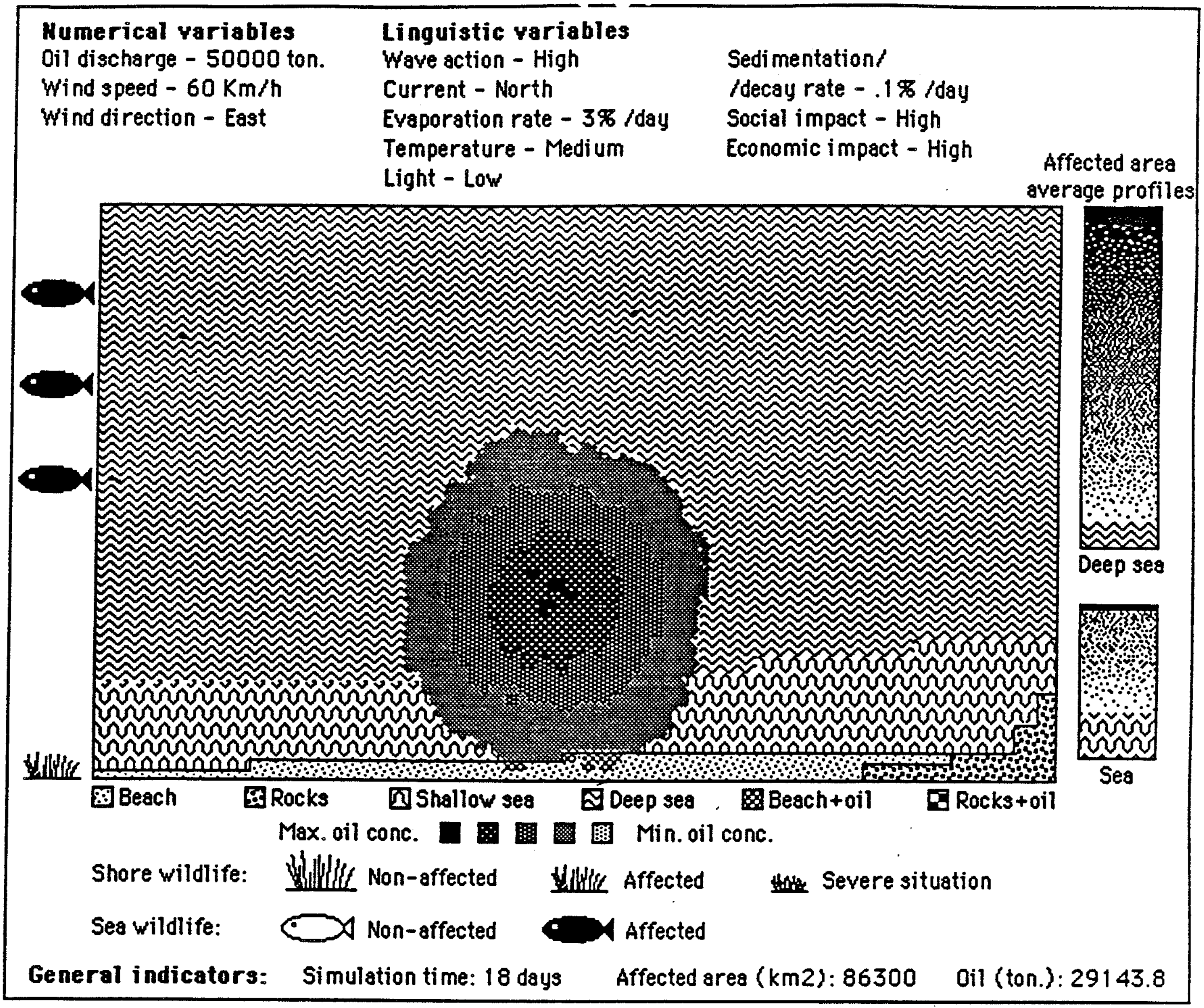


Fig. 6 - Sample output of oil dispersion model. (Câmara et al., 1990)

## SUMMARY AND CONCLUSIONS

A dynamic simulation methodology considering numerical, linguisytic and pictorial entities was presented named IDEAS, this methodology is based on casual diagrams that are translated into strictly numerical, linguistic or pictorial operations and operations representing the interaction between numerical, linguistic and pictorial entities.

The formulations proposed to handle the two least common operations, the strictly pictorial and multidimensional interactions, are discussed. They are based on simple biological analogies, set theory, logic and vector calculus.

Two resource management models were included in this paper: a fire propagation model and an oil dispersion model. These two examples show the potential applications of IDEAS to problems represented by numerical, linguistic and pictorial entities.

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