OIL SPILLS & AI: HOW TO MANAGE RESOURCES THROUGH SIMULATION

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ABSTRACT

Today, in the Mediterranean theater of the Upper Tyrrhenian, the ecological risk involving oil installations is still quite high. This is due to the fact that valuable environmental and tourist areas exist together with large industrial and port structures; in particular, recent events have demonstrated the danger involving oil spills along the Ligurian coastline. This study proposes an approach, to plan the operations that should be performed when accidents occur, based on the use of AI techniques.

INTRODUCTION

The release of polluting substances from ships is a particularly important phenomenon in the current Mediterranean configuration, in which modern tourist facilities are located close to oil terminals.

In this study, it is proposed to the use a combination of Fuzzy Logic and genetic Algorithms to create an Artificial Intelligence system designed to provide decision support when accidents occur (AI-DSS).

This system is designed to be integrated with an oil spill simulation model. Predictions about how the disaster may spread are developed by the simulation model and, by means of a time warp technique, the decision support tool plans the emergency operations.

The advantages of this approach are related to the fact that, by means of continuous re-calibration, the decision support tool corrects any erroneous estimates about the future behavior of the oil spill and about the possibility of using the requested resource in time.

The use of fuzzy logic to define the decision-related parameters (the possibility of moving barriers, etc.) when modelling exogenous variables (weather conditions, economic value of each area, etc.) makes the decision process easy to understand; on the other hand, the GAs are particularly efficient (considering the run time of the simulation developed) in "optimizing" medium-term planning. In fact, these choices depend on many different parameters and in particular on the development of variables affected by a high level of intrinsic uncertainty (due to the stochastic nature of the phenomenon).

The operating strategy is defined by regulating a set of independent exogenous variables (to minimize spreading, to protect strategic areas, etc.). The work presented also refers to a specific case to highlight the application potentials of this tool not only as an Emergency Manager DSS, but also as a means for defining the operating structures needed to handle this type of accident. In this case, it is proposed to use the DSS to recreate and evaluate the accident involving the Haven oil tanker (with a load of 140,000 tons of crude) in the port of Voltri on April 11, 1991 (an accident that put world famous Riviera tourist locations at great risk). The application of the theory of experiments is used to verify and validate the simulation model and to fine-tune the decision support tool. The accident considered emphasizes the need to reproduce special operational and complex procedures in the simulation model (towing the polluting source, containing rather than extinguishing the fire, etc.). To co-ordinate such complex procedures would be extremely difficult using the logic of traditional AI systems. However, working with combined techniques (hybrid AI systems) it is possible to generate good performances with limited development time.

THE REAL PROBLEM

The problem in question is very practical. One part consists in defining the correct disposition of the resources available in the area to guarantee that they can be used quickly. The other part involves help in managing such resources to limit the damage caused by these accidents. In the scenario considered, the operating resources include the equipment of the various public emergency forces and the apparatus of the companies which operate in the sector.

Since these are very costly tools and considering the fact that fortunately they are used only occasionally, their readiness level and deployment may be key factors in avoiding natural disasters. The system proposed, by using the DOE (Design of Experiments) theory, will identify the optimum configuration of the resources to utilize and will estimate the action time required by other structures located in contiguous areas. When a single

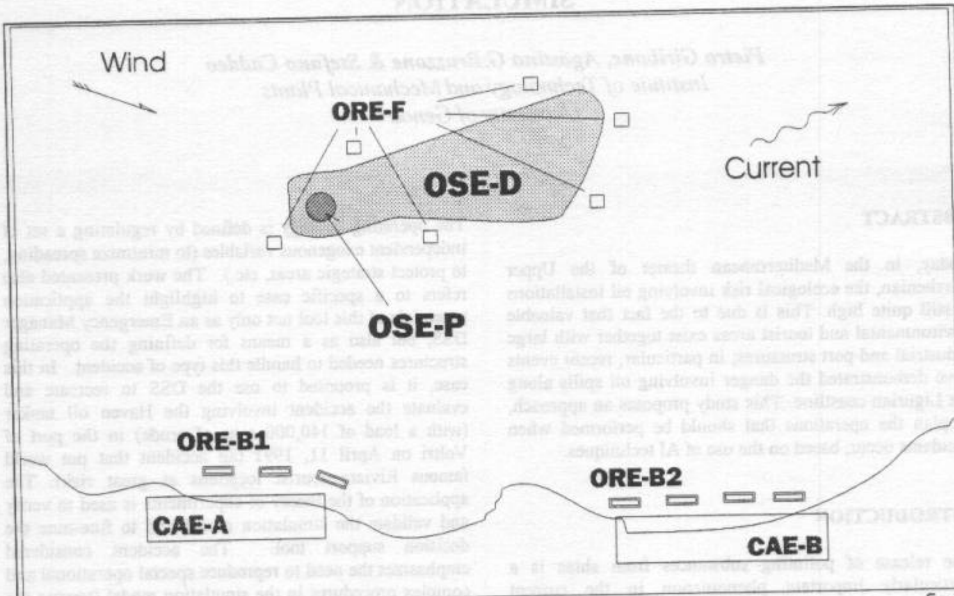

fig 1

crisis is being managed, and knowing the availability of resources, the system can propose a plan of action. Therefore, the organizational choices will be based on an in-depth analysis of the accident risk that can be obtained through the use of the simulation integrated with the DSS. In fact, from the data obtained, correct evaluations of the requirements can be extracted to reduce the risk to acceptable levels in a particular operating scenario. On the other hand, emergency planning refers to the tactical deployment of single units and the possibility of treating the spill with different methods. Thus, by using the simulator, it is possible to control the hypothetical future damage in real time in the areas close to the spill with variations in operating modalities.

MODELING THE SIMULATOR

To reproduce the behavior of the physical system being studied, a detail simulator was created to monitor and predict the behavior of the oil spill as well as its source. This simulation model was built in C++ and is very effective in terms of running speed.

The phenomenon in question is a function of aleatory variables of which at least the probability characteristics are known (type of distribution and statistical moments). The polluting sources may be defined with different modalities:

Source:

- Stationary source
- Mobile source

Polluting Phenomenon:

- Floating spill
- Crystallized sunken material

It is possible to characterize the compound released by defining its physical characteristics and resistance to different anti-polluting agents.

The simulation model must therefore use statistical distributions to extract the values simulated, using the Montecarlo technique, within the distributions introduced as input. Therefore, once these distribution are defined, it is very simple to perform a sensitivity analysis using replicated runs.

Based on the particular conformation of the bottom and typical sea currents in the area, the simulator proposed can extend the available measurements to the entire area of the sea affected by the phenomenon. The method used extends the validity of the single measurements to the entire grid being examined through the use of continuity equations. In this way, even starting with a few measurements, it is possible to obtain a comprehensive analysis of the intensity of the sea and the current in each point. The computer must be used for a certain period of time (about ten minutes on a personal computer for the equivalent of the exogenous data necessary for 12 hours of simulated time) to perform such a diffusion of the

exogenous variables over the entire grid of the map being studied. However, the data calculated in this manner can be re-used until new information becomes available and also for different simulations performed over the same time period (e.g.: replications, time warp).
This simulator was equipped with a graphic interface that can be used to quickly interpret the results obtained and to validate the model at a graphic level (fig. 1).
Once this first phase was completed, the uncertainty on the final values was calculated using replicated runs.
The experimental error of the model, due to the intrinsic stochasticity of the phenomenon, was estimated with the MSpe time analysis technique developed by this research group. Thus, not only was it possible to identify the confidence band of the model, but also the minimum run time of the simulator required to obtain congruent results. In our case, for the scenario hypotheses that we developed, this time interval was less than 6 simulated hours (less than one minute of real time).
Obviously, there is a correlation between the amplitude of the stochastic input variables and the amplitude of the confidence band on the final results.
However, without being able to generalize, it can be experimentally checked that the Mean Square pure Error has an almost uniform development for percentage variations of the wind and current parameters of around 5%. (fig. 2) For this reason, it was decided to consider this maximum amplitude segment as the reference value on the significance of the results for each case in which the input variables were affected by an uncertainty that was less than the threshold value. Otherwise, it is obvious that the tests must be repeated under those particular initial conditions to obtain an efficient estimate of the system.

THE FUZZY SETS USED

Fuzzy variables were used within the decision support process to check the management of the anti-pollution equipment. The logic system refers to the following base objects:

OSE	Oil Spill Entity
ORE	Operational Resource Entity
CAE	Coastal Area Entity

These variables basically have a dual structure:

Endogenous:
Resistance to different chemical agents (OS)
Time necessary to contaminate a certain area (OSE->CAE)
Danger Level (OSE) etc.

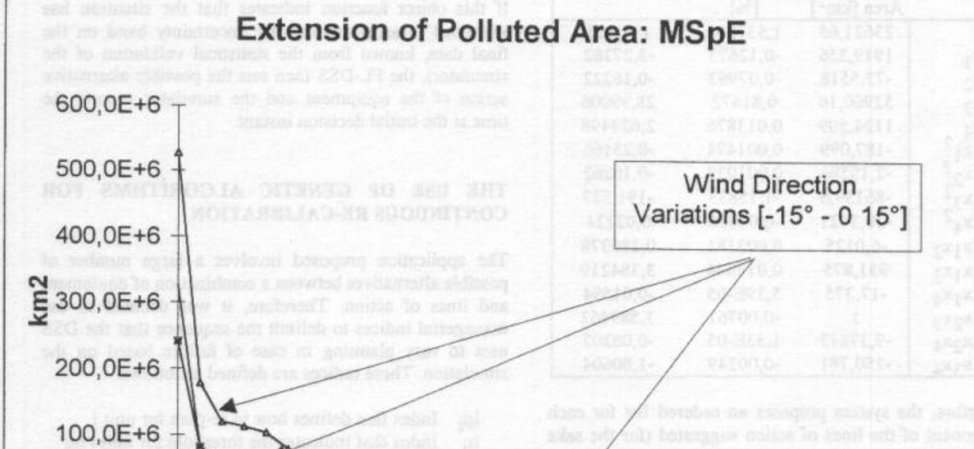

fig 2

Exogenous:
- Sea Conditions
- Wind Conditions etc.

Operating
- Spill intervention time (ORE->OSE)
- Intervention time on an area to prepare protection devices (ORE->CAE)
- Effectiveness of the possible intervention (ORE->OSE) etc.

General Strategy Decision Supports
- Priority of the areas with enhanced value
- Priority of the coastal areas
- Intervention objective (medium, short or long-term) etc.

The membership functions shown in figure 3 (-L, -M, -S, +S, +M, +L) were theorized for each fuzzy variable. The combination of this data, using fuzzy rules, determines the opportunity to take action on each possible target for each ORE (OSE or CAE depending on the type of operating equipment).

Table I : Regression Coefficients

	Y1: Extension of The Polluted Area [km^2]	Y2: Value of The Damage Tourist Area [%]	Y3: Duration of the Operations [h]
b_0	23621,65	1,557665	137,165
$b_1 x_1$	1919,356	-0,12673	-3,27282
$b_2 x_2$	-72,5518	-0,07992	-0,16222
$b_3 x_3$	52960,16	0,81472	28,99006
$b_4 x_4$	1124,509	0,013876	2,624498
$b_{11} x_1^2$	-187,099	0,001474	-0,25166
$b_{22} x_2^2$	-2,19586	0,001033	-0,10262
$b_{33} x_3^2$	-86139,6	-1,15833	-191,527
$b_{44} x_4^2$	-10,3421	-0,00026	0,02224
$b_{12} x_1 x_2$	-6,0125	0,003181	0,186378
$b_{13} x_1 x_3$	951,875	0,017844	3,384219
$b_{14} x_1 x_4$	-17,375	5,39E-05	-0,01594
$b_{23} x_2 x_3$	1	-0,00761	3,589462
$b_{24} x_2 x_4$	-9,37813	1,53E-05	-0,08207
$b_{34} x_3 x_4$	-250,781	-0,00249	-1,80604

Therefore, the system proposes an ordered list for each component of the lines of action suggested (for the sake of operating convenience, though all the alternatives are ordered, the system presents them and uses only the first ten on the ordered list in terms of opportunity) and then implements the choice that is considered to be most effective.

Table II: Statistical Test on Regression

	Sum Square	DoF	Mean Square	F0	$F(0.05,v_1,v_2)$
Y1: Extension of The Polluted Area [km^2]					
Regression	465E6	14	33.236E6	28,899	>2,48
Error	16.1E6	14	1150084		ok
L.O.F.	10.2E6	10	1024733	0,7002	<5,96
Pure Error	5.85E6	4	1463463		ok
Y2: Value of The Damage Tourist Area[%]					
Regression	1,3813	14	0,098667	265,02	>2,48
Error	0,0052	14	0,000372		ok
L.O.F.	0,0048	10	0,000480	4,7054	<5,96
Pure Error	0,0004	4	0,000102		ok
Y3: Duration of the Operations [h]					
Regression	7687	14	549,098	21,511	>2,48
Error	357,3	14	25,52522		ok
L.O.F.	325,5	10	32,55485	4,0943	<5,96
Pure Error	31,80	4	7,951153		ok

INTEGRATION WITH THE SIMULATOR

Once the fuzzy support module (FL-DSS) has supplied the data relative to each single operating procedure, the simulator makes a projection in this hypothesis with a duration equal to the period suggested by the FL-DSS.
At this point, the system calculates the contamination spread level and then compares it with the same variable at the initial time instant.
If this object function indicates that the situation has worsened (also evaluating the uncertainty band on the final data, known from the statistical validation of the simulator), the FL-DSS then sets the possible alternative action of the equipment and the simulator reports the time at the initial decision instant.

THE USE OF GENETIC ALGORITHMS FOR CONTINUOUS RE-CALIBRATION

The application proposed involves a large number of possible alternatives between a combination of equipment and lines of action. Therefore, it was decided to use managerial indices to delimit the sequence that the DSS uses to vary planning in case of failure based on the simulation. These indices are defined as follows.

- Ip_i Index that defines how to re-plan for unit i
- It_i Index that indicates the threshold for unit i on how to re-plan.

Using GAs, the system defines a set of new configurations in which each variable ORE_i re-plans the possible operations based on its list of 10 alternatives by means of two indices, choosing the j-th alternative as determined by the formula:

$$j = (int)(Ip_i/It_i)$$

Based on the level of pollution produced after the reference dt, the system orders the results of the initial set and recombines them using the GAs to obtain a new set. This operation is managed by the module called GA-DSS.
This procedure is repeated until the "normalized corrected" diameter of the search area involved delimited by the points of the n-th set is less than a predetermined percentage of the analysis range. This diameter is calculated with the formula:

$$Dc=\max(K_1) \qquad K_1 = K - K_0$$

K_0 = {Set consisting of the first ten percent of the ordered elements of K}
K = {Ordered set of the distance of Pi from Pj for each i j}

In this theoretical case, reference is made to availability that can be concentrated in about 30 different resources (for which the GA-DSS operates on 60 independent variables) and continues until the range delimited by the points obtained is equal to 5% of the initial analysis range (thus, it is possible to limit the optimum solution with a number of very reduced iterations). Once this phase has been completed, the best configuration is used as a new decision support configuration based on the value of the object function from among those proposed in the set of final points.

AN APPLICATION EXAMPLE

The disaster to be reproduced involves the Haven in the oil terminal of Genoa Pegli on April 11, 1991. At that time, due to accidental causes, a fire broke out on board the ship (140,000 tons of crude oil).
During the operations performed immediately following the outbreak, assistance vessels and support equipment were transferred from nearby areas (the Adriatic coast, the Côte d'Azur) to limit the phenomena and it was decided to tow the burning ship without extinguishing the fire in order to consume as much oil as possible through combustion.
Once the towing operation was completed and the floating barriers were prepared on the coast, the ship was sunk in an area with a shallow bottom. This was decided to make it easier to carry out the anti-pollution clean-up operations that were performed afterwards using professional divers and volunteers.
Using the proposed decision support model (AI-DDS),

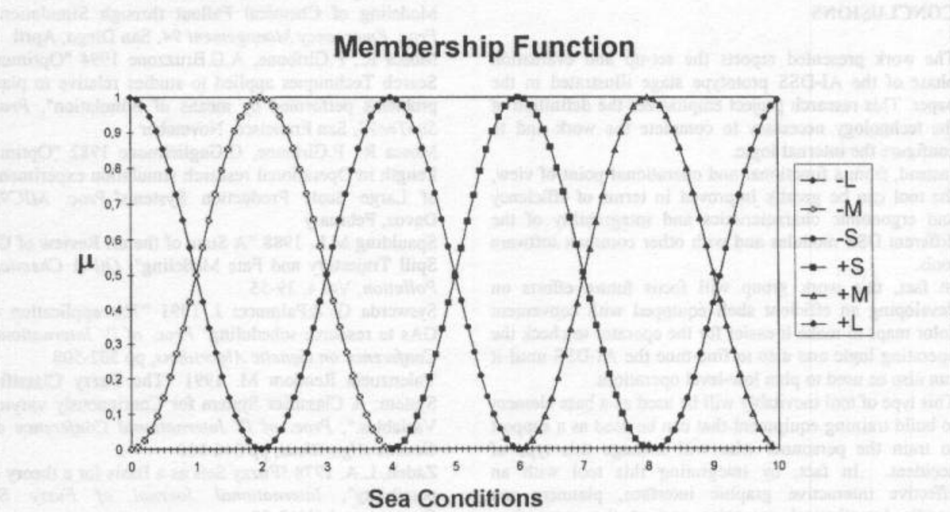

fig 3

the case in question was re-analyzed introducing a ship "in flames" as the source with a low percentage probability of sinking and with the stored oil data relative to the case.
In this situation, and starting from the initial conditions, the experiment was performed with a controlled procedure by the AI-DSS.
Several simulations were performed with reference to different scenarios relative to the following Input variables.

- Number of available extendible barriers
- Number of units which can filter.
- Percentage of the support equipment located outside the area.
- Average intervention time of the support equipment outside the area.

The following variables were controlled as output:

- Extension of the polluted area
- Value of the damaged tourist area
- Duration of the operations

The results obtained by creating a base-2 central composite design led to the identification of the most significant parameters for each variable. Thus, by constructing the polynomial meta-models (table 1), it was possible to determine the initial resources necessary to handle this type of crisis in the "best" way; table 2 reports the final numerical results.

CONCLUSIONS

The work presented reports the set-up and evaluation phase of the AI-DSS prototype stage illustrated in the paper. This research project emphasizes the definition of the technology necessary to complete the work and to configure the internal logic.
Instead, from a functional and operational point of view, the tool can be greatly improved in terms of efficiency and ergonomic characteristics and integrability of the different DSS modules and with other common software tools.
In fact, this work group will focus future efforts on developing an efficient shell equipped with convenient color maps to make it easier for the operator to check the operating logic and also to fine-tune the AI-DSS until it can also be used to plan low-level operations.
This type of tool inevitably will be used as a base element to build training equipment that can be used as a support to train the personnel who will manage this type of accident. In fact, by integrating this tool with an effective interactive graphic interface, planners can handle hypothetical scenarios and at the same time review and re-plan the operation by referring to accidents which have already occurred. In this way it is possible to incorporate the DSS fine-tuning phase with the specific training of managers who handle these emergencies and in efficiently using a decision support tool like the one proposed.

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