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DECISION SUPPORT SYSTEMS**

by

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THE DESIGN OF INTERACTIVE DECISION SUPPORT SYSTEMS

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1. INTRODUCTION

In the Netherlands there is a national research project to design 'Decision Support Systems' (D.S.S.). This research project is subsidized by the National Facility of Informatics (N.F.I.). Several universities and companies participate in this project. One of the sub-projects is a co-operation between the Erasmus University of Rotterdam and the dredging company Royal Boskalis Westminster.

It is this project which is the subject of this paper. In the first part of the paper we present our view of D.S.S. On this view the total project is based. In the next section the decision situation is described, following a more detailed discussion of one of the modules of the total system.

2. INTERACTIVE DECISION SUPPORT SYSTEMS

A definition of a D.S.S. that is acceptable to everybody is not available at this moment. The reason for this is that D.S.S. are being studied by various scientific disciplines. Each of these disciplines emphasize different aspects of D.S.S. based on their own background to the subject. It is not our intention to give a definition of a D.S.S., but we want to present our view of the matter.

We believe that the main goal of a D.S.S. is to improve the quality of the decisions to be made. A D.S.S. is seen as a subclass of information systems. Such computerized systems are desirable in those situations in which the solution of a complex decision-making problem calls for a comprehensive input of the insights, expertise and preferences of the decision maker. The decision maker must have the freedom to choose the level of support he needs for his problem.

He must be able to take a position between two extremes. In the first extreme the computer program does nothing more than register and analyze the data given by the user (the computer acting as 'assistant'). The other extreme is the situation in which the complete solution of the problem is left entirely to the computer program (the computer acting as 'advisor').

The reason that a D.S.S. must be a highly interactive computer program is to make sure that maximal use is made of the decision maker's knowledge of the problem.

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Seen in this light the following three functions are the minimal requisites of a D.S.S.:

- (a) Computing the effects of decisions proposed by the decision maker;
- (b) Generating decisions which are 'optimal' with respect to a criterion specified by the decision maker;
- (c) Sensitivity analysis of the decisions by computing the effects of changes in parameters.

In order to realize these three functions in an efficient way, it is necessary to use the facilities of man-machine interaction on the one hand and quantitative mathematical models on the other hand. The type of decision-making problems can be on a strategic, tactical or operational level in a variety of practical situations. In general these problems will be too complicated to be described in one mathematical model. Therefore it is necessary for all relevant mathematical models to be integrated in one D.S.S.

3. THE DECISION SITUATION

The main activity of Boskalis Westminster is contracting for and executing dredging works. The decision-making situation which will be supported by the D.S.S. is the tendering process which has to be carried out before acquiring a new job.

This process is characterized as a forecasting problem. The estimator has to predict productions and costs of a project that might be carried out some time in the future. This estimation problem can be extremely difficult when it is based on scarce and uncertain information.

Therefore it is very important that analyses are made of the risks involved for all possible alternatives. Usually, the company who offers the lowest tender price acquires the new job. Therefore the company is looking for that alternative which has low costs and low risks.

FIGURE 1. Flow chart depicting the decision-making process during estimation.

The tendering process can be divided into several phases (see figure 1). The first phase is the interpretation of the geological information of the area to be dredged. Calculation of the quantities and evaluation of the characteristics of all the different and relevant soil layers must be made. This involves not only estimating averages of these values, but also the evaluation of the risks of these parameters. A new method, based on the theory of stochastic processes, is being developed to help the estimator as much as possible. In the next section this D.S.S.- module is worked out in more detail as an example.

As soon as the soil evaluation phase is ended, a decision has to be made as to how the job will be carried out. This involves the selection of the necessary equipment, the design of a working method for the job and the calculation of the production capacities. Several mathematical models are available for these calculations and a method will be developed to integrate the risks of the soil information with the production estimates.

After this phase a cost estimate is made for each alternative. A plan of the work is formulated and finally a financial analysis of all relevant costs is made. In this financial analysis the costs of each activity of the job is combined with the timeplanning of the activities. Given these costs, planning and a payment schedule (according to which the client will pay for the job) it is possible to calculate all the financial costs or revenues by a given tender price.

The D.S.S.-module for this phase calculates not only the financial consequences by a given tender price, but also the optimal tender price for which the financial consequences are in accordance with the preferred profit of the estimator for the job. If the tender price is chosen too high, there will be an unwanted financial profit at the end of the job and therefore the tender price can be lowered, giving a higher chance of acquiring the new job. If the tender price is chosen too low, there will be an unwanted financial loss at the end of the job and therefore the tender price should be taken higher.

The main goal of the D.S.S., as said before, will be to help the estimator find that alternative which has the best composition of low costs and minimal risk. If the risk of this best alternative is still too high, the D.S.S. must advise whether it is useful to gather extra information to reduce the risk. Therefore it is necessary that the final risk of the tender estimate can be traced back to the individual factors that induce this risk.

4. THE SOIL EVALUATION

In the soil evaluation phase we are confronted with the following questions. Given a number of measurements (borehole information) of the thickness of a particular soil layer (e.g. sand) in different locations:

1. What is the spatial distribution of the soil layer?
2. What is the total quantity of soil in the layer over a certain area?
3. What is the uncertainty of this estimated volume?
4. Are extra expensive boreholes necessary to improve upon this estimate?
5. If so, how many boreholes should be taken and where should they be located to reduce the uncertainty as much as possible and what is the expected reduction?

In order to answer these questions the thickness of the soil layer is seen as a function over a two-dimensional domain. At each location of a measurement point the function value is known. The problem now becomes the problem of finding a suitable interpolating function in two dimensions. Desirable properties for such a function are that it should pass through all the specified measurement points exactly and that it should be continuous in all its derivatives.

Question 3 motivated us to consider the thickness of the soil layer as a realization of a stationary Gaussian stochastic process. This means that the unknown function is assumed to be embedded in a large class of functions over which a probability distribution is defined. Given such a (prior) probability distribution and the measurement points the conditional (posterior) probability distribution can be determined. The expected value of this posterior distribution is the interpolating function we are looking for. The variance of this estimated curve can also be computed. With this statistical information it is possible to give an adequate answer to the questions mentioned above. The suggested method can even be extended to three or more-dimensional domains. Therefore it is also possible to use this method to model other characteristics (e.g. the hardness) of the soil layer.

Gaussian stochastic processes are characterized by the mean- and covariance function:

$$u(\mathbf{x}) = \mathcal{E}[f(\mathbf{x})] \quad (\mathbf{x} \in \mathbb{R}^D) \quad (1)$$

$$r(\mathbf{x}, \mathbf{y}) = \mathcal{E}([f(\mathbf{x}) - u(\mathbf{x})] \cdot [f(\mathbf{y}) - u(\mathbf{y})]) \quad (\mathbf{x}, \mathbf{y} \in \mathbb{R}^D) \quad (2)$$

A Gaussian stochastic process is called stationary if its covariance function only depends on $\mathbf{h} = \mathbf{x} - \mathbf{y}$, and if the mean function is equal to a constant. Conversely, we can define a stationary Gaussian stochastic process by specifying a constant u , and a covariance function $r(\mathbf{h})$. Then, due to a famous result of Kolmogorov [1933], there exists a stationary Gaussian stochastic process possessing u and $r(\mathbf{h})$ as mean- and covariance functions.

Several restrictions on possible forms of $r(\mathbf{h})$ are necessary to make sure that a proper stochastic process is defined. Each covariance function must have the fundamental property of being of non-negative definite type. In Cramér and Leadbetter [1967] it is shown that this property of being of non-negative definite type is in fact a characteristic property of the class of all covariance functions. An important result due to Bochner [1933] states that a function on $\mathbb{R}^D$ is of non-negative definite type i.f.f. it is the characteristic function of a D -dimensional distribution function.

This means that possible covariance functions are for instance,

$$r(\mathbf{x} - \mathbf{y}) = \sigma^2 \cdot \prod_{d=1}^D \exp \left\{ - \left| \frac{x^d - y^d}{\alpha^d} \right| \right\} \quad (3)$$

$$r(\mathbf{x} - \mathbf{y}) = \sigma^2 \cdot \prod_{d=1}^D \exp \left\{ - \frac{1}{2} \left[\frac{x^d - y^d}{\alpha^d} \right]^2 \right\} \quad (4)$$

$$r(\mathbf{x} - \mathbf{y}) = \sigma^2 \cdot \prod_{d=1}^D \frac{1}{1 + \left[\frac{x^d - y^d}{\alpha^d} \right]^2} \quad (5)$$

where x^d denotes the d -th component of the vector $\mathbf{x}$.

In figure 2 these three covariance functions (divided by σ^2) are plotted against the distance h for the one-dimensional case. The scaling parameter α^D of the covariance functions in this figure are chosen in such a way that all three functions go through the point (1, 0.9).

FIGURE 2. Covariance functions divided by σ^2 .

From the theorems of Cramér and Leadbetter [1967] it follows that the realizations of the stochastic process with covariance function (3) are continuous with probability 1. The realizations of the stochastic processes with covariance function (4) and (5) can be proven to be continuously differentiable infinitely often with probability 1, so that these processes are good mathematical models for the soil layers of interest.

A Monte Carlo realization of the stochastic process with covariance function (5) is plotted in figure 3. This covariance function is of special interest to our problem, because the posterior expected integral over an interval $A \in \mathbb{R}^D$ and its variance can be calculated analytically. At the moment this is the only known covariance function for which this is possible. In Boender et.al. [1988] the analytical formulas are presented to calculate these quantities.

FIGURE 3. Realization with covariance function (5).

In the figures 4,5 and 6 we used this covariance function as an illustrative example on a test function on which only a limited number of function evaluations were used to predict the function. In figure 4 only six function evaluations were used by the model

FIGURE 4. Six function evaluations.

The dotted line is the test function and the solid line is the best interpolating function given the six function evaluations. The standard deviation is also plotted in the figures. It can be seen that the interpolating function goes through the known function values and in those points the standard deviation is zero.

FIGURE 5. Eight function evaluations.

In figure 5 two extra function evaluations are added to the six function values. The model has the good property that the standard deviation is zero in those points where the interpolating function and the test function coincide and is positive where the estimation is not exact. After twelve points the interpolation is exact (see figure 6).

FIGURE 6. Twelve function evaluations.

Currently we are building the D.S.S.-module, which is based on the statistical model described above. Due to the analytical formulae for the quantities of interest, the system is very user-friendly with respect to the response time.

Due to the fact that in actual dredging projects the number of measurement points is very limited, the model is implemented in such a way that expert-knowledge about soil layers can be incorporated in the system. By interactively adding so-called fictive measurements, it is possible to estimate the unknown parameters of the covariance function. At the moment we are extending the model to make it possible that different measurement errors in the borehole information and the subjective error in the fictive measurements can be taken along in the model. The user can interactively construct different models for unknown soil layers by changing or adding fictive measurements until he is satisfied with the results of the model.

Another way to influence the results of the system is by changing the α^d parameters of the model. By trying out several kind of levels of the α^d the user changes the interpolating function, until it coincides with his knowledge of the given soil layer at hand.

As a conclusion we notice that in the given problem the theoretical model was not strong enough to solve the problem alone. The knowledge of the soil expert was not enough either. But by integrating both it was possible to do the job. That is what D.S.S. is all about!

5. REFERENCES

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