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Sensitivity analysis of a scrap tire embankment using Bayesian influence diagrams

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ABSTRACT

Scrap tires have several properties that make them preferable to other materials as fills for embankment construction, including light weight (the dry unit weight is 1/3 that of soils), high hydraulic conductivity (up to 23.5 cm/s), and low thermal conductivity. These properties of scrap tire fills result in low lateral pressures on the abutment wall and in reduced design and construction costs. The low thermal conductivity helps to prevent permafrost action of soil layers beneath it and failure of the subgrade due to frost penetration.

However, scrap tires possess high compressibility, a property that leads to settlement of the fill and consequent failure of the embankment. Other undesirable attributes of scrap tire embankments are susceptibility to internal heating and leaching of substances into surrounding water.

An efficient means of controlling such undesirable attributes in the field is by comparing them with those simulated from a model embankment developed using Bayesian influence diagrams. In this work, the essential responses simulated using the Analytica® software program are the temperature, lateral pressure, settlements, and leachate characteristics. The most critical embankment characteristics, based on the maximum probability densities, are the settlement and horizontal pressures, which are relatively low at 0.428 and 0.0034, respectively, because the likelihood that these values will be exceeded in the field is high. Temperature response was not considered critical because the maximum probability density simulated was 0.9301. Limits for leachate concentrations were also obtained for the model embankment based on ASTM D 6270 (1998) standards.

1. Introduction

A number of alternative materials to soil have recently been considered for the construction of embankments such as fly ash, cement kiln dust, high-quality wood waste, and construction and demolition debris. Presently, scrap tires are generating a lot of interest due to their versatility as a construction material and useful properties such as high permeability, low thermal conductivity, and lightweight. However, accompanying these favorable properties are three major disadvantages – large settlement, potential for internal heating, and leachate effects.

To forestall failure, the behavior of the embankment is simulated based on the loading and exposure conditions. The response of the embankment is varied using the decision software program Analytica and compared with the actual system as well as standard specifications to detect any anomaly.

The responses simulated are the settlements, vertical pressures, horizontal pressures, temperature, and possible leachate concentrations. These are intrinsic characteristics of an embankment which depend on predictor variables that influence one another and the overall performance of the embankment during use. The levels to which the variables affect one another are expressed with the aid of influence diagrams.

An influence diagram can be described as a network for representing the probabilistic relationships between the variables that constitute the system behavior [2]. In this case, the system is the embankment behavior. The nodes represent the variables that have information stored in them such as uncertainty, decisions and objectives. The arrows represent the causal relationships between variables. The influence diagrams provide a descriptive way of analyzing the uncertainty between the variables, which is represented by a probability distribution over the states.

Influence diagrams can be used to analyze a problem so as to arrive at the best solution for it. They can be used to monitor the entire response of a system and simulate the likely occurrences if one or several of the factors are added, altered or removed. Consequently, a model that properly represents the operation of the problem can be developed. The influence diagram shows the dependencies between data and the state of knowledge at a decision point and enables evaluation of the outcome under various scenarios [3].

The aim of this paper is to formulate and solve field behavior of scrap tire embankment using Bayesian influence diagrams. The

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geometry and other inputs of the simulation model are similar to the field construction and the materials.

2. The influence diagram

The influence diagram consists of directed acyclic graphs with nodes and arcs. There are three types of nodes, namely, chance, decision, and value nodes, which are drawn respectively as a circle, a square, and a rounded rectangle. The node by nature could be deterministic (meaning that there is certainty about its value) or probabilistic (meaning that there is uncertainty about its conditioning variables). There are two types of arcs, namely, conditional arcs (which update the chance and value nodes) and informational arcs (which update the decision nodes). The influence diagram obeys a number of laws, the most important of which is that there must not be any directed cyclic paths. There should also be asymmetry in the definition of the arcs such that a conditional arc into a chance or value node indicates that there may be dependence, while an informational arc into a decision node indicates that the information must be available at the time the decision is made. The conditional arcs do not indicate causality or time precedence as exhibited by the informational arcs.

Influence diagrams are organized displays of decisions, uncertain events, and outcomes that provide a quick view of the system being represented at any point in time. They resemble decision trees because they are also descriptive tools, but the relationships between the various elements of a decision problem are easier to display using influence diagrams than decision trees [4].

An influence diagram is said to be regular if it satisfies two conditions other than being acyclic, namely, that the value node (if present) must have no successors and there is a directed path that consists of all the decision nodes (the "no forgetting property"). The Analytica software used for the analysis is based on these principles, and Table 1 shows the symbols that the software uses to perform the analysis.

2.1. Models for analyzing influence diagrams

Influence diagrams can be used to represent decision problems in compact form. A simple model based on Bayes theory that can be used to analyze such a problem is given as follows:

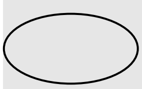
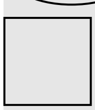
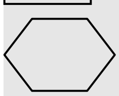
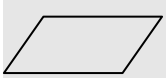
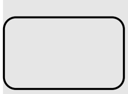
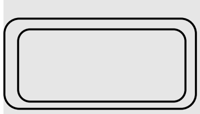
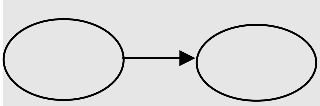
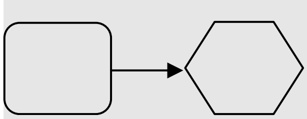
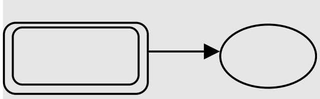
$$P(X_1|X_2) = \frac{P(X_2|X_1)P(X_1)}{\sum_{\text{all}\ i} P(X_2|X_1 = x_i)P(X_1 = x_i)} \tag{1}$$

where X_1 *and* X_2 are random variables (nodes).

The model is updated based on the observed values of the random variables. For example, if the variable X_2 exists in state x_j, applying Eq. (1) to each state of X_1 gives the probability distribution $P(X_1|X_2 = x_j)$ as

$$P(X_1|X_2 = x_j) = \frac{P(X_2 = x_j|X_1)P(X_1)}{\sum_{\text{all}\ i} P(X_2 = x_j|X_1 = x_i)P(X_1 = x_i)} \tag{2}$$

Table 1
Symbols used by analytica to build an influence diagram

Symbols	Description	Explanation
	Chance variable	An uncertain variable not under the direct control of the decision maker
	Decision variable	A policy variable under the direct control of the decision maker
	Objective node	Used for quantifying the degree to which decisions satisfy the stakeholders or a measure of utility with multiple goals
	Index variable	A variable used to define the scope and level of detail of the analysis and identify the dimensions of tables or arrays – such as time
	Standard variable	A variable that is a deterministic function of its inputs
	Module	Nodes that contain a set of variables that comprise a sub diagram of the main diagram
	Two chance nodes and an arc	The previous chance node affects the probability of the subsequent chance
	Determinate node, value node and an arc	The occurrence of the outcome depends on the determinate variable
	A module and chance node	The chance variable is being conditioned by a variable within the module