Development of an Expert System for Mine Burial Prediction

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LONG-TERM GOALS

The long-term goal of this project is to provide a mine burial prediction tool to enhance the capability for operation
al Navy Mine Counter Measure (MCM) decision making. An important factor in MCM mission planning is knowledge of whether bottom-sitting mines are fully or partially buried beneath the marine sediment.

OBJECTIVES

The objective of the present effort is to synthesize the current state of knowledge about mine burial processes into a Mine Burial Expert System Model (MBESM).

Specific technical objectives include:

- Identify and incorporate extant models for mine burial prediction as well as research in progress that will provide improved modeling capability in the near future.
- Identify and incorporate the knowledge provided by experts on mine burial processes in the national and international oceanographic and geotechnic research community.
- Obtain validation data sets from mine deployment field experiments where high-quality supporting parameters are available.
- Develope a prototype Mine Burial Expert System Model (MBESM) to provide a systematic organization of this knowledge base, combining physics-based models and the expertise of contemporary research scientists into a prediction of mine burial probability that accurately reflects the uncertainty due to the inherent imperfect knowledge.

APPROACH

The overall concept for the MBESM is illustrated in Figure 1. Central to this approach is the characterization of the relevant input parameters: the mine type and deployment conditions and the properties of the environment in which the mines are deployed. These characteristics drive the relevant burial processes: impact burial – initial burial upon impact with the ocean bottom; and subsequent burial – burial due to ocean processes including scour and bedform migration. Models of

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14. ABSTRACT
The long-term goal of this project is to provide a mine burial prediction tool to enhance the capability for operation al Navy Mine Counter Measure (MCM) decision making. An important factor in MCM mission planning is knowledge of whether bottom-sitting mines are fully or partially buried beneath the marine sediment.

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these burial processes result in predictions of the degree of mine burial, and, in the context of the expert system, the probability of burial. Efforts will focus on the two environmental regimes of prime interest for MCM: navigation channels and coastal shallow water. The concept and approach is presented in Brandt, et al. (2001).

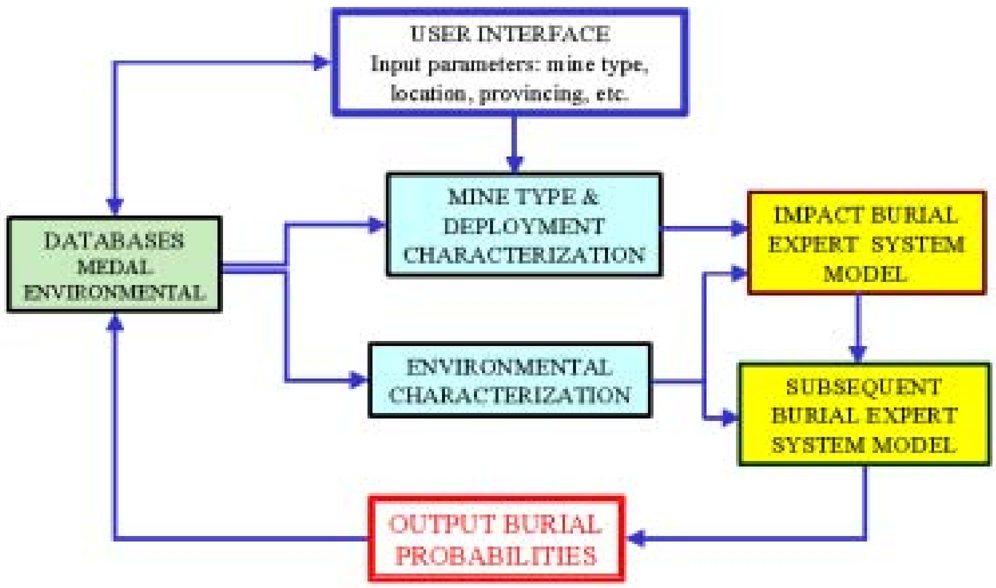

Figure 1. Conceptual Structure of the Mine Burial Expert System Model

For the expert system a Bayesian probabilistic network approach has been selected. A Bayesian network represents causal relationships among key variables as connections between nodes representing those variables. Connectivity between nodes represents knowledge of the extent to which one variable has a direct causal influence on any other. Causal influences are quantified by a conditional probability distribution (CPD) associated with the affected variable's node. These CPDs can be developed from data, deterministic modeling, expert's assessments, or any combination thereof. The advantage of Bayesian networks lies in their ability to model and reason about uncertainty, within the well-founded mathematical formalisms of probability theory and statistics, so that decision making is made through the generation of quantitative, probabilistic measures of uncertainty and error. The challenge in developing a Bayesian approach is the requirement to quantify every direct causal interaction between the variables.

WORK COMPLETED

The initial development of the MBESM has focused on the impact burial stage using the Navy model, IMPACT28 (obtained from NRL-SSC). IMPACT28 is a deterministic model that calculates the 2-dimensional fall of a cylindrical mine through the air and the water column, and its penetration into the sediment. It has a strong physics content, but relies on empirically-derived constants (Lott, 2001). In general, especially in operational scenarios, there will be uncertainties in the mine deployment conditions as well as in the environmental parameters. Particularly critical are the initial release angle of the mine and knowledge of the sediment properties. Burial estimates result from defined distributions of the input parameters and are presented as probability distributions, as determined by the Bayesian model.

An example of the MBESM for the impact portion, is shown in Figure 2. The Bayesian structure was developed using the Netica software package (NorSys Corp.) and shows the input parameters, intermediate variables at the water-sediment interface, and the predicted burial fraction, for an initial distribution of input values. A single mine type is specified whose geometry and characteristics are fully known, except for the location of the center of gravity. The CPDs for the intermediate and final nodes were developed from a MATLAB version of IMPACT28 run in a Monte Carlo simulation mode, focusing on the dominant input parameters: the initial altitude, initial angle, water depth, and the sediment shear strength. Each of the input parameters and the derived parameters are divided into bins corresponding to regimes of interest. For example, water depth is categorized as "shallow" (4 to 6 meters), "intermediate" (6 to 13 meters), and "deep" (13 to 18 meters). These categories reflect conditions on the input variables which influence the probability of mine burial.

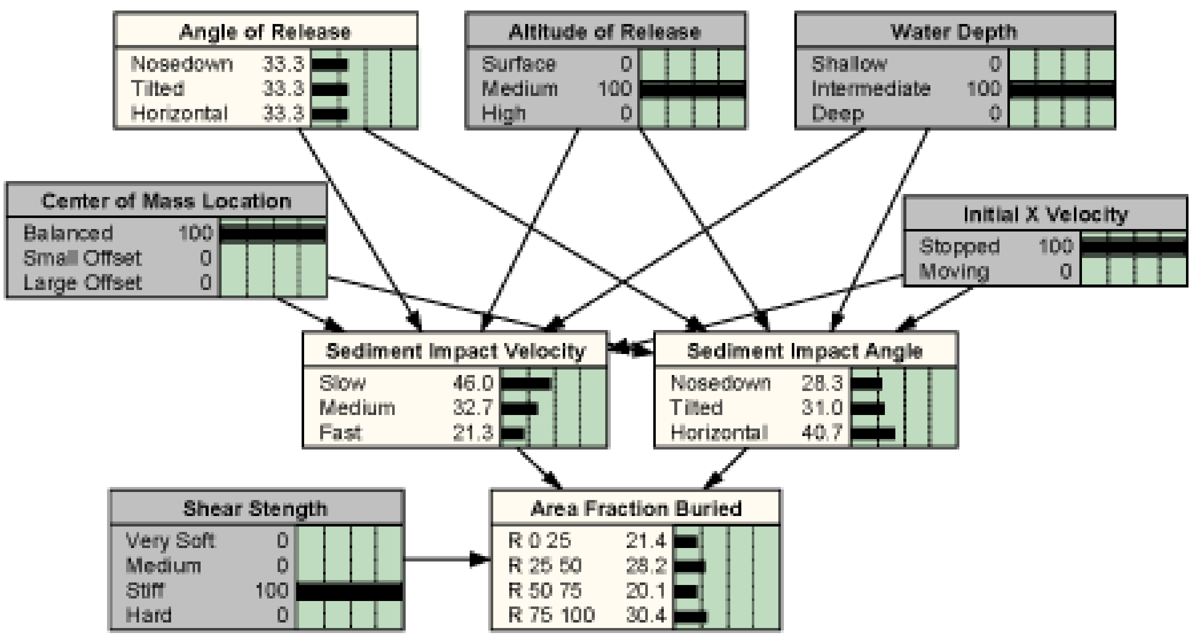

Figure 2. Example Bayesian Network for Impact Burial for a MK39n Mine.
[Input and output variables are represented as boxes(nodes) with discreet distributions shown as bar graphs. Connectivity between nodes denotes causal influence.]

In addition to the development of the overall approach and the initial implementation of the impact MBESM, efforts are in progress to locate available experimental data for model validation. Scour and bedform migration models are being reviewed for incorporation into the subsequent burial portion of the MBESM. Also, research is underway to develop a classification system to aid in obtaining values of the needed environmental input parameters in areas of denied access.

RESULTS

Using the Netica implementation of the Bayesian network, a range of mine types and conditions have been examined. The percentage burial computed for different input scenarios allows one to determine the sensitivity to the input conditions. As expected, the most crucial input parameters are the sediment shear strength and the angle of release. For example, with shear strength values in the "very soft" category (< 3 kPa), the mine was completely buried (> 75%) irrespective of the release conditions or water depth. In the example shown in Figure 2, a MK36n mine geometry was modeled, and all the input parameters except for the angle of release were assumed to be known with certainty. The angle of release was assumed to be unknown – i.e., equal probability in each of the three bins. The resulting percentage burial distribution is close to uniform, an indication of the sensitivity of the IMPACT28 model to the angle of release. These predictions and the sensitivities to the initial parameters so far reflect only the knowledge incorporated in IMPACT28. However, the expert system framework developed readily allows for incorporation of more advanced models, as they become available.

IMPACT/APPLICATIONS

The Bayesian CPD results provide a clear way to quantify the value of improving the accuracy of our knowledge of each of the input parameters. This analysis should provide valuable guidance in determining the priorities of on-going research in the Mine Burial Prediction thrust category.

TRANSITIONS

Our ultimate goal is to incorporate this expert system into the MCM Tactical Decision Aid package MEDAL, for transition to NAVOCEANO and COMINEWARCOM.

RELATED PROJECTS

We are interacting with many of the ONR Marine Geosciences division projects funded under the Mine Burial Prediction thrust category. In particular, we are consulting with D. Inman and S. Jenkins (SIO) for scour processes and coastal classification; and with D. Yue (MIT) and P. Chu (NPS) regarding improvements in the hydrodynamic portion of the impact model.

REFERENCES

Brandt, A., D.P. Watson, S.E. Rennie, S.E. Langs, C.L. Vincent, R. Dolan 2001 "Mine Burial Expert Model (MBESM) – Phase 1 Report" Johns Hopkins University Applied Physics Laboratory, Technical Report STD-01-163.

Lott, D. F. 2001 "Modeling Mine Burial Processes: A Review" Naval Research Laboratory, Stennis Space Center, 2001.