# Building a Statistical Framework for Mine Burial Predictions

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## LONG TERM GOALS

The ultimate long-term goal of the ONR mine burial prediction program is the development of mine burial probability models that incorporate dynamic coupled processes, seafloor material properties, and different mine types.

## OBJECTIVES

Although the ONR Mine Burial Program is still very much in the planning stages, early opportunities to advance the goals of the program have presented themselves. In particular, a statistical framework will be required to merge the disparate predictions of various process models (impact, liquefaction, scour, and bedform migration) into a single prediction for the percentage of mines buried under a set of environmental conditions. I will endeavor to formulate that framework early on in the program to establish a common goal for the modeling efforts.

In addition, I have served on the Mine Burial Program steering committee at Dick Bennet's invitation.

## APPROACH

The behavior of a mine, including burial, or partial burial, in a shallow-water sedimentary environment, is largely determined by the following factors:

1. the physical and mechanical properties of the sediment;
2. the fluid forces that act on the mine and the sediment in the vicinity of the mine and the interaction between the mine, those forces, and the seabed (near field);
3. the *far field* bed dynamics of the coastal area in question.

In order to predict the behavior of mines the three essential elements are:

A) accurate predictions of the fluid forces, including waves, bottom boundary layers currents and bottom pressures, surf conditions, and inshore currents, and

B) the geotechnical properties of the sediment in the vicinity of the mine; and

C) the magnitude and seasonality of regional-scale changes in the morphology of the seabed itself.

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14. ABSTRACT
**The ultimate long-term goal of the ONR mine burial prediction program is the development of mine burial probability models that incorporate dynamic coupled processes, seafloor material properties, and different mine types.**

15. SUBJECT TERMS

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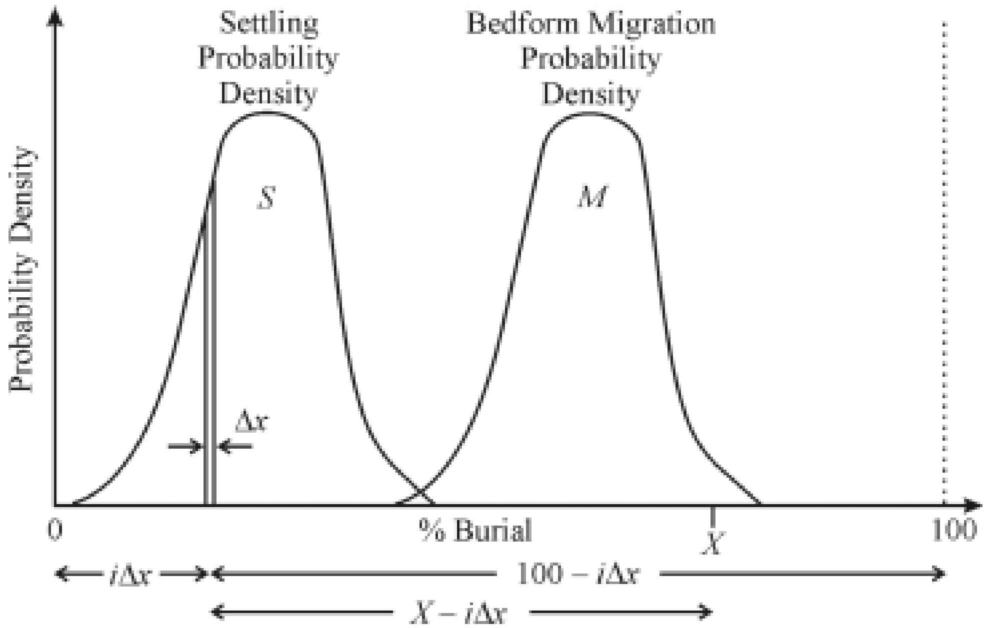
The elements of any mine burial model, as described above, are fundamental to understanding the science and engineering aspects of coupled environmental processes, sediment transport processes and seabed properties.  Modeling mine behavior and sediment transport is still an inexact science.  Wave transformation and sediment mobilization processes are difficult to understand and predict in a laboratory flume, under controlled conditions, without obstructions.  In natural environments the complexity of the non-linear interacting processes is great, and reliable measurements are difficult to obtain.  Successful prediction will depend on a comprehensive understanding of sediment fluxes, coupled environmental processes, seafloor physical and mechanical (geotechnical) properties, and consideration of the mine characteristics and associated deployment modes.  Uncertainties in all input parameters must be minimized; however, statistical understanding of the total system (environment and mine) response must be elucidated.

Development of a statistical framework for prediction was recognized at a recent ONR Mine Burial workshop as a critical goal for enabling various and diverse process studies to contribute to a single prediction for mine burial.  A principal aim of the mine burial effort is to be able to determine the percent of mines that would be buried at a particular location and time due to a given process, such as liquefaction, impact burial, settling, etc.  Ultimately, that goal is unattainable.  In reality, that estimate will have error bounds and it is incumbent on those making predictions to estimate that uncertainty. Furthermore, we need a product from each process model that can be combined to form a complete prediction.  Given these considerations, it is proposed that the end product of the process modeling should be an estimate of the probability density function (PDF) for percent mine burial.  In this way, error estimates can be derived and PDFs from different processes can be combined using statistical methods.  Generating a percent burial PDF will be a significant challenge for modelers.  The PDF must incorporate all sources of uncertainty in the predictions.  These include:  1) uncertainty in environmental parameters; 2) completeness of environmental information; 3) natural variability of the process given constant environmental input.  The complexity of the problem almost certainly will dictate Monte Carlo methods to define percent burial PDF.  An important advantage of this end product is that it provides a ready measure of sensitivity for particular environmental parameters, and a basis for cost/benefit analysis.

Combining percent burial probability density functions for different processes will be a relatively straightforward, although non-standard procedure.  Consider, for example, we have a situation where we expect both bedform migration and settling processes will have a significant contribution to mine burial.  Through modeling or empirical efforts, we might determine for each process a PDF for percent burial, such as shown in the schematic figure below.  How, then, do we determine the percent burial PDF for the combined process – that is, impact plus settling?  The obvious answer is to use the standard formulation for the sum of random variables – which is that the PDF of the sum is the convolution of the individual PDFs.  Unfortunately that would be wrong, as it is quite possible, and even likely in such a situation, to predict a non-zero probability for greater than 100% burial.  Rather, the proper way to view the combined effect of these processes is as a sequence – that is, before we can consider what portion of mines are buried by bedform migration, we must first subtract off the number of mines buried by settling, or vice versa.




$B(X)\Delta x$ = Total percent burial probability density function

$$B(X)\Delta x = \sum_i S(i\Delta x)\Delta x \bullet M\left(100\left[\frac{X - i\Delta x}{100 - i\Delta x}\right]\right)\Delta x$$

or,

$$B(X) = \sum_i S(i\Delta x) \bullet M\left(100\left[\frac{X - i\Delta x}{100 - i\Delta x}\right]\right)\Delta x$$

The proper numerical formulation (easily reducible to continuous integration) for combining two percent burial PDFs is demonstrated above. In essence, we are summing up all conditional probabilities for producing a total percent burial $X$ from a combination of settling and bedform migration. That is, conditioned on the settling percent burial being $i\Delta x$, an event with probability $I(i\Delta x)\Delta x$, the probability of $X$ - $i\Delta x$ more mines being buried by bedform migration *out of a population of* 100-$i\Delta x$ is

$$M\left(100\left[\frac{X - i\Delta x}{100 - i\Delta x}\right]\right)\Delta x$$

The total probability for that particular combination is just the multiplication of these two probabilities, and the total probability $B(X)\Delta x$ is then the sum over all such combinations, as shown above.

The above formulation is oversimplified for a couple of reasons. First, the various processes may not be independent, although I believe that will be a reasonable simplifying assumption to make for this particular case. Second, and perhaps more importantly, mine burial is not an either/or proposition. Rather, each process will bury the deployed mines by a range of proportions. Thus, where two processes are active, one process will not merely reduce the numbers available for the second process, but will also alter the starting conditions for the mines that aren't completely buried. For example, a mine that is partly buried by settling will be more easily buried completely by bedform processes than if the mine were entirely exposed at the seafloor. The methodology detailed above can readily be modified to allow for a range in starting conditions for the secondary process. The process-based predictions would likewise need to take into account a variable starting burial depths.

## WORK COMPLETED

The primary accomplishment was the development of the preliminary conceptual framework described above. Additional work extending the framework to account for variable starting conditions will take place later this year.

My funding this year has also supported my participation in the planning of Mine Burial field work to be conducted in 2002.

## RESULTS

Results will not be available until process-based predictions are made and implemented within the statistical framework.

## IMPACT/APPLICATIONS

The conceptual statistical framework is intended to merge various process-based predictions into a unified probability-based prediction that can be readily utilized by Navy tacticians.

## TRANSITIONS

No transitions have been implemented yet.

## RELATED PROJECTS

None that I am aware of.