BUILDING BETTER COST AND SCHEDULE ESTIMATES FOR ER PROJECTS: A REVIEW OF US DOE'S HAZRISK® STUDY

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ABSTRACT

Estimates of cleanup costs during the 1980s failed to provide reasonably accurate projections of actual costs. This paper summarizes the efforts of U.S. DOE's *HAZRISK®* study to better understand the cost and schedule risks of environmental restoration projects (ER). In 1988, the DOE along with seven firms in the oil and chemical industries provided support for the *HAZRISK®* project. Independent Project Analysis, Inc. (IPA) pooled their sponsor's experience and that of many others in order to develop realistic cost estimating, contingency setting and scheduling algorithms to be used for hazardous waste cleanup projects. IPA's approach involves the the systematic linking of cost and schedule outcomes with project characteristics. The *HAZRISK®* tools can be used early in the project cycle to evaluate the riskiness of a project. They can also be used for checking the reasonableness of estimates generated by other organizations.

INTRODUCTION

Over the past several years increasing attention has focused on the environmental restoration (ER) problem. Government agencies and other responsible parties tasked with addressing the ER issues are under constant scrutiny from both the public and congress to quickly and efficiently remediate the thousands of existing hazardous and toxic waste sites. The Department of Energy (DOE) will undergo particular scrutiny given that remediation costs are expected to exceed 100 billion dollars. To date, ER projects have been characterized by a high degree of uncertainty, and therefore it has been especially difficult to estimate the costs associated with remedial actions. Traditional engineering and construction methodologies have failed to provide reasonably accurate estimates of hazardous waste cleanup projects. Significant over and under-estimation of costs and schedules have occurred, which causes problems for budgets and the rational allocation of scarce resources.

This paper summarizes the *HAZRISK®** tools which were built to aid the private sector and DOE in understanding the costs, schedules and risks associated with ER projects. Much of the *HAZRISK®* research effort has focused on the development of the *HAZRISK®* database which provides a record of the ER cost estimating experience of the 1980s. This database also gives DOE the ability to identify the cost and schedule drivers of ER projects as well as build historical estimating models. The knowledge and the set of tools resulting from the *HAZRISK®* research effort can be used to more accurately assess project risk, independently review the costs of projects, and prioritize areas for cost improvement.

HAZRISK® DATABASE

Independent Project Analysis, Inc. (IPA) developed the *HAZRISK®* database for the DOE and a consortium of chemical and oil companies in order to assist them in their cost and schedule estimation processes and to provide a framework for understanding the ER problem. The database contains detailed information on over 150 completed DOE, Environmental Protection Agency (EPA) and industry assessment and cleanup projects. Additional projects, as they are completed, are constantly being added to the database. In all, over 600 variables describing each project are captured in this database including the following types of data:

- general site information
- type of contaminants
- estimated and actual project schedule
- cleanup technology
- project management information
- estimated and actual costs
- regulatory and external events

IPA has collected data on a variety of DOE sites including a large number of Uranium Mill Tailing Removal Actions (UMTRA), and those projects remediated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA). Data were also collected on Superfund sites by reviewing project documents and through discussions with project personnel using a worksheet developed by IPA, Inc. Given the diversity of data sources, we sought to minimize differences between projects caused solely by measurement problems using a num-

* HAZRISK is a registered Trademark of Independent Project Analysis, Inc.

ber of procedures such as removing the effects of inflation by inflating all cost data to constant 1989 dollars.

COST ESTIMATING IN THE 1980s

The need to accurately estimate the costs associated with particular cleanup projects is acute when fiscal resources are strained and the budgetary process is so cumbersome. We believe that one of the most useful results of our analysis is to confirm what many environmental professionals have long suspected -- that is, hazardous waste cleanup efforts are afflicted by estimating problems that vastly exceed any normal range of uncertainty. In fact, the degree of cost growth and the wide range in estimate accuracy is far more severe for cleanups than for most other classes of projects. Most large construction-type ventures suffer from cost estimation inaccuracies and hazardous waste cleanup projects are no exception. Figure 1 shows the accuracy of cost estimates for over 50 cleanup projects completed during the past decade. The vertical axis measures the percent deviation between actual project cost and estimated cost for the construction stages of a remediation project. The horizontal axis indicates the stage at which the estimate was made. The ratio of the actual cost to the estimated cost should, theoretically, average one, indicating zero percent cost growth. However, not only is the mean estimate accuracy greater than zero implying cost overruns at each project stage, but cleanup project estimate inaccuracies are highly variable. Over the last decade cleanup costs have been underestimated by as much as 250% and over estimated by as much as 50%. Likewise, schedule slip in projects at authorization ranged from a schedule overrun of 150 percent to an underrun of 50 percent.

Figures 2 and 3 show how the DOE cost estimating experience for cleanup projects differs from other organizations. Figure 2 shows the mean and the range of cost growth at authorization for 51 completed cleanups bs project lead. The figure illustrates that federally-led Superfund cleanups have, on average, experienced thelargest degree of cost growth. At project authorization cost growth averaged 75 percent for federal-led cleanups; 41 percent for cleanups conducted by U.S. DOE; 25 percent for state-led cleanups; and 15 percent for a sample of industry-led cleanups. Project authorization is the ROD (Record of Decision) for Superfund projects. For other projects, this the point at which the project was authorized to proceed with design and construction.

Figure 3 indicates that DOE cost estimation inaccuracies are more prevalent at the earlier stages of the cleanup process (assessment and authorization) than at the later stages*. Perhaps more worrisome is the fact that we can detect no trend toward more accurate estimates. In fact, as shown in Fig. 4, while there are variations from year to year, the trend in cost growth is upward. This development is

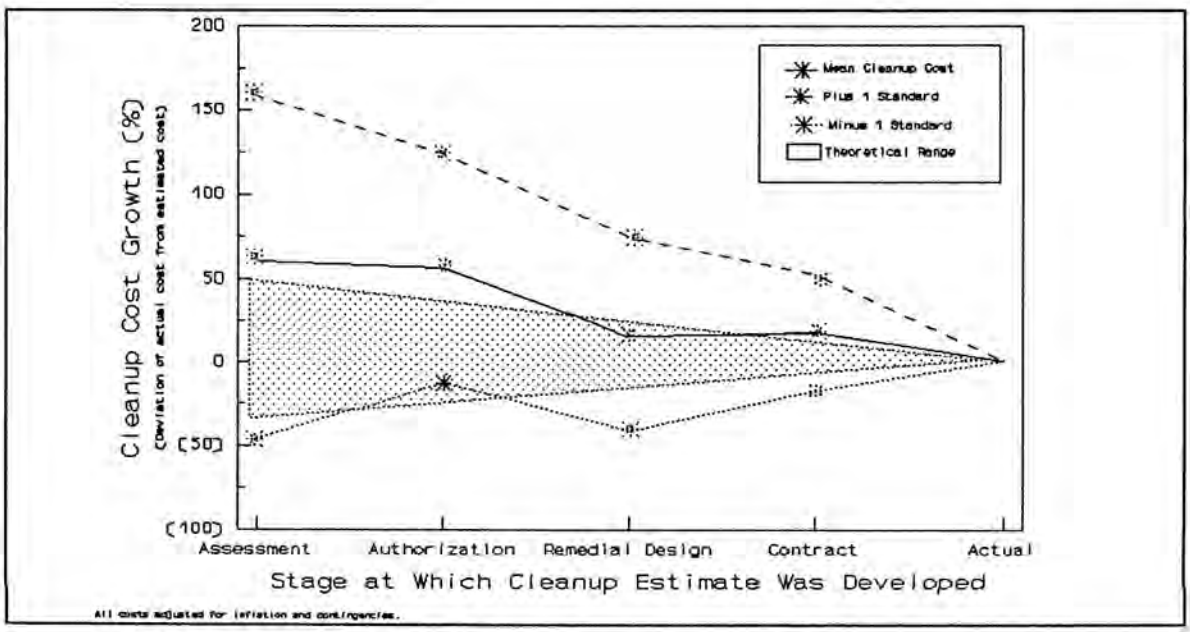

Fig. 1. Estimate Accuracy for Cleanup Projects.

* Note that DOE projects in the database represent only a segment of the department's ER experience.

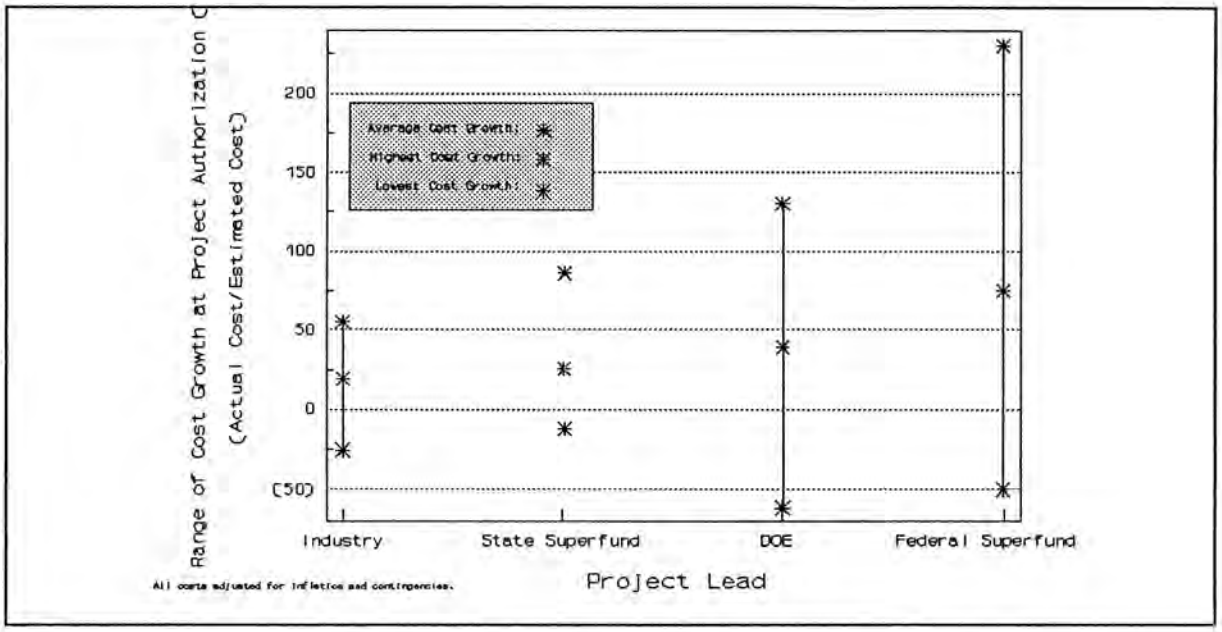

Fig. 2. Estimate Accuracy as a Function of Project Lead.

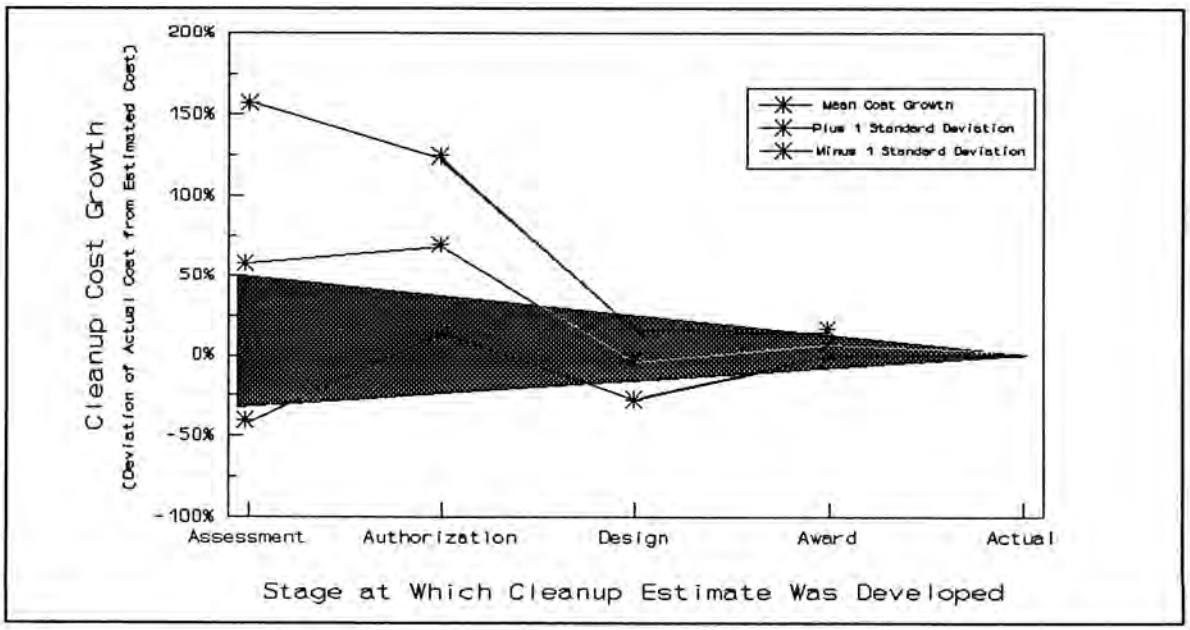

Fig. 3. Estimate Accuracy for DOE Cleanups.

contrary to the experience of most other classes of projects. As a wider pool of experience is gained, we would expect to see more accurate estimates. This evident lack of learning may be the result of several factors, such as the implementation of new regulations, new technologies, and real price increases. These factors make it difficult to replicate prior cleanup experience across a diversity of sites. Not being able to learn from past experience hampers the learning process, and consequently, the development of more accurate estimates.

Moreover, there is some indication that the primary drivers of cost and schedule estimate error (use of more

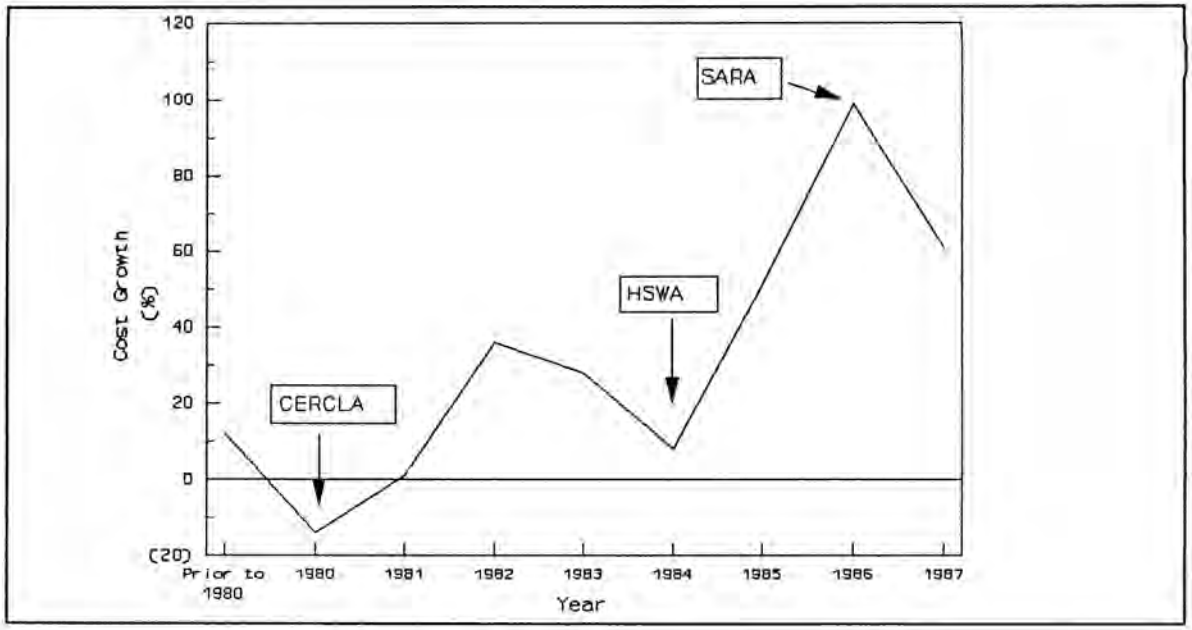

Fig. 4. Historical Trend for Cost Growth in Cleanup Projects.

complex treatment technologies, greater diversity of contaminated media and contaminants) will be even more prevalent at sites being remediated during the 1990s. Based on our research, we believe that the implementation of new and even more complex treatment technologies in the coming years will result in continuing cost growth in cleanup projects.

HAZRISK® MODELS

The *HAZRISK®* models were built to provide some level of confidence that the cost estimates associated with a cleanup project will not be overrun or underrun due to unpredicted events. We contend that if the deviations from expected costs were known on the basis of first principles, we would not consistently underestimate project costs. Therefore, we need to look at history - the record of past projects- to provide guidance. Because our research is historically based its results are not certain predictors of the future. What we provide are a set of tools that are empirically grounded and which offer an industry-wide benchmark for assessing and comparing project results. Our method is statistical in nature and provides a systematic examination of the historical relationships between project outcomes and it also provides a quantitative link between the characteristics of cleanup projects and the relative riskiness of these projects in terms of total cost and contingency requirements. These models did not establish causal relationships; they simply identified statistical linkages. The models used factors as independent variables which can be easily measured during or by the completion of the assessment. No *ex post* factors were included. The statistical models were subjected to a set of rigorous diagnostic tests for multicollinearity, influential observations, and other types of statistical errors. We were able to develop three statistical models for understanding the cost and schedule risks of cleanup projects:

- The *HAZRISK®* Cleanup Cost Estimating Model
- The *HAZRISK®* Cleanup Contingency Allowance Model
- The *HAZRISK®* Cleanup Schedule Duration Model

The *HAZRISK®* Cleanup Cost Estimating Model estimates total cleanup costs as a function of the following factors: (1) the volume of contaminated material being excavated, treated, or disposed; (2) the number an type of remedial technologies being employed; (3) the number and types of contaminated media present; and (4) the classes of contaminants present. The volume of material is overwhelmingly the most important predictor of costs. Volume does not encompass the amount of groundwater extracted or treated. Thus, this model cannot be used for exclusively groundwater "pump and treat" jobs. The primary purpose of this model is to check the reasonableness of a legitimate "good-faith" estimate. When there is a substantial discrepancy between the established estimate and the model's prediction, this fact should be used in conjunction with other data and the estimator's good judgement to raise questions about the accuracy of the estimate. This model accounts for 97 percent of the variation in cleanup costs. Volume is the most important single predictor of cleanup costs. Figure 5 graphically shows the strength of this rela-

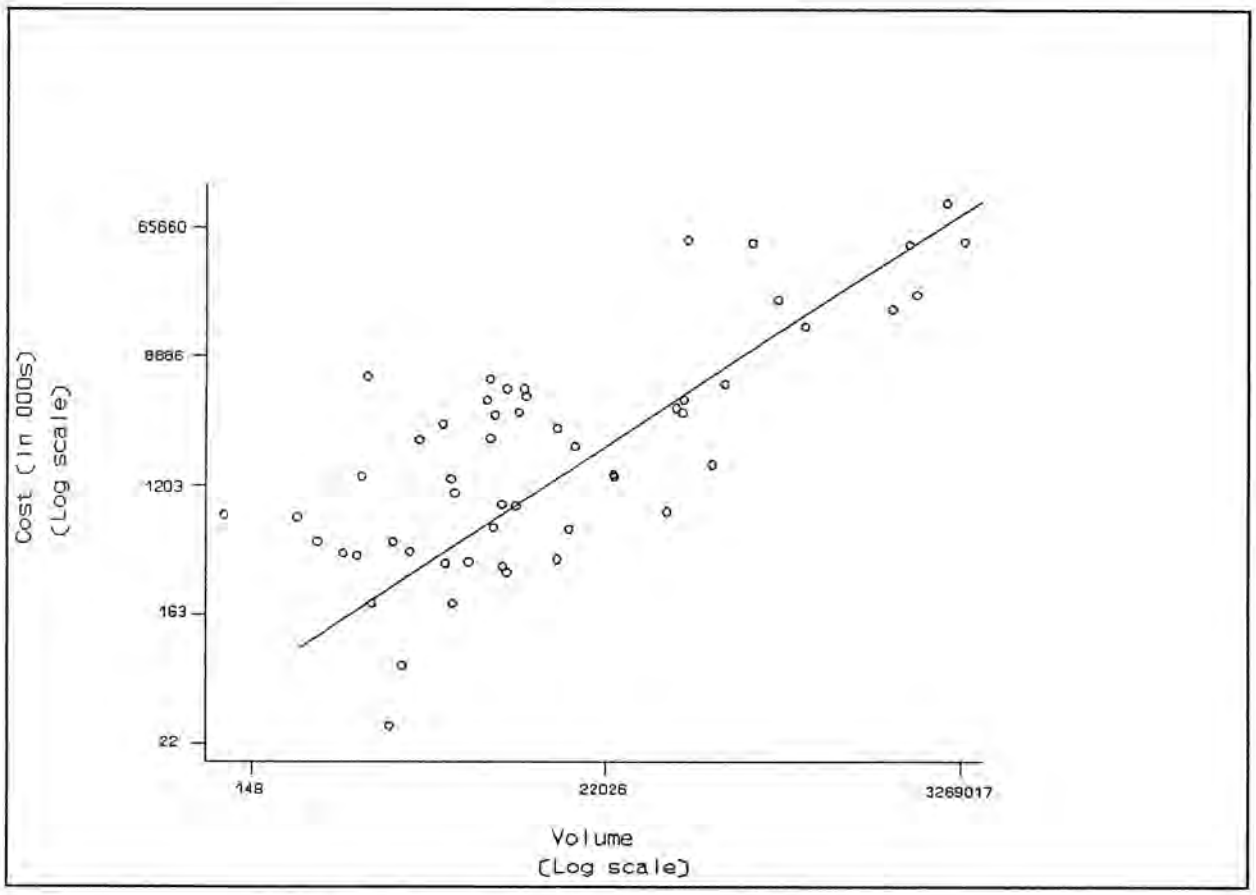

Fig. 5. Relationship Between Cleanup Cost and Volume.

tionship. The model is a useful tool for evaluating the "reasonableness" of legitimate cost estimates.

The *HAZRISK*® Cleanup Contingency Allowance Model predicts the needed contingency for a cleanup project based on four factors: (1) the level of project definition at the time of the estimate; (2) the degree of technological complexity ; (3) the media complexity ; and (4) the classes of contaminants present. The predicted contingency value from the model can be added to the base estimate in order to generate a total estimated cost. The model explains approximately 75 percent of the variance in cost growth ($R^2 = 0.73$). With the addition of new sites to the database and further refinement of our project definition scale, we believe that the variance explained can be increased significantly. One implication of the model is that it contradicts a prevailing belief among many in the environmental community that regulations are the most significant cost growth drivers. Our model suggest that the potential for cost growth in projects can be assessed early in the project cycle on the basis of site and project characteristics known by the completion of the assessment.

The *HAZRISK*® Cleanup Schedule Duration Model estimates the time required for remedial construction on the basis of the following factors: (1) estimated cost at authorization; (2) the technological complexity of the remedial technologies to be employed; (3) the contaminated media complexity; and (4) the type of contaminants present. Similar to the cleanup cost estimating model, we recommend that this model be use to check the "reasonableness" of planned schedules. This model accounts for 83 percent of the variation in cleanup schedule.

IMPLICATIONS OF THE HAZRISK® RESEARCH FOR U.S. DOE

To date, U.S. DOE has had difficulty in controlling costs in ER projects. Our research has shown that this problem is not unique to U.S. DOE. U..S. EPA Superfund sites and, to a lesser degree, industry sites have been characterized by inaccurate estimates. We believe that this is a direct result of a lack of understanding on the sources of misestimation in cleanup projects. This places program and project managers (who need good early cost estimates to support planning decisions) at a severe disadvantage. In many respects, however, U.S. DOE is in a fortunate position. The major portion of the department's cleanup effort is just getting underway. They have the opportunity to learn from the cleanup cost estimating experience of the 1980s.

The *HAZRISK®* research has demonstrated that the potential for cost growth and schedule slip as well as the reasonableness of base estimates can be assessed before major expenditures are made.

In order to improve estimating accuracy in the future, we believe:

- A consistent system measuring the thoroughness of project definition, the degree of technological complexity, and the variety and type of contaminated media and contaminants should be developed and implemented at U.S. DOE. Our research suggests that regulations are not the primary culprit driving cost growth in these projects. A review of projects in our database showed that regulations played only a very minor role in impacting the degree of cost growth. Rather, the primary factors driving cost overruns/underruns can be understood at the time of the estimate.
- U.S. DOE should adopt the use of parametric estimating tools such as the *HAZRISK®* models, as well as other ER cost estimating systems that are being developed to provide an independent check of estimates arrived at through conventional means.
- U.S. DOE should use the *HAZRISK®* database or a similar historical database to test and validate cost estimating tools developed for ER projects. The department needs a way of judging the most appropriate use and the accuracy of these systems. For example: What type of sites can the tools be applied to? What level of cost detail does the system provide? What classes of contaminants does the system address? What type of estimate does the system generate?

NEXT STEPS

The first phase of the *HAZRISK®* project demonstrated the viability of using a database of *completed* assessments and cleanups to build a battery of tools to assist U.S. DOE field and headquarters personnel in understanding the drivers of cost and schedule risks in ER projects. During this phase IPA made significant progress in collecting project data on completed U.S. DOE ER projects. The database contains nearly all of the UMTRA sites, the ER experience for nuclear testing sites in the Pacific, and various radioactive and mixed waste sites at several DOE facilities. However, there are many recently completed U.S. DOE projects for which we have no information. Since these projects represent the latest U.S. DOE ER experience, adding these sites to the database would significantly improve U.S. DOE's ability to measure and track ER project performance.

Further, as more U.S. DOE sites are included in the *HAZRISK®* database, the models can be calibrated to U.S. DOE sites. These tools need to be revised is more as understood about ER cost and schedules. A static model will not successfully account for potential changes in underlying factors that drive costs and schedules. Although the models are sufficiently straightforward, we feel that the development of a software system would aid in the numerical computations and would result in greater use of the models.

The development of the *HAZRISK®* database and models are important steps in increasing the knowledge base of U.S. DOE staff and providing them with tools that can be used to improve project preparation and estimate accuracy. It is our hope that this empirical, quantitative analysis will provide some insight for U.S. DOE and industry into the cost and schedule uncertainty surrounding cleanup projects.