TESTING A PREDICTIVE MODEL FOR REPOSITORY COST -- THE WASTE ISOLATION PILOT PLANT EXPERIENCE

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ABSTRACT

The Department of Energy (DOE) has developed a series of cost estimating models (called FAST), originally under the Assistant Secretary for Nuclear Energy and currently under the direction of Assistant Secretary for Defense Programs. One model, an equipment estimating methodology, was used extensively to test the Waste Isolation Pilot Plant (WIPP) equipment estimate validity. A mining and total repository estimating model has also been developed. Along with the other information sources, WIPP design and historical experience were used extensively in the development of this model. The primary focus of this paper will be on the progress of the WIPP Project and the state-of-the-art cost modeling of geologic waste storage facilities.

WIPP BACKGROUND

The Waste Isolation Pilot Plant, now under development near Carlsbad, New Mexico, will provide a research and development facility to demonstrate the safe disposal of radioactive waste from national defense programs. WIPP is authorized by Public Law 96-164 and is exempted from licensing by the Nuclear Regulatory Commission.

The primary objectives of WIPP are to demonstrate, through a full-scale pilot plant, the technical and operational methods for permanent isolation of defense-generated radioactive waste. It will also provide a facility for experiments on the behavior of high-level waste in bedded salt. WIPP is designed to receive, inspect, emplace, and store defense waste. It will have the capability of disposing of defense transuranic waste (TRU) and conducting experiments with defense-generated high-level waste.

The construction of permanent surface and underground facilities started in July 1983 following an extensive exploratory program. This exploratory program included two large diameter shafts and mining over 2 miles of drifts (tunnels) to confirm the subsurface geology. Construction completion is scheduled for December 1986. A test and checkout period will follow with waste receiving operations targeted for October 1988.

Beginning in late 1983 and during 1984 and 1985, construction will be at a peak effort. Enlarging the 6 foot diameter exploratory and ventilation shaft to a final 19 foot finished diameter has started. This will be the primary waste handling shaft. Sinking the third shaft for facility ventilation has also started. Major contracts for access roads, a rail spur, and a 31-mile water pipeline are in progress. The main waste handling building will be started in mid-1984.

With site characterization and site validation complete, Sandia research and development activities will emphasize in-situ experiments. These experiments and demonstrations will establish the technical basis for defense waste disposal in bedded salt. This work will be based on an extensive background of predictive model development and laboratory/field testing. Specific technology experiments will include:

- Thermal/structural interaction
- Operations demonstration
- Waste package performance

These experiments will be conducted in areas already mined during the exploratory program and in areas now being mined.

COST ESTIMATING

The task of controlling cost for the WIPP project (and all DOE projects) is a cradle-to-grave process. Initial estimates were used to conduct tradeoff analyses and justify appropriations. Follow-on estimates were used to plan project scope and schedules, award contracts, measure performance, and manage the approved projects and programs. Final estimates (at project completion) provide the historical data for the Department to more effectively estimate the cost of future projects. Competition for scarce resources both in the public and private sector has mandated more realistic prediction of costs. Failure of cost estimates to be realistic forecasts of actual cost can spell doom for project, programs, and business enterprises. Fig. 1 suggests the hazards of incorrect estimates.

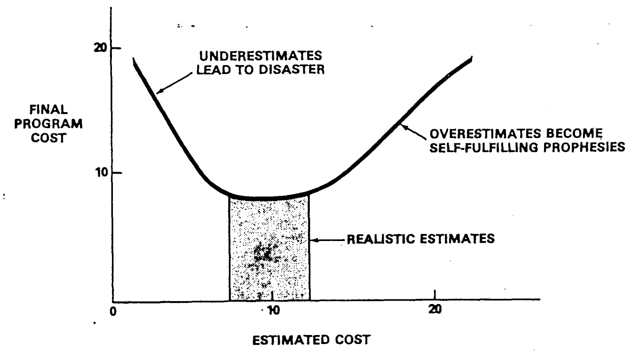

Fig. 1. Hazards of Incorrect Estimates

Goals must be realistic to be achievable. This is true of cost estimates. The underestimate leads to embarrassing situations within an agency and with Congress and damages credibility of future estimates. The overestimate becomes a self-fulfilling prophecy. Realistic estimates, on the other hand, promote efficiency and minimize the probability of cost growth. The obvious message is the need for better estimates and for better methods of checking them.

Parametric Cost Estimating

The WIPP project used several cost estimating/analysis techniques to help assure good estimates for sound planning. Among the cost techniques used was parametric cost estimating. Parametric cost estimating involves the development and use of estimating relationships between historical costs and system physical or performance characteristics. The historical costs used in the analysis can reflect the impact of system growth, engineering changes, project stretchouts, and other cost, schedule, or performance perturbations encountered in comparable projects. This method of analysis, in addition to providing the primary basis for project cost estimates in the conceptual phase, also provides an early test of the reasonableness of subsequent project estimates. Also, parametric analyses can be performed at different levels in a project; i.e., total system, subsystem, or component.

DOE Approach

The new series of parametric cost estimating models developed by the Department of Energy are intended to improve the early formulation and review of project cost estimates. These models, called FAST, include:

- FAST-E, an equipment model used primarly for equipment and systems for the energy industry.
- FAST-C, a construction model for civil engineering and commercial building applications.
- FAST-F, a funding model to assist in planning engineering and project expenditures, establishing funding needs, and providing the impact of inadequate or changing funding profiles.
- FAST-M, a mining and total project model for surface and underground operations, surface buildings, and related equipment.

The FAST models had their genesis in the PRICE parametric models developed by RCA. The PRICE models are almost universally accepted in the defense and aerospace industries. The most successful applications were to specific products such as electronics, combat equipment, and machinery. However, there are serious limitations to PRICE applications for DOE projects. Very large systems, construction of facilities, and mining operations are outside the scope of the models. In addition, the PRICE models require input criteria that are often unavailable on DOE projects or are not applicable to our projects. Also, DOE constructs many first-of-a-kind projects for which no references are readily available. FAST facilitates the synthesis of reference data from analogous sources for these first-of-a-kind projects.

The DOE approach has continued and extended the parametric approach of assessing equipment classes and characteristics. The application and refinement of the relationships to costs of weights, masses, technological states-of-the-art, performances, reliabilities, and producibilities have extended the parametric methodology to a greater range of applications. The resulting models rapidly provide overall program costs for engineering, production, and installation without the need for detailed breakouts of contributing costs.

As implied above, the FAST methodology is uniquely advanced. It is not dependent on the accumulation of detailed cause and effect data. FAST routines serve to represent the reasons "why" conditions cause their effects. For example, why and how do technological requirements affect weights and sizes; and based on the mass and performances, why and how are costs impacted? The FAST methods minimize the need for extensive empirical data. They allow the processing of new equipment concepts predicated on a single reference. Finally, there are built-in procedures to minimize the use and propagation of faulty empirical information. This feature tells the user when he is breaching the bounds of realism regarding his input data. A simple error message tells the operator that he is in far left field.

The FAST-M Mining Model

FAST-M is a computerized cost estimating model designed to calculate the costs, schedules, and cost risks of all types of mining operations. The model follows a logical breakdown of the areas and equipment into the discrete parts shown in Fig. 2. Input forms are provided enabling the user to break down a project into the smallest component for estimate detail. However, the model permits macro

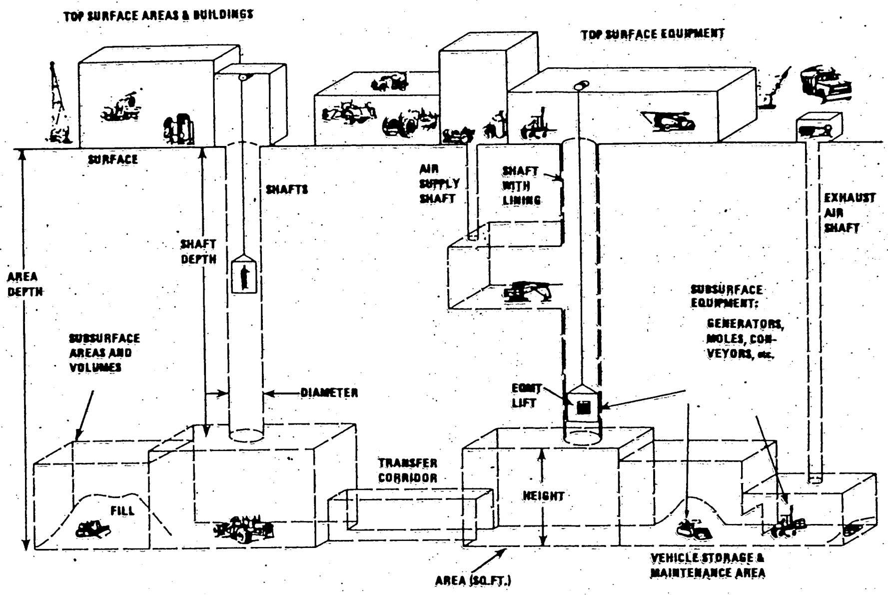

Fig. 2. Typical Repository Operations.

descriptive data to be entered where the finer construction details have not yet been determined or excessive detail is not required.

FAST-M is capable of incorporating efforts such as site work, buildings, and utilities as well as calculating the costs for acquiring and installing their equipment. These typical surface facilities as well as shafts and underground areas and equipment are covered by FAST-M. In all cases, the model uses performance schedules and incorporates their effect on costs. Applicable engineering and project management costs and schedules can also be processed.

As stated, information describing the job requirements can be totally macro, or as detailed as necessary. For example, a building may be defined as of certain size and similar to a building with a known cost experience. Alternatively, buildings and their descriptors can be synthesized -- the laboratory portion similar to this, the process portion similar to that, etc. Detailed descriptions can go as far as defining each shaft, with or without casing, mining in differing media, using different mining techniques, and for every purpose -- personnel access, equipment, ventilation, exhaust, etc. Underground areas and equipment can also be defined in micro or macro detail. FAST-M is able to process information that may represent any degree of mix between the two extremes of macro and micro.

For the macro method of describing job requirements, relating a new situation to an acceptable or comparable reference may present a problem -- there may be no such known experience. FAST-M has the ability to allow the user to modify or synthesize experiences or references in such cases to circumvent this known problem.

The FAST-M model is applied through a series of questionnaire type input forms:

- top surface construction and site preparation effort.
- installation, acquisition, and integration of equipment into various surface buildings.
- underground chambers, corridors, vehicle storage, and maintenance at different levels.
- acquisition, installation, and integration of all subsurface equipment: moles, bulldozers, ventilation fans, pumps, shoring posts, drills, etc.
- vertical shafts for solution mining, air supply, exhaust, and elevators for equipment and personnel.
- engineering and project management costs for all of the above.

Aside from the basic scope of work, the most significant conditions affecting the character of reference cost experiences are as follows:

1. Economics - The years in which the work was performed can play a major role in costs. There is a continuous annual inflation picture that must be considered. In recent years the annual rates have become crucially significant. Therefore, costs must be associated with economic time cycle.

2. Economy of Scale - Costs will vary depending upon the size of a project. As a project becomes larger, the cost/square foot or cost/cubic yard of

the same type of work will tend to become less. Cost references must be associated with their scaling basis.

3. Site and Productivity Indices - Where the project was or is to be performed can materially affect costs. Every site location has a unique index of labor and material costs. Some may be remote that will cause greater transportation costs for material as well as labor. Certain areas are subject to local or union type of economic controls. Site areas can also have varying productivities. Some projects may involve high radiation areas where workers may be limited to 1-2 hours of work per day - and yet will be paid for a full day. Other site areas will have productivity variations due to local union contract arrangements. Therefore, reference costs can be greatly influenced by site and productivity factors or indices.

4. Environmental Conditions - These conditions include seismic, tornado, and radiation. To meet the construction requirements generated by such conditions involves greater cost expenditures. Beyond increased specific construction details there are other areas of cost increases: tests, inspections, and quality control of the construction effort will become more demanding as the environmental conditions become more severe. Cost impacts for such factors can be very significant. Therefore, cost references must be identified with the character of the prevailing environmental conditions. Without such identification the use of the associated references could be very misleading.

5. Year of Technology - In the natural course of events there is a continuing process of improvements to the state of construction technology. There are new and innovative tools, equipment, construction materials, and techniques. In the construction industry such improvements are relatively slight over a short span of years. However, a span of 10 or more years has begun to have a significant impact on costs. Therefore, the year of technology can be an important factor when employing historical cost experiences. Conversely, in projecting future programs, technological advancements should be taken into account.

FAST then develops factors designed to represent references or cost experiences after being normalized to remove the effects of the conditions just described. This means that those factors can be used along with new economic performance periods, environmental conditions, project sizes, and area allocations without the need to know the equivalent conditions that were associated with the experience reference. It is this capability that enables the parametric universality of the FAST-M program.

APPLICATION OF FAST MODELS

Two examples of practical application of FAST methodologies are provided in this paper. The primary focus is on the FAST-M model. However, a FAST-E application, applied to test an early WIPP equipment estimate, is also included.

Equipment Estimate

Some TRU waste destined for WIPP must be handled remotely. This waste will be in steel containers 10 foot long and 2 foot in diameter. These containers will be received in shielded shipping casks. The waste package will be removed from the shipping cask in a hot cell and placed in a facility cask. The facility cask will be used to get the waste underground to a storage location. Once at the storage location, an emplacement machine will position the waste package into a hole drilled into the storage room wall.

Since the emplacement machine is a first-of-a-kind equipment, it was chosen as a surrogate cost reference as a weapons carrier. A weapons carrier was judged to be of the same general complexity for fabrication and of the same general magnitude of size.

In this particular study the WIPP estimate, as well as the assessment estimate, was run based on technology improvement calculations made by the FAST model. Technology improvements are improvement trends in fabrication over time due to more effective and efficient means of manufacturing and to more effective and efficient ways of testing and inspection. The future schedule was derived from the need date in the estimate (fabrication to begin in 1985, 14 months fabrication, need date, 1987). The results of the estimate without contingency were as follows:

	WIPP Estimate, 1981 $'s	FAST Estimate, 1981 $'s
1981 Technology	$404K	$412K
1985 Technology	$380K	$381K

As can be seen, the FAST-E parametric estimate compares favorably with the project estimates (or that the WIPP estimate appears reasonable). Table I is the complete documentation for the FAST-E input and output. This output is generally important only to the cost analyst trained in the FAST methodology. However, if one looks only at the top of the format, key information for managers and decisionmakers is shown. The manager is interested only in the bottom line cost and its uncertainty. Here the cost is $412,041 which represents the median cost for a normal distribution of estimates. To provide a 90 percent confidence factor to this estimate (i.e., 9 times out of 10 the cost would not exceed this level) the manager would utilize the $476,814 estimate. In essence, this adds $64,773 contingency (16 percent) to the most probable estimated costs.

Defense Waste Repository

On January 7, 1983, President Reagan signed into law the Nuclear Waste Policy Act of 1982 (P.L. 425). Section 8 of the law requires the President to evaluate the use of the disposal capacity at one or more commercial repositories for the disposal of high-level radioactive waste from atomic energy defense activities. The evaluation considers cost efficiency, health and safety, regulation, transportation, public acceptability, and national security. The Office of Civilian Radioactive Waste Management (CRWM) within DOE is responsible for implementation of the Nuclear Waste Policy Act. However, the evaluation required by Section 8 has been assigned to the Assistant Secretary for Defense Programs in conjunction with CRWM. The evaluation is in process and a final report to Congress is due in January 1985.

In performing the required evaluation, DOE is considering two options. First, defense high-level waste would be disposed of in a commercial geologic repository. A second option is constructing a repository dedicated to the disposal of only defense high-level waste.

Cost estimates are being developed for many repository scenarios for comparison purposes -- both defense and commercial. Actual costs for WIPP construction to date have been used extensively to calibrate the FAST-M model. This model has then been used to generate parametric estimates for the scenarios considered. A sample estimate is provided here for illustrative purposes. This estimate is for a defense waste only repository. The WIPP facility was the primary influence for the repository concept. The total envisioned facility is similar to the concept shown in Fig. 2. The design basis or system definition inputs for the estimate included the following:

Main Surface Facilities - These facilities include areas for waste receiving, overpacking, nondestructive examinations, and cask handling and shipping. Additional items include:

- Hoists and headframe structures
- Waste building HVAC
- Office maintenance, storage, and support services
- Repository ventilation and atmospheric protection systems
- Plant control systems

Shafts - Shaft work includes the costs for excavation, lining with concrete, rock bolts, wire mesh, and shaft related instrumentation. The repository includes three shafts:

- Waste handling - 21 foot diameter
- Rock handling and construction - 12 foot diameter
- Repository ventilation - 16 foot diameter

Site Development - Included here are site acquisition and construction elements for:

- Land and mineral rights
- Offsite developments (road, rail, water, power, etc.)
- Onsite developments (clearing, grading, drainage, roads, parking, etc.)

Underground - The underground facilities and equipment are very similar to WIPP. Principal sections are:

- Shaft pillar area
- Shaft stations and mine entries
- Underground warehouses and shops
- Storage rooms and haulage ways
- Mining and hauling equipment
- Utilities and HVAC
- Waste hauling and emplacement equipment

Support and Utilities - The surface support facilities and utility services are typical for most plants. They include:

- Substations and electrical distribution
- Safety and security systems
- Emergency power
- Yard piping and pumphouses

The data below summarize the capital cost estimates resulting from one typical scenario as described above. Specific assumptions included a total repository capacity of 20,000 defense high-level waste packages and a throughput rate of up to 1,120 canisters per year.

	$ Million
Surface Waste Facilities	$441.2
Land and Land Rights	53.0
Site Development	88.9
Shafts	103.9
Underground	168.3
Support and Utilities	28.8
TOTAL	$884.1

The results compare favorably with the current cost estimate for WIPP. The approved capital cost for WIPP is $459 million. The model tells us that, starting today, we could expect to construct a licensed defense waste repository in salt for approximately $884.1 million (in 1984 dollars). This estimate excludes research, development, and evaluation. Evaluation generally includes site characterization, safety and other studies, and institutional payments. It does not include the cost of operations or waste transportation. These excluded items could be easily estimated and factored into a total project estimate.

The FAST-M model also generates a most probable schedule based on project size, complexity, and historical experience. The schedule corresponding to the $884.1 million estimate is 60 months. This also compares favorably with WIPP construction which will require 42 months.

Table I. Input/Output for FAST-E.

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                         ***** FAST-E *****

PROJECT:   WIPP                                DATE: FRI, MAR 02 1984  12:01:56
LOCATION:  NEW MEXICO                          FILENAME: EMPLACE.1
ITEM:      EMPLACEMENT MACHINE                 ECONFILE:

                         ***** DETAIL ITEM *****

         $UNITS=        1 BASIC COST   SCHD PENALTY     TOTAL COST
         PRODUCTION       412,041.00           0.00     412,041.00

               ***** COST UNCERTAINTY DISTRIBUTION *****

        -FROM-  70% -TO-      -FROM-  80% -TO-      -FROM-  90% -TO-
PROD   385,221   438,861     369,534   454,548     347,268   476,814


                    ***** CHARACTERISTICS *****

                FASTE EQUIVALENT
                FASTE                                  3,055.075*
                  TENVLE(FASTE)                        FAS.0.303*

                         ***** INPUT DATA *****

                  ESCAL       GECON      FPER      LCURVE        CMULT
 PRJGLOB          1.000       1981       12D        0.950           1.
                  TYPE        SYSTEM     RERUN     REMBOX
 FILE             D            0         0           0
                  ALL     COST    UNCERT  LOHMAT  INPUT    FGRAPH    FDET
 FORMAT            0        1        1       0      1         0        0

                  PLTFM    ENTYPE MATVAL  TYEAR
 GLOB             1.200    83.060   1.00   1981

                  WT          WTFAC          VOL          VOLFAC
 WTVOL       35,000.00     3,258.01*       849.02*      100.00*
                  PMX         MXTYPE       ELWT      ELMX          STWT    STMX
 MXLINE           0.480*      4.475*        0.0      0.000          0.0   0.000

                  PCOST       PQTY       PECON     FOAK
 PCOST       412,041.00         1.        1981     1.000D
                  PSTART      PFIN       PSCHDX    PRDMX      PYEARC
 PSCHD            JAN.1981    MAR.1982*   98.17    2.863*       1981*
                  CONTIN      ADD
 END               0           0


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 DO YOU WISH TO MAKE CHANGES (Y/N): YY
 ENTER LINE(L), VARIABLE(V) OR NONE(N): VV
 ENTER CHANGES: PPCOCSOSTT==338811665533,,UUNNCCEERRTT==00
 ENTER CHANGES:
(NEWTER LINE(L), VARIABLE(VN) OR NONE

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The FAST-M model allows DOE to quickly synthesize typical repository estimates without the benefit of any design. It allows early management decisions to be made and strategies to be established.

FAST MODEL STATUS AND FUTURE PLANS

Future plans include the development of a FAST users data base in the form of a comprehensive reference values manual. This manual will greatly enhance user capability by allowing cost studies to be developed without having to develop calibration studies from similar historical information. In addition, a fifth model is in the planning stages. The cost-of-ownership model will provide the cost to own and operate a facility. Included in this model will be the cost of operations manpower, consumables, utilities and administration/supervision.

In summary, the FAST models provide an important tool for the engineer or program manager who needs to determine or assess costs and schedules. Universal in application and easily calibrated and used, the models give rapid analyses of equipment, construction, and mining costs, as well as schedules and funding profiles. While parametrics utilizes history, it is the wave of the future and the DOE FAST models are in the forefront of this energizing series of engineering and management tools.