FORECASTING STAFFING REQUIREMENTS FOR HAZARDOUS WASTE CLEANUP

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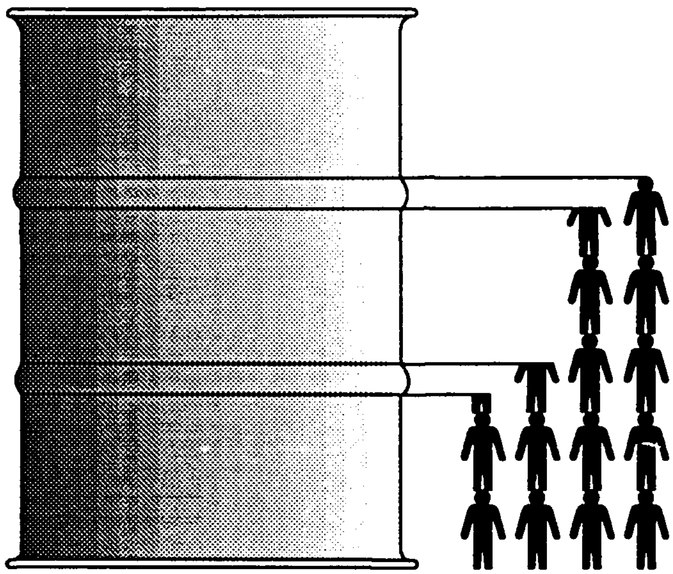

February 1991

Report CE004R1

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Executive Summary

FORECASTING STAFFING REQUIREMENTS FOR HAZARDOUS WASTE CLEANUP

The Directorate of Civil Works of the U.S. Army Corps of Engineers needs to be able to forecast the staffing levels required to supervise contractor cleanups of hazardous waste sites in support of the U.S. Environmental Protection Agency. The Corps needs those forecasts to plan for future work and to report environmental staffing needs to the Office of Management and Budget.

We have developed a Civil Works' Superfund staffing requirements model based on statistical analysis of historic workload data. It is based on the assumption that the size and complexity of future programs will be related to the size and complexity of past programs. While a wide variety of factors affect staffing levels, we found that the two most important ones are total cost and project type or complexity. By dividing the Corps' programs into different types of work, we can reliably relate dollars spent to hours worked. The three types of work we use in our model are remedial design, supervision of remedial construction, and additional technical assistance to the Environmental Protection Agency.

We used historical data to determine the relationship between dollars spent and hours expended for various types of work: the distribution of project sizes, durations, and start dates; and the functional relationship between time spent and work accomplished. Those functional relationships and distributions are embodied in a computer program – the Superfund staffing model – that takes multiyear program dollars as its primary input and produces multiyear forecasts of staffing levels and costs as its primary outputs.

We recommend that the Environmental Restoration Division of the Corps use this prototype Superfund staffing model for Superfund planning. Because the Superfund program is new, however, and the volume of historical project data incorporated in the model is currently very small, we recommend that the Corps use the prototype model with caution. For that reason, we also recommend that it collect additional project data annually from its divisions and districts at the same time that it collects the annual inputs for the staffing model. Additional project data will enable the Corps to make future refinements to the prototype model.

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CHAPTER 1

SUPERFUND STAFFING REQUIREMENTS

THE SUPERFUND LAW

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 established the strict liability of firms to clean up sites they have contaminated with hazardous substances. The original act was amended in 1986 by the Superfund Amendments and Reauthorization Act (SARA). Strict liability means that firms are responsible for cleaning up contaminated sites even if they followed practices that were legal at the time of disposal. CERCLA is commonly known as the "Superfund" law because of the $1.6 billion Hazardous Substance Response Trust Fund, which the law established.

Superfund sites are specific locations where hazardous substances were stored or spilled, most commonly created directly or indirectly by the chemical and petroleum industries. A storage site can become a potential health risk, and thus a Superfund site, if stored toxic substances begin to leak from landfills, containers, tanks, or holding ponds. The wastes at typical Superfund sites are industrial chemicals, and the most common health threat is from ground water contamination.

The main goal of the Superfund program is to eliminate the danger to health posed by these sites. Cleanups are generally paid for by the private parties responsible for initially depositing the wastes. The Hazardous Substance Response Trust Fund is available, however, to provide for emergency cleanup of contaminated sites, pending eventual recovery of the cost from the responsible parties, and for cleanup of sites for which the U.S. Environmental Protection Agency (EPA) is unable to recover costs from the responsible parties or to locate them.

The U.S. Environmental Protection Agency is the principal enforcer of the Superfund law and unlike many other Federal environmental statutes, CERCLA did not delegate administration of the law to the states. Among the responsibilities of EPA in administering the Superfund are identifying and ranking contaminated sites, identifying and recovering costs from responsible parties, notifying the public of potential toxic releases, and conducting or supervising corrective actions. In the language of Superfund, corrective actions can consist of *removal actions*, which are temporary cleanups of the hazard, or *remedial actions*, which provide more permanent cleanups.

Removal actions can consist of cleaning up or removing hazardous substances, monitoring toxic releases, limiting access to the site, and temporary evacuation. Remedial actions restore the site so that it no longer poses a direct or potential health threat. While remediation technology is constantly being improved and new processes are being developed, current remediation practices include dredging or excavation of the site, on-site treatment or incineration, repair or replacement of leaking containers, and transportation and disposal off site. Removal action is a temporary first step; EPA intends eventually to apply permanent remediation to all Superfund sites.

The U.S. Environmental Protection Agency ranks all Superfund sites according to an assessment of the risks that the site poses to human health. Those sites deemed to be the most risky are placed on the National Priorities List (NPL). EPA has currently listed or proposed for listing on the NPL over 1,200 sites and intends that the list will eventually reach 2,000. The Office of Technology Assessment estimates that EPA will eventually identify 10,000 Superfund sites. The State of New Jersey alone has 100 currently listed sites.

Moreover, EPA's computerized data base of potential sites contains summary information on over 25,000 suspected waste sites. The resources required are scarce compared to the number of sites. Each Superfund site is unique and generally poses a variety of difficult technical challenges. Even if the money to clean up these many sites were forthcoming, the supply of necessary technical expertise may not be easy to find. As a first step, it is essential to be able to plan future staffing needs for this important program. We have developed a prototype staffing model for one portion of the Superfund program: U.S. Army Corps of Engineers' (USACE's) remedial design and construction assistance for EPA.

THE SUPERFUND PROCESS

The U.S. Environmental Protection Agency has developed a seven-step process to deal with Superfund sites: (1) initial report of a potential site, (2) identification and preliminary assessment, (3) on-site inspection, (4) ranking of the site by degree of risk, (5) remedial investigation, (6) feasibility study, and (7) remediation. USACE assists EPA in carrying out the last two steps of the process.

Once EPA receives the report of a possible Superfund site, it collects background information on the site and performs a preliminary assessment of its potential hazards. In the third step, EPA makes a preliminary on-site inspection to find obvious problem signs and to take limited soil and water samples.

The U.S. Environmental Protection Agency then assesses the site against a set of factors, including the type and toxicity of wastes; the number of people potentially exposed; and the likely pathways for further exposure: air, ground water, and so forth. This assessment may result in adding the site to the NPL, which is usually updated at least once a year.

If the site ends up on the NPL, EPA authorizes a remedial investigation (step 5), which consists of thorough sampling and field analysis to determine the best method for remediation. Remedial investigation itself can cost millions of dollars and require many years. Remedial investigation is followed by a feasibility study to determine the most cost-effective solution and, finally, by the actual removal action to eliminate the hazard.

Removal actions include detailed engineering and design of the chosen remediation process, as well as the actual removal or treatment of the wastes. The remediation action is normally carried out by a contractor hired by the responsible private party. EPA monitors that process to ensure that the cleanup is carried out according to specifications.

FEDERAL LEAD PROJECTS

If EPA is unable to locate a potentially responsible party (PRP) or the PRP is unable to pay the cleanup costs, because of bankruptcy or other reasons, EPA assumes the PRP's role. Those cases are called Federal lead Superfund projects. Instead of merely monitoring the process to ensure that the cleanup meets EPA standards, EPA must award the contract and directly supervise the design and construction of the site cleanup.

When Superfund was new, EPA attempted to supervise the design and remediation actions using its own in-house personnel. As the number of sites blossomed, the tasks of engineering, contract administration, and contract supervision soon overwhelmed EPA's internal staff and they turned to other agencies for help. Since both parts of the remedial action stage - engineering and construction supervision – are similar to the type of work that the USACE Directorate of Civil Works carries out in the normal course of its business, EPA turned to USACE for help in the remediation stage.

The U.S. Army Corps of Engineers now aids EPA in three major areas. First, USACE carries out design and engineering in house for remediation actions and it supervises architectural and engineering firms that are contracted to perform such work. Second, USACE supervises construction companies who perform the actual removal or remediation. And, third, USACE provides technical assistance to EPA: work that is less intensive than design or construction but that requires the technical expertise of USACE engineers. Most technical assistance projects for EPA to date fall into two categories: feasibility studies and hazardous waste enforcement support.

When EPA assigns a Federal lead Superfund project to USACE for design and construction, USACE first provides technical assistance by reviewing the feasibility study that decided on the chosen cleanup technology. When providing hazardous waste enforcement support, on the other hand, USACE monitors PRP-led cleanup projects. In this role, USACE does not directly supervise the project because that is the PRP's responsibility. Instead, it "looks over the shoulder" of the PRP and its contractor to ensure that the project is carried out properly and that cleanup reaches the desired levels.

CHAPTER 2

DETERMINING STAFFING FACTORS

USING HISTORIC DATA

The purpose of the Superfund staffing model is to be able to reliably forecast the staffing levels needed by USACE to support the EPA's Superfund work several years into the future. We base that forecast on the statistical analysis of historical data. The historic approach is sound if two conditions hold: past work was performed efficiently and future work will continue to be similar to past work.

Predictive factors developed from historic data that include inefficiently managed projects will simply perpetuate those inefficiencies. However, since USACE's costs for design and construction management services have been shown to be comparable with those of other Federal, state, and local government agencies and with large private-sector companies,[1] which provide a measure of USACE efficiency, we can use properly sampled USACE data to develop predictive factors that reflect general industry standards. If we assume that USACE carries out Superfund work at the same level of efficiency as its other work, then historic USACE Superfund data can similarly be used to develop efficient predictive factors for restoration work.

In addition, it is possible to take account of changes in USACE's program mix over time by dividing the workload into different types of work. Thus, when shifts occur in the mix between those types of work, the model will continue to predict staffing reliably. For example, by separately forecasting staffing needs for in-house design, design contracted out, construction, and different types of technical assistance, we can continue to forecast future needs even if the program moves from

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[1]LMI Report ML215. *Management Costs of DoD Military Construction Projects*. Paul F. Dienemann, Joseph S. Domin, and Evan R. Harrington. April 1983.

LMI Report AR801R1. *Monitoring and Controlling Engineering and Construction Management Cost Performance Within the Corps of Engineers*. William B. Moore, Eric M. Small, and Jeffrey A. Hawkins. December 1988.

LMI Report AR603R3. *Cost-Competitive Construction Management: A Review of Corps of Engineers Construction Management Costs*. William B. Moore and Jeffrey A. Hawkins. June 1990.

an emphasis on remedial design to an emphasis on remedial action (construction) as more Superfund sites move from the planning and design phase to the cleanup phase.

Within those work types, we assume that future work will be similar to past work. However, since the Superfund program is relatively new, the nature of the work will possibly change in the future. For example, EPA – USACE's customer – is moving from a reliance on traditional construction contracting to a greater emphasis on cost-plus, or reimbursable, contracting. Cost-plus contracts cannot be as closely specified as conventional contracts and require more USACE supervision. We have attempted to take account of that difference by dividing construction work into reimbursable and nonreimbursable work.

Because the Superfund program is relatively new, the volume of past work is just barely sufficient for statistical analysis. In addition, much of the available data were incomplete, further restricting our ability to generate sufficient sample sizes (and, consequently, restricting our ability to subdivide the work further into different types of design and construction work). For those reasons, we recommend that USACE collect the data needed to revise and "tune-up" the prototype model, in addition to acquiring the input data needed by the forecasting model. We discuss those data needs further in Chapter 3.

In putting together a statistically based model, we must be careful to choose those factors that are the best predictors of future staffing. The predictive factors must not only perform well statistically, they must also be practical. That is, they must be relatively easy to collect without a massive annual data call. In addition, the predictive factors must be leading indicators. For example, program breakage – stops and starts in program scheduling and execution – undoubtedly affect work hours. However, changes in staffing and program breakage move concurrently; one cannot be used, in advance, to predict the other. Moreover, program breakage is already contained in the historic data so that staffing and workload factors developed from that data will include some normal or average level of breakage.

A wide variety of factors determines and influences staffing levels. Many of those factors, however, are not useful for forecasting purposes because they move randomly over time. Since we cannot predict their behavior, we cannot use them to forecast staffing. Some factors may change very slowly, so that, in practice, they have very little effect on staffing changes. Still other factors, while significant, are strongly correlated to project dollars. That is, such factors exhibit strong collinearity with the project dollar amount. For example, longer projects certainly require more hours of work but they also generally cost more. Dollar size, therefore, acts as a proxy for length. Project complexity is another significant indicator of staffing requirements, which is strongly collinear with project type.

The Logistics Management Institute's (LMI's) past experience with USACE staffing models has shown that the two most important factors are dollars and project type or complexity. Not only are those factors good indicators of staffing required, but they are also easier to use as inputs than many alternate factors.

In practice, we must choose forecasting factors that themselves can be projected into the future. One of the advantages of dollar amount is that a large portion of USACE's Superfund program in any given year consists of projects that were started in previous years. Therefore, the forecast for the next 2 to 3 years can be based largely on the existing program and only partially on a prediction of the future program.

The forecasting method uses two basic types of predictive factors. First, we must "spread" the program dollars over a number of years and second, we must relate program dollars to hours worked. While the forecasting model includes some additional subtleties, those two factors form the backbone of the predictive methodology.

SPREADING THE WORK

Since program dollars do not translate into workload for a single year only, it is necessary to spread those program dollars over a number of years. The historic data show that all types of Superfund work include projects that take anywhere from a few months to 5 years to complete. Thus, in any given year, USACE is conducting projects that started in the current as well as in the previous 4 years.

The spreading algorithm takes three factors into account: project start dates, project durations, and the relationship between chronological time and work hours. We developed spreading factors for three basic types of Superfund work: remedial design, remedial construction, and technical assistance. Ideally, we would prefer to develop spreading factors for more types of work and to check that those spreading factors are significantly distinct. However, we did not have enough data points — or large enough sample sizes – to subdivide, for example, design into in-house design and contracted design. In some cases, we ran along the margins of statistical significance even for only three project types. Future data collection should enable more sophisticated spreading calculations by including more project types.

Table 2-1 presents the distribution of project starts over the fiscal year. This factor is important, since, even if a project takes only 6 months to complete, it will cross into 2 fiscal years if started at any time after March of the fiscal year. The data show that start dates were fairly evenly distributed over the year. (For comparison, the last column in Table 2-1 shows a perfectly random distribution of start dates, the distribution that would result if one project were started per day, with a total of 365 projects.) That is, the distribution shows no particular bias toward starting projects at the beginning, middle, or end of the fiscal year; projects have a more or less equal chance of starting at any time.

The second major factor in determining how dollars are spread is the distribution of project durations: the percentage of each type of project that took less than 3 months to complete, the percentage that took from 3 to 6 months, and so on. Table 2-2 shows that distribution for the three Superfund project types. Even though the duration data for remedial design are sparse, the resulting findings are reasonable: 78 percent of the projects took less than 3 years to complete, while a few have taken as long as 4 to 5 years. Interestingly, almost half of the construction projects undertaken to date have taken, or USACE expects them to take, less than a year to complete.

The third factor that dollar spreading must take into account is the relationship between chronological time and work time. That is, even if a particular project takes exactly 2 years to complete, we cannot assume that an equal number of staff hours are spent in each of those 2 years. Figure 2-1 shows these relationships for the three major types of Superfund work. As the graph illustrates, technical assistance projects appear to require more hours up front, while construction work starts more slowly, gathers steam, and then tapers off toward the close of the project. While these relationships are based on relatively sparse data, they are consistent with our experience with military design and construction work. Future data will improve the prototype model but in practice will probably change the appearance of these relationships very little.

TABLE 2-1

DISTRIBUTION OF PROJECT START DATES BY MONTH

Month	Remedial design	Remedial action	Technical assistance	Random start date
October	6.45%	8.11%	12.73%	8.49%
November	3.23	10.81	3.64	8.21
December	12.90	10.81	5.45	8.49
January	9.68	8.11	7.27	8.49
February	6.45	5.40	14.56	7.73
March	9.68	8.11	10.91	8.49
April	9.68	5.40	5.45	8.21
May	9.68	10.81	10.91	8.49
June	3.23	8.11	7.27	8.21
July	12.89	8.11	7.27	8.49
August	6.45	8.11	5.45	8.49
September	9.68	8.11	9.09	8.21
Total	100%	100%	100%	100%
Standard deviation	3.07%	1.73%	3.19%	0.22%
Sample size	31	37	55	–

The model does not require all of the data just described as direct parameters, because we combine them to calculate a set of spreading factors for each project type. Table 2-3 shows the final result, which is incorporated in the Superfund model. As shown in Table 2-2, projects in all types of work start in program year "N" and continue for as many as 4 years beyond it. The work accomplished in the last year for all three project types, however, is a relatively small percentage of the total; the bulk of the hours are spent in the first 2 years. Appendix A details the calculation process by which the three factors are combined to result in the spreading factors.

THE RELATIONSHIP BETWEEN DOLLARS AND HOURS

We used the statistical technique of simple linear regression to derive the relationship between workload and staffing for the various project types. Despite the scarcity of data, it was essential to divide the work into more than three types since

TABLE 2-2

DISTRIBUTION OF PROJECT LENGTHS BY QUARTER

(Completion date less start date)

Project duration	Distribution		
	Remedial design	Remedial action	Technical assistance
1 quarter	0.0%	16.7%	7.1%
2 quarters	0.0	3.3	0.0
3 quarters	11.1	13.3	21.4
4 quarters	0.0	13.3	17.9
1 year	11.1	46.7	46.4
5 quarters	11.1	20.0	10.7
6 quarters	0.0	3.3	3.6
7 quarters	11.1	10.0	0.0
8 quarters	11.1	3.3	3.6
2 years	33.3	36.7	17.9
9 quarters	22.2	3.3	7.1
10 quarters	0.0	10.0	7.1
11 quarters	11.1	0.0	0.0
12 quarters	0.0	0.0	3.6
3 years	33.3	13.3	17.9
13 quarters	0.0	0.0	0.0
14 quarters	11.1	0.0	3.6
15 quarters	0.0	0.0	7.1
16 quarters	0.0	0.0	0.0
4 years	11.1	0.0	10.7
17 quarters	11.1	3.3	3.6
18 quarters	0.0	0.0	0.0
19 quarters	0.0	0.0	0.0
20 quarters	0.0	0.0	3.6
5 years	11.1	3.3	7.1
Total	100%	100%	100%
Sample size	9	30	28

Note: Numbers may not add due to rounding

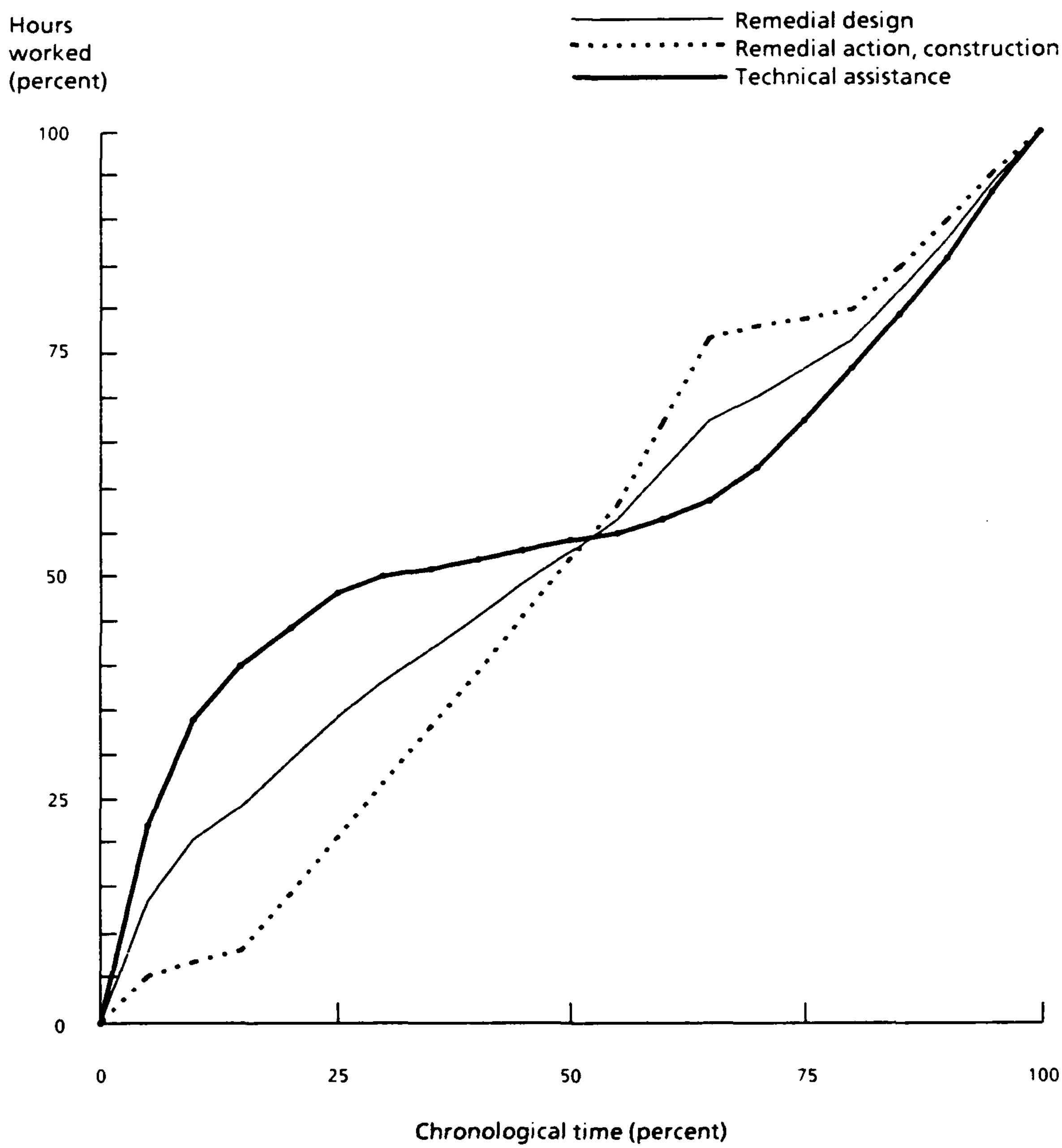

FIG. 2-1. WORK HOURS VERSUS CHRONOLOGICAL TIME

TABLE 2-3

SUPERFUND SPREADING FACTORS

Program year	Remedial design	Remedial action	Technical assistance
N	30.1%	49.3%	51.8%
N + 1	36.5	41.5	31.0
N + 2	20.6	7.5	9.2
N + 3	9.7	1.2	5.6
N + 4	3.1	0.5	2.4
Total	100%	100%	100%

we know *a priori*, for example, that in-house design should require more staff hours than the supervision of design contracted out. Nevertheless, the statistical measures of significance for our small samples show the measured coefficients to be statistically significant.

Workload was measured as program amount for design and as contract amount for construction. In all cases, we corrected the dollar amounts to FY90 constant dollars to maintain comparability between years. The basic linear regression equation was as follows:

$$\text{Hours} = c + a \times \text{Workload} + e$$

where:

Hours = the dependent variable, i.e., the quantity we want to predict,

c = a constant term that reflects the nonvariable portion of staffing per project,

a = the coefficient of workload, i.e., the weight attached to workload to predict staffing,

Workload = the independent or predictive variable,

e = an error term that accounts for random variation in staffing unaccounted for by workload.

The Superfund staffing model incorporates the results from a number of linear regression equations. Those results are shown in Table 2-4. In addition to the constant term and the coefficients, the table includes two measures of statistical significance – the t-statistic and R^2 – plus the sample size.

TABLE 2-4

REGRESSION RESULTS - DESIGN AND CONSTRUCTION STAFFING FACTORS

Work phase	Constant (hours/ project)	Coefficient (hours/ $ million)	t-statistic	R^2	Sample size
Design					
In house	0.0	2,561.79	8.6	90.3%	5
A-E	0.0	1,960.68	6.3	64.0	5
Construction					
100% complete	0.0	1,458.01	9.7	71.7	12
Current	0.0	1,940.72	7.7	66.8	18

Note: A-E = architect-engineer, i.e., supervision of design work contracted out.

The t-statistic is a statistical indicator that tests for the hypothesis that the coefficient is significant, that is, the coefficient is nonzero. If it is greater than 2, then it is at least 95 percent likely that the variable is not zero. As Table 2-4 shows, all of the t-statistics exceed 2. (The t-statistic is the ratio of the coefficient to its standard error, which is a measure of the statistical variability of that coefficient.)

The R^2 is that fraction of the variance of the dependent variable that is explained by the independent variable. In terms of our model, it is the fraction of staffing explained by the dollar workload (for each particular type of project). Even though the lowest R^2 is 64 percent, each equation predicts staffing for a single project only. When a large number of projects are combined, as in the Superfund program, the equations are summed and the variance around a single project becomes far less important. In mathematical terms, the error term (e) is random; although the error term for one particular project has the potential to be quite large, the sum of all the error terms tends to become smaller as more and more projects are summed, since the individual errors cancel each other out.

The R^2 does indicate, however, that other factors in addition to just program dollars influence staffing. That finding is not unexpected. More data may allow us eventually to split the work types into smaller subdivisions and increase the predictability of each equation. But it is also likely that the R^2 will not increase materially. It is simply true that many factors influence staffing and not all of those factors can be built into a practical model. The coefficients, however, are an unbiased estimator of staffing and on average, given enough projects, should provide forecasts that are effective for planning purposes, particularly at the headquarters level.

The measures of statistical significance show that the estimated coefficients are reasonable predictors. However, the sample sizes were very small in all cases; ideally, the sample sizes should exceed about 20 for each linear equation. The sample size requirements are based on the central limit theorem as applied to regression equations. Nevertheless, the model should suffice as a prototype, although there is an obvious need to collect more data in the future in order to expand the sample sizes and to confirm and recalibrate the relationships.

In all cases, linear regressions were calculated for an unconstrained constant, as well as a constant constrained to zero. In each case, the equation with a zero constant term exhibited the best significance indicators and so it was adopted for the staffing model.

We explored the effects of economies of scale by trying nonlinear terms – including both logarithmic and squared terms – in the regression equation. However, the statistical indicators did not show those additional nonlinear terms to be significant.

We estimated two regression equations for Superfund construction, or remedial action, work. The first equation, labeled "100% complete" in Table 2-4, represents all of the completed projects for which historic data were available. The other equation represents the incomplete, or "Current," projects. Total hours were calculated for that set of projects by adjusting for percent complete.[2] The current projects, so adjusted, indicate higher staffing requirements per dollar. While the difference may be due to the small sample sizes in both cases, or to inaccuracies resulting from the adjustment of hours, it is also conceivable that hours per dollar have increased due to an increase in cost-plus contracting. Again, while the results are acceptable for use

[2]We also adjusted incomplete design project hours, but the results were statistically poor.

in the prototype staffing model, the equation needs to be refined with additional data in the future.

TECHNICAL ASSISTANCE

The third category of Superfund work is technical assistance, which, like engineering not related to construction, is not directly tied to program dollars. Therefore, it is not possible to derive a relationship between project dollars and staff hours. Instead, we found that average hours per project type was a good predictor.

As shown in Table 2-5, we found that staff hours expended on such projects differed by the type of work. That is, feasibility studies clustered around an average of 281 hours, while hazardous waste enforcement support clustered about an average of 1,147 hours. Given the limitations of sample size, both appeared to be normal distributions with relatively low variances, for which the average is the unbiased estimator. Almost no data exist for any other types of technical assistance work.

TABLE 2-5

TECHNICAL ASSISTANCE – AVERAGE HOURS WORKED

Project types	AMPRS codes	Average hours	Standard deviation	Sample size
Feasibility studies	922	281.00	116.03	16
Hazardous waste enforcement support	923	1,147.29	679.58	7
All technical assistance	All	532.17	547.29	24[a]

Note: AMPRS = Automated Management Project Reporting System.

[a] Includes all projects in codes 922 and 923, plus one project code 926, ***Remedial Investigation/Feasibility Study***.

The model, therefore, forecasts staffing for technical assistance projects based on average hours for the type of work. For technical assistance projects other than feasibility studies and hazardous waste enforcement, the prototype model uses the average staff hours for all technical assistance projects.

THE STAFFING MODEL

The staffing model takes design program amounts, construction contract amounts, and the number of technical assistance projects as its primary inputs. All inputs are split into different project types, such as remedial response and emergency response, whether or not we were able to develop different factors for those splits. That makes it easier to modify the model's predictive factors in the future as well as making it easier to audit and to modify the model inputs. An additional input is the percent of design work that is accomplished in house versus work done by architects-engineers and supervised by USACE. Other inputs include the number of work hours per year for converting staff hours into work years.

The model first spreads the program inputs, whether dollars or numbers of projects, into multiple years before applying the regression factors (or average hour factors) to determine staff hours. The model converts all dollar amounts, input as then-year dollars, into 1990 constant dollars to preserve the original regression relationships. The coefficient for each project type is multiplied times the workload after spreading. In addition, the model multiplies the constant times the number of projects since the constant was determined for a single project.[3] The model estimates the number of projects per year by dividing the workload measure by the average project dollar size (shown in Table 2-6). The number of technical assistance projects, of course, is a direct input.

TABLE 2-6

AVERAGE PROJECT DOLLAR SIZES

Work phase	Average ($ million)	Standard deviation	Sample size
Design			
In house	1.202	1.112	6
A-E	1.366	0.886	28
All	1.337	0.932	34
Construction			
100% complete	4.781	6.931	16
Current	16.344	15.257	22
All	11.475	13.696	38

[3]Although the constant terms in the prototype model are all zero, the model retains this calculation in the event that future data produce nonzero constants.

Placement is estimated by taking a percentage of program amount, after spreading. This is displayed as a model output and is also used as an input to the calculation of division and district overhead. The model outputs staffing in work years and placement in dollars, after reconverting from 1990 constant dollars into then-year dollars.

The model also estimates the number of work years of division and district support required for the Superfund program. Since it was not possible to measure those hours directly, we adopted the overhead factors used in the Corps of Engineers Resource and Military Manpower System (CERAMMS). We assume that the CERAMMS factors – which are based on design and construction placement – reflect efficient management and will not differ significantly based on the specific type of design or construction. The constant terms in the CERAMMS division and district overhead equations were set to zero, however, since additional Superfund work (or any other type of work) will add only to the variable portion. The factors are shown in Table 2-7.

TABLE 2-7

DIVISION AND DISTRICT STAFFING FACTORS

Placement type	Variable factors (hours/$ million)	
	Division	District
Design	0.00	765.25
Construction	296.32	422.12
Other	0.00	0.00

CHAPTER 3

CONCLUSIONS AND RECOMMENDATIONS

The Logistics Management Institute has built other models that forecast staffing needs for USACE's military programs and for the Defense Environmental Restoration Program. Based on this experience, we have found, first, that historical data are a reasonable guide to future behavior. Relationships based upon these data can be modified to reflect process changes and efficiency improvements, when appropriate. We have also found that, although a great many factors affect staffing levels to some extent, the two most important factors are total dollars and project type or complexity.

The U.S. Environmental Protection Agency's Superfund efforts are relatively new and USACE's assistance to EPA started in 1983. For this reason, the small amount of project data limited our ability to analyze the data for relationships between staffing and a wide variety of factors. However, our previous experience had shown that dollars and project type were overwhelmingly the most important predictive factors for staffing.

While our statistical indicators confirm that dollars and project type are good predictors for Superfund work as well, the relatively small sample sizes mean that we have less confidence in the specific values of the coefficients that we derived for those predictive factors. If future projects continue to be similar in nature and labor-intensity to our sample of completed past projects, then the coefficients will accurately predict future staffing requirements. If, however, those past projects do not constitute a truly random sample of "typical" USACE Superfund work – they are all uncharacteristically labor-intensive, for example – then the resulting forecasts may be too high (if the opposite, then the forecast will be too low).

One indicator that the Civil Works' Superfund coefficients are not too wide of the mark is that they are of the same order of magnitude as the coefficients derived from very large sample sizes (and subsequently validated) for various types of USACE military work. For example, the supervision of military construction work for the Army requires about 1,700 hours per million dollars compared to our coefficients for Superfund construction work of between 1,460 and 1,940 hours per million dollars.

We conclude that the USACE Environmental Restoration Division can use the prototype Superfund staffing model to produce rough planning estimates and we recommend that it be used for that purpose. The divisions can also use this model to forecast their own staffing needs, but they must keep in mind that the model's results will display greater variation at the division level than at the USACE level. As the number of projects handled by each division grows, the individual variation among projects will become less important and, therefore, division forecasts will become more precise.

In addition, we strongly recommend that USACE gather more Superfund project data as additional projects are completed. USACE should use the larger sample sizes that result to rerun the statistical analyses and to refine the prototype Superfund model.

The data that USACE will collect should include spreading information for each project: start dates, percent complete, and the expected or actual completion date. In addition, USACE needs data on staffing and dollar amounts for total *actual* staff hours to date, program amount, and contract amount. To be useful, all of the data must be project-specific and must be identified by project type. We recommend identifying project types using the Automated Management Project Reporting System appropriation codes 91x through 95x (category 9, classes 1 through 5). Table 3-1 details the data required for further statistical analysis. USACE can also gather data to examine additional staffing factors if the sample sizes increase significantly.

We recommend that USACE gather the project data at the same time that it collects the input data for the staffing model, probably annually.

TABLE 3-1

DATA NEEDED FOR FUTURE STATISTICAL ANALYSIS

Data type
All project types
Project type (appropriation code)
Project name
Project number
Start date
Completion date (expected/actual)
Percent of work complete
Total actual staff hours to date
Design projects
Program amount ($ million)
Construction projects
Contract amount ($ million)
Cost-plus contracting (Y/N?)

APPENDIX A

CALCULATING SPREADING FACTORS

In Chapter 2, we stated that the model spreading factors were developed from two distributions – start dates and project durations – and a relationship – chronological time versus work hours. In this appendix, we outline the calculation that takes those distributions and that relationship as inputs and produces the summary spreading factors used in the model as outputs. The calculation of spreading factors is *not* part of the staffing model; it is part of the analysis that created the model.[1] The final model needs to incorporate only the summary spreading factors.

PREPARING THE MATRICES

The spreading calculation employs matrix multiplication to combine the various pieces of spreading data. The first two matrices, illustrated in Tables A-1 and A-2, are generic duration versus year matrices; that is, they contain the same values regardless of project type. Matrix 1 (Table A-1) simply holds the number of chronological months per fiscal year for projects that take from 1 month through 60 months to complete. For example, any projects that can be completed in a single month, if started in October, will be fully completed within the current fiscal year, while all projects that take 60 months to complete will carry over into 6 fiscal years, even if started in October, the first month of the fiscal year. Matrix 2 (Table A-2) recasts the data from matrix 1 into *cumulative* percents per fiscal year.

Matrix 3 (Table A-3) is the first to incorporate project-type-specific data. That matrix converts the cumulative chronological percents from matrix 2 into cumulative work-hour percents using the relationship between chronological time and work hours shown in Figure 2-1. Our example uses the relationship for construction. Matrix 4 (Table A-4) converts the cumulative percent work hours from matrix 3 into percent work hours per year in preparation for the next matrix multiplication.

[1]The spreading calculations are incorporated in a Lotus 1-2-3 spreadsheet – SPREAD.WK1 – that is available for model maintenance.

TABLE A-1

MATRIX 1. MONTHS PER YEAR; PROJECTS STARTED IN OCTOBER

Duration (months)	Year					
	N	N + 1	N + 2	N + 3	N + 4	N + 5
1	1.0	0.0	0.0	0.0	0.0	0.0
. . .						
60	11.5	12.0	12.0	12.0	12.0	0.5

TABLE A-2

MATRIX 2. CUMULATIVE PERCENT TIME PER YEAR; PROJECTS STARTED IN OCTOBER

Duration (months)	Year					
	N	N + 1	N + 2	N + 3	N + 4	N + 5
1	100	0	0	0	0	0
. . .						
60	19	39	59	79	99	100

TABLE A-3

MATRIX 3. CUMULATIVE PERCENT WORK HOURS COMPLETED PER YEAR; PROJECTS STARTED IN OCTOBER

Duration (months)	Year					
	N	N + 1	N + 2	N + 3	N + 4	N + 5
1	100	0	0	0	0	0
. . .						
60	8	33	58	79	95	100

TABLE A-4

MATRIX 4. PERCENT WORK HOURS PER YEAR; PROJECTS STARTED IN OCTOBER

Duration (months)	Year					
	N	N + 1	N + 2	N + 3	N + 4	N + 5
1	100	0	0	0	0	0
.						
.						
.						
60	8	25	25	21	16	5

MATRIX MULTIPLICATION

Matrix 5 (Table A-5) is a one-dimensional matrix in which the single row represents the percent of total projects completed and the 60 columns represent the number of months to complete (from 1 to 60) for remedial construction. Those data are project-type specific (see Table 2-2). We multiply matrix 4 (rows = the number of months; columns = years) by matrix 5 to produce matrix 6 (Table A-6), the spreading factors for construction projects that begin in a certain month (October, in our example).

TABLE A-5

MATRIX 5. PROJECT DURATION DISTRIBUTION

Factor	Duration (months)				
	1	2	. . .	59	60
Percent	6.7	0.0		0.0	0.0

The preceding calculations are repeated for all of the remaining months of the fiscal year, November through September, resulting in 12 versions of matrix 6, one for each month. Those matrices are combined to create matrix 8 (Table A-8), which represents the spreading factors for all months in which projects can be started.

TABLE A-6

MATRIX 6. PROJECT SPREADING FACTORS FOR OCTOBER START DATE

Start date	Percent per year					
	N	N + 1	N + 2	N + 3	N + 4	N + 5
October	74.2	12.4	7.6	4.5	1.2	0.1

Finally, matrix 7 (Table A-7), the distribution of start dates (see Table 2-1), is multiplied by matrix 8 to produce the overall spreading factors shown in Table A-9. Those factors will remain valid as long as the mix of short, medium, and long projects remains roughly the same; as long as start dates remain roughly equally spread throughout the fiscal year; and as long as the relationship between time and work does not change significantly. The spreading factors are independent of the relationship between dollars (or any other predictive factor) and work hours.

TABLE A-7

MATRIX 7. START-DATE DISTRIBUTION

Factor	Start date				
	October	November	. . .	August	September
Percent	8.5	8.2		8.5	8.2

The values in Table A-9 – the calculated spreading factors – differ slightly from those shown in Table 2-3, which shows the final spreading factors used in the model. We eliminated the small percentage in year N + 5 for practical reasons; adding that extra year simply increases the work required to input data without adding appreciably to the accuracy of the forecast. In all cases, the calculations resulted in an extremely small percentage of work hours falling in the year N + 5. Including that value in the model would require users to gather an extra year's worth of input data. However, that final percentage is so low (less than 1 percent in all

TABLE A-8

MATRIX 8. PROJECT SPREADING FACTORS FOR ALL START DATES

Start date	Percent per year					
	N	N + 1	N + 2	N + 3	N + 4	N + 5
October	74.2	12.4	7.6	4.5	1.2	0.1
.						
.						
.						
September	8.9	67.6	11.4	5.6	4.1	1.2

cases), that the effect on the staffing forecast, even supposing a huge year-to-year program swing, is negligible.

TABLE A-9

MATRIX 9. SPREADING FACTORS: CONSTRUCTION

Work hours per year	Year					
	N	N + 1	N + 2	N + 3	N + 4	N + 5
Percent	51.4	30.8	9.2	5.6	2.4	0.6

APPENDIX B

REGRESSION ANALYSIS RESULTS

In this appendix, we present details of our regression analysis of workload versus staff hours. Table B-1 displays the resulting coefficients with two summary indicators of statistical validity. A t-statistic greater than 2 indicates a greater than 95 percent chance that the predictive coefficient is nonzero; that is, it indicates that the independent variable – workload – is related to the dependent variable – hours. R^2 measures the portion of staffing that workload is able to explain. All of the regression coefficients refer to a single project.

TABLE B-1

REGRESSION RESULTS: DESIGN AND CONSTRUCTION STAFFING FACTORS

Work phase	Constant (hours/ project)	Coefficient (hours/ $ million)	t-statistic	R^2	Sample size
Design					
In house	0.0	2,561.79	8.6	90.3%	5
A-E	0.0	1,960.68	6.3	64.0	5
Construction					
100% complete	0.0	1,458.01	9.7	71.7	12
Current	0.0	1,940.72	7.7	66.8	18

Note: A-E = architect-engineer, i.e., supervision of design work contracted out

Figures B-1 through B-4 present the raw data and the resulting regression equations in graphic form. In each case, the dots represent actual projects, while the line represents the fitted regression equation. As the illustrations show, all of the equations have a constant term of zero. While the t-statistic and R^2 are reasonable (particularly since the equations refer to a singular project, and we are forecasting staffing for multiple projects), the samples are very small. We collected data for many more projects than shown, but were unable to use all of thaւ data because either hours or dollars were unavailable, or else the projects were still incomplete.

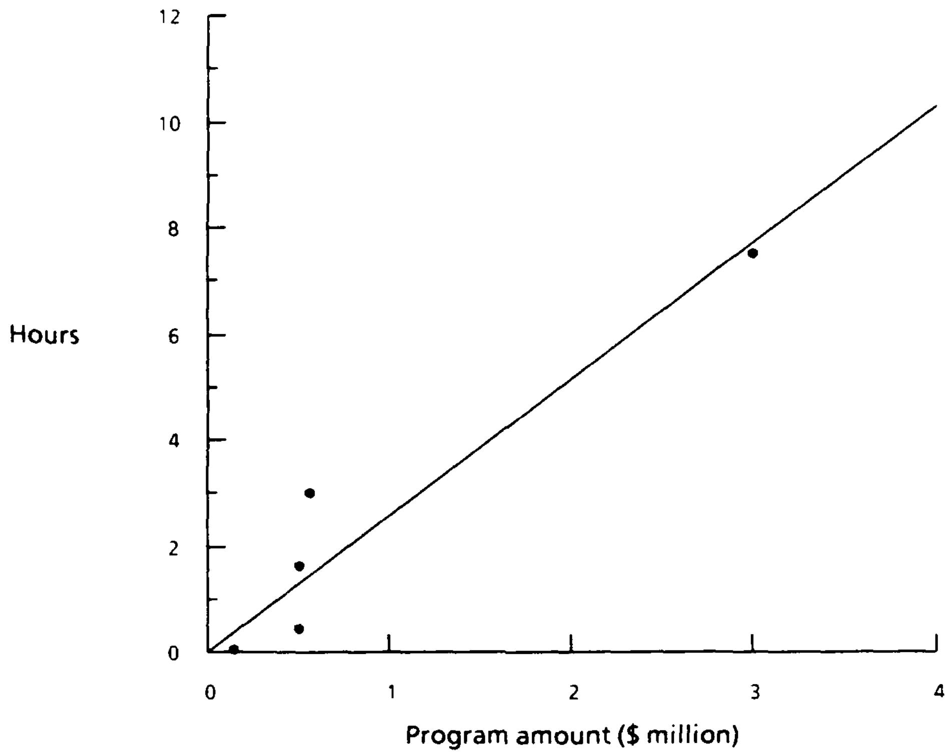

FIG. B-1. COMPLETED DESIGN PROJECTS: IN HOUSE

As the number of projects increase, the reliability of the forecast resulting from those regression equations will tend to increase because the error terms – the difference between predicted staffing and actual staffing for *each* project – tend to offset each other. Tables B-2 and B-3 illustrate that phenomenon. By simulating a set of 50 projects with variability similar to our actual project data, we have shown that a collection of only about 30 projects can reduce the difference between the actual and predicted staff hours to about 3 percent.

For our example, we have chosen design supervision of architect-engineer (A-E) firms, the regression equation which has the lowest R^2 and the smallest samples. To see how the forecasting model is likely to behave in practice, we simulated 50 observations by generating random program amounts between zero dollars and $3 million. We calculated our predicted staff hours by multiplying those simulated program amounts times the regression coefficient. The error terms were also

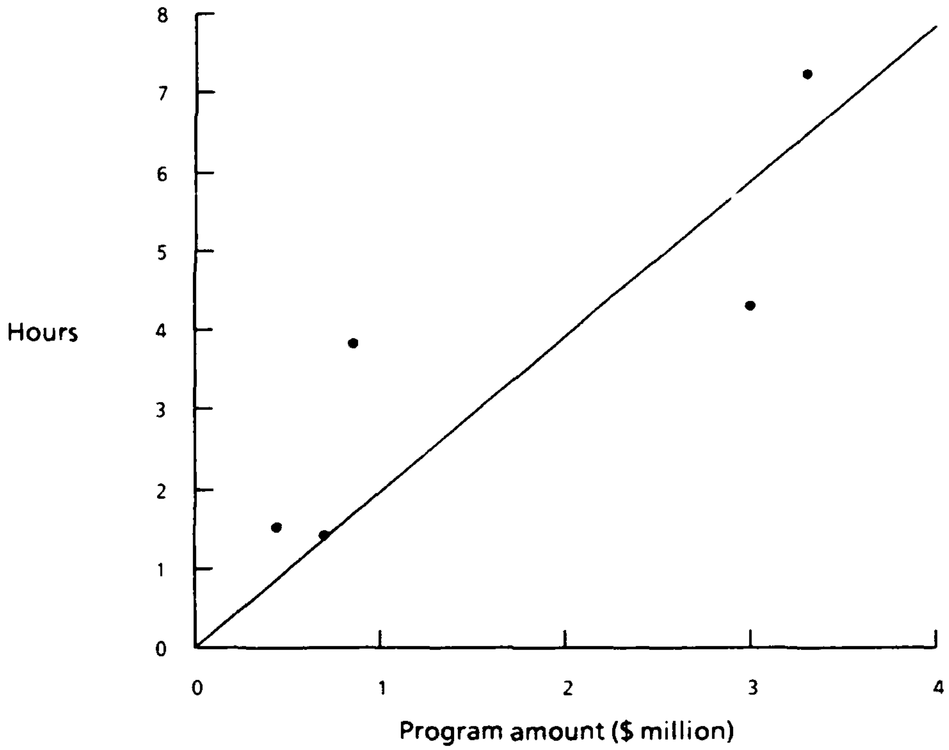

FIG. B-2. COMPLETED DESIGN PROJECTS: A-E SUPERVISION

simulated by multiplying a random error term (between 0.0 and 1.0) times twice the standard deviation of the actual errors.[1] The resulting statistics (shown in Table B-2) of the 50 simulated error terms display similar variation to the actual set of five samples. (In fact, the error terms in the sample set are slightly more dispersed than the actual error terms.)

Table B-3 illustrates what happens when we compare forecast staff hours against "actual" staff hours taking different sample sizes from the total of 50 simulated projects. The table displays the change in the percent difference between the predicted total staffing and the "actual" total staffing as the number of "projects" increases. For small numbers of projects, the difference moves about randomly and can be relatively high, but in our particular example, it falls to 2.6 percent at 30 projects and stays relatively low thereafter.

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[1]There is a 95 percent chance that an observation will fall within two standard deviations of the mean, assuming a normal distribution.

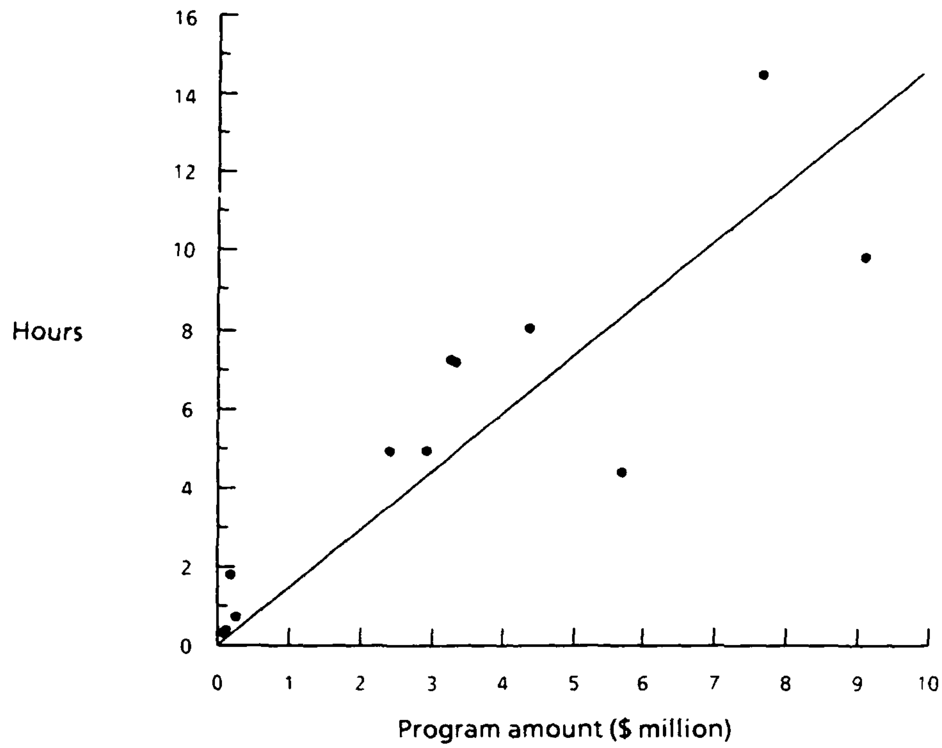

FIG. B-3. COMPLETED CONSTRUCTION PROJECTS

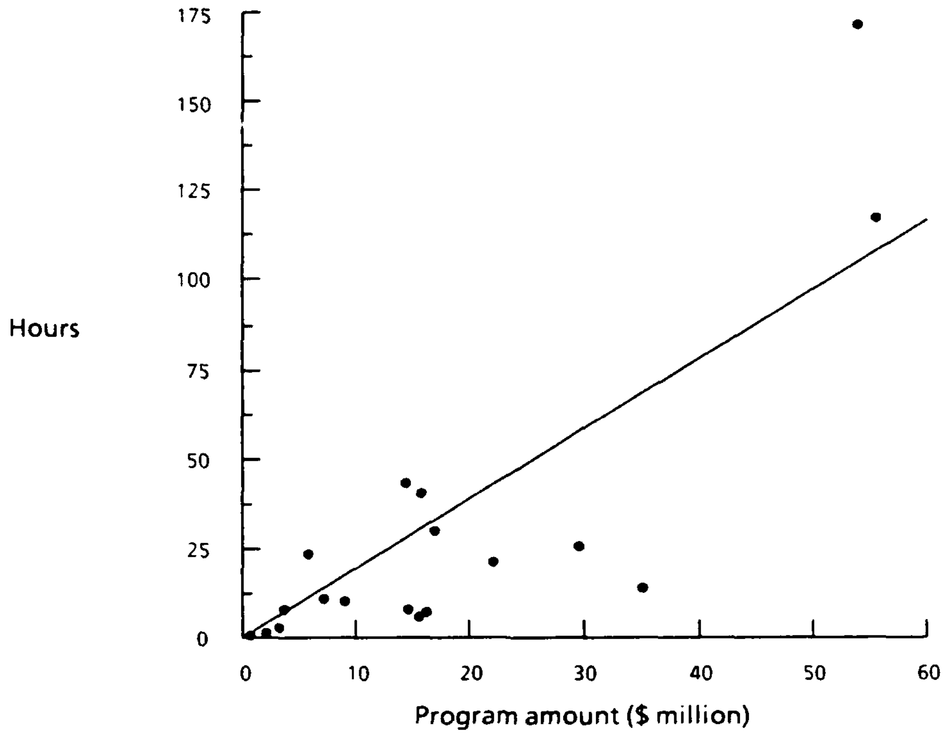

FIG. B-4. CURRENT CONSTRUCTION PROJECTS

TABLE B-2

A-E DESIGN PROJECTS: SIMULATED VERSUS ACTUAL OBSERVATIONS

	Simulated errors	Actual errors
Sample size	50	5
Hours		
Average	30	414[a]
Standard deviation	1,325	1,218
Maximum	2,348	2,173
Minimum	(2,271)	(1,585)

Note: Errors are the difference between actual hours worked and forecast hours for a single project

[a] If we did not constrain the constant term of the regression equation to zero, the average of the errors would equal zero by definition

TABLE B-3

A-E DESIGN PROJECTS: PREDICTED VERSUS ACTUAL TOTAL HOURS

Number of projects	Percent difference	
	Simulated errors	Actual errors
5	7.3	11.3
10	5.9	–
15	9.1	–
20	14.5	–
25	10.7	–
30	2.6	–
35	2.3	–
40	3.8	–
45	3.2	–
50	3.2	–

Note: The percentages represent the absolute difference between actual total hours and predicted total hours, divided by predicted total hours

REPORT DOCUMENTATION PAGE

Form Approved
OPM No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
February 1991

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Forecasting Staffing Requirements for Hazardous Waste Cleanup

5. FUNDING NUMBERS
C DACW31-90-D-0076

6. AUTHOR(S)
Robert W. Salthouse

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Logistics Management Institute
6400 Goldsboro Road
Bethesda, MD 20817-5886

8. PERFORMING ORGANIZATION REPORT NUMBER
LMI–CE004R1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Colonel Wayne S. Scholl
Acting Chief of Environmental Restoration Division
U.S. Army Corps of Engineers, Pulaski Building
Washington, DC 20314

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
A: Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Directorate of Civil Works of USACE needs to be able to forecast the staffing levels required to supervise contractor cleanups of hazardous waste sites in support of the U.S. EPA. The USACE must report environmental staffing needs to OMB.

We have developed a Civil Works' Superfund staffing requirements model based on statistical analysis of historic workload data, on the assumption that the size and complexity of future programs will be related to the size and complexity of past programs. We found that the two most important factors affecting staffing levels are total cost and project type or complexity. By dividing the Corps' programs into different types of work, we can reliably relate dollars spent to hours worked. The three types of work we use in our model are remedial design, supervision of remedial construction, and additional technical assistance to the EPA.

The functional relationship between time spent and work accomplished and distributions are embodied in a computer program – the Superfund staffing model – that takes multiyear program dollars as its primary input and produces multiyear forecasts of staffing levels and costs as its primary outputs.

We recommend that the Environmental Restoration Division of USACE use this prototype model for Superfund planning. Because the Superfund program is new, a small volume of historical project data is in the model. We recommend that the prototype model be used with caution. We also recommend that USACE collect additional project data annually from its divisions and districts at the same time that it collects the annual inputs for the staffing model. More project data will enable USACE to make future refinements to the prototype model.

14. SUBJECT TERMS
Manpower Modeling, Hazardous Waste, Resource Allocation

15. NUMBER OF PAGES
42

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	18. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL