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Chapter Author: Maynard M. Hufschmidt, Jacques Gerin

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SYSTEMATIC ERRORS IN COST ESTIMATES FOR PUBLIC INVESTMENT PROJECTS

MAYNARD M. HUFSCHMIDT
University of North Carolina at Chapel Hill
AND
JACQUES GERIN
Consulting Engineer and Planner, Montreal, Canada

Introduction

This paper deals with one aspect of uncertainty in public investment on which very little research has been done—the extent, nature, and causes of error in estimating costs of public investment projects. Although there is general agreement among public investment specialists that cost estimates for project proposals typically fall short of actual costs of projects when completed, this view is based upon fragmentary information, often obtained from superficial comparison of project or program documents and reports.[1]

There is no over-all reporting of cost experience for federal public works; some reports of individual agency experience do exist, but much of the information lies unassembled and unanalyzed in federal, state, and local agency files. More significant for our purpose, even the

NOTE. Special thanks are due to the following for providing information and valuable comments and suggestions on the subject of this paper: G. P. Palo, Manager of Engineering Design and Construction, and members of his staff, Tennessee Valley Authority; Wendell E. Johnson, Chief, Engineering Division, Civil Works, Corps of Engineers, Department of the Army; Harry Shooshan, Deputy Undersecretary for Programs, U.S. Department of the Interior, and Blair Bower, Resources for the Future, Inc.

[1] Cost as used throughout this paper is defined as the money cost of construction and installation of capital facilities of a public works project; it excludes operation, maintenance and replacement costs. The definition does not include opportunity cost considerations. This definition excludes interest during construction (except where otherwise noted) and, with this exception, corresponds to the capital cost information collected by federal water-resource agencies and used as inputs to benefit-cost analyses.

readily available information has not been analyzed in terms of the extent, nature, and probable causes of difference between original estimates and final realized costs.

This paper makes only a small sortie into this largely unexplored field. Time and resources restricted the search to only one sector of U.S. federal investment—water-resource investment, by the Army Corps of Engineers, Tennessee Valley Authority and Bureau of Reclamation. The restricted scope of this study limits our ability to make generalizations. It also points to the need for much additional research on this aspect of public investment.

Extent of Previous Research

Our admittedly sketchy search of sources revealed very little published work on the cost question. This is true even in the field of water-resource investment, which has an extensive literature on benefit-cost analysis. For example, of six major books on water-resource economics,[2] only Eckstein's (1958) gives more than cursory attention to this question, and his discussion is limited to Corps of Engineers cost experience prior to 1951.[3] Altouney made a limited analysis (1963) of Bureau of Reclamation experience based on data collected by the Bureau in 1955.[4] Two of the most useful studies were concerned with cost experience overseas. Healey analyzed 13 water control projects built in India during the period 1946–60,[5] while a Select Committee on Nationalized Industries in Great Britain studied the cost experience of the North of Scotland Hydro-Electric Board in constructing twenty-four hydroelectric power plants.[6] A statistical study by two French

[2] Otto Eckstein, *Water-Resource Development: The Economics of Project Evaluation*, Cambridge, 1958; Roland McKean, *Efficiency in Government Through Systems Analysis, with Emphasis on Water Resources Development*, New York, 1958; John Krutilla and Otto Eckstein, *Multiple Purpose River Development, Studies in Applied Economic Analysis*, Baltimore, 1958; Jack Hirshleifer, James C. De Haven, and Jerome W. Milliman, *Water Supply: Economics, Technology and Policy*, Chicago, 1960; Arthur Maass *et al.*, *Design of Water Resource Systems*, Cambridge, Mass., 1962; Robert H. Haveman, *Water Resource Investment and the Public Interest*, Nashville, 1965.

[3] Eckstein, pp. 149–151.

[4] Edward G. Altouney, *The Role of Uncertainties in the Economic Evaluation of Water Resources Projects*, Institute in Engineering-Economic Systems, Stanford University, 1963.

[5] J. M. Healey, "Errors in Project Cost Estimates," *Indian Economic Journal*, Vol. 12, July–September 1964.

[6] Select Committee on Nationalized Industries, *Report to the House of Commons*, Session Documents, Vol. 7, No. 304, 1956–57, London, H.M.S.O., 1957;

engineers of bias toward cost underestimation rounds out the list.[7] Details on these studies are provided later in the paper.

Scope and Nature of the Analysis

The analysis contained in this paper deals with the cost experience of the three largest United States water-resource construction agencies—the Army Corps of Engineers, Bureau of Reclamation and TVA—from 1933 to the early 1960's. Data on cost experience of the Corps of Engineers were obtained from (1) an analysis made by the Corps in 1951 for the House Committee on Appropriations,[8] and (2) a followup survey by the Corps in 1965.[9] Similarly, Bureau of Reclamation cost experience data came from studies made by the Bureau in 1955 and 1960.[10] Information on TVA experience was provided by the TVA staff.[11]

As an introduction to the analysis, a number of commonly held notions on the occurrence of and reasons for systematic errors are introduced. The actual experience of the three U.S. water-resource agencies is then examined in detail, and the findings are analyzed in terms of the preconceptions or hypotheses which had been advanced

and *Report to the House of Commons on the Electricity Supply Industry*, Session Papers, Vol. 7, No. 116, 1961–62, London, H.M.S.O., 1962.

[7] R. Giguet and G. Morlat, "Les Causes d'erreur systématique dans la prévision du prix des travaux," *Annales des Ponts et Chaussées*, Paris, 122e Année, No. 5, September–October 1952.

Robert Haveman reports (July 1968) that he and Terrell Langworthy have completed a study of cost experience on 86 Corps of Engineers water-resource projects for which construction was started in fiscal year 1956.

[8] U.S. Army, *Annual Report of the Chief of Engineers*, 1951, Part 1, Vol. 3; U.S. Congress, *Investigation of Corps of Engineers, Civil Works Program, Hearings* before and *Report* of the Subcommittee on Deficiencies and Army Civil Functions, Committee on Appropriations, House of Representatives, 82nd Congress, 1st Session, August 1951; U.S. Congress, *The Civil Functions Program of the Corps of Engineers, Report* to the Committee on Public Works from the Subcommittee to Study Civil Works, House of Representatives, 82nd Congress, 2nd Session, December 1952.

[9] Office of the Chief of Engineers, Headquarters, Department of the Army, "Engineering and Design, Project Cost Estimating-Civil Works," Engineer-Circular No. 1110-2-1301, February 3, 1965. A large amount of detailed data not contained in the Circular was provided by Mr. Wendell E. Johnson, Chief, Engineering Division, Civil Works, Office of the Chief of Engineers.

[10] U.S. Bureau of Reclamation, "Analysis of Reclamation Projects," October 1955, cited in Altouney, *op. cit.*; "Analysis of Reclamation Projects," March 1960.

[11] Internal TVA document entitled "Comparison of Estimates with Final Costs: Major Multipurpose and Single-use Projects Constructed by TVA," November 15, 1967, plus supporting materials provided by TVA staff.

earlier. A brief review of information of British, Indian, and French experience is presented. Finally, certain tentative conclusions are advanced and recommendations made for further research on this neglected subject.

Perception of Errors in Cost Estimates

The view most commonly advanced by the expert and the informed layman is that costs of public works projects are consistently underestimated at the time the decision is taken to build the project. Associated with this view is the belief that the variance between estimated and actual costs is often extremely high. Much evidence on specific cases is available to support this view: the Rayburn Office Building on Capitol Hill and the Interstate Highway Program are dramatic examples of this. The reader probably can supply many examples from his own experience.

The following are the major reasons advanced for variations between cost estimates and final realized costs:

1. Changes in general construction price level between that assumed in the project cost estimate and that prevailing during construction of the project.
2. Changes in the size and scope of project between original estimate and final design and construction.
3. Structural modifications and changes in design standards from those assumed at time of original estimate.
4. Changes in the least-cost construction schedule assumed in the original estimate; for example, "speedup" as in World War II or stretch-out arising from budgetary constraints.
5. Occurrence of unforeseen events—strikes, floods—with important cost implications.
6. Inadequate information of certain physical characteristics with important cost implications; for example, insufficient knowledge of dam foundation conditions, including character of soils and rock.
7. Inadequate information on extent and nature of relocations and on land acquisition costs.
8. Unconscious bias toward underestimation of costs arising from estimaters' identification with agency goals for maintaining a construction program.
9. General inadequacies and poor performance in planning and estimating.

In the agency analyses of their cost experience, many of these reasons are often given as explanations of major differences between estimated and actual costs. Detailed analysis of estimated and realized costs for individual projects in the context of the history of design and construction of each project would be necessary to assess the contribution of these factors to cost increases or decreases. No such detailed analyses were made by us; rather, we relied on information provided in published reports or by the federal agencies.

The Cost Record of the U.S. Water Resource Agencies

In the following, the cost experiences of the Corps of Engineers, TVA, and Bureau of Reclamation are summarized and the distribution of "errors" in the three agency programs are compared. Details of the analyses are shown in the text tables and in the Appendix.

Corps of Engineers Experience

A 1951 study made by the Corps at the request of the House Appropriations Committee revealed that the 182 rivers and harbors and flood control projects then current showed a total cost overrun of 124 per cent of the original estimates.[12] The 1951 estimate of cost for these projects was $5.9 billion as compared with the original project estimates totaling $2.6 billion. Because original cost estimates for most of these projects were made in the 1930's, it was to be expected that price increase would account for much of this overrun. In the analysis the Corps explained the overruns as follows: construction price increase, 57.7 per cent; changes in project design, 24.7 per cent; extensions in project scope, 17.6 per cent; changes in local needs and unforeseen conditions, 12.6 per cent; and inadequacies in planning and estimating, 5.8 per cent.

This record of performance came under criticism by the House Appropriations Committee in 1951, a subcommittee of the House Public Works Committee in 1952, and the Task Force on Water Resources and Power of the Second Hoover Commission in 1955. The House Appropriations Committee concluded that investment decisions made by Congress were based on grossly inaccurate cost data. Major reasons advanced by the Committee were the inadequacy

[12] A reminder: cost is defined throughout as construction or capital cost.

of the survey reports, which were too superficial to provide accurate cost information, and the large backlog of projects that imposed a time lag of many years between completion of original survey and start of construction. Thus, cost estimates for the original project were often drastically increased as local conditions changed, new demands arose, and engineering and structural design standards were modified.

These critics strongly recommended that the Corps improve its estimating procedures, curtail new authorizations until the backlog was reduced, and provide a detailed planning report, with refined cost data, at the time when requests were made for funds to start a project.

In 1964, the Corps of Engineers updated its survey of cost experience in an analysis of 184 projects completed during the period 1951–64 (technically, fiscal years 1951–65).[13] This survey revealed that total costs of $3.14 billion exceeded the original project estimates of $2.31 billion by 36.1 per cent. This represented a substantial improvement over the 124 per cent overrun in the 1951 survey. When the original cost estimates were adjusted to account for price changes between time of original estimate and time of actual construction, actual costs were 18.3 per cent less than escalated survey costs. This record is in sharp contrast to the 1951 record which showed actual costs to be 30 per cent greater than escalated survey costs.

Because many of the projects reported in the 1964 analysis had been originally surveyed before 1950, a separate analysis was made by us of sixty-eight projects for which the original survey had been made in 1954 or later. This analysis revealed that the total of actual cost and original estimated costs were less than 1 per cent apart; when price level adjustments were made, actual cost for the sixty-eight projects was 23 per cent below original estimated cost. These data clearly show that the Corps has significantly improved its performance since the early 1950's, when its cost estimating record first came under severe criticism by the Congress.

The Corps left to each of its districts the selection of the precise method for construction price level adjustments. Most districts used the *Engineering News-Record* construction cost index. A single national index is only a crude approximation of actual price changes operative for an individual project. When applied to projects with a long time lag between survey and completion, price index adjustments become very large. For example, *ENR* construction price index adjustments for projects with lags of fifteen to thirty-four years range from 100 per cent to 336 per cent above base-year levels. Such large

[13] Office of the Chief of Engineers, *op. cit.*

TABLE 1

CORPS OF ENGINEERS: SUMMARY OF ESTIMATING PERFORMANCE

	1951 Report	1964 Report		Total
		Old Projects	Recent Projects	
Period of record	to 1951	1933–53	1954–65	1933–65
Number of projects	182	116	68	184
Estimated cost, original survey (billions of dollars)	2.64	1.59	0.72	2.31
Escalated cost, original survey (billions of dollars)	4.53	2.91	0.94	3.85
Actual cost (billions of dollars)	5.91	2.42	0.72	3.14
Overruns (per cent of survey cost)				
Original survey cost	124.1	52.6	[a]	36.1
Escalated survey cost	30.6	−16.8[b]	−23.0[b]	−18.3[b]
Frequency of overruns (per cent of occurrence)				
Original survey cost	n.a.	84	51	72
Escalated survey cost	n.a.	34	29	32

IMPROVEMENT IN PERFORMANCE (CHANGE IN PER CENT OVERRUN)[c]

	Based on Original Survey Cost	Based on Escalated Survey Cost
1951 to 1964 (old)	57.6	145.0
1964 (old) to 1964 (recent)	100.0	37.0

n.a. = not available. [a] Less than 1 per cent underrun. [b] Underrun (actual cost less than estimate).

[c] Increase in size of underrun is here considered as an "improvement" for purposes of comparison (hence values in excess of 100 per cent). "Real improvements" should be measured as net reduction of error; thus present trends toward overestimation are not real improvements in accuracy.

price adjustments made with a crude index tend to distort the true relationship of price adjustment to other factors contributing to project overruns.

Corps of Engineers estimating performance is summarized in Table 1 below. The total overrun (or underrun) is shown as a per cent of original and escalated survey costs. In addition, the frequency of overruns as a per cent of total number of projects is shown, both for original and escalated survey costs.

The TVA Experience

The TVA has provided data on cost experience of thirty-four projects with costs in excess of $1 million. These projects, many of which were started during the 1930's, include twenty-three multiple-purpose dams and reservoirs, nine fossil fired electric generating plants, one flood protection project, and one water control system. Because many of the projects were built in stages, TVA provided data on sixty-one separate project units.

As shown in Table 2, the actual cost of the thirty-four projects ($2.33 billion) is $130 million below the original estimates of cost

TABLE 2

TENNESSEE VALLEY AUTHORITY
SUMMARY OF ESTIMATING PERFORMANCE

Period of record	1933–66
Number of projects	34
Number of separate estimates	61
Estimated costs (billions of dollars)	2.46[a]
Actual costs (billions of dollars)	2.33
Overrun (per cent of survey costs)	–5.3[b]
Frequency of overruns (per cent of occurrence)	
Independent projects	32.4
Separate estimates	34.4

[a] Wherever possible TVA includes projected price increases in its original estimate. Thus no separate escalated estimates are provided. Interest during construction included for some steam plant cost estimates and final costs. See Appendix Table 5.

[b] Underrun.

of $2.46 billion; this represents a total cost underrun of 5.3 per cent. Approximately one-third of the thirty-four projects, and, similarly, approximately one-third of the sixty-one project units, have experienced cost overruns. In terms of project type, none of the fourteen cost estimates for steam plant units has been less than final costs; total cost underrun for steam plants is 9.3 per cent. In contrast, 45 per cent of the estimates for dams and reservoirs have been less than final project costs; total overrun for this category is 21.7 per cent of estimated cost. Most of these overruns occurred on projects which were built or begun during World War II, when stoppages or accelerated construction was the rule.

Bureau of Reclamation Experience

In common with the Corps of Engineers, the Bureau of Reclamation performance on cost estimation came under critical scrutiny by Congress in 1955. The Bureau report of 1955 has been summarized and analyzed by Altouney, and the analysis of 1955 data presented here is derived from Appendix Table 5 in his report.[14]

Table 3 shows that, for the 103 projects in the 1955 survey, total estimated 1955 cost of $7.3 billion was 177 per cent above the original estimates of $2.6 billion, and almost double the escalated estimates ($3.7 billion) which reflect adjustments for construction price rises between times of original estimates and 1955. (The Bureau of Reclamation uses its own index of construction prices which reflects price changes in the major labor and material inputs to Reclamation projects.) Furthermore almost 90 per cent of all projects showed cost overruns from the original estimate, whether measured on nominal or escalated cost basis. In most cases, the 1955 costs were not final project costs, but were current cost estimates for projects not yet completed.

A subsequent review by the Bureau of Reclamation in 1960 showed a substantial improvement in performance over the 1955 record. Data in the report have been disaggregated to show performance on all projects (128) started between 1935 and 1960, a subset of seventy-nine projects over the same period which excludes units in the Missouri River Basin and Colorado River Storage Projects, and a subset of fifty-four projects surveyed and started since World War II. The seventy-nine projects exclusive of the MRBP and CRSP showed

[14] Altouney, *op. cit.*, pp. 102–105.

TABLE 3
BUREAU OF RECLAMATION: SUMMARY OF ESTIMATING PERFORMANCE

	1955 Report	1960 Report		
		All Projects	Exclusive of CRSP & MRBP[a]	Projects Since 1946
Period of record	to 1955	1935–60	1935–60	1946–60
Number of projects	103	128	79	54
Estimated cost: Original survey (billions of dollars)	2.64	3.78	2.51	1.32
Escalated cost: Original survey (billions of dollars)	3.72	4.36	3.02	1.50
Actual cost (billions of dollars)	7.29	6.49[b]	3.43[b]	1.44[b]
Overruns (per cent of survey cost)				
Original survey cost	177	72	36	9.4
Escalated survey cost	96	49	13	−4.1[c]
Frequency of overruns (per cent of occurrence)				
Original survey cost	89	75	67	52
Escalated survey cost	86	63	52	35

IMPROVEMENT IN PERFORMANCE (CHANGE IN PER CENT OVERRUN)

	Based on Original Survey Cost	Based on Escalated Survey Cost
1955 report to 1960, post-war projects	95	104[d]

[a] CRSP: Colorado River Storage Project. MRBP: Missouri River Basin Project.
[b] Includes estimate of final cost, as of March 1960, for projects not completed. [c] Underrun.
[d] Underrun is here considered an improvement, hence a value in excess of 100 per cent.

a total overrun of 36 per cent of original estimates, and 13 per cent of original estimates adjusted for price increases. The record for the fifty-four projects surveyed and started since World War II shows a total overrun of 9.4 per cent of original estimates, and an underrun of 4.1 per cent of escalated estimates. The 1960 study includes projects under construction as well as those finally completed. For example, in Table 3, of the seventy-nine projects exclusive of CRSP and MRBP, fourteen were not completed at the time of the study in 1960. Some of these were only at the beginning stage of construction. Similarly, of the fifty-four projects begun after World War II, six were not completed in 1960. Final costs for these projects may be considerably different than the 1960 estimates.

Comparison of Agency Performance

To aid in comparing agency performance on cost estimation, summary data for the three agencies are brought together in Table 4. In terms of both size and frequency of overrun, the TVA has the best record. TVA performance is best, even with the steam plants eliminated from the analysis. With no adjustments for construction price levels, TVA total overrun for dams and reservoirs is 22 per cent of original estimated cost; Corps of Engineers overrun is 124 per cent for projects built or building prior to 1951, and 36 per cent for projects completed between 1951 and 1964; while Bureau of Reclamation overrun is 177 per cent for projects built or building prior to 1955 and 72 per cent for all projects built or building in 1960. In terms of frequency of overruns, 45 per cent of TVA dams and reservoirs experienced overruns; the record for the Corps of Engineers is 72 per cent of all projects completed between 1951 and 1964, and, for the Bureau of Reclamation, 89 per cent of all projects built or building prior to 1955, and 75 per cent of all projects built or building in 1960.

The performance record of both the Corps of Engineers and Bureau of Reclamation is much better on projects for which surveys (and hence cost estimates) were made after World War II. For example, actual cost of sixty-eight Corps of Engineers projects surveyed, authorized and built between 1954 and 1964 was 0.2 per cent *below* estimated costs for the projects. For fifty-four Bureau of Reclamation projects surveyed, authorized and built or building between 1946 and 1960, actual costs were only 9.4 per cent above cost estimates. In the case of each agency, frequency of overruns was slightly over 50 per cent for postwar performance.

TABLE 4

COMPARISON OF AGENCY PERFORMANCE: MAGNITUDE AND FREQUENCY OF OVERRUNS, TVA, CORPS OF ENGINEERS, BUREAU OF RECLAMATION

	Number of Projects	Size of Total Overrun (per cent)		Frequency of Overruns (per cent)	
		From Original Estimate	From Escalated Estimate	From Original Estimate	From Escalated Estimate
TVA:					
Dams	25	21.7	[b]	45	[b]
Steam plants	9	−9.6[a]	[b]	0	[b]
Total	34	−5.3	[b]	34.4	[b]
Corps of Engineers:					
Flood control:					
1951 report	122	152.9	[c]	[c]	[c]
1964 report, all projects	103	58.5	−7.8	83	42
1964 report, recent projects	30	10.0	−14.3	73	47
Rivers and harbors:					
1951 report	60	99.6	[c]	[c]	[c]
1964 report, all projects	81	27.9	−22.3	58	20
1964 report, recent projects	38	−5.1	−27.2	34	16
Total:					
1951 report	182	124.1	30.6	[c]	[c]
1964 report, all projects	184	36.1	−18.3	72	32
1964 report, recent projects	68	−0.2	−23.0	51	29
Bureau of Reclamation:					
1955 report	103	177.0	96.0	89	86
1960 report, exclusive of CRSP & MRBP	79	36	13	67	52
1960 report, all projects	128	72	49	75	63
1960 report, postwar projects	54	9.4	−4.1	52	35

NOTE: See appendix tables. [a] Minus sign indicates underrun. [b] Not applicable. [c] Not available.

DISTRIBUTION OF ERRORS.[15] An analysis of distribution of errors was made for each agency program. The detailed distributions are shown in Appendix Figures 1 through 6. A summary of the means, modes, medians, standard deviations, and extreme values in terms of per cent of deviation of actual cost from estimated cost is contained in Table 5. Again, the TVA has the best record, with mean, mode and median errors showing underruns, and with a standard deviation of 17.5 per cent. In contrast, best performance of the Corps of Engineers, on projects surveyed and built between 1954 and 1964, shows mean and median errors as overruns and a relatively high standard deviation of 45 per cent. For Bureau of Reclamation projects at least 50 per cent complete by 1960, mean error was 25.8 per cent, median error, 3 per cent, and standard deviation 42 per cent.

Summary of Performance

In summary, the TVA program and recent Corps of Engineers experience (even with no construction price level adjustments for Corps projects) show no consistent bias toward underestimation of project costs. When construction price level adjustments are made for the most recent Bureau of Reclamation program, it too shows no bias toward underestimation. (This assumes that price level adjustments are approximately correct; some information on price adjustments is contained in Appendix Table 4.)

Whatever the measure used (magnitude or frequency of overrun, or distribution of errors), recent estimating performance of the Corps of Engineers and Bureau of Reclamation has improved significantly over performance before World War II and in the 1940's. For the Corps of Engineers, project cost estimates made since 1954 have been significantly better than previous estimates in that total cost overrun as per cent of total program cost has been reduced to 10 per cent without any adjustment for construction cost increases. This compares with a huge cost overrun of 124 per cent according to a 1951 survey of projects whose costs were estimated in the 1930's and 1940's. Similarly, the 9.4 per cent total cost overrun for Bureau of Reclamation projects surveyed since World War II shows a tremendous improvement over the 177 per cent cost overrun revealed in a 1955 survey for projects surveyed in the 1930's and 1940's.

[15] The term error as used here is any departure of estimated cost from actual cost.

TABLE 5

COMPARISON OF AGENCY PERFORMANCE:
DISTRIBUTION OF ESTIMATING ERRORS,
TVA, CORPS OF ENGINEERS AND BUREAU OF RECLAMATION

	Number of Projects	Mean (per cent)	Standard Deviation	Mode (per cent)	Median (per cent)	Maximum Overrun (per cent)	Maximum Underrun (per cent)
TVA (all projects)	61	−1.7	17.5	−5.0	−5.0	53	33
Corps of engineers:							
All projects, 1964 report, escalated estimate	182[a]	−6.18	43	−17.5	−17.5	198	70
Projects since 1954, original estimate	68	+10.66	45	−12.5	+3.4	216	57
Projects since 1954, escalated estimate	68	−9.48	33	−22.5	−14.0	120	70
Bureau of Reclamation, original estimate							
1955 report	103	+163.0	n.a.	+10.0	+100.0	1000	20
1960 report[b]	79	+27.4	58	0.0	+7.0	326	39
1960 report[c]	63	+25.8	42	0.0	+3.0	165	39

n.a. = Not applicable.

[a] Excluding two projects with overruns of 259 per cent and 656 per cent.

[b] All projects exclusive of Colorado River Storage Project and Missouri River Basin Project.

[c] Projects at least 50 per cent complete, excluding two projects with overruns of 251 per cent and 326 per cent.

Although the TVA record has been more consistent throughout the thirty-three-year period of its activity, there is some evidence that its recent cost estimating performance is better than its earlier record.

The Causes of Error

In the agency analysis of cost experience, the deviations of actual from estimated cost are ascribed to various factors, some of which are identical with the nine reasons advanced in the Introduction to this paper. These factors, which may be thought of as proximate causes of error, can be divided into exogenous factors, over which the agency has little or no control, and endogenous factors, which can be modified by improving agency administration.

Proximate Causes

In the Corps of Engineers 1951 survey, about 58 per cent of the $2.8 billion excess of actual over estimated cost was ascribed to price increases and another 22 per cent was traced to authorized project extensions or changed local needs (see Table 1 in the Appendix). These causes are largely exogenous; the agency has no control over general construction price increases, and increases in project size and scope are usually the result of demands arising outside of the agency. The remaining 20 per cent of excess cost, ascribed to structural and engineering modifications, unforeseen conditions and inadequacies in planning, are largely subject to agency control. In analyzing the Corps 1951 survey, a House Appropriations Subcommittee report pointed to the following weaknesses in the Corps' performance:

(a) Price increase arising from structural modifications were over 10 per cent of estimated project cost in one-third of the projects; approximately one-sixth of the projects had price increases exceeding 40 per cent; the largest relative increase was 727 per cent;

(b) unforeseen conditions caused price increases of 10 per cent or more on 38 per cent of the projects; increases of 40 per cent or more showed up on 20 per cent of the projects; the largest increase was 502 per cent;

(c) increased relocation costs were an important factor; for the 182 projects, average increase in relocation costs was 177 per cent; some relocation costs were up to fifty times the original estimate;

(d) increases in land acquisition costs averaged 123 per cent, in part caused by a 42 per cent increase in total acreage required; the largest relative increase of acreage for a single project was 287 per cent;

(e) cost increases ascribed to general inadequacies in planning and estimating (presumably because the increases were otherwise unaccounted for) were in excess of 10 per cent for 28 per cent of the projects; the largest relative increase was 217 per cent.

Much of the cost increase can be traced to the long time lag between project conception in the survey stage and actual construction. This problem of lag was aggravated by World War II; during the years 1941–1945 water resources construction was effectively suspended. Also significant, however, was the fact that project plans and cost estimates were often based on very sketchy information and inadequate analytical techniques. This was particularly true of surveys completed before and during World War II.

Corps of Engineers, 1964 Report

Of the 184 projects reported in this survey, forty-three had actual costs more than 10 per cent in excess of the original estimates adjusted to take account of construction price increases. These excess costs, which amounted to $177 million, were distributed as follows:

Land acquisition	14 per cent
Relocation	31 per cent
Design changes	51 per cent
Higher bid prices than expected	4 per cent

Of fifteen cases of increased land acquisition costs, four were traced to rises in land values and eleven involved changes in project scope. Relocation costs were increased because of increases in project scope and adoption of new legal or administrative criteria and changed design standards, requiring, for instance, rebuilding of roads to higher standards than those of existing roads. One-third of the design changes were ascribed to increases in project scope and two-thirds to geologic and hydraulic conditions different from those assumed at the survey stage.

It is difficult to make a clear separation between exogenous and endogenous factors influencing costs from the sketchy data of the 1964 report. Increase in land values, new legal requirements and changes in project scope are largely exogenous; these factors account for 43 per cent of all reasons cited as causes of increases. On the other hand, design changes probably reflect both exogenous factors, such as new conditions arising from delay between survey and construction stages, and endogenous factors associated with inadequate information at the survey stage.

Tennessee Valley Authority

Examination of the explanations provided by TVA for major cost overruns reveals the following:

(a) Changes in project construction schedules were an important factor, especially during World War II. Some projects, under construction when the U.S. entered the war, were stopped in 1942 and resumed only the after war; construction was accelerated on a few key projects during the war, thus increasing costs; in addition, there were a few instances of schedule stretchout due to delayed or reduced appropriations by Congress;

(b) in some cases, appropriations for construction were made before cost estimates were completed; this was the case for six dams begun in 1936 and for a later project constructed on an emergency basis;

(c) in only a few cases did changes in project scope increase costs significantly; also, there were few situations where costs increased because local conditions were different than anticipated.

BUREAU OF RECLAMATION. For seventy-nine projects (exclusive of project units in the Colorado River Storage Project and Missouri River Basin Program) surveyed by the Bureau of Reclamation in 1960, 55 per cent of the total increase in project costs was ascribed by the Bureau to exogenous price increases. Changes in project scope accounted for 22 per cent; reanalysis of work quantities and unit costs was responsible for another 12 per cent. The remaining 11 per cent was attributed to unforeseen conditions, structural modifications and miscellaneous reasons. Exogenous factors (price increases, changes in project plans) accounted for almost 80 per cent of the increase, but the remaining 20 per cent ascribed to controllable factors provides a significant opportunity for improvement by the agency.

Underlying Factors Influencing Accuracy of Cost Estimates

The underlying factors fall into two broad classes: those related to the project and the timing of survey and construction—type, size, complexity, time lag between survey and construction; and those related to the administrative and institutional framework—nature of preauthorization surveys, organizational structure, estimating pressures and biases. Major findings with respect to these factors are presented here:[16] details are contained in the Appendix tables.

Factors Related to Projects and Their Timing

PROJECT TYPE. Type of project clearly influences the accuracy of the estimates. As shown in Table 6 and Appendix Table 2, Corps of Engineer flood control projects (levees, channel excavation, flood control reservoirs, local protection works) have a higher total and greater frequency of cost overruns than rivers and harbors projects (dredging, harbor construction, locks and dams including power facilities and multiple purpose dams with power facilities). This inferior performance of flood control projects is maintained when construction price adjustment is applied to original estimates for both rivers and harbors and flood control projects. In terms of project subtypes, frequency of overrun is least for dredging and locks and dams, and greatest for local protection works and reservoirs—flood control and multipurpose. Cost estimation for dredging is relatively straightforward and involves few uncertainties. On the other hand, local protection projects often require land acquisition and extensive relocations in urban settings. Changes in land values are important factors, especially when there is a long time lag between survey and construction. In the case of storage reservoirs, geological and hydrological uncertainties are important elements leading to cost increases. Poor foundation conditions not anticipated at the survey stage can increase costs significantly, as can design changes involving large increases in spillway size occasioned by occurrence of large floods between time of survey and time of detailed project design.

[16] The analysis is in single-factor form. Because of small sample sizes, a multifactor statistical analysis was not undertaken. We recognize that some factors such as size and type of project are positively correlated.

TABLE 6

CORPS OF ENGINEERS

ESTIMATING PERFORMANCE BY PROJECT TYPE[a]

Period	Flood Control[b]		Rivers and Harbors[c]		Total	
	1933–53	1954–65	1933–53	1954–65	1933–53	1954–65
Number of projects	73	30	43	38	116	68
Overruns (per cent of survey cost)						
Original survey cost	88.3	10.0	41.3	−5.1	52.6	−0.2
Escalated survey cost	−5.3	−14.3	−20.8	−27.2	−16.8	−23.0
Frequency of overruns (per cent)						
Original survey cost	86	73	79	34	83	51
Escalated survey cost	40	47	23	16	34	29
Performance coefficient[d]						
Original survey cost	1.03	1.43	0.95	0.67	1.0	1.0
Escalated survey cost	1.17	1.59	0.70	0.54	1.0	1.0

[a] All data from 1964 report.

[b] Includes the following types of projects: levees, channel excavation, flood control reservoirs, local protection works.

[c] Includes the following types of projects: locks and dams, with and without power, multipurpose dams with power, harbor construction, beach replenishment, dredging.

[d] Performance coefficient $= \dfrac{\text{number of overruns in group}}{\text{all overruns}} \div \dfrac{\text{number of projects in group}}{\text{all projects}}$

If coefficient $= 1.0$, group has same share of overruns and of projects;

> 1.0, group has a greater proportion of overruns than of projects;

< 1.0, group has a smaller proportion of overruns than of projects.

TABLE 7

TENNESSEE VALLEY AUTHORITY
ESTIMATING PERFORMANCE BY PROJECT TYPE

	Dams	Steam Plants
Number of estimates	40	14
Original estimate (millions of dollars)	896.1[a]	1565.0
Actual cost (millions of dollars)	915.6[a]	1415.1
Total overrun (per cent)	21.7[a]	−9.6[b]
Frequency of overruns (per cent)	45.0	None
Distribution of errors (per cent)		
Mean	+8.25	−10.71
Mode	+7.5	−12.5
Median	−1.6	−10.4
Standard deviation	18.2	6.1
Maximum overrun	50.0	None
Maximum underrun	33.0	21.8

[a] For 47 estimates including miscellaneous projects related to dams and reservoirs.
[b] Underrun.

Table 7 shows the striking difference between cost estimating experience of TVA with dams and steam plants. The obvious explanation is the relative freedom from estimating uncertainties in the steam plant case. These are summarized for steam plants by TVA as follows:

(1) Area and cost of land for site are fairly well known at the outset;
(2) unforeseen foundation conditions do not greatly affect total costs;
(3) a large percentage of total cost is for equipment (for which cost estimates are fairly firm);
(4) good data are available on past experience for similar projects;
(5) setbacks due to floods or bad weather are improbable;
(6) good prospect of only small changes, affecting cost, between initial planning and final design.

PROJECT SIZE. The data show no conclusive evidence that project size (in terms of total estimated cost) is related to frequency of overruns. Altouney found no evidence of such correlation in his analysis of projects in the 1955 Bureau of Reclamation study.[17] TVA data suggests an inverse relationship between size of project and frequency of overrun, as shown by the following:

Cost Range (millions of dollars)	Number of Projects	Frequency of Overrun (Per Cent)
1.0–9.9	21	57
10.0–49.9	26	27
50.0–216.0	14	14

However, many of the large projects are steam plants and the good record of the large projects is probably more related to the nature of the projects than to their size.

No detailed analysis of influence of size was made for Corps of Engineers projects, but we consider it unlikely that such analysis would show significant correlations that are independent of other factors.

PROJECT TIMING. The timing of project construction in relation to completion of the project survey is important on two counts. When elapsed time between survey and construction is long, increase in construction prices becomes important and actual costs due to this cause alone turn out to be very much larger than estimated cost. For example, using the ENR construction cost index as the measure of price change, a project whose costs were estimated on the basis of 1950 prices would almost double in cost if built in 1965—a time lag of fifteen years. TVA's good record on costs is in part due to the extremely short time lag between completion of survey and start of construction (usually not more than two years). This allows TVA to base its estimates on short-term projected prices.[18]

The second consequence of long time lag concerns changes in project scope and in design standards. Typically these operate to increase project costs. This is shown in the Corps of Engineers data. After adjusting for construction prices, the 119 Corps projects with time lags up to fourteen years have a 28 per cent frequency of overrun, while 38 per cent of the sixty-six Corps projects with time lags of fifteen to thirty-four years have experienced overruns.

Calendar time also appears to be an important factor. Corps of

[17] Altouney, *op. cit.* p. 48.

[18] TVA makes its estimates on the basis of man-hours where possible, and makes separate estimates of projected increases in cost of labor, materials and equipment, rather than applying a single price adjustment factor to a current price estimate.

Engineers and Bureau of Reclamation projects which were surveyed before World War II have poor performance records on costs, as revealed by the 1951 and 1955 studies.[19] In contrast, the record of both agencies is much better for projects with surveys completed since World War II. For TVA, cost overruns were most serious for projects built during World War II, when unusual conditions prevailed in the construction industry.

In summary, time lag between survey and construction is an extremely important factor; fortunately, this factor is amenable to administrative and policy control.

Factors Related to Nature of Planning and Decision Process

There is considerable variation among water resource agencies on the procedure followed in obtaining authorization and appropriations for projects. The Corps of Engineers submits a project or river basin survey report to the Congress (after Presidential clearance) to serve as a basis for *authorization* of the work. The cost estimate prepared at this survey stage is an input to the benefit-cost analysis which Congress relies upon, in part, for making its decision on authorization. Typically authorization acts (Omnibus River and Harbors or Flood Control Acts) are enacted every two years. There may thus be a delay of as much as two or three years between date of cost estimate and authorization of the project. A separate procedure to obtain appropriations for the project must then be followed, which usually involves an additional year or two of delay. Delays of three or four years are common and some projects have even longer lags. Although project costs (and benefits) are updated at the time decisions are made to appropriate funds, the authorization decision is usually the controlling decision on *whether* to proceed with construction. It is not surprising, therefore, that actual costs deviate significantly from the original estimates, especially when the level of precision of cost estimating at the survey stage is considerably less than that appropriate for the engineering design stage.

Bureau of Reclamation procedures are generally similar to those of the Corps in that projects also must proceed through separate authorizing and funding stages. In contrast, the TVA project authorization step is an internal decision of the Board of Directors, usually followed

[19] See footnotes 4 and 8 above.

expeditiously with a request to the President and Congress for appropriations or authority to commit TVA corporate funds. In most cases, the time lag is short and project cost estimates are quite realistic.

The probable influence of authorizing and funding procedures is revealed by a comparison of the standard deviation of estimating errors of TVA and the Corps of Engineers, as shown in Table 5. For TVA projects, the standard deviation of error (as a per cent of estimated project cost) is 18, while for Corps of Engineers projects built since 1954 (which reflect the best record of the Corps) the standard deviation is 33, after price level adjustments have been made.

UNITARY VERSUS DECENTRALIZED ADMINISTRATION. TVA operations are managed from a single headquarters staff with centralized control of planning, estimating, design and construction. TVA has an excellent record of staff continuity allowing the agency to reap the benefits of cumulative experience. In contrast, the Corps of Engineers, with a nationwide program much larger than that of TVA, operates on a decentralized basis with thirty-seven districts and eleven intermediate divisions, which report to the Office of the Chief of Engineers in Washington.

From the standpoint of size of program and geographical scope, TVA project planning and construction (in contrast to its major power operations) is probably comparable to civil works planning and construction in a division of the Corps. TVA cost estimating performance is better than the performance of the Corps as a whole. Yet there are significant differences in performance among Corps divisions. As shown in detail in Appendix Table 3, for projects surveyed and built since 1954, the North Central and South Atlantic divisions had the lowest frequency of cost overruns (15 per cent and 22 per cent, respectively) while the Ohio River, and North Pacific had the highest frequencies (100 per cent).

Because frequency of overrun may also be influenced by project type, a separate analysis was made of projects included in the 1964 report to account for this factor. As shown in Appendix Table 3, the ratio of actual to expected overruns was computed for each Corps of Engineers division, based on the project mix of each division. On this basis, the North Central, North Atlantic and South Atlantic divisions had significantly better performance records than the others, while the Ohio River and North Pacific divisions again had the poorest record. Project mix did not change the rankings significantly.

METHOD OF PROJECT CONSTRUCTION. TVA performs all construction itself by force account while the Corps of Engineers and Bureau of Reclamation rely almost entirely on independent contractors via competitive bidding. It would appear that competitive bidding should lead to more economical construction than force account. But the TVA has made efficient use of force account, because it has had relatively close control of its construction schedule. Within limits it has been able to schedule construction to make best use of its administrative and supervisory personnel. It operates with the relative certainty of well-known labor costs and productivity levels and centralized management.

The Corps of Engineers and Bureau of Reclamation, on the other hand, are subject to both the positive and negative aspects of dealing with independent contractors and independent labor forces. This is likely to result in a highly variable performance, with economies achieved when construction work is slack and bidders are competing vigorously, and higher than normal costs the rule when construction work is plentiful. Although we cannot quantify the importance of this factor in our study, the over-all record of TVA performance indicates that its use of force account has led to important economies.

INSTITUTIONAL BIASES. Planners, designers and estimators are always subject to some environmental pressures in the performance of their work. Can any of these factors affect performance in a consistent fashion, thus leading to an unconscious bias? All three agencies operate within an institutional momentum that provides incentive for doing things, that is, with some oversimplification, to build as many projects as possible. Because economic justification (a favorable benefit-cost ratio) is a necessary condition for obtaining project authorization, there is a definite advantage in maintaining cost estimates as low as possible. The countervailing pressures are the legitimate professional pride of estimators in a task well done. They strive to provide correct information and to be accurate. They are sensitive to the penalties for poor work—criticism of their professional peers, and unfavorable criticism of their agency by Congress and the informed public. It is impossible to gauge accurately the relative weights of these opposing pressures and any judgment would be very rash. It would seem however that the pressures placed upon the Corps of Engineers and Bureau of Reclamation by their relationships with local interests, their greater dependence upon Congressional committees for support and the widespread impact of their programs are at least outwardly much stronger than those imposed upon TVA. All three agencies have a strong professional pride and this factor may well be dominant. The striking improvement in performance by the Corps and the Bureau since 1951 is an indication of this factor in operation.

Secular Changes over Time

The most obvious secular change associated with improvement of performance is the accumulation of experience including increased knowledge of the areas under the jurisdiction of the agencies and increased awareness of the major sources of problems. A second factor, which cannot be measured easily but can be safely assumed, is the improvement in the management of the agencies, the increased professionalization of staffs and improved working procedures. A third factor, which has been particularly important in removing elements of uncertainty at the planning-estimating stage, is the considerable improvement in engineering knowledge and skills that has affected every step of design and construction. Geological and geophysical survey techniques have improved the advance information obtainable at costs within the bounds of preliminary surveys; construction methods provide greater certainty as to the requirements of certain operations (for instance in determining the exact overbreakage required and feasible in rock excavation work). Thus, improved engineering not only increases the effectiveness of construction operations, but, by providing better information, allows for more accurate estimates at the survey stage.

Some Evidence from India, Great Britain and France

In an analysis of thirteen hydroelectric power and irrigation projects built in India during the period 1946–60, Healey found a consistent high bias toward underestimation of costs.[20] As shown in Appendix Table 10, total cost overrun for the thirteen projects was 41.3 per cent of estimated cost. Maximum overrun was 230 per cent and minimum overrun 5 per cent of estimated costs. The very large overruns are ascribed to the following causes in the following proportions:

[20] Healey, *op. cit.*

(a) Poor planning and management, 50 per cent; inadequate or wrong information from preliminary investigations; major changes in project scope due to misinterpretation of project purpose and potential (ignorance of the real production function); considerable mismanagement at site; delays; over supply of equipment; failure to call for tenders;
(b) price increases, 25 per cent; a detailed analysis of cost components show that price increases are not the major factor;
(c) unexplained, 25 per cent—which is probably due to estimating errors.

Healey explains the dominance of poor planning and management as a cause of error by the great difficulty of estimating overhead costs and of implementing proper accounting and management controls in a developing country.

A Select Committee on Nationalized Industries in Great Britain discovered even larger, and more consistently substantial, errors in a 1957 study of the experience of the North of Scotland Hydro-Electric Board.[21] Details are shown in Appendix Table 10. The Committee found two major causes for the large difference (107.5 per cent) between actual and estimated costs: price increases, and the inexperience of the managing authority established after the war. The Committee made a number of administrative recommendations to improve the situation and requested that annual reviews be made of estimates and costs for all projects. The possibility of substantial improvement in procedures is revealed by the results of the Committee's second investigation, in 1962. The improvement is particularly striking in the projects designed between 1951 and 1955 (before the first Committee report but after some 17 years of experience). The overrun was reduced to 6.6 per cent of estimated cost.

A Statistical Approach: France

In 1952 two engineers of Electricité de France published a statistical analysis tending to demonstrate the existence of a bias toward underestimation independent of the optimism or the deliberate attitudes of the estimators.[22] They accept the bias as a fact and seek to remove part of the responsibility for its existence from the shoulders of the estimators. They made two separate analyses of the problem:

[21] Select Committee on Nationalized Industries in Great Britain, *op. cit.*
[22] Giguet et Morlat, *op. cit.*

(a) *Dissymmetry of the probability distribution of errors*. The major factors that cause project costs to be greater than estimates are not independent but related. The engineers who design projects will determine the probability of existence of such factors (for instance unsound rock in a tunnel excavation) and will design so as to minimize the probability of occurrence of costly events. Whenever such events occur, the actual cost of projects will increase so that over the long run the mean value of actual project costs will be larger than the value estimated as most probable.

(b) *Systematic program errors*. The authors postulate a list of possible projects from which only a limited number will be selected and a normal distribution of errors (under- and over-estimates) of mean zero. The projects to be chosen are those which, for equal benefits, are estimated to have a cost lower than a given cut-off cost (y_0) determined by budgetary constraints. These projects will be (1) those with an actual cost (x) equal to the estimated cost (y), (2) those which, because of errors in the estimates, have actual costs greater than estimated costs and (3) (as demonstrated by the authors) some projects which have been overestimated, but which, because of the presence of the limit y_0, have a smaller proportional error than the underestimated projects. Projects which have been overestimated and are expected to cost more than the cut-off budget ($y > y_0$) will not be chosen although their actual cost would have turned out to be less than y_0. Thus, the actual cost of the total program will be greater than estimated and the size of the overrun will be inversely proportional to the percentage of projects to be selected from the list (as determined by the value of y_0).

Although this brief summary does not do justice to Giguet and Morlat's statistical analysis, it is difficult to accept the general validity of their statement. Its validity becomes more evident when considering limit cases: if a very small proportion of the total list is to be selected, those projects with the largest underestimation (for a given level of net benefits) will receive priority; conversely, if the total list is to be implemented, the distribution of errors will be normal, as assumed, and the average error of the estimates will be zero.

Both analyses rely on a number of constraining assumptions that reduce their validity as descriptions of the real world. However as one of the few known attempts to formulate an explanation for the perennial problem of systematic bias it opens new perspectives for research.

Findings and Implications for Public Works Policy and Administration

Our analysis has shown a significant difference among agencies in the accuracy of cost estimates. TVA, with the best record, has more organizational autonomy and a more centralized administration than the other agencies. This leads to the tentative conclusion that organizational and administrative context is the important variable influencing cost estimation performance.

A second finding is that the agencies have achieved very great improvements in estimating performance since the early 1950's. The poor performance of the Corps and the Bureau prior to 1950 can be attributed to the unusual conditions of the 1930's and the immediate postwar years. Agency planning staffs had grown rapidly during the 1930's, had been decimated during the war and were again built up rapidly immediately after the war. Pressures to complete survey reports were strong, and the information required for accurate cost estimates was often seriously deficient. Spurred by the Congressional criticism of the early 1950's, the agencies worked to improve their planning and cost estimating procedures and techniques. Technological change and improvements in engineering design skills have been positive factors also. The results were impressive: recent estimating performance by the Corps and the Bureau has begun to approach the good record of TVA.

The third important finding is that *current* performance of these agencies shows no significant bias toward underestimation of project costs. TVA, which uses projected construction costs and has a short lag period between completion of survey and start of construction, now makes estimates which are typically within 10 per cent of realized costs; recent bias has been toward overestimation. The Corps of Engineers, which typically encounters long time lags between survey and construction and which computes costs on a current price basis, still shows, in its performance since 1954, actual costs running higher than estimated costs. When adjustments are made for price increases, however, this bias disappears. Recognizing the many uncertainties associated with the data, including the crudity of the price adjustments, one can say that *recent* Corps performance (in contrast to earlier performance) shows no obvious bias toward underestimation of real costs.

The fourth point to be made is that recent agency experience reveals persistence of a sizable variance of error, in spite of the great improvements shown over earlier performance. To the extent that this wide spread is not traceable to changes in project scope or purpose, there is opportunity to reduce it through improving planning methods and cost estimating techniques.

The major technical factor which contributes to error in estimation is physical uncertainty; in water-resource projects the most important uncertainties involve geologic structure and hydrologic regime. Estimates at the survey stage must usually be based on incomplete information on these physical aspects. When more complete information becomes available at the design or construction stage, "bad" geologic structure or hydrologic circumstance often impose sizable additional construction cost on the project; rarely does more complete information on these aspects result in a lowering of actual cost from estimated cost. It appears reasonable to conclude that the presence of physical uncertainty carries with it a bias toward underestimation of costs. It is possible to reduce the degree of such uncertainty at the planning stage by increasing the information input, although this will entail extra survey costs.

Although technical uncertainty may be an important factor for a particular class of projects—storage reservoirs, for example—over-all, it appears to be much less important as a cause of error than administrative and institutional factors.

Implications for Policy and Administration

The need for accurate cost estimates as an input to the decision process is obvious. To the extent that cost estimates for an entire program (such as the Interstate Highway program) are below actual costs, the entire schedule will be disrupted in the pressure of a budgetary constraint based on the original estimate. When cost estimates for individual projects fall well below actual costs, the very worthwhileness of the project may be undercut.

The fact that significant improvements in performance can be achieved, as in the water resource examples studied, points to the conclusion that significant payoffs may be possible through study of the planning and estimating process of public works agencies, as a part of over-all management improvement activities. Further, the important role played by institutional structure in the water-resource case points to the need for examining this crucial variable. Some specific suggestions for changes in administration are made below.

THE PLANNING PROCESS. Inadequacies in the planning process seem to be a larger source of error than preparation of cost estimates as such. The superficial nature of the surveys and information used as input to cost estimates has been a major problem. The answer appears to lie in adoption of an approach much like TVA's that a decision to proceed on a project (project authorization) must be taken only on the basis of a reasonably detailed survey. In terms of many public works programs, such as Corps of Engineers civil works, this may involve eliminating the project authorization step, and relying on the appropriation step, as the basis for decision to proceed. In any event, the solution appears to be in more complete and detailed planning before firm decisions to build are taken.

THE COST ESTIMATING PROCESS. Even with reasonably detailed planning and information, uncertainties may still be large at the cost estimating stage. When the cost of additional information to reduce uncertainty is prohibitive, project cost data can be presented in terms of ranges or degrees of accuracy, element by element, and an over-all range of error noted for the project. This prescription is obviously applicable to benefit estimates also, and over-all benefit-cost data could be presented in terms of ranges rather than single-valued estimates. The important information for decision makers is on the differences in range of cost and benefit for individual projects and classes of projects.

More sophisticated use of contingency factors would also provide a means of increasing accuracy of estimates. The presence of large contingency factors, on the order of 20 to 25 per cent, is usually an indication that the information base is inadequate. TVA reports that the contingency factor is considered to cover the following:

(a) Changes in project scope between planning and design stages, including adding minor structures, features and systems not included at the outset;
(b) errors, oversights, and imperfections in estimating methods;
(c) deviations in efficiency of project construction;
(d) variation between estimated and actual cost of equipment and material.

With this concept of contingency, TVA has been able to reduce its contingency factor for large steam plants from a previous range of 10 to 13 per cent to a level of 5 per cent. The point is that contingency factors should not be used as a substitute for detailed cost estimating. The computation of a contingency factor as a residual, element by element, would seem to be a desirable practice.

PRICE CHANGES. It would be most desirable to compute costs on the basis of projected price levels for the labor, materials and equipment components of projects. This is generally the practice of TVA. Where uncertainty as to the date of construction does not permit such procedure, estimates could be supplemented by the addition of a projected price index in order to provide some indication of project costs according to various possible construction periods. Such a scale should however also include the increases in nominal benefits (in fact it would be an adjusted benefit-cost ratio) in order to avoid the fallacy that a delayed project will necessarily be inferior in terms of net gain to the nation. The greatest value of such an index, other than its indication of changes in net benefits, if any, might be simply to acknowledge in advance the influence of the price factor over the estimates in order to "protect the record" of the estimating agency.

CHANGES IN ADMINISTRATIVE STRUCTURE. Improvements in cost estimating could be achieved by fundamental changes in administrative structure in which regional or river basin agencies were given general authority such as TVA has to plan, design, construct and manage a water-resource system subject only to outside control over appropriations. Short of such sweeping change, there could be more centralization of the planning and cost estimating task in the division offices of the Corps of Engineers. Greater competence could be built in a few estimating staffs than now exists in the many districts. More fundamental perhaps is a change in the project authorization procedure which now forces decisions on projects to be made with inadequate information as to cost. The water resource agencies should have general authority to include projects in a regional plan, but actual decision to undertake a project should be deferred until the appropriation stage. Cost estimates made at this time should be reasonably firm because there would be no long delay between completion of the cost (and benefit) estimates and start of the project.[23]

[23] Robert Haveman reports that an analysis by Terrell Langworthy and himself reveals that, for 86 Corps of Engineers projects initiated in fiscal year 1956, *total* costs as estimated at the appropriations stage and as finally realized were remarkably close. A substantial variance existed among projects, however.

Suggestions for Further Research

As stated at the outset, the limitations of this study suggest the need for much further research on this subject. In particular, research is needed on other major public works programs—highways, public buildings, water and sewer systems among others—and at other levels of government—state and local.

In this study, we only touched on the detailed process of cost estimation as carried out by planning and engineering staffs, including such important issues as use of contingency estimates and use of projected construction costs. Studies of this process should be made in detail, perhaps using actual cases and tracing through in detail how the estimates were made and how actual costs varied from estimates on this detailed basis. A study could also be made of the professionals' attitudes toward cost estimation. In our interview with TVA personnel, we noted a professional pride in the agency's good record on cost estimation and a deep concern for doing a good professional job. But detailed studies of attitudes and behavior of professionals are required before one can be definitive about this aspect of cost estimation.

As indicated earlier, our statistical analysis of the available data was quite crude. A multivariate analysis would seem to be indicated, but this should probably be done on a much larger sample than we had available.

Our finding that institutional and management factors probably have a greater effect on accuracy of cost estimates than technical factors should be tested by comparative studies of public works planning. Perhaps the state highway departments are useful places to begin such studies.

Another subject for useful research is to study the relationship between the cost of obtaining additional information and the value of the increased estimating accuracy. Perhaps data can be obtained on cases where lack of information on geologic structure at the estimating stage led to gross underestimation of cost. The cost of obtaining the necessary geologic information to reveal the essential geologic structure (and associated cost) could then be related to the decisions made under the two situations.

In conclusion, it is well to put the problem of cost estimation in its true perspective. In terms of investment decision making, the estimates of money cost of construction are much firmer than are estimates of benefits or consideration of opportunity costs or external costs. But, as we have shown, variations in accuracy of estimates between agencies and even between subdivisions of agencies are very great. It behooves an analyst to know the performance record of the agency whose project he is examining.

We conclude on a note of hope for the many victims and authors of gross miscalculations. John Sawyer, in a paper on "Entrepreneurial Errors and Economic Growth"[24] relates how many of our most important public works would never have been built had it not been for gross errors in the estimates of their costs and benefits. He cites among others the British turnpikes and canals of the 18th century, scores of railroads and canals built in the United States in the 19th century, and more significantly, the Panama Canal, the Welland Canal and the Sault Ste. Marie Canal!

Appendix

TABLE 1

CORPS OF ENGINEERS

CAUSES OF INCREASES IN PROJECT COSTS[a]

Factor	Size of Increase (millions of dollars)	Per Cent of Total Increase	Per Cent of Original Estimate
Price increases	1,887.9	57.7	71.6
Authorized project extension	576.8	17.6	21.8
Changed local needs	134.5	4.1	5.1
Structural and engineering modifications	206.2	6.3	7.8
Unforeseen conditions	279.5	8.5	10.6
Inadequacies in planning and estimating	189.0	5.8	7.1
Total	3,273.9	100.0	124.0

[a] Data from 1951 report.

[24] John E. Sawyer, "Entrepreneurial Error and Economic Growth," *Explorations in Entrepreneurial History,* Cambridge, Vol. IV, no. 4, May 1952.

TABLE 2

CORPS OF ENGINEERS
FREQUENCY OF OVERRUNS BY PROJECT TYPE
1964 REPORT

Type	All Projects			Projects Since 1954		
	Number	Frequency of Overrun (per cent)		Number	Frequency of Overrun (per cent)	
		Original	Escalated		Original	Escalated
Individual types						
1. Levees	17	76	41	0	0	0
2. Channel excavation for flood control	8	75	38	4	50	50
3. Flood control reservoir	48	79	31	5	67	40
4. Local protection	30	94	60	11	91	55
5. Lock and dam, no power	11	55	9	6	17	0
6. Lock, dam and power	3	33	0	0	0	0
7. Multipurpose dam	9	78	22	0	0	0
8. Harbor construction	8	62	12	5	60	0
9. Beach replenishment	1	0	0	1	0	0
10. Dredging	49	57	24	26	35	23
Grouping by major elements						
"Construction" (types 1, 4, 8)	55	83	47	16	81	37
"Dams" (types 3, 5, 6, 7)	71	73	25	21	52	29
"Excavation" (types 2, 9, 10)	58	59	26	31	35	26
Grouping by function (by Corps of Engineers)						
Flood control (types 1, 2, 3, 4)	103	83	42	30	73	47
Rivers and harbors (5, 6, 7, 8, 9, 10)	81	58	20	38	34	16
Total (all projects)	184	72	32	68	51	29

TABLE 3
CORPS OF ENGINEERS
FREQUENCY OF OVERRUNS BY ADMINISTRATIVE DIVISIONS, 1964

Division[a]	1964—All Projects: Number of Projects	Frequency of Overruns (per cent): Original Estimate	Frequency of Overruns (per cent): Escalated Estimate	R^b	1964—Projects Since 1954: Number of Projects	Frequency of Overruns[c] Original Estimate (per cent)	R
NED	18	78	38	1.03	10	80	1.57
NAD	16	69	19	.88	7	43	.59
SAD	17	41	6	.71	9	22	.61
NCD	26	38	19	.79	13	15	.39
ORD	17	94	35	1.26	5	80	2.09
MRD	15	87	67	.99	2	100	1.10
LMVD	16	75	50	1.10	6	33	1.17
SWD	21	81	19	1.50	7	86	1.38
NPD	10	30	30	1.33	2	100	1.82
SPD	25	87	44	1.14	7	57	1.32
POD	3	67	67	1.01	0	—	—

NOTE: The table leads to no firm conclusions but to suggestions of real differences between divisions because of the large variations in performance between divisions and the relative consistency of performance within the divisions.

Differences between divisions. The differences between minimum values ("best performance") and maximum values ("worst performance") are considerable for all indicators:

Indicator	Minimum Value	Maximum Value
All projects:		
Per cent overruns (original estimate)	38	94
Per cent overruns (escalated estimate)	6	67
R	0.71	1.50
Recent projects:		
Per cent overruns (original estimate)	15	100
R	0.39	2.09

Consistency within divisions. The same two divisions (South Atlantic and North Central) rank "best" for all indicators; indicators of "poor" performance are less concentrated but Ohio River, Missouri River and North Pacific Divisions rank generally the worst.

Improvement over time. The general improvement noted of more recent projects does not apply consistently to all divisions; indeed, the two "best" divisions perform better in the recent projects and the "worst" fare worse.

These data must be interpreted with care. Some categories are too small to provide significant information, particularly concerning the most recent performance; and a number of significant factors have not been controlled such as date of estimate and duration of project.

[a] *Divisions and Districts*

NED: New England (no districts)
NAD: North Atlantic (New York, Baltimore, Philadelphia, Norfolk)
SAD: South Atlantic (Wilmington, Charleston, Jacksonville, Savannah, Mobile)
NCD: North Central (Chicago, Rock Island, Detroit, St. Paul, Buffalo)
ORD: Ohio River (Nashville, Pittsburgh, Louisville, Huntington)
MRD: Missouri River (Kansas City, Omaha)
LMVD: Lower Mississippi Valley (Memphis, Vicksburg, St. Louis, New Orleans)
SWD: South West (Albuquerque, Fort Worth, Galveston, Tulsa, Little Rock)
NPD: North Pacific (Seattle, Portland, Walla Walla, Anchorage)
SPD: South Pacific (San Francisco, Sacramento, Los Angeles)
POD: Pacific Ocean (Honolulu)

[b] R = Ratio of actual to expected overruns, based on original estimates. Controls for the different "project mix" of each division. The expected frequency of overruns in each division is obtained by multiplying the frequency of overruns for each project type by the number of projects of each type in the division.

[c] Escalated estimate is not analyzed; too few projects for significance.

TABLE 4

CORPS OF ENGINEERS
SIZE OF PRICE ESCALATING FACTOR

Duration of Project (years)[a]	Number of Projects	Size of Price Escalator (per cent)			Per Cent Variation from Mean	
		Mean	Maximum	Minimum	Largest[b]	Smallest[c]
30–34	1	174	—	—	—	—
25–29	11	210	336	68	60	68
20–24	27	197	293	154	49	22
15–19	26	102	281	27	175	73
10–14	48	56	196	12	250	79
5–9	61	28	119	9	337	68
0–4	10	9.8	18	1	84	90

NOTE: Mean, maximum and minimum size of price escalator as a function of project duration (1964 report, all projects).

[a] Time lapse between original estimate and project completion.

[b] Per cent difference between largest escalator of group and mean.

[c] Per cent difference between mean and smallest escalator of group.

TABLE 5

TENNESSEE VALLEY AUTHORITY ESTIMATING PERFORMANCE

Project	Type[a]	Date of Appro-priation	Com-pletion Date	Original Estimate (thou-sands of dollars)	Final Cost (thou-sands of dollars)	Error (per cent)[b]
Kentucky Dam	DRP	1941	1949	109,167	116,302	+6.5
Pickwick Dam	DRP	1934	1939	32,530	29,701	−8.6
	AGU	1939	1943	4,532	4,327	−4.5
	AGU	1949	1954	8,900	9,129	+2.3
Total				45,962	43,157	−6.1
Wilson Dam	AGU	1939–47	1952	14,947	13,529	−9.4
	Lock	1952	1963	38,000	38,012	+0.1
	AGU	1958	1963	24,000	21,265	−15.8
Total				76,947	72,806	−5.3
Wheeler Dam	DRP	1933	1939	32,117	29,295	−8.7
	AGU	1939	1942	3,572	3,225	−8.6
	AGU	1941	1947	10,085	10,570	+5.0
	Lock	1961	1964	6,000	6,802	+13.3
	AGU[c]	1959	1964	24,500	19,877	−18.8
	Lock	1960	1964	16,000	15,632	−2.3
Total				92,274	85,401	−7.0
Guntersville Dam	DRP	1935	1940	36,335	31,801	−12.4
	AGU	1949	1954	4,400	4,717	+6.8
	Lock	1962	1967	16,500	16,416	−0.6
Total				57,235	52,934	−7.5
Hales Bar	AGU	1940	1949	7,000	8,808	+25.7
	AGU	1949	1955	15,200	14,100	−7.2
Total				22,200	22,908	+3.2
Chickamauga	DRP	1935	1941	43,128	34,368	−20.2
	AGU	1949	1953	4,000	4,228	+5.0
	Channel	1962	1967	1,821	1,675	−8.0
Total				48,949	40,271	−17.8
Watts Bar	DRP	1939 & 1941	1946	38,400	32,977	−14.0

(*continued*)

TABLE 5 (CONTINUED)

Project	Type[a]	Date of Appropriation	Completion Date	Original Estimate (thousands of dollars)	Final Cost (thousands of dollars)	Error (per cent)[b]
Fort Loudoun	DRP	1940	1946	28,500	34,941	+22.4
	AGU	1941	1950	4,400	4,797	+9.1
Total				32,900	39,738	+20.6
Norris	DRP	1933	1939	31,025	30,508	−1.6
Hiwassee	DRP	1935	1941	19,484	15,923	−18.4
	AGU	1952	1957	5,900	6,384	+8.5
Total				25,384	22,307	−12.3
Cherokee	DRP	1940	1944	31,500	29,765	−5.4
	AGU	1951	1955	7,200	5,536	−23.6
Total				38,700	35,301	−8.8
Ocoee Number 3	DRP	1941	1946	6,600	7,988	+21.2
Appalachia	DRP	1941	1946	20,000	22,559	+13.0
Chatuge	DRP	1941	1946	5,000	7,037	+40.0
	AGU	1952	1957	2,900	2,217	−21.1
Total				7,900	9,254	+17.7
Nottely	DRP	1941	1946	5,000	5,379	+8.0
	AGU	1952	1957	3,200	2,655	−18.8
Total				8,200	8,034	−2.4
Fontana	DRP	1941	1948	47,000	70,421	+50.0
	AGU	1950	1955	3,900	4,310	+10.5
Total				50,900	74,731	+46.4
Douglas	DRP	1942	1945	32,000	40,244	+24.4
	AGU	1942	1950	3,000	2,069	−33.0
	AGU	1951	1955	4,000	2,959	−27.5
Total				39,000	45,272	+16.1
Watauga	DRP	1946	1951	29,500	32,369	+9.8
South Holston	DRP	1947	1952	31,500	31,242	−0.9
Boone	DRP	1950	1955	27,500	27,192	−1.1
Fort Patrick Henry	DRP	1950	1955	13,000	12,420	−4.6
Melton Hill[d]	DRP	1960	1965	34,000	38,489	+13.2

TABLE 5 (*CONCLUDED*)

Project	Type[a]	Date of Appropriation	Completion Date	Original Estimate (thousands of dollars)	Final Cost (thousands of dollars)	Error (per cent)[b]
Beech River	Water control	1962	1966	6,000	9,238	+53.3
Bristol	Flood protection	1963	1966	2,900	2,175	−24.2
Watts Bar	SP	1940–41	1946	20,000	19,746	−1.5
Johnsonville	SP	1950	1955	98,000	94,284	−3.8
	SGU	1956	1960	83,000	75,705	−8.8
Total				181,000	165,989	−8.3
Widows Creek	SP	1951	1958	103,000	93,826	−8.9
	SGU[e]	1958–60	1967	154,000	132,916	−13.7
Total				257,000	226,742	−11.8
Kingston	SP	1951–53	1961	213,000	198,200	−6.9
Colbert	SP	1951–52	1958	110,500	99,104	−10.3
	SGU[f]	1959	1966	80,000	65,363	−18.2
Total				190,500	164,467	−13.6
Shawnee	SP	1951–52	1959	216,500	213,536	−1.4
Gallatin	SP	1952	1960	85,000	76,051	−10.6
	SGU	1956	1960	73,000	61,864	−15.2
Total				158,000	137,915	−1.3
John Sevier	SP	1952–53	1960	96,000	84,103	−12.4
	SGU	1956	1960	28,000	21,850	−21.8
Total				124,000	105,953	−14.5
Paradise	SP[g]	1959	1966	205,000	178,586	−12.9

[a] DRP = dam, reservoir and powerhouse; AGU = additional generating units; SP = steam plant; SGU = additional steam generating units.

[b] Overrun denoted by +, underrun by −.

[c] Interest during construction included in final cost but not in original estimate.

[d] Interest during construction included in final cost but not in original estimate of power facilities portion.

[e] Interest during construction included for generating unit 8 (original estimate \$68 million) in both original estimate and final cost.

[f] Interest during construction included in final cost but not in original estimate.

[g] Interest during construction included in both original estimate and final cost.

TABLE 6: TENNESSEE VALLEY AUTHORITY PERFORMANCE BY PROJECT TYPE, DATE OF APPROPRIATION, AND PROJECT SIZE

Group	Number of Projects	Frequency of Overruns[b] Number	Frequency of Overruns[b] Per Cent	Performance Coefficient[a]
Project type				
1. Dams and reservoirs	21	10	47.6	1.61
2. Additional hydro-generating units	19	8	42.0	1.22
3. Locks	4	2	50.0	1.28
4. Channel dredging	1	0	0.0	0.0
5. Multipurpose water control	1	1	100.0	2.50
6. Flood protection	1	0	0.0	0.0
7. Steam plants	9	0	0.0	0.0
8. Additional steam generating units	5	0	0.0	0.0
All dams (lines 1 and 2)	40	18	45.0	1.30
All steam plants (lines 7 and 8)	14	0	0.0	0.0
Others (lines 3, 4, 5, and 6)	7	3	42.8	1.27
Total	61	21	34.4	1.0
Date of appropriation				
1933–39	8	0	0.0	0.0
1940–44	14	10	72.0	2.09
1945–49	8	5	62.5	1.85
1950–54	15	2	13.3	0.36
1955–59	8	1	12.5	0.38
1960–64	8	3	37.5	1.08
Actual cost of project (in millions of dollars)				
50–260	14	2	14	0.44
10–50	26	7	27	0.77
1–10	21	12	57	1.67

[a] Performance Coefficient =

$$\frac{\text{Number of Overruns in Group}}{\text{Total Number of Overruns}} \div \frac{\text{Number of Projects in Group}}{\text{Total Number of Projects}}$$

[b] Almost 50 per cent of dams have overruns while steam plants have no overruns; the only periods with more than 50 per cent overruns are 1940–44 and 1945–49 (war time and immediately thereafter); the frequency of overruns appears to decline as project size increases. Caution: no cause-effect relationships can be determined; the complementarity of these factors is very high: wartime construction and lower cost ranges are associated with dam construction; recent construction and large size projects correspond to the steam plants.

TABLE 7

TENNESSEE VALLEY AUTHORITY, DISTRIBUTION OF ERRORS

	Item	Mean (per cent)	Mode (per cent)	Median (per cent)	Standard Deviation
1	Distribution of all estimates by 5 per cent classes				
1.1	All projects (61 estimates)	−1.76	−5.0	−5.0	17.5
1.2	Dams only (40 estimates)	+0.25	+7.5	−1.6	18.2
1.3	Steam plants only (14 estimates)	−10.71	−12.5	−10.4	6.1
2	Individual distributions, complete projects only				
2.1	Steam plants (9 projects)	−8.02	n.a.	−7.5	5.5
2.2	All dams (23 projects)	+3.40	n.a.	−1.1	14.7
2.3	Dams, except Fontana (22 projects)	+1.45	n.a.	−1.6	11.6
3	Dams only, overruns and underruns				
3.1	Underruns only (13 projects)	−6.87	n.a.	−6.1	5.2
3.2	Overruns only, excluding Fontana (9 projects)	+13.48	n.a.	+13.2	6.1

n.a. = not applicable (projects not grouped by class).

NOTE. Plus sign signifies overrun (actual cost greater than estimate); minus sign signifies underrun (actual cost smaller than estimate). Estimates in Item 1 are grouped by classes corresponding to ranges of errors of 5 per cent; in Items 2 and 3 the projects are distributed individually. Item 1 includes all estimates (61); Items 2 and 3 include estimates for project totals only.

TABLE 8

BUREAU OF RECLAMATION: CAUSES OF INCREASES IN PROJECT COSTS[a]

	Exclusive of CRSP and MRBP[b]			All Projects[c]		
	Size of Increase (millions of dollars)	Per Cent of Total Increase	Per Cent of Original Estimate	Size of Increase (millions of dollars)	Per Cent of Total Increase	Per Cent of Original Estimate
Price increases	507.7	55.5	20.0	1,310.5	48.2	34.7
Changes in project plans	198.4	21.6	7.8	957.9	35.3	25.4
Structural engineering modifications	1.3	0.2	0.1	−16.9	−0.7	−0.4
Unforeseen conditions	69.9	7.6	2.7	87.3	3.2	2.3
Reanalysis of quantities and unit costs	105.8	11.6	4.2	291.4	10.8	7.7
National emergencies	9.3	1.0	0.4	9.6	0.4	0.3
Other	22.4	2.5	0.8	75.7	2.8	2.0
Total	914.8	100.0	36.0	2,715.5	100.0	72.0

[a] Data from 1960 report.
[b] Totaling 79 projects. CRSP = Colorado River Storage Project; MRBP = Missouri River Basin Project.
[c] Totaling 128 projects.

TABLE 9

BUREAU OF RECLAMATION: DISTRIBUTION OF ERRORS

Case	Number of Projects	Mean (per cent)	Standard Deviation	Mode (per cent)	Median (per cent)	Maximum Error	
						Overrun (per cent)	Underrun (per cent)
1955 Report[a]	103	+163.0	n.a.	+10	+100	1000	20
1960 Report[b]							
All projects[c]	79	+27.4	58	0	+7	326	39
All projects except two worst[d]	77	+20.6	38	0	+7	165	39
1960 Report[b]							
Projects at least 50 per cent complete	65	+33.8	62	0	+3	326	39
Projects 50 per cent complete except two worst[e]	63	+25.8	42	0	+3	165	39

n.a. = not available.

[a] Based on original estimate.

[b] Based on original estimates only; exclusive of CRSP and MRBP.

[c] This case comparable with data in Table 3 in the body of the paper.

[d] Projects with overruns of 251 and 326 per cent.

[e] Projects with overruns of 251 and 326 per cent. This case is most significant for purposes of comparison with other agencies.

TABLE 10

ESTIMATING PERFORMANCE: INDIAN AND BRITISH EXAMPLES

Item	India 1960[a]	Great Britain			
		1957[b]	1962i[c]	1962ii[c]	1962 (total)[c]
Period of Record	1946–56	1944–50	1944–50[d]	1951–55	1944–55
Type of Projects	Hydro-power & Irrigation	Hydro-electric Power Plants			
Number of Projects	13	11	5	8	13
Estimated Cost (millions)	Re 6,307	£18,351	£21,400	£33,342	£54,742
Actual Cost (millions)	Re 8,904	£38,100	£51,810	£35,530	£87,340
Overrun (per cent)	41	107	142	6	59
Frequency of Overruns (number)	13	11	5	5	10
(per cent)	100	100	100	62	77
Maximum Overrun (per cent)	230	265	187	29	187
Minimum Overrun (per cent)	5	60	107	−4[e]	−4[e]
Average Overrun (per cent)	74	124	149	6	61

[a] Adapted from J. M. Healey, "Errors in Project Cost Estimates," *Indian Economic Journal*, Vol. 12, July–September 1964.

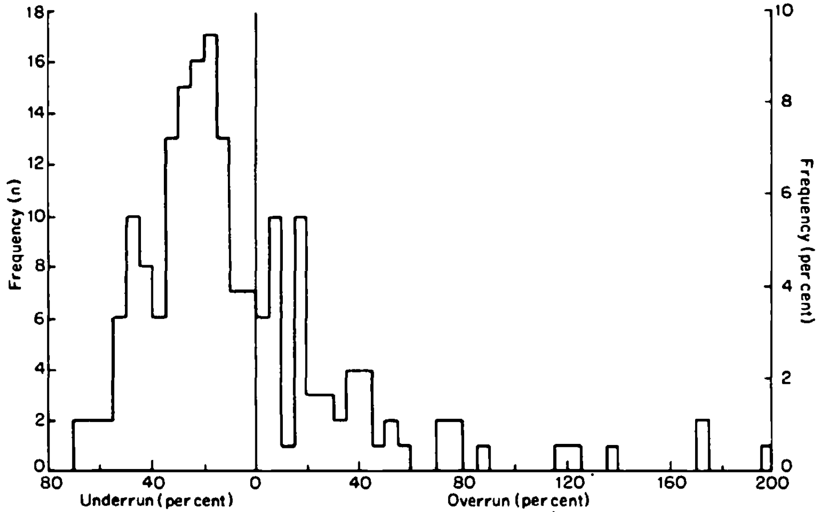
[b] Adapted from Select Committee on Nationalized Industries, *Report to the House of Commons*, Session Documents, Vol. 7, No. 304, 1956–57, London, H.M.S.O. 1957.

[c] Adapted from Select Committee on Nationalized Industries, *Report to the House of Commons on the Electricity Supply Industry*, Session Papers, Vol. 7, No. 116, 1961–62, London, H.M.S.O., 1962.

[d] Projects in this column completed later than those in previous column. [e] Underrun.

FIGURE 1

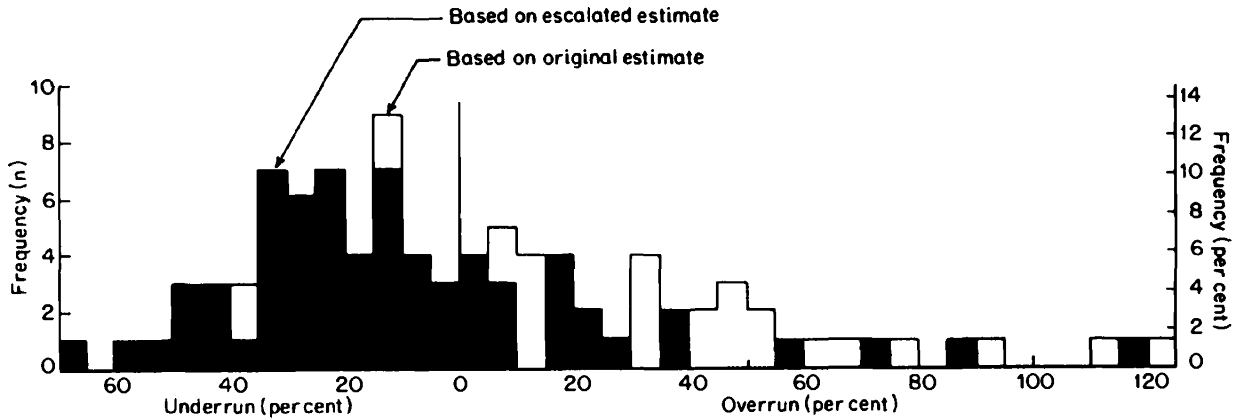
CORPS OF ENGINEERS
DISTRIBUTION OF ERRORS
182 PROJECTS—1933–65



SOURCE: Data from 1964 Report, excluding two projects with overruns of 259 and 656 per cent. Based on escalated survey estimate.

FIGURE 2

CORPS OF ENGINEERS
DISTRIBUTION OF ERRORS
68 PROJECTS—1954–65



SOURCE: Data from 1964 Report.

FIGURE 3
TENNESSEE VALLEY AUTHORITY
DISTRIBUTION OF ERRORS
61 ESTIMATES

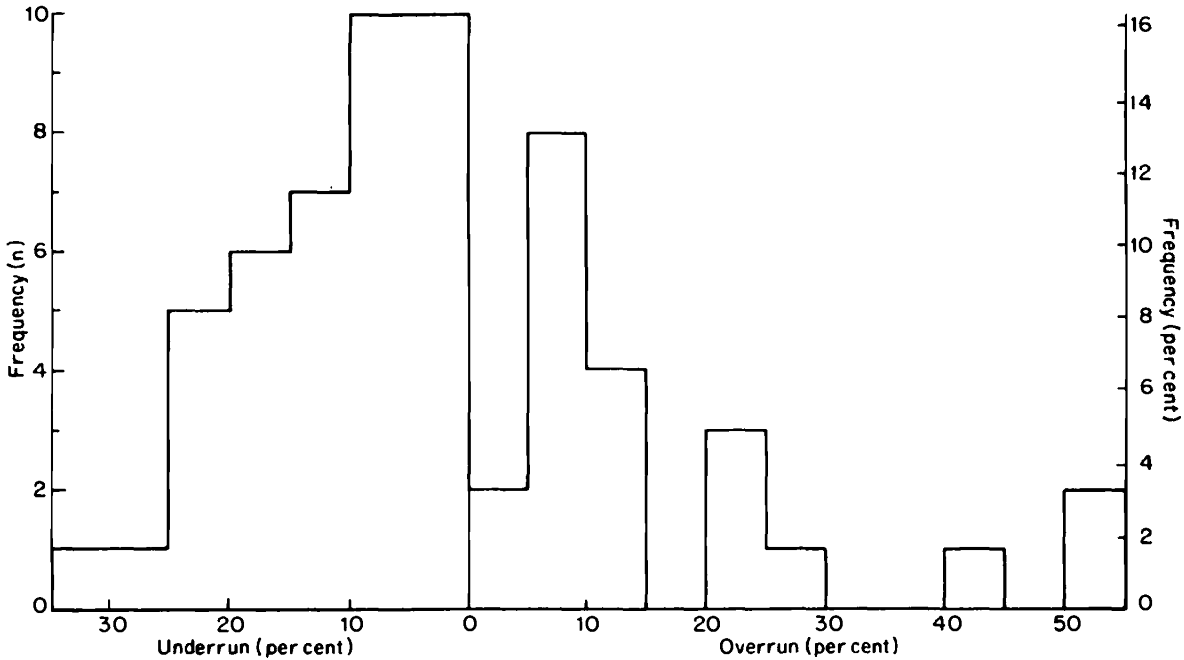


FIGURE 4
TENNESSEE VALLEY AUTHORITY
DISTRIBUTION OF ERRORS BY PROJECT TYPE
54 ESTIMATES

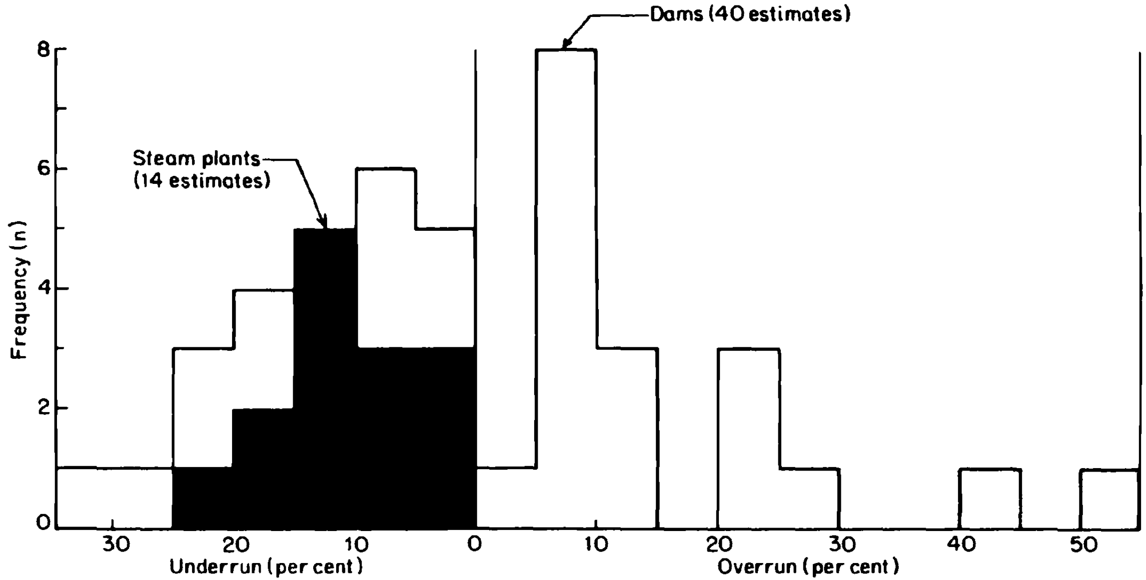
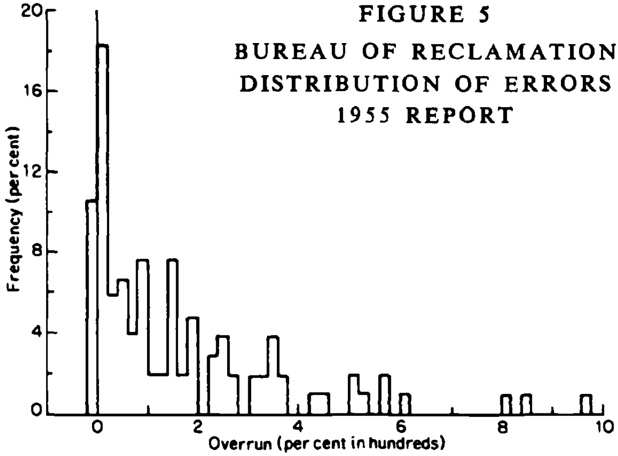


FIGURE 5

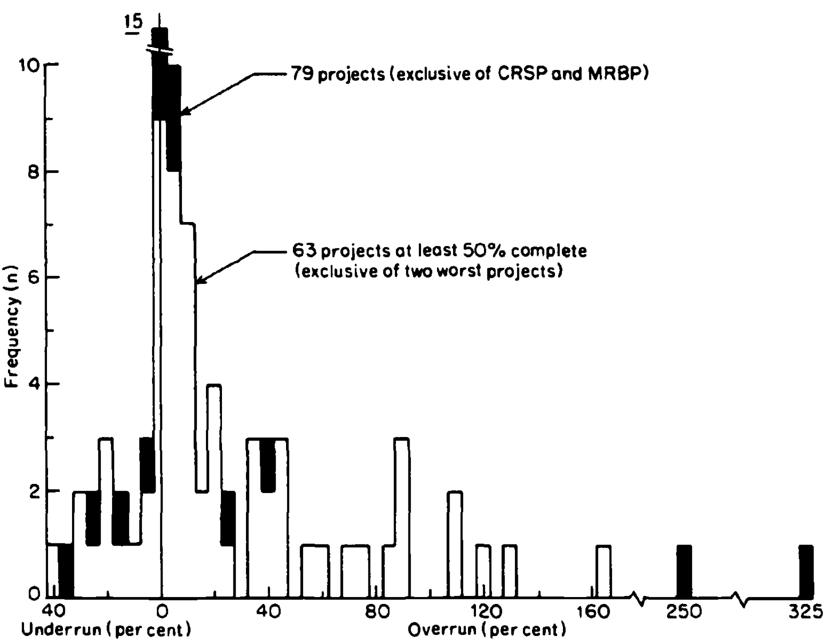
BUREAU OF RECLAMATION DISTRIBUTION OF ERRORS 1955 REPORT



NOTE: Adapted from Edward G. Altouney, *The Role of Uncertainties in the Economic Evaluation of Water Resources Projects,* Institute in Engineering-Economic Systems, Stanford University, 1963. (Based on 103 projects; original estimate.)

FIGURE 6

BUREAU OF RECLAMATION DISTRIBUTION OF ERRORS 1960 REPORT



NOTE: Based on initial authorization cost.