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I. Objective

Large cost overruns on public projects make good newspaper copy. Journalists appear duly horrified and the world seems to continue as before. There is little historical perspective presented on typical cost overruns in such articles.

In 1966 the question of the emerging cost overrun for San Francisco's rapid transit project sold a lot of newspapers and started an attitude of criticism toward the Bay Area Rapid Transit (BART) District. The purpose of this paper is to present some findings on cost overruns so that, for example, we can look at the 45 per cent by which BART exceeded its forecast costs and decide whether that experience is poor or not.

II. Summary

Many of the large, risky investments in the past two centuries have had enormous cost overruns, but for many benefits have exceeded expectations by even greater margins. Economic development has not been hampered by low cost estimations.

Studies of military procurement have shown that cost overruns can be explained to some extent and even predicted. Other studies on water resource projects, highways, and buildings also imply that overruns can be predicted and may have been anticipated in some recent cost estimates. Unfortunately, anticipating overruns in cost estimates appears to lead to laxity in cost control.

Cost overruns studied are positively related to size of project, incompleteness of preliminary surveys, engineering uncertainty, inflation, project scope enlargement, length of time to complete project, exogenous delays, complexity of administrative structure, and inexperience of administrative personnel.

We present cost estimates and overrun experience for almost 200 large projects in Tables 8 through 12. The BART cost overrun of 45 per cent does not compare unfavorably with other rapid transit projects but is poorer than the average overrun for other types of projects. Our extensive data may prove useful for further investigations of cost overruns and policy recommendations for cost estimating.

III. Problems in Analysis of Cost Overruns

There are two principal reasons for examining past cost overruns. One is to be able to predict cost overruns and to intervene to prevent them. Another is a more modest goal. That is simply to observe the historical facts and know what to expect. Our purpose in this study is rather limited. We propose to survey cost estimation experience in several categories of projects and compare that to cost estimation experience in recent urban rapid transit projects in this country and abroad. This modest effort is not to prevent cost overruns but merely to discriminate the truly unusual from the more pedestrian. Furthermore, it may be true that the effort to prevent cost overruns by "debiasing" cost estimates will result in a worse problem: that of higher costs.

In gauging the seriousness of cost overruns, it is important that we look at estimated and actually realized cost figures that are comparable. Often several cost estimates are made as a project progresses toward completion. Summers[10] and Tucker[11] have shown that these tend to improve as the project advances. The particular estimate important for resource allocation is the one upon which the investment decision was based. For public projects this is generally the estimate used when the project is authorized. Although future estimates may differ from the authorization estimate, projects are seldom discontinued. We have opted to use only the authorization estimate for comparison with actual costs in our data.

Sometimes cost estimates are given for only part of a project, or for the whole project minus one part (such as a dam exclusive of power generating facilities), and this partial nature may not be readily apparent. The necessity of the estimate's corresponding to the unit used for actual cost hardly needs to be emphasized. Also it is sometimes difficult to tell whether estimates are made in terms of constant or current dollars. Tucker has noted that in the case of newspaper reports which do not specify otherwise, costs may safely be assumed to be in current dollars (of each year in which they accrue), so that no price indexes need be applied to each year's expenditure figures to compare total cost with estimated cost.

If a contingency factor for inflation has been included in the cost estimate, it should be removed before a price change adjustment is made. Although this may seem obvious, it should not be overlooked. One wonders if an error of this type is responsible for the reported recent consistent overestimation of costs by the Corps of Engineers and Tennessee Valley Authority.

Cost overruns occur for uncontrollable and controllable reasons. The most important cause of overruns is inflation which is uncontrollable but often can be foreseen. The proper price deflator to use may be economy-wide, industry-wide, or specific to an area. There exist geographic differences in price changes that are not equalized by the movement of factors of production, especially in the short run. Price changes in San Francisco may be quite different from those in

Atlanta. There are some indexes available that differentiate between geographic areas. The Construction Cost Index published in Architectural Record and those in Engineering News Record are examples.

The second usual cause of overruns is unforeseen scope changes after the authorization of the projects. These may be due to technological problems which could not be predicted in the best of preliminary surveys. Also some delays in construction may be entirely unforeseeable; e.g., those caused by wars, new laws, or jurisdictional strikes.

Controllable overruns are due to poor administration of projects, starting with incomplete surveys of engineering, financial and legal problems which might have been anticipated ahead of time. Poor administration may also include overly complex organizational structures for planning and constructing projects, poor contracting practices, unnecessary scope changes, and simple inexperience of personnel for the type of project or the area in which the project is undertaken.

IV. Some Studies of Cost Overruns

Cost overruns are disturbing if a problem arises as to the source of financing for the unexpected costs, as it did with BART. They are also troublesome if a benefit-cost analysis and decision was predicated on one cost estimate which was later found inaccurate hence misleading. Nevertheless, those attentive to cost overruns only may fairly be called Scrooge. A very provocative paper by John E. Sawyer[9] surveys historical cost experience. He shows that if the true costs were known beforehand many projects would not have been undertaken, to the country's economic detriment. Construction of the Troy and Greenfield Railway opened from northern Massachusetts a gateway west to the Hudson. Tunneling through Hoosac Mountain cost ten times what was projected; nevertheless in the end it was a wise enterprise. In the planning of the Welland Canal between Lakes Erie and Ontario the promotor estimated "at 30 feet a cut through a ridge that nature had fixed at not less than 60 feet." The Suez Canal cost twenty times its 1838 estimate and three times its 1887 estimate. The Panama Canal cost twice its original estimate and 1.7 times its first U. S. estimate. The author concludes, "One cannot read far in the history of great economic undertakings -- particularly great developments in transport and the opening up of new resources, for example --without being struck by the recurrence of an apparently quite contrary phenomenon: instances in which entrepreneurial error or misinformation not only is massively present but where it appears to have been a condition of successful enterprise." Of course, this does not negate the theory behind benefit-cost analysis. It simply means that benefits may be more grossly underestimated than costs.

Robert Summers /10/ wrote an early paper on cost overruns which was quite controversial at RAND. He showed that past cost overruns could be "explained" to a large extent. Some argued that the results ought to be used to "debias" cost estimates so that a better idea of true costs could be used as inputs to the decision process. Others claimed that expected cost overruns would lead to even greater cost overruns. I am of the second persuasion. I believe that keeping costs low is more important than estimating costs correctly. Therefore, if a low cost estimate acts as a restraint on costs, then it is better than a more "realistic" estimate.

In observing cost estimation experience for weapon systems Summers studied the ratio of actual cost to estimated cost, which we call R. On the average, actual cost was 3.25 times estimated cost. After making adjustments for the quantity procured and inflation he found the mean ratio of adjusted actual cost to estimated cost (adjusted R) to be 1.79. The equation which best explained the variation in adjusted R (together with standard errors of the regression coefficients) was

$$\begin{aligned} \text{Ln } R = 2.479 &+ \underset{(.205)}{.097t} - \underset{(.019)}{.032tA} - \underset{(.189)}{.311A} \\ &+ \underset{(.007)}{.015A^2} + \underset{(.002)}{.008L} - \underset{(.020)}{.075(T-1940)} + u \end{aligned}$$

where t = fraction of project length complete at time of cost estimate

A = estimated degree of technological advance

L = length of development program in months

T = calendar year in which the estimate was made

u = an error term

Summers' estimated formula is not too useful in predicting cost overruns because several of his predetermined variables cannot be known at the outset of a project. This is true of t, the time of the estimate within a development program and L, the length of the development period. Before a development is complete, there is no way of knowing how long it will take.

One approach that may be fruitful is to explain the error without regard to whether the variables are ex ante or ex post, and then try to find ex ante surrogates for the ex post variables.

A more recent study of the military procurement area by the General Accounting Office [15] found that the estimated cost of 77 weapon systems increased $28.7 billion or 31 per cent from initial cost estimates. This represented an improvement from the previous year's performance in which a 40 per cent increase was reported on 61 weapon systems. Such reports are usually taken to mean that cost experience has improved over time. It may, however, mean that initial cost estimates have become more liberal. This may be a benefit in the sense that the Office of the Secretary of Defense is better informed about what it is getting into when it initiates work on a weapon system proposed by a particular Service.

James Tucker/11/ addressed the problem of cost estimation in civil works projects by observing cost predictions and results for 39 water resources projects, 39 highway projects, and 29 building projects. Unfortunately, he compared estimates immediately prior to construction rather than estimates at time of project authorization with actual cost results. Tucker found cost prediction experience worst in buildings, followed by highways and water projects. Table 1 summarizes his results.

Table 1 COST ESTIMATION EXPERIENCE IN SEVERAL AREAS OF PUBLIC WORKS

Type of Project	Mean R	Standard Deviation
Water resources	1.11	(.31)
Highways	1.15	(.41)
Buildings	1.46	(.16)

Source: James F. Tucker/11/

The degree of cost escalation in buildings is relatively predictable whereas experience in highways and water projects is more erratic.

Tucker's estimated regression equation to explain cost estimation inaccuracy (with standard errors in parentheses) is:

$$R = \underset{(.0017)}{.0233L} - \underset{(.0033)}{.0092}\ (T-1940) + \underset{(.0008)}{.0019C} - \underset{(.0032)}{.0066t}$$

T = calendar year of estimate

L = project length in years

C = estimated project cost

t = fraction of project length complete at time of cost estimate

It is interesting that larger projects are more difficult to manage. This was demonstrated in the Oakland subway experience where the contract had to be divided into smaller parts to obtain reasonable bids. Project cost management seems to be getting better over time, however. The most significant fact is that the longer the project continues the greater is likely to be the cost overrun. This is not surprising at all. Project delay and cost overruns tend to go hand in hand even after adjusting for inflation and scope.

Maynard Hufschmidt and Jacques Gerin[4] explored the estimation behavior of the Corps of Engineers, U. S. Army, the Tennessee Valley Authority, and the Bureau of Reclamation for water resource projects, looking at the extent, nature and causes of cost estimate errors.

Aware of possible changed estimation behavior for the Corps of Engineers after a 1951 House Committee on Appropriations hearing, Hufschmidt and Gerin show that for 184 projects completed between 1951 and 1965 (some estimates prior to 1951) the raw R was 1.361 and an R adjusted for price changes was .817. For 68 projects, originally surveyed in 1951 or later, "the total of actual cost and original estimated costs were less than 1 per cent apart," and the adjusted R, .77[12].

The Tennessee Valley Authority between 1933 and 1966 had an R = .947 and the frequency of overruns was 32.4 per cent (TVA estimates include projected price level changes). Many of the projects surveyed were either delayed or accelerated due to World War II.

A Bureau of Reclamation 1955 survey/12/ showed cost overruns for 90 per cent of the projects. A 1960 survey/13/ would seem to show improvement. Table 2 records cost estimating accuracy for two overlapping periods.

Table 2 BUREAU OF RECLAMATION COST ESTIMATING EXPERIENCE*

Period	Mean R	Mean Adj. R
1935-1960	1.36	1.13
1946-1960	1.09	0.96

*Some 1960 "actual" costs are estimates for unfinished projects. The Bureau of Reclamation uses its own cost index.

Source: /4, p.272/.

Table 3 COMPARISON OF AGENCY PERFORMANCE: DISTRIBUTION OF ESTIMATING ERRORS

	No. projects	Mean R	Std. dev.
TVA	61	.983	(.175)
Corps of Engineers:			
since 1954 raw R	68	1.1066	(.45)
since 1954 adj R	68	.9052	(.33)
Bureau of Reclamation			
1955 report	103	2.63	n.a.
1960 report	79	1.274	(.58)

Source: /4, p.280/.

In the case of each agency, frequency of overruns was slightly over 50 per cent for postwar performance. In summary, Hufschmidt and Gerin concluded that TVA and recent Corps of Engineers performance, as well as Bureau of Reclamation recent estimation taking into account construction price level adjustments, show no consistent bias toward underestimation of project costs./4, p.279/

Hufschmidt and Gerin also point out that large price adjustments made with a crude index (the Engineering News Record Construction Cost Index) tend to distort the true relationship of price adjustment to other factors. Thus the price effect may be overstated.

In 1951, the public works agencies furnished information on the causes of estimation error:

Table 4 ANALYSIS OF COMPONENTS OF COST INCREASES - 1951

	Per Cent	
	Bureau of Reclamation	Corps of Engineers
Price changes	30.2	57.7
Changes authorized by law	43.3	17.6
Structural and engineering modification	2.8	6.3
Changing local needs and unforeseen conditions	6.6	12.6
National emergency	5.7	
Administrative decision	8.0	
Inadequacy in planning	5.7	5.8
Other	2.9	

Source:/4, pp. 299, 308/ and /12/.

Tennessee Valley Authority errors were mainly caused by changes in the construction schedule and incomplete estimates. Typically, all agencies' errors could be accounted for because of time lags (price and scope changes) -- exogenous -- and estimates based on inadequate, sketchy preliminary surveys and changing concept of the project. Approximately 80 per cent of the deviations could be characterized as exogenous. Yet the remaining 20 per cent does reflect upon agency areas for control.

The 1960 report by the Bureau of Reclamation/13/ showed price level increases responsible for 55 per cent of the deviations from actual costs. Scope changes were responsible for 22 per cent of the deviations./5/ Other elements were unforeseen conditions and structural modifications (responsible for 11 per cent), reanalysis of work quantities and unit costs (12 per cent)./4, p.283/

The Corps of Engineers 1964 survey, after adjustment for price changes, broke down the remaining variation as in Table 5.

Table 5 SOURCES OF COST OVERRUNS, ADJUSTED FOR INFLATION, PER CENT

Land acquisition	14
Relocation	31
Design changes	51
Higher bids than expected	04

Source: See text.

Hufschmidt and Gerin proceed to discuss and illuminate the factors influencing cost estimate accuracy:

1) Project type and timing of survey and construction

The higher overruns occurred in flood control projects (levees, channel excavation, reservoirs, and local protection which involves land acquisition and relocation). Lower estimate overruns occurred in straightforward rivers and harbors projects.

Timing between survey and construction again appear important in cost overruns with TVA having short time-lag projects, while the other two agencies have lengthy authorization to construction periods with numerous project backlogs.

2) Planning and decision process

Hufschmidt and Gerin accept the view that estimation errors vary with administrative and organizational context. The best estimation performance is exhibited by an agency centrally staffed, where decisions are internal and construction is undertaken by the agency force, indicating tighter construction scheduling control. The Corps of Engineers and the Bureau of Reclamation rely on independent contractors and the resulting variable construction performance.

Interestingly, these two decentralized agencies show variable performance by geographic divisions, higher overruns in the North Pacific and Ohio River than the North Central and South Atlantic divisions. Hufschmidt and Gerin noticed no significant change in the rankings when analyzed by project mix, thus corroborating their feeling that institutional changes over time influence the estimation accuracy. Accumulation of experience, knowledge of area environment, anticipating sources of problems, and management technique all probably improve with the passage of time.

A study of estimation performance in India by J. M. Healey/3/ indicates the need for institutional and management maturity in estimation accuracy. There, 50 per cent of the error was attributed to poor management and planning -- uncertain knowledge of overhead costs, poor accounting and management controls in a developing country -- 25 per cent to estimation error, and 25 per cent to price increases.

In the United States, Hufschmidt and Gerin report that recent Corps and Bureau experience show no significant bias toward underestimation of project costs. Persistence of a sizeable variance of error still apparent in recent agency estimating performance even when adjustment for scope is considered suggests room for improved planning methods and cost estimation techniques. They conclude, "Although technical uncertainty may be an important factor for a particular class of projects . . . overall it appears to be much less important as a cause of error than administrative and institutional factors."/4, p.295/ When price adjustments are made, there in fact appears to be an overestimation bias. Hufschmidt and Gerin readily indicate that "real improvements should be measured as net reduction of error, thus the present trends toward overestimation are not real improvements in accuracy."/4, p.273/

Hufschmidt and Gerin proposed the following policy and administrative recommendations:

1) The problem of incompleteness in preliminary surveys, logically, can account for the major part of cost estimate inaccuracy. Patently, the information basis for cost estimates should be as near complete and detailed as possible.

2) When the cost of additional information to reduce uncertainty is beyond the given estimate and survey funds, then cost estimates should be presented in ranges. Also, the contingency factor could be used as a residuals index; i.e., a large contingency factor would indicate an inadequate information base.

3) Certainly, the large share of estimate inaccuracy has been price level changes and will probably continue to considerably affect estimate reliability. Therefore, the authors suggest that projected price changes could be included in the cost estimate.

4) Change administrative structures to reduce the time lags between authorization and beginning construction. They also advocate closer agency authority over planning, design, construction, and management for public works projects.

The recent agency bias toward overestimation is possibly more disturbing than underestimation in that such estimates institutionalize some of the inefficient agency operations. As mentioned by Hufschmidt and Gerin, this overconservatism is not an improvement in net estimation accuracy.

Now that we have explored the nature of the cost estimation problem, let us take a look at the problem in urban rapid transit projects and a closer look at the Bay Area Rapid Transit District performance.

V. A Synopsis of BART District Cost Estimate Errors

In 1962 the BARTD project was estimated to cost $923 million/8/ without rolling stock. As of 1971, BART was expected to cost $1,390 million to complete, a 51 per cent overrun. Tucker's appendix/11/ on ad hoc projects adjusted the BART raw R for price changes using two price indices of Engineering News Record, (the Construction Cost Index and the Building Cost Index). If we adjust the BART estimate for price changes there is virtually no cost overrun.

		Adjusted R	
	Raw R	ENRCCI	ENRBCI
BART	1.51	.97[a]	1.12[a]

a Source: Tucker/11/

There are two factors confounding these comparisons. The BARTD cost estimate included some projected price increase and Tucker compared the cost of the structures without the transbay tube to actual costs with the tube. These factors tend to counteract one another.

Our synthesis should include rolling stock. If it is, the 1962 cost estimate was $994 million. Predicted total costs as of April 1971 were $1,391 million. This yields a raw R of 1.40. The 1962 estimate, however, contemplated the acquisition of 430 cars while the 1971 estimate is based on the planned procurement of only 250 cars. If 430 cars were procured, the entire system would cost about $1,441 million and the raw R would be 1.45.*

*This estimate accounts $66.7 million as the cost of the first 250 cars and $275,000 per car for the next 180. That is the price of B cars. A cars with the control pod should be more expensive. Two factors are operating. The learning curve suggests that the price of subsequent cars should go down, but inflation suggests that the current dollar price would go up. Apparently, inflation is swamping the learning curve in this case. Even if all R&D costs are included, the average price of the first group of cars was $267,000. If we deduct the cost of developing the prototype vehicle, the average cost of the first 250 cars was $247,000.

A letter from the California Legislative Analyst in April 1966 to State Senator McAteer substantiated the major error factor to be inflation. Factors in the cost overrun according to this letter were:

unanticipated inflation	$ 46.6 million
delays	145.1
inflation and delays combined	107.0
	$ 298.7
design changes	69.3
	$ 367.0 million

The report cites inflation, delays, poor community cooperation, "cost plus" latitude for the Joint Venture, inadequate assessment of bidding climate for contract size causing design changes, misspecification, and added engineering costs as factors affecting the cost overrun.

A disaggregated analysis of cost overruns by component shows large overruns for stations and train control. Utility relocation under San Francisco Bay was more costly than forecast as were engineering changes. These statements are based on Table 6.

Table 6

RAW R RATIOS
Components of BART from 1971 Estimate

Construction Costs

Track and Structures	Stations	Yards & Shops	Elect.	Train Control	Util. Reloc.	Engr. Charges	Right of Way
1.805	2.335	2.003	.798	2.305	.997	2.249	1.399

Transbay Line

Track and Structures	Elect.	Train Control	Util. Reloc.	Engr. Charges	Right of Way
1.835	.415	3.724	2.831	1.268	.920

Rolling Stock
1.71

Source: Calculated from Merewitz and Sparks /6, p. 12/.

Table 7 MAJOR COST OVERRUN COMPONENTS OF BART CONSTRUCTION

BASIC SYSTEM	TRANS-BAY LINE
Raw R $\geq$ 2.0	Raw R $\geq$ 2.0
stations train control engineering charges yards and shops	train control utility relocation
2.0 > R > 1.0	2.0 > R > 1.0
track and structures right of way	track and structures engineering charges
Raw R $\leq$ 1.0	Raw R $\leq$ 1.0
utility relocation electrification	right of way electrification

Source: Derived from Table 6.

VI. BART by Comparison

Tables 8 through 12 present Raw R ratios for over 180 projects in water resources, highways, buildings, miscellaneous construction, and rapid transit systems. Our objective is to compare BART's cost overrun with those of other rapid transit systems and with all other projects.

Table 8 WATER RESOURCES PROJECTS

	Est.	Year	Act.	Year	Yrs. to complete	R
New Hogan Dam[1]	18	(61)	14.8	(64)	3	0.82
Carbon Canyon Dam[2]	6	(58)	5.2	(61)	3	0.87
Coyote Valley Dam[3]	15.2	(56)	17.6	(62)	4	1.16
Middle Creek Levees[4]	1.6	(59)	2.7	(67)	8	1.69
Sommerville Reservoir[5]	18.8	(62)	23.7	(67)	5	1.26
Milford Reservoir[6]	61.2	(62)	48.3	(67)	5	0.79
Terminus Reservoir[7]	23.6	(58)	19.7	(62)	4	0.83
Success Dam[8]	61.2	(58)	48.3	(62)	4	0.79
Hills Creek Reservoir & Dam[9]	32.1	(52)	45.8	(62)	10	1.43
Cougar Dam & Reservoir[10]	30.8	(47)	54.7	(64)	17	1.78
Dardanelle Lock & Dam[11]	94.6	(57)	82.0	(67)	10	0.87
Keystone Reservoir[12]	137.0	(57)	123.0	(67)	10	0.90
Sam Rayburn Reservoir[13]	50.0	(57)	60.0	(67)	10	1.20
Greers Ferry Reservoir[14]	52.1	(57)	46.7	(64)	7	0.90
Garrison Reservoir[15]	129.4	(45)	292.3	(64)	19	2.26
Walter F. George Lock & Dam[16]	87.0	(58)	82.1	(64)	6	0.94
Bonneville Reservoir (10 unit)[17]	75.0	(39)	81.4	(44)	5	1.09
Bonneville Reservoir (2 unit)[18]	40	(34)	42.4	(37)	3	1.06
Shasta Dam & Reservoir[19]	116.3	(47)	118.8	(58)	11	1.02
Keswick Dam[20]	9.2	(55)	10.2	(58)	3	1.11
Fall Creek Dam & Reservoir[21]	13.3	(47)	21.2	(67)	20	1.59
Lookout Point Reservoir[22]	68.4	(47)	87.9	(57)	10	1.29
Green Peter Reservoir[23]	34.9	(47)	82.3	(67)	20	2.36
Detroit Dam & Reservoir[24]	60.0	(47)	62.7	(58)	11	1.05
Fern Creek[25]	4.6	(47)	5.0	(51)	4	1.09

Table 8 WATER RESOURCES PROJECTS (continued)

	Est.	Year	Act.	Year	Yrs. to complete	R
St. Anthony Falls, Upper Lock[26]	10.3	(50)	18.4	(63)	13	1.79
St. Anthony Falls, Lower Lock[26]	10.2	(50)	12.4	(63)	13	1.22
Ft. Leavenworth Bridge Removal[27]	0.4	(36)	0.3	(64)	28	0.75
Alma Harbor[28]	0.08	(62)	0.06	(64)	2	0.75
Wabasha Harbor[28]	0.04	(62)	0.04	(64)	2	1.00
St. Paul Harbor[28]	0.2	(62)	0.2	(64)	2	1.00
Baker Project[29]	0.2	(31)	0.3	(32)	1	1.50
Burnt River Project[29]	0.5	(35)	0.6	(38)	3	1.20
Belle Fourche[29]	2.1	(04)	5.4	(38)	34	2.57
Friant-Kern Canal[30]	36.8	(47)	61.3	(58)	11	1.67
Delta-Mendota Canal[30]	71.2	(47)	48.4	(58)	11	0.68
Madera Canal[30]	2.6	(47)	3.4	(58)	11	1.31
Contra Costa Canal System[30]	5.4	(47)	7.8	(58)	11	1.44
Chief Joseph Dam[31]	141.0	(46)	145.0	(62)	16	1.03
The Dalles Dam[32]	326	(50)	247	(64)	14	0.76
Fort Randall[33]	133	(46)	183	(56)	10	1.38
Clark Hill Reservoir[34]	37	(45)	78	(55)	10	2.11
Kerr Reservoir[35]	40	(45)	86	(57)	12	2.15
Wolf Creek Reservoir[36]	35	(41)	78	(53)	12	2.23
McNary Lock & Dam[37]	130.7	(46)	284	(58)	12	2.17
Oroville Dam[38]	550	(58)	497.4	(67)		
Sacramento River Deep Water Channel[39]	16	(46)	41.8	(62)	16	2.61
Glen Elder Dam[40]	17	(44)	78	( )		4.59
St. Lawrence Seaway[41]	600	(54)	650	(59)	5	1.08
Niagara Power Project[41]	625	(58)	720	(61)	3	1.15
					MEAN.	1.39

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1953 estimate: *Ibid.*, 1953, I:1, p. 1240

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40. *U. S. Congressional Record*, 87th Congress, 2nd session, 1962, p. 21323. The 1944 estimate was $17 million to supply water to irrigate 26,000 acres of farmland and provide a storage capacity of 300,000 acre-feet. The 1962 estimate was $60 million and it was to irrigate 21,000 acres of farmland and a storage capaciity of 800,000 acre-feet.

41. Robert Moses, *Public Works: A Dangerous Trade*

Table 9

HIGHWAY PROJECTS

	Est.	Year	Act.	Year	Yrs.to complete	R
Carquinez Br. Superstructure[1]	9.5	(55)	9.8	(58)	3	1.03
Carquinez Br. Substructure[1]	5.5	(55)	5.9	(58)	3	1.07
Contra Costa Approach, Carquinez[1]	7.1	(55)	7.4	(58)	3	1.04
Crockett Interchange[1]	4.7	(55)	4.7	(58)	3	1.0
Solano Approach, Carquinez Bridge[1]	1.8	(55)	1.9	(58)	3	1.06
Tacoma Narrows Bridge[2]	6.0	(38)	6.4	(40)	2	1.07
Brooklyn Bridge[3]	6.7	(1867)	13.2	(1883)	16	1.97
Harvard Bridge[4]	0.5	(1887)	0.5	(1892)	5	1.0
Golden Gate Bridge[5]	32.8	(30)	35.0	(37)	7	1.07
Holland Tunnel[6]	22.3	(19)	35.0	(27)	8	1.57
George Washington Bridge[7]	50.0	(27)	55.0	(31)	4	1.10
Key West Extension[8]	15.0	(07)	49.0	(13)	6	3.27
Manhattan Bridge[9]	13.0	(04)	14.1	(09)	5	1.08
Williamsburg Bridge[10]	7.5	(1897)	14.2	(03)	6	1.89
Queensboro Bridge[11]	8.0	(1895)	13.5	(09)	14	1.69
Mackinac Bridge[12]	76.3	(51)	100.0	(57)	6	1.31
Sacramento River Bridge, Rio Vista[13]	2.7	(56)	1.1	(59)	3	0.41
Petaluma Creek Bridge[13]	2.3	(56)	2.5	(59)	3	1.09
53-7VC30[14]	2.6	(52)	3.0	(55)	3	1.15
53-7VC38F[14]	2.5	(52)	2.6	(55)	3	1.04
54-5VC2F[14]	1.1	(53)	1.2	(54)	1	1.09
54-8VC2F[14]	2.3	(53)	2.7	(54)	1	1.17
53-7VC51F[14]	1.2	(53)	1.3	(54)	1	1.08
56-11VC12[14]	2.9	(55)	3.3	(57)	2	1.14
56-7VC40F[14]	3.2	(55)	3.6	(57)	2	1.13

RTE.69, .9 mi. Eastshore Freeway[15]	6.4	(56)	5.5	(59)	3	0.86
RTE. 34, Ret. Lancha Plana, Martinez [15]	1.0	(56)	1.3	(59)	3	1.30
RTE. 75, Pleasant Hill Road to Walden Road[15]	7.5	(56)	9.3	(60)	3	1.24
US 101, Dyerville to Englewood[15]	2.6	(56)	7.0	(59)	3	2.69
RTE. 1, Patricks Point to Big Lagoon[15]	1.3	(56)	1.1	(59)	3	0.85
RTE. 187, Sandia Turn, Alamorio[15]	1.5	(56)	1.1	(59)	3	0.73
US 99, Ft. Tejon to Grapevine[15]	6.9	(56)	8.0	(61)	5	1.16
US 101, Hollywood Fwy.Ext.[15]	5.9	(56)	4.7	(59)	3	0.80
RTE. 4, 3.9 mi. Freeway[15]	3.4	(56)	3.2	(59)	3	0.94
MacArthur Freeway, Park to Buell[16]	8.7	(60)	7.8	(64)	4	0.90
RTE. 108, Fremont to RTE. 107	6.2	(60)	6.0	(64)	4	0.97
US 199, 4.2 mi. S. from Oregon	3.0	(60)	2.5	(64)	4	0.83
S. F.-Oakland Bay Bridge[17]	72.0	(30)	78.0	(36)	6	1.08
Richmond-San Rafael Bridge[18]	46.0	(51)	55.6	(56)	5	1.21
Verrazano Narrows Bridge[19]	78.0	(49)	325	(64)	15	4.17
San Diego-Coronado Bridge[20]	33	(62)	48.0	(69)	7	1.45
Triborough Bridge[21]	32.0	(29)	44.2	(36)	7	1.38
Brooklyn Battery Tunnel[22]	105.0	(39)	125.0	(50)	11	1.19
Marine Parkway Bridge[22]	6.0	(36)	6.0	(37)	1	1.00
Bronx Whitestone Bridge[22]	18.0	(38)	17.8	(39)	1	0.99
Throgs Neck Bridge[22]	93.0	(55)	92.0	(61)	6	0.99

Table 9 HIGHWAY PROJECTS (continued)

Henry Hudson Bridge[22]	3.0	(35)	3.1	(36)	1	1.03
Palisades Interstate Pkwy.[22]	40.0	(50)	50.0	(58)	8	1.25
Road Project in Iran[23]	157.1	(59)	210	(64)	6	1.37
					MEAN.	1.26

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Table 10 BUILDINGS (costs in thousands)

	Est.	Year	Act.	Year	Yrs.to complete	R
Agnews Farm Colony Ward[1]	213	(48)	320	(50)	2	1.50
Agnews Ward Bldg. Unit 2[1]	585	(48)	904	(50)	2	1.55
Agnews Warehouse[1]	27	(49)	40	(50)	1	1.48
Cabrillo Garage[1]	35	(48)	53	(49)	1	1.51
Cabrillo Physicians Residence[1]	28	(48)	42	(50)	2	1.50
Napa Wards 2 and 3[1]	1104	(48)	1656	(49)	1	1.50
Napa Continued Treatment Bldgs.[1]	192	(48)	288	(49)	1	1.50
Norwalk Firehouse & Residence[1]	24	(49)	36	(50)	1	1.50
Patton Tubercular Unit[1]	1200	(49)	2100	(51)	2	1.75
Stockton Auditorium & Chapel[1]	133	(49)	200	(50)	1	1.50
Stodkton Ward Building[1]	433	(49)	650	(50)	1	1.50
Sonoma 5 Ward Buildings[1]	809	(48)	1348	(50)	2	1.67
Chico State Science Bldg.[1]	305	(48)	350	(49)	1	1.15
Humboldt State Industrial Arts[1]	130	(49)	195	(50)	1	1.50
San Diego State Library Ext.[1]	95	(48)	143	(49)	1	1.50
S. F. State Gymnasium[1]	653	(49)	1025	(50)	1	1.57
San Jose State Womens Gym[1]	270	(49)	405	(50)	1	1.50
Cal. Poly Lib/Class Bldg.[1]	600	(47)	600	(49)	2	1.00
School for Blind, Kdgn.[1]	38	(48)	57	(49)	1	1.50
Berkeley School for Deaf Dormitory[1]	216	(48)	324	(49)	1	1.50
U.C. Berk. Chem. Exp.[1]	800	(46)	1114	(49)	3	1.39
La Jolla Library, Museum[1]	167	(40)	250	(50)	10	1.50
UCLA Bus. Adm. and Econ.[1]	1000	(46)	1400	(48)	2	1.40
UCLA Student Health Center[1]	800	(50)	1200	(52)	2	1.50

Table 10 **BUILDINGS (continued)** (costs in thousands)

	Est.	Year	Act.	Year	Yrs. to complete	R
UCLA Medical School[1]	12,000	(50)	15,500	(52)	2	1.29
Mt. Hamilton Reflecting Telescope[1]	1,200	(49)	1,800	(54)	5	1.50
S. F. Hastings College of Law[1]	1,450	(50)	1,450	(51)	1	1.00
U. C. Santa Barbara Gym[1]	466	(50)	700	(51)	1	1.50
Capitol Add., Sacramento[1]	2,400	(49)	3,600	(50)	1	1.50
BERKELEY CITY PROJECTS:						
Berkeley Grove Library[2]	65	(57)	66.5	(61)	4	1.02
Firehouse #1[2]	100	(63)	104	(67)	4	1.04
Firehouse #2[2]	194	(62)	194	(64)	2	1.00
Firehouse #3[2]	70	(60)	69	(62)	2	0.99
Firehouse #4[2]	78.6	(51)	102	(60)	9	1.30
Firehouse #5[2]	116	(62)	120	(62)	0	1.03
Center St. Garage[2]	521.7	(54)	692.6	(57)	3	1.33
Animal Shelter[2]	50	(54)	63.7	(58)	4	1.27
Bowling Greens Clubhouse[2]	25	(58)	27.8	(61)	3	1.11
San Pablo Rec. Center[2]	30,000	(64)	31,200	(67)	3	1.04
City Recreation Center[2]	165,000	(58)	177,800	(64)	6	1.08
Willard Swim Center[2]	175,000	(61)	200,800	(64)	3	1.15
Garfield Swim Center[2]	185,000	(62)	182,400	(67)	5	0.99
Burbank Swim Center[2]	175,000	(62)	180,800	(67)	5	1.03
(All figures below are in Million Dollars)						
Rockefeller's Mall (or Albany S. Mall)[6]	250	(62)	1,500	(71)		6.00
Components -- Cultural Ctr.[3]	65.4	(64)	140.5	(70)		2.15
Platform[3]	134.7	(64)	298.7	(70)		2.22

Table 10 BUILDINGS (Continued) (costs in millions)

	Est.	Year	Act.	Year	Yrs.to complete	R
Meeting Center[3]	14.6	(64)	48.6	(70)		3.33
Health Laboratory[3]	21.6	(64)	82.7	(70)		3.83
Office Tower[3]	46.1	(64)	66.4	(70)		1.44
Four Agency Buildings[3]	41.5	(64)	78.1	(70)		1.88
Motor Vehicles Building[3]	36.4	(64)	57.9	(70)		1.59
Legislative Building[3]	29.6	(64)	51.3	(70)		1.73
Justice Building[3]	10.1	(64)	25.9	(70)		2.56
Hayden Planetarium[3]	0.80	(64)	0.80	(70)		1.00
Gouverneur Hospital, N.Y.C.[4]	8.0	(61)	30.0	(71)	5	3.75
Andrews AFB, Camp Springs, Md., 30 unit Bachelor Officers' Quarters[5]	0.08	(51)	0.177	(52)	1	2.21
3,000-man airman's barracks[5]	5.125	(51)	8.175	(52)	1	1.60
Readiness Room[5]	0.165	(51)	0.154	(52)	1	0.93
Airfield pavement: 836,200 sq. yds.[5]	0.650	(51)	1.442	(52)	1	2.22
Alert hangar[5]	0.213	(51)	0.330	(52)	1	1.55
					MEAN.	1.63

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Table 11 AD HOC PUBLIC WORKS PROJECT

	Est.	Year	Act.	Year	Yrs. to complete	R
Long Beach Queen Mary[1]	8.75	(67)	57.7	(71)	4	6.59
Stanford Linear Accelerator[2]	114	(62)	114	(67)	5	1.00
Damrosch Park Guggenheim Band Shell[3]	0.832	(59)	1.529	(69)	10	1.84
John F. Kennedy Center[4]	31.0	(61)	60.0	(69)	8	1.94
New McCormick Place, Chicago[5]	72	(67)	95	(70)	3	1.32
World Trade Center, N.Y.C.[6]	270	(62)	600	(69)	7	2.22
U.N. Headquarters[7]	65	(47)	68	(52)	5	1.05
New Queens Zoo[7]	1.9	(66)	3.5	(68)	2	1.84
Zero Gradient Synchrotron (ANL)[8]	42		108.5	(68)		2.58
200 Bev Accelerator, Weston, Ill.[9]	250		403	(77)?		1.61
New Orleand Stadium[10]	35	(66)	95	(68)	2	2.71
Kansas City Stadium[11]	43	(67)	53	(68)	1	1.23
Madison Square Garden[12]	75	(61)	150	(68)	7	2.00
Lincoln Center[13]	55	(58)	160	(66)	8	2.91
Container Terminal, 7th St.[14]	24	(67)	32	(71)	4	1.33
					MEAN.	2.14

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3. 1959 Estimate: Ibid., October 13, 1959, p. 1
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Table 12 RAPID TRANSIT PROJECTS (in millions)

	Est.	Year	Act.	Year	R
Lindenwold[1]	54.2	(62)	94	(70)	1.73
Skokie Swift[2]	.524	(62)	.700	(66)	1.34
Cleveland Transit System: Southeast[3]	19.1	(60)	30	(67)	1.57
Oslo, Norway[4]	40.1	(54)	60.3	(67)	1.50
Cologne, Germany[5]	240.	(68)	255.5	(70)	1.06
Rotterdam (Main Line)[6]	468.1	(58)	913.3	(68)	1.95
(Recent addition)	89.4	(62)	125.6	(70)	1.40
				MEAN.	1.51
S. F. Bay Area Rapid Transit	1391	(62)	1446	(72)	1.45

1. Civil Engineering 40, No. 9, (Sept. 1970) p. 60

2. Thomas Buck, Skokie Swift, The Commuter's Friend (Chicago Transit Authority, May, 1968)

3. Gaspare A. Corso, "Green Light for Transportation," Cleveland Transit System, 1967

4. Letter from Mr. Ove Skaug, General Manager of A/S Oslo Sporveier, 2 September 1971

5. Letter from Kolner Verkehrs-Betriebe AG dated 13 September 1971

6. Letter from Rotterdamse Elektrische Tram, 1 September 1971

Table 13 SUMMARY OF COST ESTIMATION EXPERIENCE

Type of Project	No. of Projects	Mean Ratio Actual/Estimate
Water Resources	49	1.39
Highway	49	1.26
Building	59	1.63
Rapid Transit	8	1.51
Ad Hoc	15	2.14
Grand Mean	180	1.50

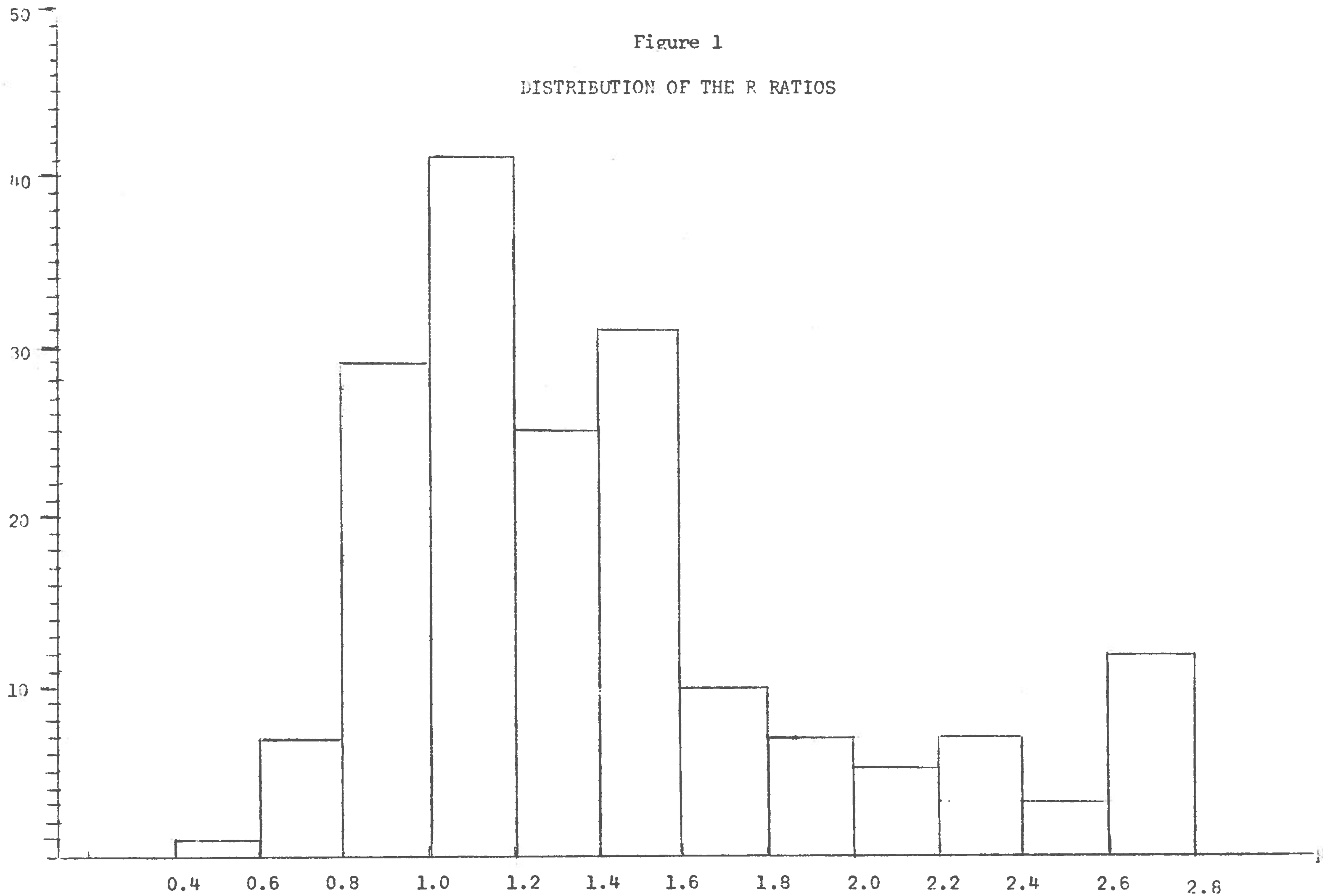
On the basis of our gross comparisons, as available in Table 13, it appears that costs are most seriously underestimated in _ad hoc_ public works. The costs of buildings are difficult to predict also. Rapid transit projects lie midway in the subsamples and midway between the mean R of 2.14 among _ad hoc_ projects and the mean R of 1.26 in highway projects.

Does the evidence suggest that there is a real difference among projects of the five types we have enumerated? This question would normally be answered by a statistical test, called an R test.

The question we would be asking, in statistical terms, is: Do all the groups of the sample appear as if they are drawn from the same population? If not, can we say that there are significant differences among groups in the sense that elements of a sample of one group, e.g. buildings, more nearly resemble each other than they do all other types of public works projects? The distortion of R ratios is given in Figure 1. It is clear that this distribution is not normal. Therefore it is not legitimate to do an analysis of variance because the R-test assumes normality. We must move instead to a test which does not depend on any particular parametric characteristic of the distribution, a distribution-free or nonparametric test. Figure 1 makes it apparent that the distribution of R is not even symmetric, usually a minimum property even for a nonparametric test. Several transformations of the R variable were used and it was found that the common logarithm (to base ten) was distributed symmetrically.

Figure 1

DISTRIBUTION OF THE R RATIOS



To assess which types of projects have better than average cost estimation performance, and which types have worse than average, a Wilcoxon signed rank test was performed.[1] This nonparametric test permits exact significance levels without the specification of a particular probability distribution for the R ratios. The Wilcoxon test does require the distribution to be symmetric, however, so the test was based on the common logarithms of the data points. This transformation yielded a distribution with reasonable symmetry.

The arithmetic average of all of the observations was taken, and each type of project was tested for significant difference of its mean from this average, using the one-tailed test which yielded the smaller P-value. A two-tailed P-value was obtained by doubling this one-tailed P-value. With one exception, the results are exact significance levels.[2] The results are tabulated below, where in each case the null hypothesis is that $R_i = R_o$, where R_i is the mean of the distribution of project type i, and R_o is the mean of the entire sample.

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[1] For a description of the method, see Frank Wilcoxon, "Individual comparisons by ranking methods," Biometrics, 1:80-83 (1945).

[2] For buildings, the exception, a normal approximation was used because the available tables did not cover sample sizes larger than 50.

Table 14 HYPOTHESIS TESTS ON MEAN R IN DIFFERENT PROJECT GROUPS

Project type	Alternative hypothesis	P-value
Water Resources	$\bar{R}_{water} < \bar{R}_o$	.0335
	$R_{water} \neq \bar{R}_o$ (two-tailed)	.0670
Highways	$\bar{R}_{highways} < \bar{R}_o$	.0001
	$\bar{R}_{highways} \neq \bar{R}$ (two-tailed)	.0002
Ad hoc	$\bar{R}_{ad\ hoc} > \bar{R}_o$	.0062
	$\bar{R}_{ad\ hoc} \neq R_o$ (two-tailed)	.0124
Rapid Transit	$\bar{R}_{transit} > \bar{R}_o$	.0977
	$\bar{R}_{transit} \neq \bar{R}_o$ (two-tailed)	.1954
Buildings	$\bar{R}_{buildings} > \bar{R}_o$	.054
	$\bar{R}_{buildings} \neq \bar{R}_o$	.108

Also tested was the hypothesis that the man of all rapid transit projects other than BART is different from the mean of BART, H: $\bar{R}_{other} = \bar{R}_{BART}$ vs. A_1: $\bar{R}_{other} > \bar{R}_{BART}$ and A_2: $\bar{R}_{other} \neq \bar{R}_{BART}$. These two tests yielded P-values of .4063 and .8126, respectively.

Table 14 can be interpreted as follows: For each class of projects the question is posed: is its mean R significantly different from the overall mean of the sample 1.50? In each case an alternative hypothesis was suggested by the data, e.g., that water resources cost estimation experience was better than average. In each case the null hypothesis is that the means are equal. The P-value is the probability of Type I error is given for the two-tailed alternative where cost experience could conceivably be better or worse within a particular group. This probability is always twice the probability of making an error of the first type in a one-tailed test.

These results allow us to say that cost overruns are smaller in water and highway projects than they are for all public works projects. Cost overruns are higher on the average in ad hoc, building, and probably rapid transit projects (although there we have almost a 10 per cent chance of Type I error in making that statement). While BARTD's cost estimating experience is a bit better than average for all types of projects, there is no evidence to indicate that it is appreciably different from transit projects in the United States and Europe. That is, BART is a typical member of the population of rapid transit projects in this respect.

I do not feel that this should end the analysis of these data. More data could be gathered on rapid transit cost experience. Perhaps there is material for a Ph.D. dissertation here. Factors affecting these cost overruns could be studied by regression analysis in the spirit of Summers and Tucker. Care should be taken, however, to use only variables which could have been known before projects were undertaken if a method to predict and prevent cost overruns is sought.

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