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COLLECTED BELOW are some valuable raw data. Their analysis has just begun. They begin to develop some historical perspective on the question of cost overruns. This subject is beclouded by myopia. The only project people recall is the present one, and they are horrified by large cost overruns. In fact, substantial cost overruns are the rule rather than the exception in public projects. The case is known for military weapon systems. It is true for other public works and could be shown, I suspect, for private projects as well were the data known. Elsewhere I have reviewed studies on military and on civilian public projects.[1] This paper will present basic data on cost overruns in five areas of public spending: water resources, highways, buildings,[2] "ad hoc" projects, and urban rapid transit projects. The general focus is to see whether the cost estimating experience in urban rapid transit projects differs from that in other areas. We shall pay special attention to the San Francisco Bay Area Rapid Transit project (BART) as a gesture to our own myopia.

We compare estimated costs at the time the decision was made to pursue the project with actual costs when the project was complete. Thus, we are indifferent whether total costs changed because of changed design or because of increasing prices. Whatever the reason, the citizen is entitled to know what his public servants are likely to spend when he votes for a bond issue of $500 million. So is the legislator when he casts his vote.

One hypothesis arising from earlier work is that the ratio of actual to estimated cost, R, is larger on bigger projects.

The 1962 cost estimate for BART was $994 million including $71.2 million for 430 cars. Predicted costs to completion as of July, 1972, are $1,346 million for construction and pre-operating expense plus a cost of $130 million for enough rolling stock to be comparable with the 1962 estimate. Thus, the total cost for the BART system is $1,476 million which yields an R of 1.49. Looking at just construction and pre-operating expense, the R for BART is 1.46.

A disaggregated analysis of the BART cost overrun in Table 1 shows large overruns for stations, engineering, train control, yards and shops, and tracks and structures. Train control, utility relocation and track and structures under San Francisco Bay were more costly than forecast on the transbay line.[3] Pre-operating expenses were quintuple those predicted. This was due to a 3½ year delay in complete construction.

Tables 2 through 6 present raw ratios of actual to predicted cost (R) for over 180 projects in water resources, highways, buildings, miscellaneous construction, and rapid transit systems. Our objective is to compare cost overruns on rapid transit projects with those of other public projects. Mean ratios within groups are given in Table 7. Our purpose is to inquire whether there are significant differences among types of projects in cost overrun experience.

On the basis of our gross comparisons, as available in Table 7, it appears that costs are most seriously underestimated in ad hoc public works. The costs

TABLE 1

EXTENT OF COST OVERRUN ON MAJOR COMPONENTS OF BART: ACTUAL COSTS (1972) DIVIDED BY ESTIMATED COSTS (1962)

BASIC SYSTEM		TRANS-BAY LINE	
	$R \geq 2.0$		
Stations	2.4	Train Control	3.6
Engineering and Charges	2.4	Utility Relocation	2.9
Train Control	2.3		
	$1.0 < R < 2.0$		
Yards and Shops	1.9	Track and Structures	1.9
Track and Structures	1.8	Engineering and Charges	1.2
Right of Way	1.3		
Utility Relocation	1.1		
	$R \leq 1.0$		
Electrification	0.8	Right of Way	1.0
		Electrification	0.4
	- - - - -		
Pre-Operating Expense	5.3		
Rolling Stock	1.8		

Data gathered by Randall Pozdena from San Francisco Bay Area Rapid Transit District, Comparative Data Report, 1 July 1972.

How Do Urban Rapid Transit Projects Compare in Cost Estimating Experience?

by

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of buildings are difficult to predict also. Rapid transit projects lie midway in the subsamples between ad hoc projects and highway projects.

Does the evidence suggest that there is a real difference among projects of the five types we have enumerated? The distribution of R is not normal nor even symmetric, usually a minimum property even for a nonparametric test. Therefore, we cannot proceed naturally to do Snedecor's F-test as we could if we could assume R was normally distributed.

To assess which tvnes of projects have better than average cost estimation performance, and which tvnes have worse than average, a Wilcoxon signed rank test was performed.[4] This nonparametric test permits exact significance levels without the specification of a particular probability distribution for R.

The arithmetic average of the group means was taken,[5] and each type of project was tested for significant difference of its mean from this average, using a one-tailed test and a two-tailed test. The two-tailed test is probably more appropriate since we had no a priori hypothesis that one type of project should be subject to smaller overruns than another. The two-tailed significance level is obtained by doubling the one-tailed level. With one exception, the results are exact significance levels.[6] The results are tabulated in Table 8 where in each case the null hypothesis is that $\overline{R_i} = \overline{R_o}$, where $\overline{R_i}$ is the mean of the distribution of project type i, and $\overline{R_0}$ is the mean of the subsample means.

Table 8 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 1.59?" 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, 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.

Cost overruns are significantly smaller in water and highway projects executed by established government agencies. Such bodies have accumulated experience doing such projects and must maintain credibility with legislators to obtain resources to do future projects. Cost overruns are greater in ad hoc public works projects as well. Ad hoc projects are typically done once for all with neither learning nor a need to establish credibility. The experience on urban rapid transit projects is worse than average but this difference is not significant in a statistical sense.[7] Urban rapid transit projects have often been constructed by inexperienced bodies which become operating transportation properties after passing an initial construction phase. They may construct extensions later. Toronto cost estimation experience did not improve over time, but probably other factors were operating. It would be interesting to adduce the experience of Montreal and Mexico City. They are alleged to have had no cost overruns but I have not had authoritative references for them yet. They were constructed by experienced Frenchmen.

A similar Wilcoxon test shows that the cost overrun experience on BART construction is not significantly different from other urban rapid transit experience in Europe and North America.

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TABLE 2
WATER RESOURCES PROJECTS
(Costs in millions of dollars)

	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
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)	318	(70)	12	0.58
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		1.38

WATER RESOURCES PROJECTS (continued)
SOURCES (Table 2)

1. 1961 estimate: U.S. Army, Civil Works Activities, **Annual Report of the Chief of Engineers**, (Washington: Government Printing Office, 1961) p. 1772. 1964 Act.: Ibid., 1964.
2. 1958 estimate: Ibid., 1958. 1961 Act.: Ibid., 1961, p. 1616.
3. 1956 estimate: Ibid., 1956, p. 1582. 1962 Act.: Ibid., 1962, p. 1718.
4. 1959 estimate: Ibid., 1959. 1967 Act.: Ibid., 1967, p. 1444.
5. 1962 estimate: Ibid., 1962, p. 882. 1967 Act.: Ibid., 1967, p. 718.
6. 1962 estimate: Ibid., 1962, p. 986. 1967 Act.: Ibid., 1967, p. 845.
7. 1958 estimate: Ibid., 1958, p. 1600; 1962 Act.: Ibid., 1962, p. 1802.
8. 1958 estimate: Ibid., 1958, p. 1600. 1962 Act.: Ibid., 1962, p. 1802.
9. 1952 estimate: Ibid., 1952, p. 2162. 1962 Act.: Ibid., 1962, p. 1902.
10. 1947 estimate: **Review of Survey, Willamette River and Tributaries, Oregon.** Corps of Engineers, Oct. 15, 1947, p. D-145. 1964 Act.: **Annual Report of the Chief of Engineers**, 1964.
11. 1957 estimate: Ibid., 1957, p. 802. 1967 Act.: Ibid., 1967, p. 775.
12. 1957 estimate: Ibid., 1957, p. 840. 1967 Act.: Ibid., 1967, p. 818.
13. 1957 estimate: Ibid., 1957, p. 745. 1967 Act.: Ibid., 1967, pp. 726-727.
14. 1957 estimate: Ibid., 1957, p. 819. 1964 Act.: Ibid., 1964, p. 740.
15. 1945 estimate: Ibid., 1945 I:2, p. 1885. 1964 Act.: Ibid., 1964, p. 870.
16. 1958 estimate: Ibid., 1958, p. 480. 1964 Act.: Ibid., 1964, p. 501.
17. 1939 estimate: Ibid., 1939. 1944 Act.: Ibid., 1944, I:2, p. 1628.
18. 1934 estimate: Ibid., 1934, p. 1334. 1937 Act.: Ibid., 1937.
19. 1947 estimate: Ibid., 1947. 1958 Act.: Ibid., 1958.
20. 1955 estimate: Ibid., 1955. 1958 Act.: Ibid., 1958.
21. 1947 estimate: **Review of Survey, Willamette River and Tributaries, Oregon**, U.S. Army Corps of Engineers, October 15, 1947, p. D-135. 1967 Act.: **Annual Report of the Chief of Engineers**, U.S. Army, 1967, p. 1523.
22. 1947 estimate: **Review of Survey, Willamette River and Tributaries, Oregon**, U.S. Army Corps of Engineers, Oct. 15, 1947. 1957 Act.: **Annual Report of the Chief of Engineers**, U.S. Army, 1957.
23. 1947 estimate: **Review of Survey. Willamette River and Tributaries, Oregon**, U.S. Army Corps of Engineers, Oct. 15, 1947. 1967 Act.: **Annual Report of the Chief of Engineers**, U.S. Army, 1967.
24. 1947 estimate: **Review of Survey, Willamette River and Tributaries**, Oregon, U.S. Army Corps of Engineers, Oct. 15, 1947. 1958: Act.: **Annual Report of the Chief of Engineers**, U.S. Army, 1958, p. 1685.
25. 1947 estimate: **Review of Survey, Willamette River and Tributaries, Oregon**, U.S. Army Corps of Engineers, Oct. 15, 1947. 1951 Act.: **Annual Report of the Chief of Engineers**, U.S. Army, 1951.
26. 1950 estimate: Ibid., 1950, p. 1441. 1963 Act.: Ibid., 1963, p. 1200.
27. 1964 Act.: Ibid., 1964.
28. 1962 estimate: Ibid., 1962, p. 1850. 1964 Act.: Ibid., 1964, pp. 800 and 1100.
29. Estimates: **Bureau of Reclamation, Project Feasibilities and Authorizations**, U.S. Dept. of Interior, 1957. Actuals: **Summarized Data on Federal Reclamation Projects**, U.S. Dept. of Interior, 1939.
30. 1947 estimate: **Annual Report of the Chief of Engineers**, U.S. Army, 1947. 1958 Act.: Ibid., 1958.
31. 1946 estimate: Ibid., Part I, Vol II, 1946, p. 2472. 1962 estimate: Ibid., Vol. II, 1962, p. 1943.
32. 1950 estimate: Ibid., 1951, Part I, Vol. 2, p. 2191. 1964 estimate: Ibid., 1964, Vol. 1, p. 1514.
33. 1946 estimate: Ibid., 1946, I:2, p. 1530. 1956 estimate: Ibid., 1956, I, p. 937.
34. 1945 estimate: Ibid., 1945, I:1, p. 707. 1955 Act.: Ibid., 1955, I, p. 339.
35. 1945 estimate: Ibid., 1945, I:1, p. 586. 1957 Act.: Ibid., 1957, I, p. 384.
36. 1941 estimate: Ibid., 1941, I:2, p. 1328. 1953 estimate: Ibid., 1953, I:1, p. 1240.
37. 1946 estimate: Ibid., 1946, I:2, p. 2321. 1958 Act.: Ibid., 1958, I, p. 1787.
38. 1958 Est.: Ibid., 1958, II, p. 1569. 1970 Est.: Ibid., 1970, II, p. 1066.
39. 1946 estimate: Ibid., 1946, pp. 2272, 2274. 1962 estimate: Ibid., 1962, pp. 1521-1526.
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 capacity of 800.000 acre-feet.
41. Robert Moses, **Public Works: A Dangerous Trade.** (New York: McGraw-Hill, 1970).

TABLE 3
HIGHWAY PROJECTS
(Costs in millions of dollars)

	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

HIGHWAY PROJECTS (continued)

	Est.	Year	Act.	Year	Yrs. to complete	R
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
56-7VC4OF[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]	2.06	(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[16]	6.2	(60)	6.0	(64)	4	0.97
US 199, 4.2 mi. S. from Oregon[16]	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
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

SOURCES (Table 3)

1. State of Calif., Dept. Public Works, Div. Highways, Thirteenth Annual Report to the Governor by the Director of Public Works, Jan. 1960, p. 93 and the Tenth Annual Report, Jan. 1957, pp. 193-195.
2. The Failure of the Tacoma Narrows Bridge, A Report to the Hon. John M. Carmody, Administrator, Federal Works Agency, Washington, D.C., March 28, 1941, pp. 5, 17.
3. 1867 estimate: Report of John A. Roebling, C.E., to the President and Directors of the New York Bridge Company on the Proposed East River Bridge, 1870, p. 32. 1883 Act.: Department of Bridges, City of New York, Annual Report, 1912, p. 272.
4. Harvard Bridge, Boston to Cambridge, by Harvard Bridge Commissioners, 1892, pp. 13, 29.
5. 1931 estimate: Golden Gate Bridge and Highway District, Report of the Chief Engineer, August 1930, p. 71. 1937 estimate: Joseph B. Strauss, The Golden Gate Bridge (San Francisco Golden Gate Bridge and Highway District, September 1937) p. 48, said 23.4; San Francisco Chronicle, May 27, 1937, said $35 million.
6. 1919 estimate: Leg. Doc. #60, Report of New York St. Bridge and Tunnel Comm., 1920, p. 64. 1927 Act.: Leg. Doc. #92, Report of New York St. Bridge and Tunnel Comm., 1929, p. 4.
7. 1927 estimate: Scientific American, November 1927, pp. 418-20. 1931 Act.: Archibald Black, The Story of Bridges, 1936, p. 14. These figures only cover the upper deck construction.
8. 1907 estimate: The Outlook, Vol. 86, no. 1, May 4, 1907, p. 11. 1913 Act.: Archibald Black, The Story of Bridges, 1936, p. 142.
9. 1904 estimate: Scientific American, Jan. 23,

1904, pp. 57, 62-63. 1909 Act.: Dept. of Bridges, City of New York, Annual Report, 1912, p. 272.

10. 1897 estimate: Scientific American, Aug. 7, 1897, p. 91. 1903 Act.: Department of Bridges, City of New York, Annual Report, 1912, p. 272.

11. 1895 estimate: Harper's Weekly, January 19, 1895, p. 52 (Does not include the terminals). 1909 Act.: Department of Bridges, City of New York, Annual Report, 1912, p. 278.

12. David B. Steinman, Miracle Bridge at Mackinac, 1957, pp. 25, 21.

13. California Highways and Public Works, State of California, Dept. of Public Works, Sacramento, Nov.-Dec., 1956. Annual Report to the Governor of California by the Director of Public Works, State of California Dept. of Public Works, Sacramento, 1959-62.

14. California Highways and Public Works, State of California, Dept. of Public Works, Sacramento, 1952. Annual Report to the Governor of California by the Directors of Public Works, State of California, Dept. of Public Works, Div. of Highways, Sacramento, 1955.

15. California Highways and Public Works, State of California, Dept. of Public Works, Sacramento, Nov.-Dec., 1956, pp. 32-33. Annual Report to the Governor of California by the Directors of Public Works, State of California, Dept. of Public Works, Sacramento, 1959-1962.

16. California Highways and Public Works, State of California, Dept. of Public Works, Sacramento, Nov.-Dec., 1960. Annual Report to the Governor of California by the Directors of Public Works, State of California, Dept. of Public Works, Sacramento, 1962-1964.

17. 1930 estimate: Report of the Hoover-Young S. F. Bay Bridge Commission to the President of the United States and the Governor of the State of California, August 1930, p. 160. 1936 Act.: "The San Francisco-Oakland Bay Bridge" by U. S. Steel, 1936, p. 93.

18. 1951 estimate: Ralph Tudor and Coverdale and Colpitts, A Report of Public Works, Division of San Francisco Bay Toll Crossings Richmond-San Rafael Bridge (January, 1951). 1956 estimate: State of California, Department of Public Works, Division of San Francisco Toll Crossings, Annual Report Financial Supplement various years 1965-1969.

19. 1964 Act.: New York Times, November 21, 1964, p. 1. 1949 estimate: New York Times, May 26, 1949, p. 31.

20. 1962 estimate: Division of Highways, State of California, Report to the California Toll Bridge Authority on a Toll Highway Crossing of San Diego between the cities of San Diego and Coronado, Aug. 1962. 1969 Actual: Goodsell, Wayne L. "A Comparative Analysis of Estimated Versus Actual Costs of Public Goods" Course Paper B.A. 202 (University of California, Berkeley) March 8, 1971, pp. 4, 5.

21. 1936 Act.: A. Black, The Story of Bridges, 1936, p. 119.

22. Robert Moses, Public Works: A Dangerous Trade.

23. "Transport for Development: A Retrospective Analysis of a Road Project in Iran," by Robert L. Geske, BA 202, p. 14.

TABLE 4
BUILDINGS
(Costs in thousands of dollars)

	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
Stockton 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 Women's 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

BUILDINGS (continued)

	Est.	Year	Act.	Year	Yrs. to complete	R
UCLA Student Health Center[1]	800	(50)	1200	(52)	2	1.50
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]	30.0	(64)	31.2	(67)	3	1.04
City Recreation Center[2]	165	(58)	177.8	(64)	6	1.08
Willard Swim Center[2]	175	(61)	200.8	(64)	3	1.15
Garfield Swim Center[2]	185	(62)	182.4	(67)	5	0.99
Burbank Swim Center[2]	175	(62)	180.8	(67)	5	1.03
(Costs in Millions of Dollars)						
Rockefeller's Mall (or Albany S. Mall)[6]	250	(62)	1,500	(71)	9	6.00
Components—Cultural Ctr.[3]	65.4	(64)	140.5	(70)	6	2.15
Platform[3]	134.7	(64)	298.7	(70)	6	2.22
Meeting Center[3]	14.6	(64)	48.6	(70)	6	3.33
Health Laboratory[3]	21.6	(64)	82.7	(70)	6	3.83
Office Tower[3]	46.1	(64)	66.4	(70)	6	1.44
Four Agency Buildings[3]	41.5	(64)	78.1	(70)	6	1.88
Motor Vehicles Building[3]	36.4	(64)	57.9	(70)	6	1.59
Legislative Building[3]	29.6	(64)	51.3	(70)	6	1.73
Justice Building[3]	10.1	(64)	25.9	(70)	6	2.56
Hayden Planetarium[3]	0.80	(64)	0.80	(70)	6	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

SOURCES (Table 4)

1. Tucker, James Franklin, "Cost Estimation in Public Works," Master of Business Administration Thesis, (University of California, Berkeley), September 1970, pp. 59, 60.
2. Goodsell, Wayne L., "A Comparative Analysis of Estimated versus Actual Costs of Public Goods," Course Paper B.A. 202B (University of California, Berkeley) March 8, 1971, pp. 4, 5.
3. 1964 estimate, 1970 estimate: "What Price Glory on the Albany Mall," **Fortune**, 83, no. 6, June 1971, pp. 92-95, 165-167.
4. "Hospital's Delay Almost Expected," **The New York Times, May 23, 1971.**
5. **Construction of Andrews Air Force Base, Report of the Committee on Expenditures in the Executive Departments,** 82nd Congress, 2nd session, House Report No. 1623.
6. 1962 estimate: **Wall Street Journal. March** 18, 1971, p. 32. 1971 estimate: **Ibid. $330 million** had been spent to that time.

TABLE 5

AD HOC PUBLIC WORKS PROJECT
(Costs in millions of dollars)

	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 Be V Accelerator, Weston, Ill.[8]	250		403	(77)		1.61
New Orleans Stadium[9]	35	(66)	95	(68)	2	2.71
Kansas City Stadium[9]	43	(67)	53	(68)	1	1.23
Madison Square Garden[10]	75	(61)	150	(68)	7	2.00
Lincoln Center[11]	55	(58)	160	(66)	8	2.91
Container Terminal, 7th St., Oakland, Calif.[12]	24	(67)	32	(71)	4	1.33
				MEAN		2.14

SOURCES (Table 5)

1. 1967 estimate: San Francisco Chronicle, 7/9/70, p. 11. 1971 estimate: San Francisco Examiner, 2/27/71.
2. 1962 estimate: New York Times, May 2, 1962, p. 10. 1967 Act.: Ibid., September 10, 1967, p. 15.
3. 1959 Estimate: Ibid., October 13, 1959, p. 1. 1969 Act.: Ibid., May 23, 1969, p. 36.
4. Newsweek, March 10, 1969, p. 109.
5. Chicago Daily News, January 2-3, 1971, p. 4.
6. 1962 estimate: New York Times Magazine, November 25, 1962, p. 36. 1969 estimate: Reader's Digest, July, 1969, p. 217.
7. Robert Moses, Public Works: A Dangerous Trade (New York: McGraw-Hill, 1970).
8. U. S. General Accounting Office, "Analysis of Estimated and Actual Costs of Certain Major Research Facilities of the Atomic Energy Commission," B-159678, February 20, 1969.
9. Sports Illustrated, May 20, 1968, p. 13.
10. 1961 estimate: Time, August 4, 1961, p. 68. 1968 estimate: Time, January 5, 1968, p. 68.
11. 1958 estimate: Newsweek, December 21, 1964, p. 74. 1966 Act.: Nation, March 22, 1965, p. 203.
12. Port of Oakland, Port Progress, May 1971. U. S. Department of Commerce, Economic Development Administration, A Study of the Future of a Marine Terminal Industry and the Possibility of Developing New Marine Terminal Facilities in Oakland, California Phase III Report, Kaiser Engineers, April 1967.

TABLE 6

URBAN 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]	240.0	(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
San Francisco Bay Area Rapid Transit	923.0	(62)	1346.0	(72)	1.46

URBAN RAPID TRANSIT PROJECTS (continued)

	Est.	Year	Act.	Year	R
San Bernardino Freeway[7] Los Angeles Exclusive Bus Lane	34.0		58.0	(73)	1.71
Toronto:					
Yonge St. Line[8]		(46)	67.0	(54)	
Bloor-Danforth[9]	200.0	(58)	279.0	(66)	1.39
Bloor-Danforth Extensions[10]	77.0	(65)	77.7	(68)	1.009
North Yonge Street Extension, Eglinton to Sheppard[11]	57.0	(65)	102.5	(73)	1.80
Sheppard to Finch[11]	21.0	(68)	37.5	(74)	1.79
Paris:[12]	MF		MF		
Nation to Boissy-St. Leger	509.0	(64)	800.0	(71)	1.57
Auber to Nanterre; Nanterre to St. Germains en Laye modernization	1335.0	(64)	2150.0	(71)	1.61
Gambetta-Gallieni	136.0	(67)	220.0	(68)	1.62
Charenton Ecoles to Carretour de l'Achat	86.0	(67)	125.0	(69)	1.45
			MEAN	. . . .	1.54
Mexico City[13]	240	(67)	400	(70)	1.66
Montreal[14]	132	(61)	228	(67)	1.73

SOURCES (Table 6)

1. **Civil Engineering 40,** No. 9, September 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, p. 35.
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.
7. **Los Angeles Times,** 13 February, 1973, p. 1.
8. Actual 1954 Costs: **Modern Transport,** 5 March 1966 and Toronto Transit Commission, **Transit in Toronto,** p. 64.
9. **Ibid.**
10. **Ibid.,** pp. 49, 66 for 1968 actual costs; also in **Railway Age,** June, 1968. Estimated costs in **Metropolitan,** November 1965, "Emerging Toronto: After Metro What?" p. 45.
11. **Railway Age,** 3 June 1968, **Op. Cit.,** pp. 16-19, and Toronto Transit Commission, **Loc. Cit.,** and **Metropolitan, Op. Cit.**
12. Letter from M. Barbier, Institut D'Amenagement et D'Urbanisme de la Region Parisienne, 10 January 1973.
13. "Metro of Mexico City, D.F." **City and Suburban Travel,** September, 1969, No. 104, p. 5. Montreal and Mexico City, according to the popular press of San Francisco had no cost overruns. This and the next datum were discovered after the analysis was completed.
14. G. Derou, "The Montreal Metropolitan Railroad," U.I.T.P. **Revue** vol. 16, No. 4, 1967, p. 314.

To summarize, urban rapid transit cost estimating experience is not significantly different from that on other non-military public works projects and BART is a typical member of its group no better or no worse than the others. I do not feel that this should end the analysis of these data. Someone would brighten my day if they could give me an authoritative cost estimate for the Yonge Street line in 1946 to fill a gap in my paper. 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[8] and Tucker.[9] 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.

TABLE 7
SUMMARY OF COST ESTIMATION EXPERIENCE

Type of Project	No. of Projects	Mean Ratio R = Actual/ Estimate
Water Resources	49	1.38
Highway	49	1.26
Building	59	1.63
Rapid Transit	17	1.54
Ad Hoc	15	2.14
Grand Mean	189	1.59

TABLE 8

HYPOTHESIS TESTS ON MEAN R IN DIFFERENT PROJECT GROUPS

Project type	Alternative hypothesis	P-value
Water Resources	$\overline{R}_{water} < \overline{R}_o$	.0068
	$R_{water} \neq \overline{R}_o$ (two-tailed)	.0136
Highways	$\overline{R}_{highways} < \overline{R}_o$	.0000
	$\overline{R}_{highways} \neq \overline{R}$ (two-tailed)	.0000
Ad Hoc	$\overline{R}_{ad\ hoc} > \overline{R}_o$	.0240
	$R'_{ad\ hoc} \neq R_o$ (two-tailed)	.0480
Rapid Transit	$\overline{R}_{transit} > \overline{R}_o$	.0727
	$R'_{transit} \neq R_o$ (two-tailed)	.1454
Buildings	$\overline{R}_{buildings} > \overline{R}_o$	.3015
	$\overline{R}_{buildings} \neq \overline{R}_o$ (two-tailed)	.6030

FOOTNOTES

1 Leonard Merewitz, "Cost Overruns in Public Works" in William Niskanen, et al., **Benefit-Cost and Policy Analysis Annual 1972**, (Chicago: Aldine, 1973); Also see L. Merewitz and S. H. Sosnick, **The Budget's New Clothes: A Critique of Planning-Programming-Budgeting and Benefit-Cost Analysis**, (Chicago: Markham, 1971), pp. 212-225.

2 In the section on buildings, many buildings built for proprietary firms are analyzed. Perhaps later it would be instructive to segregate these from the public buildings.

3 See L. Merewitz and T. Sparks, **A Disaggregated Comparison of the Cost Overrun of The San Francisco Bay Area Rapid Transit District**, Working Paper No. 156/BART 3, Institute of Urban and Regional Development, Berkeley, California, 10 May, 1971.

4 For a description of the method, see Frank Wilcoxon, "Individual Comparisons by Ranking Methods," **Biometrics**, 1:80-83 (1945). Also see J. L. Hodges, Jr. and E. L. Lehmann, **Basic Concepts of Probability and Statistics**, Second Edition (S. F.: Holden-Day, 1970), pp. 346-369.

5 The overall mean was calculated as the average of the group means. The number of projects in each subsample was not systematically determined, and we did not intend to weight our evidence in this way.

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

7 This may seem ironic because the mean is higher for all projects than for urban rapid transit projects. This is true for a comparison of the arithmetic means but our test worked with logarithms and it is not necessarily true that the mean of a group of arithmetic values is equal to the antilogarithm of the mean of the logarithms. The transit distribution is less widely dispersed and also less skewed than the overall distribution of cost overrun data. The result of transforming to logarithms pushes the overall mean back further to the left than the rapid transit mean. Thus transit cost estimation experience is worse than the median experience of public projects. The Wilcoxon test further does not involve statements about means or any other parameters of distributions. It is a non-parametric test operating with individual differences rather than the mean of any distribution. The larger deviations from the grand mean logarithm among urban rapid transit projects were positive. Negative deviations tended to be smaller in absolute value. Therefore, the hypothesis suggested by the data is that rapid transit cost experience is worse than mean cost experience. But we can say that there is a significant difference only if we are willing to accept a 14.5% probability of rejecting a true hypothesis in repeated applications of such a test.

8 R. Summers, "Cost Estimates as Predictors of Actual Costs: A Statistical Study of Military Developments" in T. Marschak, Glennan and Summers, **Strategy for R & D**, (New York: Springer-Verlag, 1967).

9 James F. Tucker, **Cost Estimation in Public Works**, Master of Business Administration thesis, University of California, Berkeley, California, September, 1970.