AN ANALYSIS OF ENERGY CONSERVATION MEASURE COSTS

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The Denver Support Office completed a project to evaluate cost estimation in the Institutional Conservation Program. Unit cost characteristics and cost prediction accuracy were evaluated from 1,721 Energy Conservation Measures (ECMs) and 390 Technical Assistance (TA) reports funded in the last six years. This information is especially useful to state and DOE review engineers in determining the reasonableness of future cost estimates.

The estimated cost provisions for TA report grants were generally adequate to cover the actual costs. Individually, there was a tendency for TA reports to cost less than estimated by about 10%. TA report unit costs averaged $.09 to $.11 per square foot, and decreased as the building size increased.

Individually, there was a tendency for ECMs to cost more than estimated by about 17%. Overall, the estimated costs of the 1721 measures were $20.4 million, while the actual costs were $21.4 million. This 4.6% difference indicates that, overall, ECM cost estimates have provided a reasonable basis for grant awards. There was a high variation in ECM unit costs. The data did not support speculation that there is a tendency to manipulate cost estimates to fit ECMs within the simple payback eligibility criteria of 2 to 10 years.

INTRODUCTION

The U.S. Department of Energy, Denver Support Office (DSO) is responsible for Federal administration of the Institutional Conservation Program (ICP) in the states of Colorado, Idaho, Montana, North Dakota, South Dakota, Utah, and Wyoming. The ICP provides matching grants to schools and hospitals to conduct Technical Assistance (TA) engineering studies and to implement recommended Energy Conservation Measures (ECMs).

The investment value of the ICP funded projects is determined by two factors: the project capital cost and the resulting energy cost avoidance. Both are estimated prior to the award of an ICP grant since the simple payback (initial cost divided by annual energy cost savings) determines ECM eligibility, and since the grant awards are based on the cost estimates. DOE cost allowance guidelines form the basis for cost estimates of TA reports. Licensed engineers and architects prepare cost and energy savings estimates of ECMs. State and DOE engineers review ECM cost and savings estimates before grants are awarded.

Generally the majority of effort expended in the analysts' preparation of TA reports is directed toward the estimation of energy use and prediction of energy savings. Consequently, state and Federal engineers who review TA reports expend most of their effort analyzing estimated energy use and savings. However, the cost estimates are equally important to the total success of a project, and as such merit greater attention in the overall review and evaluation process.

The Denver Support Office initiated this project to evaluate cost estimation in the ICP. This was

accomplished by determining ECM and TA report unit cost characteristics, evaluating the accuracy of cost predictions, and by investigating the possibility of correlations between cost tendencies and project size or estimated payback.

METHODOLOGY

Data was collected from completed TA and ECM grant projects funded from Cycles 4-9 (1982-1987). For both types of grants, the actual and estimated costs were recorded along with the appropriate cost units. Actual costs were always taken from grantee final reports.

The estimated TA report costs were provided in approved TA grant budgets. These budgets were determined by grantee application and state recommendation, and were subject to a maximum allowance range of $.12 to $.15 per square foot. The cost unit of a TA report was always the building square footage.

The estimated ECM cost and the cost units were provided in the TA reports or in subsequent change of scope documentation. The ECM cost unit was specific to each ECM. For example, the cost unit of windows was square feet, pipe insulation was linear feet, motors was horsepower, etc.

The data were organized by state, whether from an urban or a rural institution, and building type (School, Hospital, University, or other). Other important information such as whether a grant involved hardship or a change of scope, the estimated simple payback of a measure, and the TA analyst was recorded so that possible correlations or comparisons to the cost analyses results could be investigated. The data were accumulated in a computer database, and organized to provide simple manipulation.

Actual Unit Cost Analysis

Actual cost characteristics were determined by calculating the average cost per unit of measure and the standard deviation. The average cost per unit was calculated by two methods. First, the individual average, which is the average of the cost per unit for each individual building or measure was calculated as shown in Equation 1.

$$\text{Ind. Avg.} = \frac{\sum_{i=1}^{n} \frac{\text{Cost}_1}{\text{Unit}_1} + \frac{\text{Cost}_2}{\text{Unit}_2} + \frac{\text{Cost}_3}{\text{Unit}_3} + \ldots + \frac{\text{Cost}_n}{\text{Unit}_n}}{n} \quad (1)$$

Then, the aggregate average, which is actually the sum total cost divided by the sum total units was calculated as shown in Equation 2.

$$\text{Ind. Avg.} = \sum_{i=1}^{n} \frac{\text{Cost}_1 + \text{Cost}_2 + \text{Cost}_3 + \ldots + \text{Cost}_n}{\sum_{i=1}^{n} \text{Unit}_1 + \text{Unit}_2 + \text{Unit}_3 + \ldots + \text{Unit}_n} \quad (2)$$

The difference between these two evaluation measurements is that the aggregate average is influenced more heavily by large projects while the individual average gives equal weight to all projects.

Cost Prediction Accuracy Analysis

Cost prediction accuracy and over/underrun tendencies were determined from the ratio of the actual cost to the estimated cost (A/E) and the total numbers of overruns and underruns. The ratio of the actual to the estimated cost was calculated in two ways. The sum total actual was divided by the sum total estimate to provide an aggregate average A/E ratio. The individual average of the A/E ratio of each project was also calculated.

Cost Tendency Correlations

Further analyses were considered to determine if there were any trends toward over/underruns based on the size of the project or the estimated simple payback. Graphs were constructed comparing the ratio of the actual to estimated cost with: the building square footage of TAs, estimated cost of ECMs, and estimated simple payback of ECMs.

TA COST INFORMATION

Results - Actual Unit Costs and Cost Prediction Accuracy

The overall regional results are shown in Table 1. Overall, the aggregate average cost per square foot ($.09/ft^2) was somewhat smaller than the individual

Table 1. Summary of Region-Wide TA Report Cost Results

Number TA Reports	390
Aggregate Sum Total Cost / Sum Total Sq. Ft.	$.09
Individual Average Actual Cost / Sq. Ft.	$.11
Standard Deviation	$.05
Aggregate Sum Total Actual / Sum Total Estimate	.850
Individual Average of Actual / Estimate	.924
Number of Overruns	53
Number of Underruns	232
Number Same Cost	105
Highest Actual Cost	$28,630.00
Average Actual Cost	$3769.51
Lowest Actual Cost	$191.00
Highest Square Footage	267,936
Average Square Footage	39,901
Lowest Square Footage	1,696

average ($.11/ft^2). This is an indication that large buildings may cost less per square foot, since the aggregate average is more heavily influenced by larger projects. The standard deviation of the individual average was .05. Overall, there was a tendency towards cost underruns. The ratio of sum actual to sum estimate was 0.85, the individual average of actual to estimate was 0.92, and 232 out of 390 TA reports experienced cost underruns. This indicates grant budgets have generally been adequate to provide for costs of TA reports.

Summary results for institution types and urban and rural locations are shown in Table 2. These results indicate that TA reports for rural institutions cost slightly less than for urban institutions. Schools (K-12) were the lowest cost institution type while hospitals were the highest.

Cost Tendency Correlation

Relationships between building size and tendencies toward cost overruns or underruns were investigated by comparing the ratio of the actual to estimated cost to the building square footage, as shown in Figure 1. Figure 1 is a bar graph plotting the individual average of the A/E cost ratio for each square footage range. The Figure indicates a greater tendency for cost overruns at lower square footages. There are two possible reasons for this tendency.

First, the allowable grant budgets for Cycles 1-7 were generally based on a fixed amount per square foot (usually $.12/ft^2) regardless of building size. This allowance did not consider there is a certain fixed amount of effort and cost associated with preparation of a TA report which is independent of building size. Therefore, budgets may have been allowed for smaller buildings which did not adequately represent real costs, thus increasing the tendency to overrun. The DSO policy was changed prior to Cycle 8 to reflect this consideration. Currently the DSO allows up to $.15 per square foot for schools and up to $.20 per square foot for hospitals with a minimum allowance of $1500.

Second, there were four central plants reviewed in this project. Central plants are quite different from most buildings which receive TA reports in ICP. They typically have a great deal of mechanical and electrical equipment in a small amount of space. The required effort and cost for a TA report in a central plant is much more dependent on the complexity of the equipment than the building size. Therefore, a cost allowance for central plant TAs which is solely dependent on square footage will probably be inadequate. The actual cost for the four central plant TAs in this project averaged $.27 per square foot, three of the four had cost overruns, and

Table 2. Summary of Region-Wide TA Report Cost Results By Category

Category	#	Agg. Cost	Ind. Cost	Std. Dev.	Agg. A/E	Ind. A/E
Rural	185	$.09	$.11	.04	.79	.85
Urban	205	$.10	$.12	.05	.90	.99
Schools	236	$.08	$.10	.04	.80	.88
Hospitals	32	$.12	$.13	.05	.88	.91
University	82	$.11	$.12	.05	.94	1.04

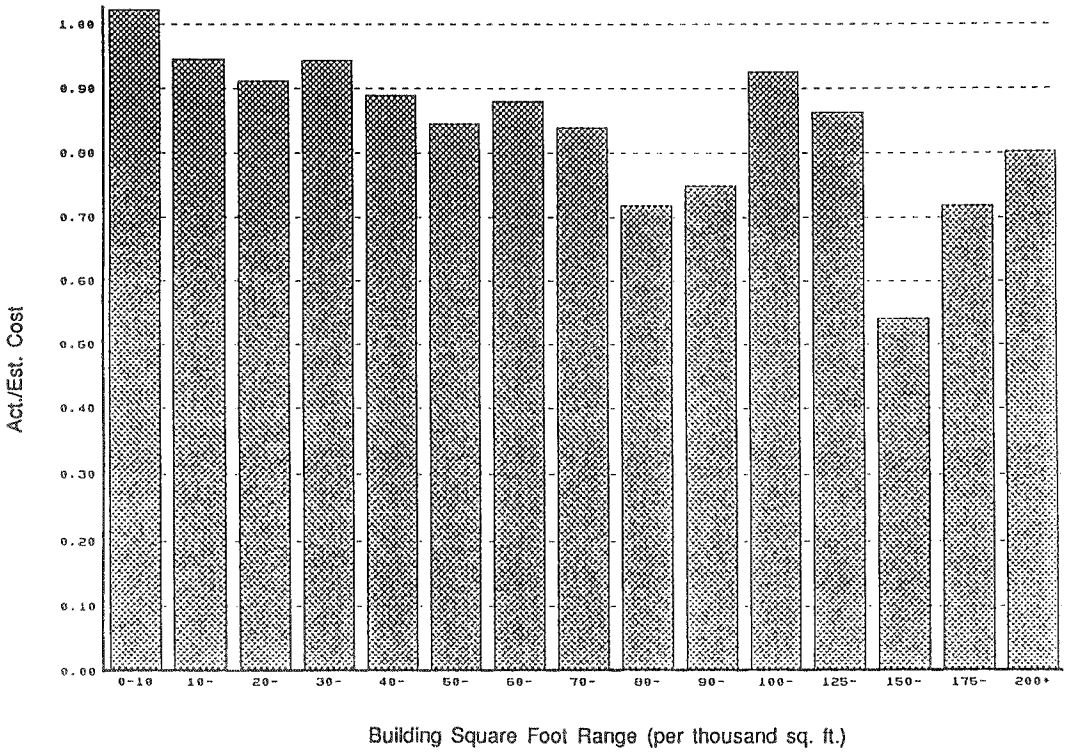

Figure 1. Ind. Average Act./Est. Cost vs. Square Foot Range for TA Grants

the individual average of the ratio of actual to estimated cost was 3.44.

ECM COST INFORMATION

Results - Overall

A total of 1721 ECMs was included in this assessment. The overall results are shown in Table 3.

The aggregate average ratio of 1.046 indicates that the sum of all actual costs for all measures was 4.6% higher than the estimated costs. For 1721 measures the estimated cost was $20,467,371 and the actual cost was $21,411,168. In addition 882, or about 51.2%, experienced cost overruns, and 759, or 44.1%, experienced cost underruns. The remaining 80 ECMs had the same actual as estimated cost.

Table 3. Summary of Region-Wide ECM Cost Results

Number of Energy Conservation Measures	1,721
Aggregate Avg. Sum Total Actual / Sum Total Estimate	1.046
Individual Average of Acutal / Estimate	1.169
Number of Overruns	882
Number of Underruns	759
Number Same Cost	80
Highest Actual Cost	$358,987.00
Average Actual Cost	$12,441.12
Lowest Actual Cost	$20.86
Highest Estimated Cost	$358,052.00
Average Estimated Cost	$11,892.72
Lowest Estimated Cost	$15.00
Average Payback	6.12 Years

On an overall basis these results appear to be within reasonable expectations.

The individual average A/E cost ratio of 1.17 indicates that for any individual measure there was an average cost overrun of 17%. This result is somewhat unexpected since the individual average A/E ratio is based on an equal contribution from each ECM, regardless of magnitude, and since there were only about 5% more ECM cost overruns than the total of ECM cost underruns and same cost ECMs (882 vs. 839 respectively). The unexpectedly high individual A/E cost ratio and the fact that it differs significantly from the sum average A/E cost ratio suggest there was a difference in the overall character of ECM cost underruns and overruns.

The apparent difference in the nature of ECM cost overruns and underruns was investigated further by comparing the results for each category. The results are shown in Table 4.

The average estimated cost of both overruns and underruns was about the same, $12,100. The average cost overrun was $3510 and the average underrun was $2922. The average individual A/E ratio for all overruns was 1.58 while for underruns it was .71. These results indicate cost overruns which did occur were on average greater in magnitude than cost underruns.

Results - Individual ECM Types

There were a total of 54 ECM types reviewed in this project. A sampling of results for six of the more common ECM types is shown in Table 5. The ECMs could have been separated by state, urban/rural, and building type. However, only a few measures occurred in sufficient quantity to attempt this type of breakdown.

The standard deviation on all projects was significantly large compared to the individual average. There are probably several reasons for this high cost variation.

Retrofit projects are by nature non-uniform. Each project may have a unique degree of effort required for design, demolition, equipment, and installation. For example, some lighting retrofits require simple replacement of existing fixtures using the same wiring and switching. Other similar lighting retrofits which use the same type of replacement fixtures may require completely new fixture patterns, wiring, and switching, thus increasing the cost. Costs may also vary according to the availability of products and the degree of competition present for design and contractor services.

Certain categories of ECM may be more accurately estimated on a unit basis than others. Generally the level of effort and cost for architectural, insulation,

Table 4. Results for ECM Overruns and Underruns

Type	#	Avg. Act. $	Avg. Est. $	Total Act. $	Total Est. $	Avg. Diff.	Sum A/E	Ind. A/E
Over	883	$15,616	$12,106	$13.8M	$10.7M	$3510	1.29	1.58
Under	759	$9,227	$12,149	$7.0M	$9.2M	$2922	.77	.71

Table 5. Individual ECM Type Cost Results

ECM Type and (#)	Sum Avg. Cost/Unit	Ind. Avg. Cost/Unit	Std. Dev.	Ind. Avg. A/E	Sum Avg. A/E
Shut down controls (294)	$397/point	$694	$1,094	1.06	.89
Window panels (172)	$7.19/sq.ft.	$9.38	$9.65	1.36	1.17
Fluorescent lights (137)	$125/fixture	$118	$81	1.14	1.16
Batt Ceiling Insul. (62)	$.75/sq.ft.	$1.69	$4.53	1.00	.84
Pipe Insulation, 0-2" (59)	$5.52/lin.ft.	$5.98	$3.79	1.10	1.15
Energy Mgt. System (57)	$561/point	$849	$903	1.04	.99

and lighting measures seem to be more dependent on the specified units, i.e. square feet, linear feet, entrances, fixtures, etc. Generally, the costs for heating and cooling plant, distribution, and control measures are more difficult to predict on a unit basis. These measures tend to be unique for each application and have a greater variation in complexity.

ECM project description information was taken from TA documents. This documentation provides a general description of the scope of a project, but does not provide the level of detail of actual design specifications. Therefore, there could be some measures where the actual installation differed somewhat from the TA description. There are also a few cases where engineering judgment was used to estimate the cost units.

The high cost variation indicates that the ECM cost per unit information generated in this project may be meaningful from a general, region-wide perspective, but not necessarily for a specific project. The information may be especially meaningful to state and DOE engineers reviewing TA reports to determine whether costs are near the region average or within a relevant range. However, the results should not be used by analysts in the preparation of TA reports since the cost estimate of every project must include distinctive characteristics

such as ECM details, local labor and material costs, and competitive design and contractor rates.

Cost Tendency Correlation - Manipulation to Achieve Eligibility

There has been speculation that cost estimates may be manipulated by TA analysts for the sole purpose of qualifying ECMs within program eligibility criteria. The eligibility criteria for Cycles 1-7 (1980-1985) were that the estimated simple payback of a measure fall between 1 and 15 years. Currently the simple payback must be between 2 and 10 years to be considered eligible. If cost estimates are intentionally manipulated, it might be expected that the cost of measures around the lower payback threshold would be overestimated and the cost of measures around the higher threshold would be underestimated. This would result in an abnormal incidence of actual cost underruns around the lower threshold and an abnormal incidence of cost overruns around the higher threshold.

This concern is investigated by comparing the individual average ratio of actual to estimated costs to the estimated simple payback in one year increments as shown in Figure 2. Note for this graph that the 0-1 year simple payback bar includes only those measures where the simple payback is rounded down to 1.0 year. Only 150 ECMs out of the total of 1721 analyzed in this project were awarded in Cycles 8 or 9. Therefore, the applicable threshold criteria for assessing tendencies to manipulate cost estimates from the graph are estimated simple paybacks of 1 and 15 years, since 92% of the represented ECMs were awarded when these were the eligibility limits. A visual assessment of these figures does not reveal any tendencies toward cost underruns around lower paybacks and cost overruns around high paybacks.

These data do not provide quantitative support for speculation that there are general tendencies to manipulate ECM cost estimates to fit them within eligibility criteria. They also do not prove that cost estimate manipulation does not take place in isolated cases.

Cost Tendency Correlation - Accuracy as a Function of Project Size

The tendencies of measures to experience cost overruns or underruns as a function of project size were also investigated. The actual/estimated cost ratio was compared to the estimated ECM cost in Figure 3.

A visual assessment reveals that there is apparently a significantly greater likelihood for the A/E ratio to be greater than one for measures less than $10,000. There are also a particularly high number of measures where the actual cost was 2 to 4 times higher than the estimated when the estimated cost was in the $0 - $1,000 range. In addition the majority of measures are in the $0 - $10,000 range.

While this comparison indicates that cost estimates have been less accurate on a ratio basis for lower cost projects, this does *not* provide a basis for concluding that there is a real problem for cost estimating in this range of projects or that the result is even unexpected. The ratio basis in reality has different ramifications for different sized projects. For example a cost overrun of $200 on a $300 controls project would be more acceptable and have far less of an impact than an overrun of $200,000 on a $300,000 controls project, even though the ratio of actual to estimated cost would be the same. The results simply support an expected conclusion that there is greater variation in the actual cost to estimated cost ratio as the size of the project becomes smaller.

SUMMARY/CONCLUSIONS

1. A total of 390 TA reports were included in this analysis. The regional average cost per square foot was $0.09 to $0.11 per square foot. The ratio of actual to estimated costs was 0.85 to 0.92. Overall, there were 53 cost overruns and 232 cost underruns. Overall, cost estimates appear to provide adequate grant budgets for institutions which procure TA reports in the ICP.

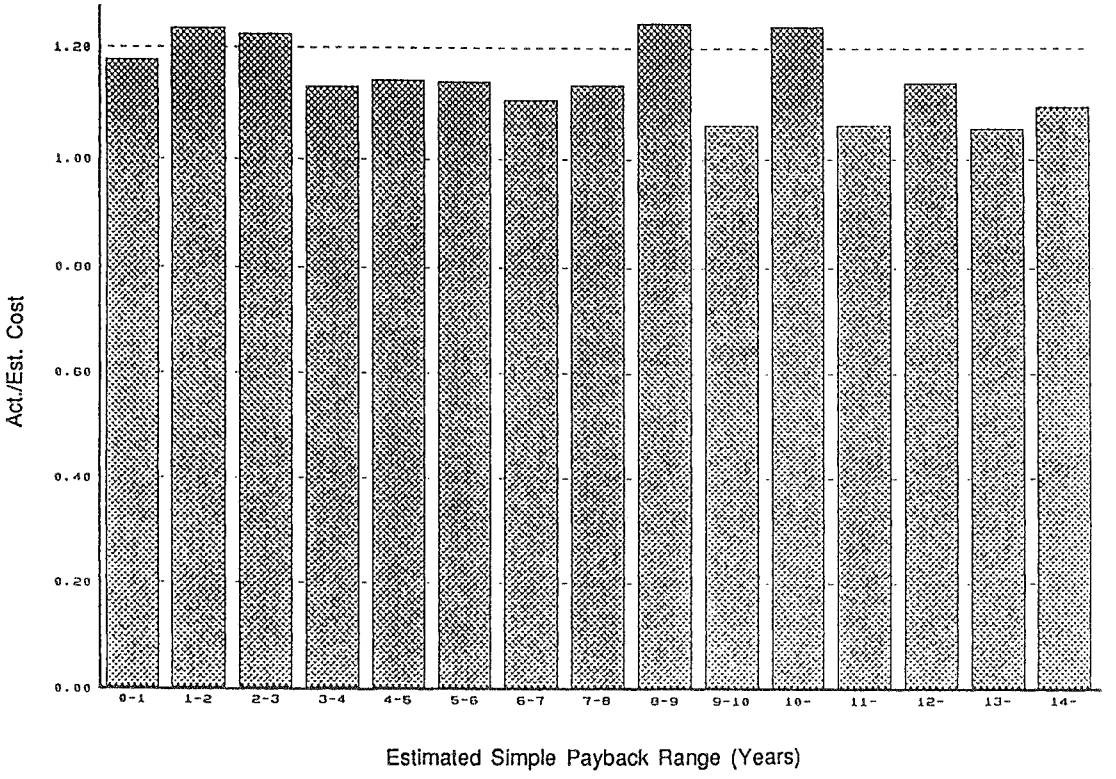

Figure 2. Ind. Average Act./Est. Cost vs. Simple Payback for ECM Grants

2. TA reports generally cost less per square foot as the building area increases.
3. A total of 1721 ECMs were included in this analysis. On an overall basis the ratio of the sum of actual costs to the sum of estimated costs was 1.046. There were cost overruns in 51.2% of the measures and cost underruns in 44.1% of the measures. The actual cost was the same as the estimated in 4.7% of the measures. Overall, the results appear to be within reasonable expectations.
4. On an individual ECM basis there was an individual average ratio of actual to estimated costs of 1.17. This is somewhat higher than expected and may be attributed to the fact that average ECM cost overruns were larger in magnitude than average ECM cost underruns. The average overrun was $3510 and the average underrun was $2922.
5. There was a very high variation in actual ECM unit costs. Because of this high variation, the ECM unit cost information generated in this project may be meaningful from a general, region-wide perspective, but not necessarily for a specific project. The information may be especially meaningful to state and DOE review engineers. The results should *not* be used by analysts in the preparation of TA reports since the cost estimate of every project must include distinctive characteristics such as ECM details, local labor and material costs, and competitive design and contractor rates.
6. The data do not provide quantitative support for speculation that there are general tendencies to manipulate ECM cost estimates to fit them within eligibility criteria. The data also do not prove that cost estimate manipulation does not take place in isolated cases.

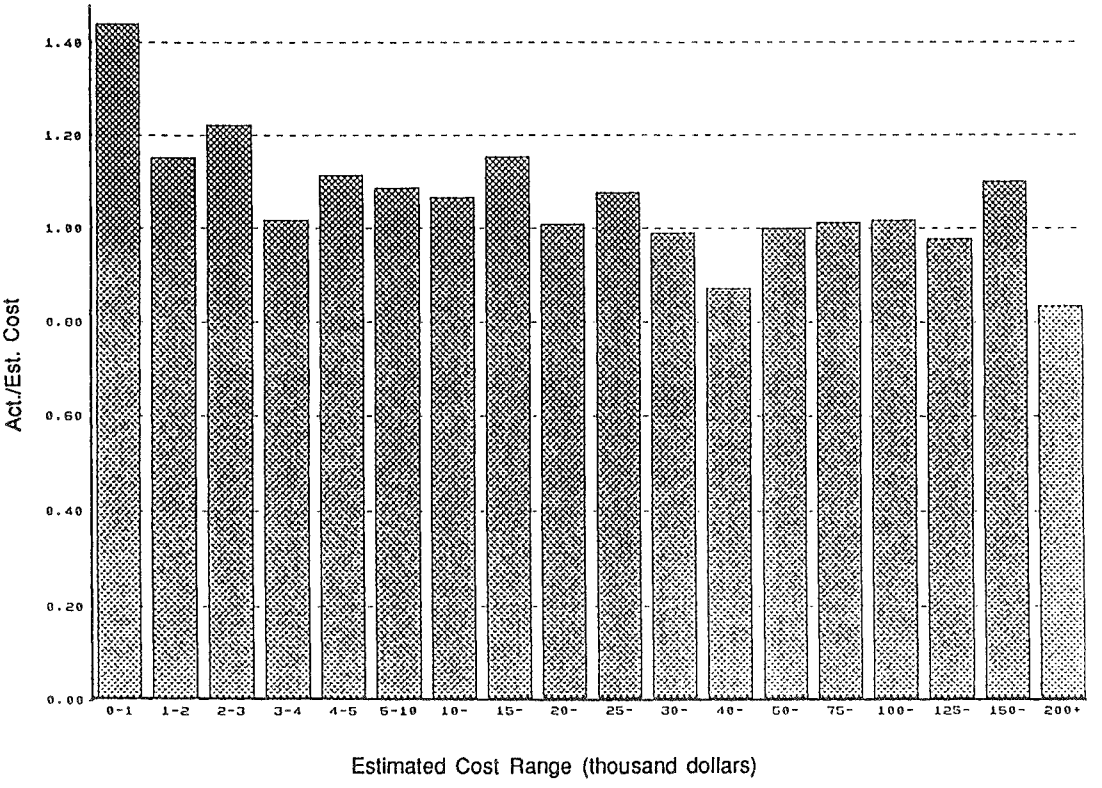

Figure 3. Ind. Average Act./Est. Cost vs. Estimated Cost Range for ECM Grants

7. There were a significantly greater number of measures where the actual to estimated cost ratio was greater than one when the cost was in the $0-$10,000 range. There were also a high number of measures where the actual cost was 2 to 4 times higher than the estimated when the estimated cost was in the $0-$1,000 range. A majority of measures were in the $0-$10,000 range.

While this comparison indicates that cost estimates have been less accurate on a ratio basis for lower cost projects, this does *not* provide a basis for concluding that there is a real problem for cost estimating in this range of projects or that the result is even unexpected.