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16. Abstract This study was undertaken to analyze costs, quality, and policy of using consulting services by the SDHPT for preliminary or pre-construction engineering. The issue arises out of essentially non-technical grounds rather than any need for a fundamental assessment of SDHPT's performance and policy. Briefly, the amount of preliminary construction engineering work being contracted to consultants rose from $9.2 million in FY 1980 to $36.97 million in FY 1986. This was principally caused by an unprecedented increase in the Department's construction program fueled by both State and Federal user tax increases. To handle this peak load of work, SDHPT selected and utilized a number of consulting engineering firms to prepare plans, specifications, and estimates that historically have been done by the in-house engineering staff.

As a result of this large increase in the market for their services, consulting engineering firms are now seeking to maintain an amount of highway work that is higher than historical levels and larger than is currently deemed necessary by the SDHPT. Although the resolution of this issue will not be accomplished herein, the results of this study will provide some useful information to help understand the implications.

The essential results:

1. Cost of engineering services is lower when using State forces instead of consultants.
2. Quality of work is similar in comparison between State forces and consulting engineering firms.
3. Policy for peak load and specialty work using consultants need not be altered.

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UTILIZATION OF CONSULTANTS BY SDHPT

by

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Research Report 1100-1F
Research Study Number 2-1-86-1100

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The Texas A&M University System
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SUMMARY

This study was undertaken to analyze **costs, quality,** and **policy** of using consulting services by the SDHPT for preliminary or pre-construction engineering. The issue arises out of essentially non-technical grounds rather than any need for a fundamental assessment of SDHPT's performance and policy. Briefly, the amount of preliminary construction engineering work being contracted to consultants rose from $9.2 million in FY 1980 to $36.97 million in FY 1986. This was principally caused by an unprecedented increase in the Department's construction program fueled by both State and Federal user tax increases. To handle this peak load of work, SDHPT selected and utilized a number of consulting engineering firms to prepare plans, specifications, and estimates that historically have been done by the in-house engineering staff.

As a result of this large increase in the market for their services, consulting engineering firms are now seeking to maintain an amount of highway work that is higher than historical levels and larger than is currently deemed necessary by the SDHPT. Although the resolution of this issue will not be accomplished herein, the results of this study will provide some useful information to help understand the implications.

In summary, the essential results reported here are:

1) **Costs of providing engineering services produced in-house and by consultants** - our study found that the cost of doing PS&E is lower using State forces than using consultants.

2) **Quality of engineering services produced in-house and by consultants** - our study found that the quality of work tended to be similar in comparison.

3) **Policy of using consultants for peak load and specialty work** - our study found no compelling set of reasons to suggest that this policy should be altered at this time.

Of course, there will be differences in opinion, emphasis, and definitions regarding the data, methods, and analysis used. Similarly each of the findings summarized above is multi-faceted when examined in detail.

The discussion that follows examines many aspects of the costs and quality comparisons that were the focus of the study.

INTRODUCTION AND STUDY APPROACH

The SDHPT is continuously monitoring and periodically evaluating the performance of consulting firms hired by the Department to undertake pre-construction highway engineering tasks. The Department's utilization of consultants needs to be based on many considerations including costs, quality of work, effective use of in-house and consultant services, the ability of SDHPT to supervise consultants, and others. The purpose of this study is to develop analyses, information, and data that will aid SDHPT decision-making in deciding the best way to utilize consultants in its preliminary engineering process.

Objectives

The objectives of this study are:

(1) Compare the cost of using consulting engineers vs. doing the work in-house;

(2) Assess the quality of work being performed by the consulting engineers vs. the work being done in-house;

(3) Assess the policy of SDHPT's usage of consulting engineers for handling peak loads and specialty jobs.

The work being reported here proceeded according to the following task descriptions.

Task 1. Project Selection. SDHPT will assist in selection of the projects for use in the comparison of in-house vs. consultant activities. These projects will contain PS&E-type work that is done in preliminary engineering.

Task 2. Data Collection. Cost and quality data will be obtained for projects selected in Task 1. This task includes the collection and evaluation of data concerning the use of consultants and in-house personnel to conduct preliminary engineering activities. Data collection will be a principal effort, since the needed data will have to be obtained from several sources including SDHPT, consultants, and contractors. The overall effort of this task will include personal interviews, written questionnaires, and field visits. Data, information, and opinions from the consulting engineering industry will be obtained.

Task 3. Data Analysis. Methodologies will be developed to make the comparisons of cost and quality aspects of projects done by consultants and by in-house SDHPT engineers. Costs, direct and indirect, will be documented, analyzed, and compared. For purposes of this study, indirect cost will include the cost incurred for those items which have not been identified as direct labor or direct material utilized in the performance of preliminary engineering. More specifically, these indirect or overhead costs relate to costs that cannot be identified in a practical manner with specific units of production or activity and, therefore, cannot be included in specific or direct cost as direct material or labor cost.

Where possible, project pairings will be used. Advisory panels of experts from TTI and SDHPT will determine the most important characteristics affecting the quality of the pre-construction engineering plans provided by consultants and SDHPT. The data developed in Task 2 will be analyzed on the basis of significant factors that will allow an objective analysis of the quality of the pre-engineering work previously mentioned. Subsequently, the quality of projects prepared in-house will be compared with the quality of projects prepared by consultants.

Task 4. Conduct Policy Analysis. This task of the study will result in an assessment of SDHPT's policy to utilize consulting engineering services for peak load work and specialty jobs. Information from the Department and the consulting engineering industry will serve as the principal data base for this assessment.

STUDY DEVELOPMENT

The Chairman of the Texas Highways and Public Transportation Commission directed that a study be undertaken to compare the costs and quality of preliminary engineering done both by State forces and consultants. The overall methodology used was to select projects (initially 60) that were paired for comparison purposes. The need for comparability of projects led to the selection of a set of comparable projects by SDHPT personnel at D-8 (Highway Design). To make a fair comparison between consultant and in-house (State) work, project pairs, having the same or similar characteristics and belonging to the same general project category, were chosen. The projects compared were paired according to level of complexity evaluations made by knowledgeable SDHPT staff.

The selection of the projects, though carried out initially by SDHPT's highway design division, included input from the three study teams (TTI, CTR, and E&W), SDHPT's district engineering staffs, and representatives of the consulting engineering industry. The concept of comparability of projects was discussed several times in meetings attended by the study team, SDHPT and the consulting engineers representatives. In the initial selection of comparable projects, chosen by D-8 staff, thirty project pairs were identified; however, some exception was taken as to the comparability of a few of these projects. Subsequent to the first round, other disputed projects were removed from the data base leaving the 24 pairs used in the study, which are listed on the following page.

The issue of comparability was pursued further by the study staff. In the survey instrument (interview guide) utilized in the study, SDHPT district personnel responding to the survey were queried as to how comparable the given project pairs in their district were. These rating categories were used: very comparable, comparable, similar and dissimilar. The results of this evaluation by the districts is given below:

District #	Project Pair	Project Comparability
12	1 1A	Similar
	2 2A	Dissimilar
	5 5A	Dissimilar
	12 12A	Similar
14	6 6A	Similar
	7 7A	Similar
	8 8A	Very Comparable
	10 10A	Very Comparable
15	13 13A	Dissimilar
	14 14A	Very Comparable
	15 15A	Similar
16	16 16A	Similar
	17 17A	Similar
18	18 18A	Very Comparable
	19 19A	No Evaluation
	20 20A	Similar
20	21 21A	Similar
	22 22A	Similar
	23 23A	Similar
	24 24A	Very Comparable
24	25 25A	Similar
	25 25B	Similar
	26 26A	Similar
	27 27A	Similar

Although 20 pairs were deemed comparable, TTI's cost analysis has primarily looked at 18 pairs. The projects in District 15 were all bridge designs and were subsequently grouped into a single pairing for inclusion (See "Project Pairings" later this section). The 18 pairs were used because: (a) they were evaluated as similar or better; and (b) adequate cost data were available for the in-house projects.

Consultant Industry Information

In addition to the above-described on the paired projects, the study staff sought and acquired additional information from the members of the consulting industry and the Consulting Engineering Council of Texas. Approximately 125 consulting firms were contacted by letter and given the opportunity to meet with the study staff or submit a written statement. Representatives of twelve firms were interviewed in sessions of 1-3 hours duration. Another twenty-two responded by letter. While these thirty-four firms comprise only 27% of the contacted population (125 firms), they have contracted about 75% of SDHPT's preliminary engineering consulting work during the period 1980-86.

Throughout the remainder of this report, salient results from this information will be brought to bear on the issues of costs, quality, and SDHPT policy of consultant usage.

Study Time Table

- February 1986 - TTI & CTR contract signed
- March 1986 - E&W selected from 7 candidates
- March 1986 - Project Coordinating Committee appointed, including John Richardson from CEC
- April 1986 - E&W contract signed
- April 28, 1986 - Kickoff meeting of study with tri-consultants (TTI, CTR, and E&W) and coordinating committee. Identify projects, flow of study and set up schedule for data collection efforts
- Apr 28/29, 1986 - Tri-consultants met with SDHPT divisions to discuss data collection
- May 5, 1986 - Group meeting of Coordinating Committee, Tri-Consultants and District contact persons to explain thrust of study, the approach, time table, etc.

- May 19, 1986 - Quality Review Committee (from 3 districts, 4 divisions) meeting with tri-consultants and Coordinating Review Committee to review tri-consultants draft of quality indicators

- June 4, 1986 - Tri-consultant questionnaires sent to applicable districts

- June 30 - July 3, 1986 - Meet with SDHPT headquarters divisions

- June 17 - July 24, 1986 - Tri-Consultants interviews with applicable districts

- July 25, 1986 - Project Coordinating Committee meeting with tri-consultants to see if satisfactory data base was collected. (Problem of retrieving data prior to SDHPT use of FIMS & some software)

- July 25 - December 31, 1986 - Tri-consultants continue to analyze data and SDHPT pursues retrieval of project cost data

- Nov 4, 1986 - SDHPT expands scope of project to include Commission policy on utilization of consultants and additional input from the consulting industry

- December 8 - January 8, 1987 - Meet with representatives of consulting community

- February 1987 - Submit draft copy of report to SDHPT Highway Design Division D-8

Data and Information Base

The study staff had access to many people and records to obtain information for subsequent analysis. Principal components of this information were as follows.

Costs. Accounting records, project ledgers, cost estimates, and other information provided by SDHPT for the sample projects (in-house). Consultant contracts and data sheets prepared by the consultants on the sample projects. Additional information on overhead and cost estimating was provided by a select few consultants during the interview process. To be included in the comparison were SDHPT's direct and indirect (overhead) cost for performing preliminary engineering and consultant costs as well as any costs SDHPT may have incurred as a consequence of the consultant project.

Quality. Opinions, comments, data, and information was provided, via interview guides, by SDHPT personnel. A special TTI panel was assembled to analyze and critique the questionnaire data and other information on the quality dimension of the study. Subsequent information was provided by selected consultants and others during the interview process. Additional information was provided by four separate highway contractors.

Policy Issues. The consultants utilized the interview process and written submissions to provide opinions and information on this topic. Also, SDHPT personnel contributed similar information via the written interview guides and subsequent interview discussions.

Comparability. The concept of project comparability has been a prime focus of the SDHPT, the consulting engineering industry, and the study team. At the outset, it can be agreed that no two projects are ever exactly alike in every respect. Were that to occur, then by definition there would be no difference in any project aspect be it cost, quality, or whatever. The notion of comparability has many dimensions, each which has relative merits and faults. Some of these are:

Type of project being designed: Generally in this study there are two categories: bridge and roadway. Throughout, we have paired roadway designs (state forces) with roadway designs (consultants). Similarly, bridge designs, especially in District 15, were closely paired. Within the mix of paired projects, though, some roadway projects also have some bridge designs, and these are not always perfectly matched in the pair.

Cost/Estimated Cost to Construct: The project pairs were not created with this dimension uppermost in the criteria. Thus, there is some disparity in the pairings where construction cost is concerned. This is important to note, because in the sample projects, most of the pairs have the following characteristic: the consultant project design has a larger construction cost than does its SDHPT paired project.

Complexity: A qualitative indicator - project complexity - was used to aid in project pairing. In general, complex urban designs were paired; more simple rural roadways projects were paired; interchange structures projects were paired; etc.

Opinions of Experts: Finally, SDHPT engineers in the field were asked to assess the comparability of the projects paired in their district. In this process, twenty of the original thirty pairs were evaluated as being similar or very comparable.

Chronological Comparability: Most of the consultant projects in the pairings have occurred relatively recently (since 1982). In some cases, recent consultant projects were paired with SDHPT projects more remote in time--the most extreme example is a SDHPT project completed in 1970 that is paired with a consultant project completed in early 1986. In this and similar instances, improved comparability of projects was attempted by applying cost indices to reduce the effects inflation/deflation in the project cost items. This is further discussed in the next section.

Statistical Comparability: Though clearly not a perfect set of matched projects, these pairs that remained in the data base have been scrutinized using several dimensions, SDHPT opinions, consulting industry representatives opinions, and study staff assessments. To further quantify the concept of comparability, the study staff developed an analytical procedure that establishes the purely statistical comparability of a project pair. This procedure determines the statistical comparability of a project pair based on length, number of non standard plan sheets, number of bid items and ADT (See results in Appendix 1).

COST

Basic Concepts of Cost Measurement

One objective of this study is to determine the cost of performing preliminary engineering (PS&E) in-house vs. using consultants. The cost to the SDHPT of consultant preliminary engineering services is simple to determine. To derive consultant costs: (1) take the contract amount; and (2) add an estimate of direct and indirect effort SDHPT expends in obtaining and supporting the consultant's services and monitoring the consultant's work. To obtain SDHPT's costs of performing preliminary engineering, the study staff obtained information from many SDHPT personnel, existing records, and expert opinions, including interpretations of SDHPT's accounting data and record-keeping system.

Although historical costs are an important factor, they are not the only factor useful for decision making. In fact, a Transportation Research Board survey conducted in 1984 found that of 40 state transportation agencies surveyed more than two thirds do not use cost comparisons to determine whether work should be performed by in-house personnel or consultants. Further, changes in prices for labor or raw materials may make past labor or materials costs irrelevant. Adjustments for price differences help restore comparability of costs through time. Nevertheless, data on past cost behavior can be useful to illuminate future cost behavior. This analysis utilizes recent and present data, but does not attempt to forecast future costs. FY 1985 is the base year for most of the cost analysis herein.

Assignment of Direct Costs

The direct costs of accomplishing an activity, such as preliminary engineering, are routinely charged to that activity by the organization's accounting system. For example, direct labor is normally charged to an activity, using time sheets or cards. Direct material costs should also be charged to an activity.

Assignment or Allocation of Overhead Costs

Overhead costs are more difficult to assign because they cannot be assumed to be directly associated with a department or activity, either because there is no obvious relationship or **because the cost of analysis and record keeping is too great.**

Overhead costs typically include the cost of service, support, administrative departments, and rental space. Many other items can best summarized in list form:

- Operating supplies
- Repairs, maintenance and utilities
- Training costs
- Safety and OSHA supplies
- Supervision - salaries of supervisors, managers, etc.
- Technical and clerical employees
- Indirect labor - janitors, security, inventory personnel
- Overtime premiums
- Fringe benefits - FICA taxes, group life, pension, etc.
- The "opportunity cost" of using buildings which have already been paid for
- Outside services - clerical temporary employees
- Travel

While not exhaustive, this list contains some of the more generally accepted components of overhead costs.

In selecting a procedure for the present study, the two evaluation methods used to calculate overhead costs were considered: the Effort Related Transfer Price Method, which assigns support or service costs to a division or department according to the amount of effort incurred, as it is incurred. Thus, the cost of a division could be charged to a particular project according to the number of hours it used. This method is not very useful for the present study since such detailed data are not consistently maintained by SDHPT. Another method, Estimated Effort Allocation, assigns overhead costs to divisions or departments periodically, according to an estimate of the effort incurred. This procedure requires the manager or director of each "overhead department" to estimate the percentage of the department's efforts during the period expended on behalf of other departments or divisions. **It is the estimated effort allocation which is the basis for this analysis.** For those SDHPT divisions where direct estimates were not provided, estimates were calculated by the study staff.

At the initial meeting of the study teams with the Project Coordinating Committee, the representative of the Consulting Engineers Council told the group that an appropriate overhead charge needed to be assigned to SDHPT projects to facilitate comparisons with consultants' costs. Much of the data collection, refinement, and analysis was subsequently focused on that single issue: what is an appropriate overhead rate for SDHPT preliminary engineering activities for use in comparing state forces with consultant costs? In the last stage of data collection, in-depth interviews with individual engineering consultant firms reconfirmed their genuine concern that the cost of doing business for SDHPT include the overhead amounts. We have always known that assessing the overhead rate for SDHPT projects was both crucial and very difficult. In the following section, the discussion shows how we proceeded. For any who need it, this caveat is in order: **we did not conduct an audit.**

Overhead Concept

Overhead is a cost concept that will be used to describe the value of administrative and indirect activities that help produce the preliminary engineering products and services by SDHPT's in-house staff. We have attempted to capture for FY 85 all such costs that could be identified and should be assigned to SDHPT production of in-house PS&E activities.

The concept of SDHPT overhead that is most applicable for present purposes derives from the activities and expenses that support in-house, and in-house alone, preliminary engineering. Three things must be done:

(1) identify **all** SDHPT expenses for **all** preliminary engineering;

(2) identify those support costs that would be incurred whether preliminary engineering work is done in-house or by consultants. These common costs are not to be included in either SDHPT overhead charges or consultant overhead charges;

(3) allocate the remaining expenses to the in-house preliminary engineering activities.

Systematically, each division/district was asked to provide data for the overhead cost calculations.

This approach utilizes procedures from the cost comparison handbook outlined by OMB in its Circular A-76 (Revised)--Performance of Commercial Activities. There, in Part IV, the following appears:

> **include only those overhead costs that will not continue in the event of exclusive use of contracted-out services. (p. IV-27).**

While the present study does not address the full complexity of issues subject to the A-76 analysis, the recommended A-76 procedure to estimate "avoidable and unavoidable costs" is analogous in concept to the task of attempting to identify costs assignable to in-house engineering and plan preparation.

Essentially, there are several SDHPT activities (e.g., motor vehicle registration, materials testing, anti-litter efforts) that are not at all related to preliminary engineering. These activities, obviously, should not be included (in any amounts) in the overhead pool for preliminary engineering. More importantly, though, there is a large number of activities that provide support for preliminary engineering and **would be + necessary whether or not engineering planwork was done in-house.** Conceptually, these activities are similar to those identified in the A-76 analysis that will continue at the same levels in both situations, i.e., all preliminary engineering done in-house or all preliminary engineering done by consultants. This type of expenditure should not be included as an overhead charge for either in-house or consultant preliminary engineering.

According to SDHPT, the following necessary support activities are needed whether the department is doing the work with State forces or is using consultants for PS&E:

1. Bridge design -- D-5 activities for preparation of standard design sheets, specifications, review of plan work; preparation of manuals; and processing work with railroads, FHWA, etc.

2. Highway design -- D-8 activities for preparation of standards, manuals, review of plan work and specifications; processing EIS; coordination with other agencies, advertising projects; FHWA liaison. D-18 activities including sign standards, preparation of manuals, pavement management data, plan review.

3. Planning and Research -- D-10 activities of traffic counting, traffic forecasting, map preparation, urban transportation planning and studies, coordination with FHWA, design and management of R&D activities, research implementation.

Calculation of SDHPT's Overhead Rate

The best estimate of the direct cost of preliminary engineering begins with the data produced by the SDHPT which capture all direct cost (Function Codes) assigned to preliminary engineering. This includes principally all the project charges at the district level and those similar charges (on bridge projects) by D-5, D-8, and D-19 (photogrammetry). This amount represents a minimum amount of direct costs that should be included in the base amount.

Total in-house direct expenditures for Preliminary Engineering FY 85 were $43.95 million. Approximately 78% of the total amount expended was for labor, as reflected in the accounts of the Project Ledgers. This labor expense includes benefits paid to employees such as pension, insurance premiums and other items the employees of SDHPT receive. SDHPT's finance division (D-3) has calculated this benefit as consisting of 42% of an employees gross salary, e.g. for every dollar paid in salary, the SDHPT pays an additional 42 cents in benefits.

To undertake this cost comparison study, an "allocative base" must be derived. This allocative base includes direct charges and direct labor expenses resulting from a given activity. In this case, the labor additive portion of the total amount of preliminary engineering expense must be removed to obtain an allocative base. Such removal will leave direct labor, photogrammetry, project travel, etc. -- all direct charges for preliminary engineering.

So, we derive the labor portion (78% of $43.95 million) or $34.28 million--which is total labor expense. As mentioned earlier this labor expense includes a 42% labor additive which must be extracted. Using a multiplier factor equal to:

$\frac{42}{142}$ = 29.57%, which shows that 29.57% of total labor expense comprises an "additive" or overhead item. This portion needs to be removed to derive direct labor charges for preliminary engineering, thus:

29.57% of \$34.28m = \$10.14m additives, which
when subtracted from \$43.95m
yields \$33.81m, the allocative base.

This is essential in calculating an overhead rate for in-house preliminary engineering to determine indirect costs assignable to SDHPT designed projects. Note that the allocative base contains non-labor items. As noted earlier, 78% of total direct expense for preliminary engineering is composed of labor expense. The remaining 22% consists of other direct support.

To capture the indirect costs of preliminary engineering, the study team sought to determine the extent of SDHPT support activities in preliminary engineering at the headquarters, division, and district levels. To accomplish this, the study team visited each division and interviewed the director or assigned representative to determine the percentage of that given division's effort/budget was for preliminary engineering or support of preliminary engineering. The results of this data assessment follow.

D-5 Bridge Design. The amount of indirect expenses incurred by D-5 to support in-house preliminary engineering was \$82,950 for FY 85.

D-8 Highway Design. According to SDHPT's budget monitoring reports (R-22's), virtually all of D-8's portion of 302 expenditures was expended for support of all preliminary engineering. This would be spent as such regardless how the PS&E was done--consultant services or in-house forces. The amount of D-8 expenses assignable to the overhead pool for in-house planwork was \$90,000--an amount that SDHPT (D-8) expends for in-house, and in-house alone, engineering support.

D-10 Transportation Planning. Initial interviews with D-10 personnel showed that much of D-10's expenditures (with the exception of public transportation planning and intracoastal waterway) are in some way supportive of preliminary engineering. Subsequent confirmation of data by current D-10 administration established that 72% of D-10's research expenditure and 50% of D-10's planning expenditure should be captured in the overhead pool for preliminary engineering. These expenditures are not assignable to in-house preliminary engineering. These D-10 activities are considered necessary to support preliminary engineering, whether or not it is accomplished in-house or through contracted consultants.

D-18 Safety and Maintenance. D-18's principal activities in support of PS&E are traffic engineering and landscape developments. All of their activities would remain the same for in-house or consultant preparation of PS&E. Thus, none of these activities are assigned to the in-house overhead pool.

D-19 Automation. D-19's estimated FY 85 amount of support for in-house preliminary engineering was $3.3 million, principally for CADD equipment and operations.

Additionally, Divisions 3, 4, 6, and 13 were analyzed. These divisions, with the exception of D-6, were deemed to contribute to preliminary engineering. D-3, D-4 and D-13 as well as D-1 (Administration) have supportive expenditures for in-house preliminary engineering. Due to their nature as "support divisions," their costs can be considered to be "part of doing business" for the entire department. Thus the selected means to calculate their support expenditures for in-house preliminary engineering was on a pro-rata basis. According to personnel assignments, SDHPT's preliminary engineering staff comprise 9.38% of all SDHPT personnel. By extension, 9.38% of the support divisions expenditure/effort was pro-rated to support in-house preliminary engineering. These amounts are:

D-1 (administrative) support amounts to,

$311,000.00, which is for supporting all preliminary planwork and is not assignable to either in-house or consultant projects.

D-3 (finance) support of in-house preliminary engineering,

$278,000.

D-13 (human resources) support of in-house preliminary engineering,

$122,000.

The special nature of D-4's operation as a procurement agency precludes the same pro-rata treatment of its entire operation. However, there are certain items in D-4's budget subject to a pro-rata estimate of its contribution to in-house preliminary engineering. These are as follows:

- o Executive Administration
- o Building Maintenance and Utilities
- o Administration and Staff
- o Upkeep and protection of building
- o Mailroom, Main office
- o Duplication Annex
- o Duplication Camp Hubbard

The total of these activities for FY 85 was $2.93m. The pro-rata amount (9.38%) assigned to preliminary engineering overhead is $274,480.

An important factor also to be considered in determining the cost of in-house preliminary engineering is building use. The indirect cost of SDHPT preliminary engineering building use is calculated as follows.

The cost of space to house preliminary engineering must be estimated since there is no data available showing current (1985) values of SDHPT buildings. It was assumed that state-owned space was at least as valuable as leased space, so that market rates for leased space were used to calculate an amount of indirect "costs" that should be added to the overhead pool for preliminary engineering. Input data, acquired from D-18, were:

1) $.80/sq ft per month is the market value of leased spaced suited for preliminary engineering, and
2) 225 sq. ft. per person is the amount of space needed by persons engaged in preliminary engineering in the districts.

Preliminary engineering staff at district level is 1,173 persons. Average building use cost based on a statewide average of rented space $.80 per sq. ft/per month (includes maintenance and utilities). Thus 1,173 X 225 sq. ft. = 263,925 sq. ft. utilized by districts for preliminary engineering. Further, 263,925 X $.80 per sq. ft. = $211,140 per month, or $2.534m per year for space.

Information obtained from seven districts was used to estimate an amount of support expenses in the district assignable to the overhead pool for cost comparison of preliminary engineering activities. From this information, two conclusions emerged:

(1) most of the districts' <u>support</u> of preliminary engineering would not be changed even if all PS&E work was done by contract; and
(2) those support items which would change were principally administrative support of design staff. Combined, these amount to approximately 3% of the allocative base for in-house preliminary engineering.

All of the above described data were combined as follows to produce the overhead rate for in-house SDHPT preliminary engineering activities (FY 85). In summary, total in-house expenditure for preliminary engineering in FY 85 was $43.95m, which had an allocative base of $33.81 million. The following percentages are proportions of the base which comprise the overhead pool:

Labor additive	29.99%
D-5	.25
D-8	.27
D-19	9.76
D-3	.82
D-13	.36
D-4	.81
Building Use	7.50
District Admin.	3.21
Total	52.97%

This rate will be used to produce cost data for SDHPT projects that are conceptually comparable to costs incurred by consultants. But, there are at least two aspects that should be recognized right away.

First, there is no estimate for legal or "insurance" costs assigned to the overhead pool for SDHPT preliminary engineering. Lengthy discussion with personnel in D-8, D-3, the Attorney General's Office (Highway Division) convinced the study staff that, for at least the past 5 years, no identifiable legal costs have arisen due to preliminary engineering activities, e.g., faulty design. No dollars have been paid out in settlements or lawsuits arising from design flaws of in-house preliminary engineering work. Thus, as an item in overhead, this does not exist in the FY 85 calculations.

Second, although the allocative bases for SDHPT's and each individual consultant's overhead rates are not precisely the same, existing data in SDHPT records show that consultant overhead rates are higher than the overhead rate for SDHPT. How does the 52.97% compare to consultant overhead rates? One comparison is based on an audit done by SDHPT's Internal Review section on 13 consultant contracts in FY 84, 85, 86. This audit showed an average overhead rate of 128.63%. Also, another Internal Review listing of 24 consultant proposals from December 1985 through May 1986 yielded an average overhead rate of 139.75%. Finally, SDHPT's data on the ten firms currently doing the most business with SDHPT shows that the average overhead rate of those ten firms is 149%.

Note on Inflation Adjustment

For four projects pairs being compared (10-10A, 21-21A, 22-22A, and 25-25A), the study staff concluded that the completed cost items of the earlier projects should be adjusted to the period of completion of the more recent project. The index utilized for the construction adjustments was the construction component of the highway cost index provided by SDHPT. The index used to adjust the preliminary engineering cost items was the State government deflator calculated and reported by the U.S. Department of Commerce.

These data are provided in the Appendix. The reader will note that the behavior of the Construction Component of HCI went from 34.15 (est.) in 1971 to 122.64 in 1980. After it peaked, it once again fell to 109.23 in 1984. The deflator for preliminary engineering, however, was monotonically increasing, throughout the 15 year period under review, from 53.95 in 1971 to 157.64 (est) in 1986.

Notes from Consultant Interview Process

In the interview process, consultants generally expressed the opinions that:

(1) an overhead rate for in-house projects must be established before cost comparisons can be attempted;

(2) cost comparisons of in-house vs. consultant projects would be difficult (if not impossible) to make because of different cost accounting systems;

(3) if "true" costs could be established, consultants would be no more costly and would likely be less costly in performing work similar to in-house forces;

(4) competition serves to keep consultant costs and overhead rates at low levels; and

(5) insurance costs are now one of the most significant contributors to their overhead pools.

Cost Data Used on Project Pairs

The cost data utilized in the project comparisons were obtained from SDHPT. The consultant projects include the consultant cost and any costs incurred by SDHPT on any given consultant project. The estimates of how much was spent on any consultant project by SDHPT were provided by the Department. The State costs include the total direct costs plus the direct costs multiplied by the rate of overhead as determined by the study staff.

Project Pair 1 and 1A

District 12

#1 CSJ 3256-2-28 - Consultant No. 1

#1A CSJ 3256-2-13 - In-house SDHPT District 3 Wichita Falls

Project 1A is unique in the data set in that it was designed for SDHPT District 12 by SDHPT District 3. Project 1 is also unique in that it underwent a considerable change in scope from a 16 million dollar construction job to a 25 million dollar construction job. Both projects included roadway, structural and bridge design which according to District 12's assessment are of medium to high complexity. Both projects are designed for existing facilities.

Both District 12 and consultant on Project 1 report having had excellent support on the project. District 12 reported being satisfied with the consultant's quality of work and performance. The consultant reported that particular attention was given to insure the quality of scheduling of this project.

The comparability of these projects was evaluated as similar by District 12.

1 & 1A	State Project	Consultant
Start Date	6/81	9/28/84
Completion Date	5/82	N/A

#1A

$332,207 Total in-house recorded cost

As established previously approximately 78% preliminary engineering expense is labor expense. Again, the labor additive portion must be removed to obtain the direct cost base. Thus:

$259,121 Labor portion

$76,622 Labor additive

So, $332,207 Total recorded cost
- 76,622 Labor additive
$255,585 Direct cost
+ 135,383 Overhead 52.97% of direct cost
$390,968 Total Cost

Construction cost
$21,665,247 est.
%PE 1.8%

#1

Total cost of consultant project including in-house expense with overhead factor:

$503,896	Consultant Cost
$90,527	In-house direct*
$47,952	In-house Overhead Amount
$642,375	TOTAL

Construction cost
$13,703,587 est.
%PE 4.7%

Overhead rate on consultant contract: 135%

*Does not include 42% labor additive.

Project Pair 6 and 6A

District 14

#6 CSJ 1539-01-003 - Consultant No. 6

#6A CSJ 1378-6-2 - SDHPT District 14

In this pair the state project has been constructed. The consultant project has not been constructed. As of the date of the survey, PS&E was underway and 90% complete. Both projects included roadway and bridge design of medium complexity. The State design project was completed without major incident; unfortunately, this was not the case with the consultant project. Indeed the consultant project was subject of some controversy. The county (Hay's) within which the project was taking place did not have sufficient funds to purchase ROW. Property owners would not allow access, and a number of public agencies were not responsive. Both projects involved design for a new construction at a new location in a rural setting. Both had some bridge design; however, the consultant project had 2 bridges (one was a special design), and the state project had only 1 standard design bridge. Other than the consultant's special bridge design (medium complexity), the two jobs were considered by District 14 to be low complexity jobs. RDS and THYSYS were used on both jobs. According to the study teams information request, the SDHPT design team had experience with this type of design work, whereas the consultant design team had none.

Plan development on the state job started 9/29/77 and was completed 6/10/80, with no significant delays. The consultant plan development started 11/1/84 and was not completed as of 6/30/86. It had experienced significant delays. The comparability of the projects was evaluated as being similar.

6 & 6A	State Project	Consultant
Start Date	9/29/77	11/1/84
Completion Date	6/80	Not complete as of 7/86

#6A

$64,429	Total recorded cost
- 14,861	Labor additive
$49,568	Direct cost
+ 26,257	Overhead
$75,825	Total project cost

Construction cost
$955,246
%PE 7.9%

#6

Total cost of consultant project including in-house expense with overhead factor:

$214,665	Consultant Cost
1,627	In-house direct
862	In-house Overhead amount
$217,154	TOTAL

Construction cost
$2,240,000 (est)
%PE 9.7%

Overhead rate on consultant contract: 106.8%

Project Pair 7 and 7A

District 14

#7 CSJ 19-9-69 - Consultant No.7

#7A SDHPT District 14

The construction on the in-house job has been completed, as of survey date 6/30/86. The PS&E as the consultant project was underway and 15% complete. The consultant project consisted only of roadway design as opposed to the State project, which included two bridges. Both jobs were for new construction on existing facilities in a rural setting. According to District 14 staff the state project was of overall low complexity. The consultant project was, however, of medium complexity overall. The consultant project was affected by significant delays in putting out the design work. These delays prevented District 14 from commenting on the consultant project in any detail.

7 & 7A	State Project	Consultant
Start Date	9/83	12/17/84
Completion Date	11/84	N/A

#7A

$72,281	Total recorded cost
- 16,671	Labor additive
$55,610	Direct cost
+ 29,456	Overhead
$85,066	Total project cost

Construction cost
$1,302,313
%PE 6.5%

#7

Total cost of consultant project including in-house expense with overhead factor:

$73,899	Consultant Cost*
$2,250	In-house direct
$1,192	In-house Overhead amount
$77,341	TOTAL

* This project is not complete, but the contract amount is $73,899. A pro-rated amount of in-house cost would be $2250. The expected total cost will be, therefore, $77,341 (est.)

Construction cost
$981,000 est.
%PE 7.9% assuming full estimated cost is incurred.

Overhead rate on consultant contract is: 125%

Project Pair 8 and 8A

District 14

#8 CSJ 265-1-66 - Consultant No. 8

##8A CSJ 151-9-23 IPE 447 SDHPT District 14

Projects #8 and 8A both included roadway design, structural design, and bridge design. This pair was evaluated as being comparable in all design portions by District 14. The complexity of both projects was medium over all. Both jobs were designed to be new construction on an existing facility in an urban setting. There were two standard design bridges included in each project as well as a need for traffic control plans. Each utilized RDS and THYSYS. The State's project was completely re-designed after initial completion of PS&E. The consultant utilized interactive graphics; the State did not. Both consultant and State staff report having good communication and a satisfactory working relationship.

There have been some schedule problems with the consultant project; however, these problems have been due to the location of this job and changes in scope of work. For this project, a main lane was added, additional retaining walls were included, and more illumination added. Since this job is local to Bergstrom AFB, coordination was required with the U.S. Air Force and U.S. Army Corps of Engineers. Also, there was a delay by SDHPT in final review.

8 & 8A	State Project	Consultant
Start Date	8/1/75	12/17/84
Completion Date	3/31/81	7/26/86

#8A

$259,751	Total recorded cost
- 59,911	Labor additive
$199,840	Direct cost
+ 105,856	Overhead
$305,696	Total project cost

Construction cost
$3,213,037
%PE 9.5%

#8

Total cost of consultant project including in-house expense with overhead factor:

$308,222	Consultant Cost
$9,003	In-house direct
$4,768	In-house Overhead amount
$321,993	TOTAL

Construction cost
$5,121,350 est.
%PE 6.3%

Overhead rate on consultant contract: 130.1%

Project Pair 10 and 10A

District 14

#10 CSJ 3136-1-39 - Consultant No.10

#10A SCJ 15-13-149 - SDHPT District 14

Both consultant and State designs include roadway, structural, and bridge design--all of complex design. The location of these projects is urban new construction on an existing facility. Both in-house and consultant staffs are very experienced, and consequently any delays or problems were non-engineering based.

District 14 expressed satisfaction with both its work and the consultant's work. Consultant reports that excellent communication and coordination was established with the District.

Overall, in both projects, all parties feel the end result was of high quality.

10 & 10A	State Project	Consultant
Start Date	1973	11/5/84
Completion Date	4/26/76	11/86

#10A

$665,722	Total recorded cost
- 153,546	Labor additive
$512,176	Direct cost
+ 271,300	Overhead
$783,476	Total project cost

Construction cost
$35,086,368
%PE 2.2%

Construction cost adjusted for inflation $80,445,194
Preliminary engineering cost adjusted for inflation $1,563,576
Adjusted %PE 1.9

#10

Total cost of consultant project including in-house expense with overhead factor:

$1,565,975	Consultant Cost
$248,859	In-house direct cost
$131,821	In-house Overhead amount
$1,946,655	TOTAL

Construction cost
$40,000,000 (est)
%PE 4.9%

Overhead rate on consultant contract: 170%

Project Pair 14/15 and 13A/15A

District 15

#14 CSJ-2452-2-22 - Consultant No. 14
#15 CSJ-2452-2-28 - Consultant No. 15

#13A CSJ-3508-1-1 - SDHPT District 15
#15A CSJ-3508-1-5 - SDHPT D-5

These jobs were re-combined by SDHPT into the pairing as shown to improve the comparability of the resulting designs. Both the State and consultant jobs are PS&E (structures) for pre-stressed I-beam grade separations. They all were of average complexity.

Consultant Projects #14/15. Bridge structures. Average complexity. New prestressed concrete spans on existing facility. Rated as a good project with good communications with consultants through frequent review of drawings. Good quality of work by consultants and completed within a short time schedule. Good performance by minority subcontractors as well. Total sq. footage of designed bridge deck - 223,534.

State Projects #13A/15A. Bridge structures. Average complexity. New construction on new location. Experienced district design team and D-5 designers. Total sq. footage of bridge deck - 262,437.

Both sets of projects (state and consultants) were solely bridge design and contained no other design activities. Combined 14/15 rated very comparable with combined 13A/15A by SDHPT personnel.

14/15 and 13A/15A	State Projects	Consultant
Start Dates	(Proj. 13A) 5/85 (Proj. 15A) 4/86	(Proj. 14) 7/84 (Proj. 15) 9/84
Completion Dates	(Proj. 13A) 2/86 (Proj. 15A) 7/86	(Proj. 14) 8/84 (Proj. 15) 11/84

#13A/15A

$148,999	Total recorded cost
34,366	Labor additive
$114,633	Direct cost
60,721	Overhead
$175,354	Total project cost

Construction Cost
$8.96m (est.)
%PE 2.0%

#14/15

$207,212	Consultant cost
20,773	In-house direct cost
$11,003	In-house overhead amount
$238,988	Total project cost

Construction cost
$5.97m (est.)
%PE 3.9%

Overhead rate on consultant contract (Project 14): 175%

Overhead rate on consultant contract (Project 15): 123.3%

Project Pair 16 and 16A

District 16

#16 CSJ 255-01-043 - Consultant No. 16

#16A CSJ 86-11-26 - SDHPT District 16

These projects are fairly simple rural highway work with some culvert structures (25 State, 53 Consultant). There is some bridge work on the State project but this was performed by SDHPT's bridge division (D-5), Austin. Neither project experienced major difficulties or controversy. District 16 was very pleased with consultant work and in fact felt confident enough to say they would recommend this consultant for future work

16 & 16A	State Project	Consultant
Start Date	9/82	11/84
Completion Date	3/83	5/85

#16A

$198,682	Total recorded cost
- 45,825	Labor additive
$152,857	Direct cost
+ 80,968	Overhead
$233,825	Total project cost

Construction cost*
$3,955,720
%PE 5.9%

#16

Total cost of consultant project including in-house expense with overhead factor:

$272,630	Consultant Cost
90,850	In-house direct
48,124	In-house Overhead amount
411,604	TOTAL

Construction cost*
$10,714,997
%PE 3.8%

Overhead rate on consultant contract: 130.1%

*Construction cost for consultant project is relatively high as compared to State's project because base design utilized high cost asphalt stabilized base while the state project had flexible base design. Design processes for these alternatives should be approximately the same.

Project Pair 17 and 17A

District 16

Project 17 CSJ 371-03-80 - Consultant No.17

#17A CSJ 371-3-77 IPE 344 SDHPT District 16

These jobs contain roadway design, structural, and bridge design--all of low complexity. Both are rural projects with no particular difficulties or delays of any sort.

Project 17 was one of the first projects to be awarded locally. There was some time spent by SDHPT familiarizing the consultant with SDHPT procedures and standards, as well as, with RDS.

17 & 17A	State Project	Consultant
Start Date	8/80	1/14/85
Completion Date	4/15/81	8/31/85

#17A

$110,946	Total recorded cost
- 25,590	Labor additive
$ 85,356	Direct cost
+ 45,214	Overhead
$130,570	Total project cost

Construction cost*
$3,590,265
%PE 3.6%

#17 Consultant project

$253,042	Consultant cost
39,033	In-house direct cost
20,676	In-house overhead amount
$312,751	Total project cost

Construction cost*
$9,125,700 est.
%PE 3.4%

Overhead rate on consultant contract: 158%

*Construction cost for consultant project is relatively high as compared to State's project because base design utilized high cost asphalt stabilized base while the state project had flexible base design. Design processes for these alternatives should be approximately the same.

Project Pair 18 and 18A

District 18

Project 18 CSJ 47-7-12 - Consultant No. 18

#18A CSJ 94-3-53 SDHPT District 18

This pair included bridge, structural, and roadway design of high complexity. The complexity of the consultant project necessitated substantial supervision by SDHPT. Both jobs are in an urban location and involve design of new construction on an existing facility. There was some public controversy concerning both jobs, yet only the consultant job suffered from delays. The complexity of the pair is parallel in that bridge design was of medium complexity and roadway design of high complexity for both projects. The ADT in both these jobs is high and required some fancy traffic control. According to district personnel, despite considerable efforts, their own and the consultant's traffic management plans could have been somewhat improved.

18 & 18A	State Project	Consultant
Start Date	1/81	10/3/83
Completion Date	6/6/83	10/15/85

#18A

$422,685	Total recorded cost
- 97,489	Labor additive
$325,196	Direct cost
+ 172,256	Overhead
$497,450	Total project cost

Construction cost
$16,191,078
%PE 3.1%

#18

Total cost of consultant project including in-house expense with overhead factor:

$1,226,049	Consultant Cost
$74,195	In-house direct cost
$39,302	In-house Overhead amount
$1,339,546	TOTAL

Construction cost
$39,833,648 est.
%PE 3.4%

Overhead rate on consultant contract: 134%

Project Pair 19 and 19A

District 18

#19 CSJ 8090-18-4 - Consultant No. 19

#19A CSJ 8076-18-2 SDHPT District 18

The in-house project has had construction completed on it; the consultant project at the time of this inquiry had PS & E 90% complete. These are both urban jobs of medium complexity. Both included structural, roadway and bridge design. The design for both was for new construction on an existing facility. The District was not able to comment on the consultant's final plans and PS & E because they had not yet been submitted. The District stated that from the preliminary plans they received, the consultant's work is above average.

19 & 19A	State Project	Consultant
Start Date	9/78	10/28/80
Completion Date	10/81	12/86 (est)

#19A

$125,615	Total recorded cost	Construction cost
- 28,973	Labor additive	$3,200,000
$ 96,642	Direct cost	%PE 4.6%
+ 51,192	Overhead	
$147,834	Total project cost	

#19

Total cost of consultant project including in-house expense with overhead factor:

$221,689	Consultant Cost	Construction cost
$16,815	In-house direct cost	$2,850,000 est.
$ 8,907	In-house Overhead amount	%PE 8.7%
$247,411	TOTAL	

Overhead rate on consultant contract: 124%

Project Pair 20 and 20A

District 18

#20 CSJ 48-1-28 - Consultant No. 20

#20A CSJ 91-5-24 SDHPT D-8G

These projects are urban new construction on existing facility designs. The consultant job differs in that it has one bridge design and twelve structures. The consultant project also had retaining work and some challenging terrain to deal with. The District reports that numerous field changes had to be made on the consultant project. Also, the consultant project overran the original schedule by 885 days. It is the District's assertion that the consultant underestimated the complexity of the job during negotiations. By the same token, District 18 feels that the quality of the State plans, including traffic control, are of lesser quality than usual.

20 & 20A	State Project	Consultant
Start Date	1/83	4/78
Completion Date	7/14/85	4/26/83

#20A

$158,038	Total recorded cost	Construction cost
- 36,451	Labor additive	$6,838,086
$121,587	Direct cost	%PE 2.7%
+ 64,405	Overhead	
$185,992	Total project cost	

#20

Total cost of consultant project including in-house expense with overhead factor:

$304,191	Consultant Cost	Construction cost
$39,350	In-house direct	$5,675,951
$20,844	In-house Overhead amount	%PE 6.4%
$364,385	TOTAL	

Overhead rate for consultant contract: 121%

Project Pair 21 and 21A

District 20

#21 CSJ 593-1 - Consultant No. 21

#21A CSJ 307-1-96 SDHPT District 20

District 20 in this case had good comments concerning both projects. It evaluated its own project as good and the consultant project as excellent. The delays experienced by the consultant project were caused by railroad agreements and railroad structural review. The complexity of both projects is low. Both are in an urban setting and consist of new construction on an existing facility. The projects consisted of roadway and bridge design as well as some structural design on the consultant project.

21 & 21A	State Project	Consultant
Start Date	7/70	11/83
Completion Date	11/71	1/86

#21A

$40,186	Total recorded cost	Construction cost
- 9,268	Labor additive	$579,824
$30,918	Direct cost	%PE 8.2%
+ 16,377	Overhead	
$47,295	Total project cost	

Construction cost adjusted for inflation $2,052,890
Project cost adjusted for inflation $134,998
Adjusted %PE 6.6%

#21

Total cost of consultant project including in-house expense with overhead factor:

$268,115	Consultant Cost
$11,922	In-house direct cost
$ 6,315	In-house Overhead amount
$286,352	TOTAL

Construction cost
$4,042,000
%PE 7.1%

Overhead rate on consultant contract: 170.8%

Project Pair 22 and 22A

District 20

#22 CSJ 28-7-43 - Consultant No. 22

#22A CSJ 8025-20-1 SDHPT District 20

These projects consisted of roadway design of average complexity. Neither has any bridges and the SDHPT project has four structures. Again, District 20 rated its own project a good project and referred to the consultant project as excellent. In fact the consultant project was considered an exceptional consultant project by District 20. Both are in an urban location and are designs for new construction at an existing facility.

22 & 22A	State Project	Consultant
Start Date	12/76	1/85
Completion Date	2/77	9/85

#22A

$136,630	Total recorded cost
- 31,513	Labor additive
$105,117	Direct cost
+ 55,680	Overhead
$160,797	Total project cost

Construction cost
$2,812,000
%PE 5.7%

Construction cost adjusted for inflation $5,725,720
Project cost adjusted for inflation $298,284
Adjusted %PE 5.2%

#22

Total cost of consultant project including in-house expense with overhead factor:

$251,871	Consultant Cost
$33,479	In-house direct cost
$17,734	In-house Overhead amount
$303,084	TOTAL

Construction cost*
$12,215,000 est.
%PE 2.5%

Overhead rate on consultant contract: 78.1%

*Project 22 (consultant's) consisted of removing 4 lanes of existing concrete roadway and replacing with 7 lanes. This paving work amounted to over $7,000,000 of the total cost and required little engineering costs since the state did pavement design and furnished standards and specifications for concrete pavement.

Project Pair 23 and 23A

District 20

#23 CSJ 667-2-45 - Consultant No. 23

#23A CSJ 710-2-39 SDHPT District 20

The type of design work on both these projects consisted of roadway design work of average complexity. There were a few structures (11 State, 15 Consultant) and one bridge design (State). Both projects were evaluated as being "good" projects by District 20 and of average overall complexity. The design was for new construction on an existing facility in an urban setting. Neither project was very controversial, and the delays on the consultant project were due to utility adjustments.

23 & 23A	State Project	Consultant
Start Date	N/A	3/85
Completion Date	5/83	7/86

#23A

$97,451	Total recorded cost
- 22,477	Labor additive
$74,974	Direct cost
+ 39,714	Overhead
$114,688	Total project cost

Construction cost
$2,847,463
%PE 4.0%

#23

Total cost of consultant project including in-house expense with overhead factor:

$327,313	Consultant Cost
$7,204	In-house direct cost
$3,816	In-house Overhead amount
$338,333	TOTAL

Construction cost
$4,500,000 est.
%PE 7.5%

Overhead rate on consultant contract: 126%

Project Pair 24 and 24A

District 20

#24 CSJ 389-2-36 - Consultant No. 24

#24A CSJ 932-1-58 SDHPT District 20

The two jobs were evaluated as "good" by District 20. The District staff reported that the consultant project, the first ever in District 20, was delayed due to their inexperience in working with consultants. The consultant work on drainage and safety treatment could stand improvement. The construction on the in-house project is complete. The consultant project had PS & E 90% complete as of 1/7/86. Both included bridgework (2 State, 4 Consultant) and culvert structures (6 State, 4 Consultant) as well as roadway design. The complexity of all facets of these jobs was average.

24 & 24A	State Project	Consultant
Start Date	4/81	4/85
Completion Date	4/83	12/85

#24A

$74,023	Total recorded cost
- 17,073	Labor additive
$56,950	Direct cost
+ 30,166	Overhead
$ 87,116	Total project cost

Construction cost
$1,568,764
%PE 5.6%

#24

Total cost of consultant project including in-house expense with overhead factor:

$307,781	Consultant Cost
$9,735	In-house direct cost
$5,156	In-house Overhead amount
$322,672	TOTAL

Construction cost
$8,474,586 (est.)
%PE 3.8%

Overhead rate on consultant contract: 152%

Project Pair 25 and 25A

District 24

#25 CSJ 2552-4-12 - Consultant No. 25

#25A CSJ 3552-4-8 SDHPT District 24

The District 24 assessed the quality of the in-house project as good; the consultant's plans were considered to be satisfactory. According to District staff, a great deal of guidance by State personnel was needed to produce the consultant plans. The roadway and bridge design of both projects is of medium complexity, whereas the structural of both is of low complexity. The location of both these projects is an urban/rural combination design for new construction on an existing facility.

25 & 25A	State Project	Consultant
Start Date	3/9/77	3/1/84
Completion Date	10/27/77	2/25/85

#25A

$35,959	Total recorded cost
- 8,293	Labor additive
$27,666	Direct cost
+ 14,655	Overhead
$42,321	Total project cost

Construction cost
$1,153,677
%PE 3.7%

Construction cost adjusted for inflation $2,156,300
Preliminary engineering cost adjusted for $72,764
Adjusted %PE 3.4%

#25

Total cost of consultant project including in-house expense with overhead factor:

$101,739	Consultant Cost	Construction cost
$28,332	In-house direct cost	$2,803,000 est.
$15,008	In-house Overhead Factor	%PE 5.2%
$145,079	TOTAL	

Project Pair 25 and 25B

District 24

#25 CSJ 2552-4-12 - Consultant No. 25

#25B CSJ SDHPT District 24

The consultant project of this pair has been paired with two separate in-house projects. The projects are similar in every respect to the previous pair. The State project is not particularly unique; it is a "typical project."

25 & 25B	State Project	Consultant
Start Date	7/26/79	3/1/84
Completion Date	2/12/81	2/25/85

#25B

$41,089	Total recorded cost
- 9,477	Labor additive
$31,612	Direct cost
+ 16,745	Overhead
$48,357	Total project cost

Construction cost
$1,495,183
%PE 3.2%

#25

Total cost of consultant project including in-house expense with overhead factor:

$101,739	Consultant Cost
$28,332	In-house direct cost
$15,008	In-house Overhead amount
$145,079	TOTAL

Construction cost
$2,803,000 est.
%PE 5.2%

Overhead rate on consultant contract: 144.8%

Project Pair 26 and 26A

District 24

#26 CSJ 2121-2 and 3 - Consultant No. 26

#26A CSJ 2121-3-83 SDHPT District 24

The State project of this pair has been evaluated as a good project with no difficulties encountered. Problems encountered in the consultant project were due to delays brought about by additional work required by FHWA. Overall and despite delays, the consultant project was evaluated as a good project by the District 24 staff. Both projects included roadway, bridge, and structural design of medium complexity. The type of construction work for this project is for new construction on an existing facility in an urban location. Overall the complexity of the State project was evaluated as being above medium complexity, and the consultant project was determined to be of high overall complexity. The most difficult portions of this project pair were the bridge widenings (4 State, 3 Consultant).

26 & 26B	State Project	Consultant
Start Date	11/83	9/4/84
Completion Date	7/84	6/3/86

#26A

$142,536	Total recorded cost
- 32,875	Labor additive
$109,661	Direct cost
+ 58,087	Overhead
$167,748	Total project cost

Construction cost
$3,600,000
%PE 4.7%

#26

Total cost of consultant project including in-house expense with overhead factor:

$1,403,639	Consultant Cost
$54,175	In-house direct cost
$28,696	In-house Overhead amount
$1,486,510	TOTAL

Construction cost
$16,765,000 est.
%PE 8.9%

Overhead rate on consultant contract: 124.6%

Project Pair Summaries

The percent that engineering costs are of construction costs (%PE) was smaller for the in-house projects in 15 of the 18 pairs. The 18 consultant projects were generally rated as good to excellent by SDHPT district evaluators. Most of the in-house projects were similarly assessed as good to excellent.

The adjustments for inflation on some projects had the effect of more than doubling both the construction and the engineering costs. The %PE's didn't change very much as a result.

The lowest %PE for in-house projects was 1.8% and for consultants was 2.6%. The highest in-house %PE was 9.5%; the highest for consultants was 9.7%.

As shown in Table 1 (next page), the average %PE in-house was 2.8% and was 4.9% for consultants. The sensitivity of this result was examined by hypothetically reducing the state's portion of the consultant project total charges. When the state component of the consultant's projects was completely removed, the %PE for the consultant's average falls to 4.2%, still well above SDHPT's 2.8 %PE.

Finally, the size of project 10A is so large relative to the state forces total construction that it creates some dominance in the data. Removing project pair 10-10A from the data base results in %PE for consultants at 4.9% and for state forces at 3.5%.

The composite results for the projects in the data base are summarized in Table 1 on the next page.

Table 1. Construction Costs and P.E. Costs, All Projects

	Consultant		In-house	
	Construction	PE	Construction	PE
1 & 1A	$13,703,587	$642,375	$21,665,247	$390,968
6 & 6A	2,240,000	217,154	955,246	75,825
7 & 7A	981,000	77,341	1,302,313	85,066
8 & 8A	5,121,350	321,993	3,213,037	305,696
10 & 10A	40,000,000	1,946,655	80,445,194	1,563,576
14/15 and 13A/15A	5,970,000	238,988	8,960,000	175,354
16 & 16A	10,714,997	411,604	3,955,720	233,825
17 & 17A	9,125,700	312,751	3,590,265	130,570
18 & 18A	39,833,648	1,339,546	16,191,078	497,450
19 & 19A	2,850,000	247,411	3,200,000	147,834
20 & 20A	5,675,951	364,385	6,838,086	185,992
21 & 21A	4,042,000	286,352	2,052,890	134,998
22 & 22A	12,215,000	303,084	5,725,720	298,284
23 & 23A	4,500,000	338,333	2,847,463	114,688
24 & 24A	8,474,586	322,672	1,568,764	87,116
25 & 25A	2,803,000	145,079*	2,156,300	72,764
25 & 25B	2,803,000	145,079*	1,495,183	48,357
26 & 26A	16,765,000	1,486,510	3,600,000	167,748
TOTALS	$185,015,819	$9,002,233	$169,762,506	$4,716,111

Average Consultant %PE 4.9%   Average In-House %PE 2.8%

Average All Projects %PE 3.9%

*Only one of these projects is included in the totals and averages.

Use of Cost Curves

Several state and national agencies (Consulting Engineers Council of Texas, Texas Society of Professional Engineers, and the American Society of Civil Engineers) publish manuals which contain several generally accepted methods of compensating the consulting engineer for the services he performs. These manuals include different curves of median compensation. The curves plot the compensation for engineering services in percent versus the construction cost of the authorized work. There are different curves for projects of varying complexity and guidelines for applying these methods to aid in estimating the proper amount of compensation.

As Figures 1 and 2 show, two separate curves have been used--one for relatively larger, more complex jobs and another for relatively smaller, less complex jobs. Although the curves are primarily used to aid in assessing fees for contract work, their acceptance over many years also affords a guide for judging the reasonableness of the costs of engineering services. The plots of the values in Figures 1 and 2 are derived from the projects in the study data set (Table 2).

As shown in Figure 1 for projects above average complexity, SDHPT forces have noticeably lower %PE's (2.4% weighted avg.) than do consultants (5.0% weighted avg.). In fact in only one of six projects was the in-house %PE above the TSPE median curve. And four of the six were off the scale on the low side. For consultants projects of above average complexity, half of the %PE's were on or above the median TSPE curve.

For projects of average or below average complexity, the plots on Figure 2 data show about the same results for in-house %PE and consultant %PE. Five projects of each source (in-house; consultant) are above the median TSPE curve; seven projects of each source are below the curve. The weighted

Table 2. % Engineering Costs of Construction Costs and Construction Costs, by Project Complexity

Above Average Complexity	Consultant % PE	Consultant Const. $$	In-House % PE	In-House Const. $$
1	4.7%	$13.7m		
1A			1.8%	$21.7m
8	6.3	5.1m		
8A			9.5	3.2m
10	4.9	40.0m		
10A			1.9	80.4m
18	3.4	39.8m		
18A			3.1	16.2m
20	6.4	5.7m		
20A			2.7	6.84m
26	8.9	16.8m		
26A			4.7	3.6m
Wtd. Avg.	5.0%	Wtd. Ave.	2.4%	
Average or Below Average Complexity				
6	9.7%	$2.2m		
6A			7.9%	$.96m
7	7.9	.98m		
7A			6.5	1.3m
14/15	3.9	5.97m		
13A/15A			2.0	8.96m
16	3.8	10.7m		
16A			5.9	3.96m
17	3.4	9.13m		
17A			3.6	3.59m
19	8.7	2.9m		
19A			4.6	3.2m
21	7.1	4.0m		
21A			6.6	2.1m
22	2.5	12.2m		
22A			5.2	5.7m
23	7.5	4.5m		
23A			4.0	2.9m
24	3.8	8.5m		
24A			5.6	1.6m
25	5.2	2.8m		
25A			3.4	2.2m
25B			3.2	1.5m
Wtd. Avg.	4.8%	Wtd. Avg.	4.3%	

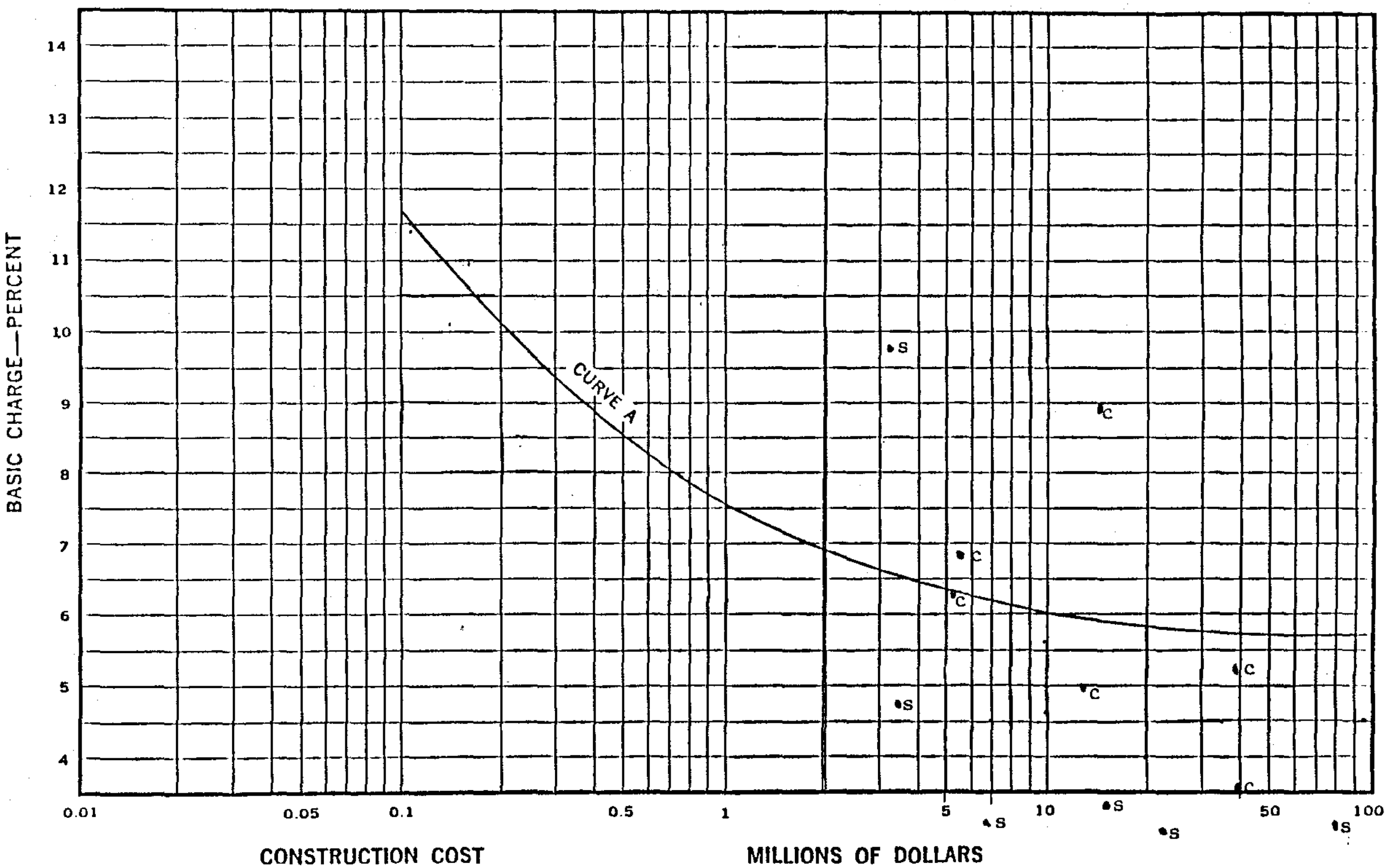

Figure 1. Relationship of Engineering Costs (as a % of Construction Costs) to the Construction Value (for above average complexity projects)

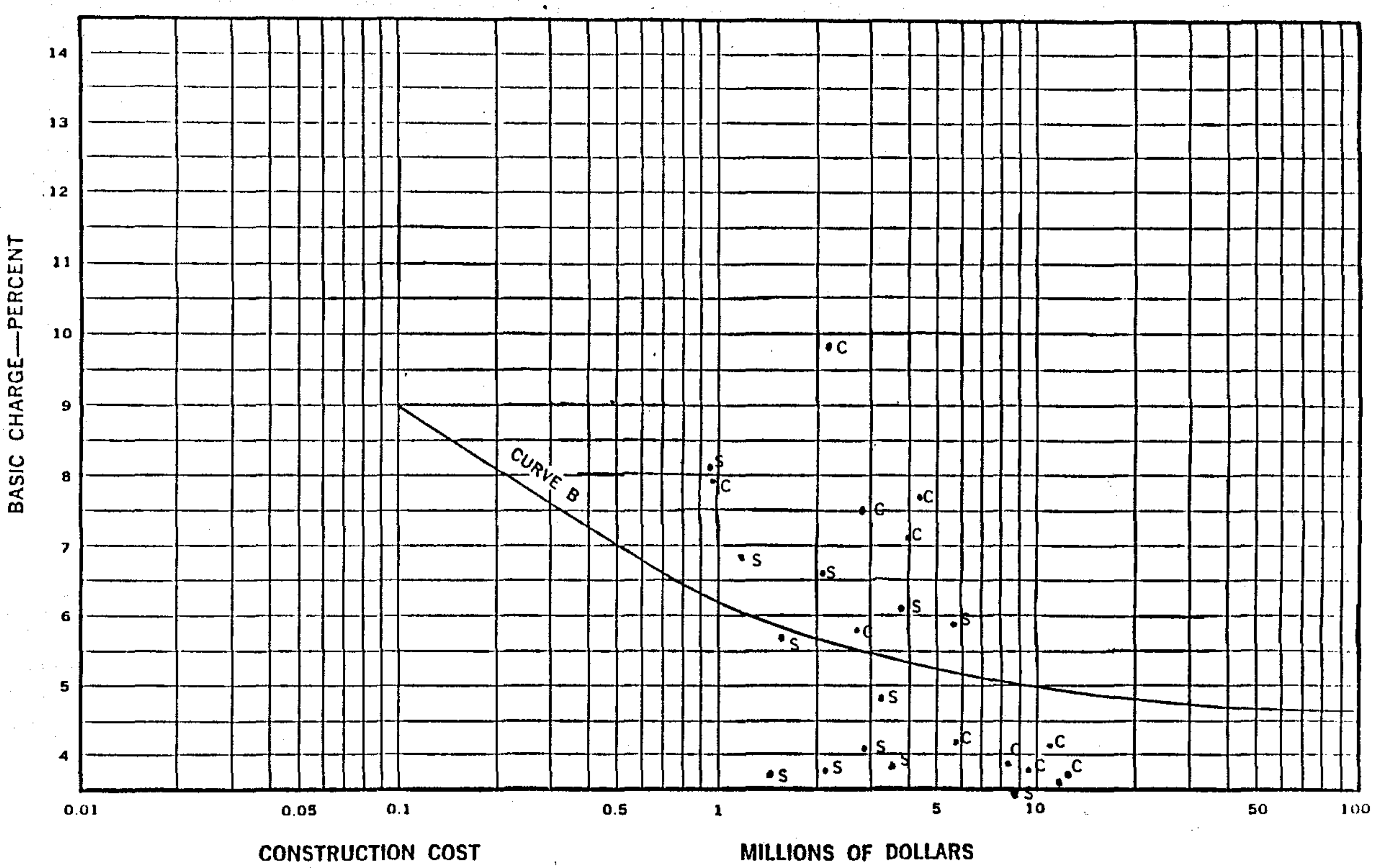

Figure 2. Relationship of Engineering Costs (as a % of Construction Costs) to the Construction Value (for average to below-average complexity projects)

average %PE for in-house projects of average or below average complexity is 4.3% PE. The similar datum for consultants is 4.8% PE.

If the TSPE curves are generally correct, then it would expected that (in the present data comparison) relatively larger projects would exhibit relatively smaller %PE's. To check this, another assessment of the data was made to evaluate the usefulness of the %PE in explaining the differences between in-house and consultant engineering outcomes. The data in Table 3 show the relative sizes of construction and %PE for each of the 18 project pairs. Thus, for example, in Project 1A and 1, the in-house project was the larger of the pair in terms of construction and it also resulted in the smaller %PE. Examination of the data in Table 3 shows that in 11 of the 18 pairs, the larger project was associated with the smaller %PE. Interestingly, though, in all seven cases in which a reversal of the tendency occurs, the in-house project (though less costly) produced the smaller %PE.

Table 3. Relative Size of Construction Costs and %PE, by Project Pairs

Project Pair	Larger Project in Pair	Smaller %PE in Pair
1A & 1	State	State
6A & 6	Consultant	State
7A & 7	State	State
8A & 8	Consultant	Consultant
10A & 10	State	State
13A/15A & 14/15	State	State
16A & 16	Consultant	Consultant
17A & 17	Consultant	Consultant
18A & 18	Consultant	State
19A & 19	State	State
20A & 20	State	State
21A & 21	Consultant	State
22A & 22	Consultant	Consultant
23A & 23	Consultant	State
24A & 24	Consultant	Consultant
25A & 25	Consultant	State
25B & 25	Consultant	State
26A & 26	Consultant	State

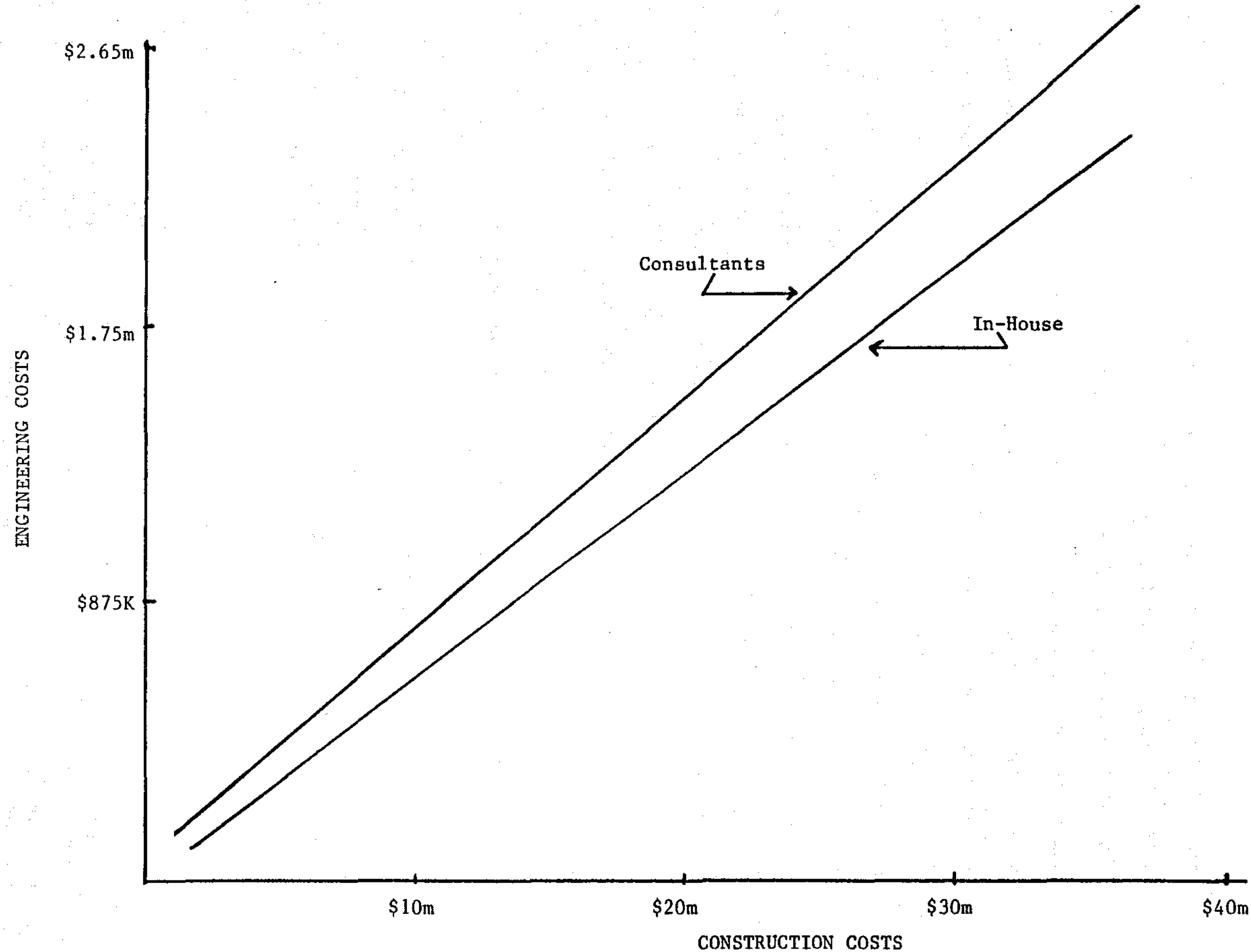

Figure 3. Regression Lines for Consultant and In-house Preliminary Engineering and Construction Cost

Regression Analysis

To further analyze the relationship between preliminary engineering cost and construction cost, a regression analysis was performed to estimate the relationship of preliminary engineering cost to cost of construction. The results of this analysis are summarized in Figure 3, which shows that for any given cost of construction, consultant preliminary engineering cost tends to be higher than similar in-house preliminary engineering cost. Additional details of this regression analysis are presented in data and charts in Appendix 1.

Sensitivity Analysis

In addition to the analyses already discussed in this chapter, the study staff analyzed the effects of hypothesized changes in the magnitude of the SDHPT's overhead rate. In terms of the %PE values for SDHPT projects, the overhead rate used to calculate project costs must be almost quadrupled before the %PE for SDHPT projects becomes greater than that for the consultant projects in this study. Importantly, the SDHPT support costs for the consultant projects were also subject to this sensitivity analysis. Thus, any increase in SDHPT's overhead rate also yields, *ceterus paribus*, an increase in the cost of the SDHPT support provided to consultants.

Additionally, a recalculation of SDHPT's overhead rate was performed utilizing a method that included only direct labor in the allocative base. For example, recalculating the project cost items (using an overhead rate based upon direct labor) for Project 1A yielded the following results:

$182,499	direct labor
76,622	labor additive
73,086	other direct
$332,207	Total recorded cost

When the amount of "other direct" is added to the previously derived overhead of $135,383, the newly calculated overhead costs increase to $208,469. However, and more importantly, close examination and comparison with the original calculations for Project 1A show that, as expected, **the total project cost remains absolutely unchanged.** Thus, the "bottom-line" cost relationships (as reflected in the calculated average %PE's) still show that the cost of doing in-house work is less than the cost of comparable work done by consultants.

Finally, the utilization rate for SDHPT labor was examined to observe its effects upon the cost relationships. The results showed that, principally due to accounting procedures, different assumptions about utilization rates for labor (e.g., 100%, 95%, 90%) produced minimal changes in the total project costs. The overall results were not at all sensitive to different assumed levels of labor utilization.

Some Conclusions on Cost Comparisons

From this part of this study these principal points emerge:

i) the comparative costs of conducting preliminary engineering (PS&E) in-house are less than costs of similar work done by consultants.

ii) overhead rates for consultants are larger than the overhead rate assignable for in-house preliminary engineering.

iii) %PE for in-house projects is lower than for consultants projects in all categories:

  a) more complex projects
  b) average/simple projects
  c) all projects

QUALITY ASSESSMENT

The data that were analyzed, evaluated and assessed to measure the quality of the selected projects came from four areas in the interview guide. These areas are: (a) organization structure, personnel and size of operations, (b) use of consulting engineers, (c) quality of work appraisal completed by both SDHPT personnel and consultants, and (d) comparison of in-house and consultant project characteristics. [See Appendix 2 and 3].

All the seven districts interviewed unanimously responded that the controlling factors or reasons associated with the use of consultants are twofold: (a) lack of available work force in the districts with which to complete programmed projects on schedule especially during peak load periods, and (b) for extremely complex or specialized design techniques requiring the particular expertise not available in-house (e.g. cable-stayed bridge span; excavation, removal and disposal of toxic soils; special structural or marine problems, etc.).

Regarding the usage of consultants to particular types of projects, 4 out of the 7 districts interviewed reported that they do not restrict the usage of consultants to a unique type of project. The remaining three (3) districts restrict the use of consultants to particular types of projects for the second reason given in the previous paragraph. Six out of seven Districts responded "no" to the question on the usage of consulting engineers for <u>only</u> certain activities in the preliminary engineering and PS&E processes.

The districts interviewed establish the budgets for each in-house project using a percentage factor of the estimated construction costs modified by the location and complexity of the project. This factor is based on historical data and fluctuates between 2% and 5%. All the districts conduct quality review of both consultant and in-house work.

Consultant work is reviewed by the contact or resident engineer at weekly or bi-monthly monitoring visits and also at 30%, 60%, 90% and final stages. Thus, consultants' work gets multiple reviews. Because the SDHPT's work is done in-house, the review efforts tend to occur more continuously or simultaneously and are less informal than with the review for a consultant's work. The work characteristics normally evaluated, according to responses received, include: (a) completeness of plans, specifications and provisions, (b) clarity of drawings or plans, (c) accuracy of computations of quantities, (d) adherence to schedule as well as to number and nature of supplemental agreements, (e) need and extent of in-house monitoring and review effort, (f) thoroughness of degree of coordination with other governmental, public and private entities, (g) meeting budgetary requirements, and (h) instructions followed or to be followed.

Four out of the seven (7) districts interviewed think that the PS&E prepared in-house and by consultants have approximately the same quality. The remaining 3 districts reported that in-house work is of better quality, as a general rule than the consultant work. Most of the districts can fairly well control the quality of consultants' work to their satisfaction especially if consultants are local.

Further, interviews with some SDHPT field and headquarters (principally bridge design) personnel indicated a concern that consultant plans tend to be over-designed. When it occurs, over-design has cost as well as quality implications that SDHPT thinks warrant close scrutiny. Finally, it is important to note that many aspects of quality are unknown until construction is completed. To date, a fairly small percentage of consultant prepared plans have been built.

Information on Quality from the Consulting Industry

In the interview and data collection process, several consultants contributed information and opinions about the comparison of quality plans done by State forces and consultants. Some of the generally held views were:

(1) project quality is very difficult to assess and compare;

(2) plan quality done by consultants is probably superior, certainly no worse, than plan quality by in-house forces;

(3) quality will probably vary widely from consultant to consultant and range from bad to excellent;

(4) computerized techniques improve quality; and

(5) incentives in the private sector tend to produce high quality outputs.

Quality Analysis

Interview guides were used to obtain data on the quality of planwork done on the pairs of projects in the study. Questions were developed in 17 major response areas to discern indicators of plan quality. District personnel most familiar with the projects were responsible for filling out the interview guide and discussing the quality aspects with the study team.

To perform subsequent analysis on these data, an advisory panel at TTI was appointed and tasked to: (a) analyze the most important characteristics affecting quality of the pre-construction engineering plans that can be quantified; and (b) assess the quality of each of the forty-eight projects studied using these characteristics and the data supplied by SDHPT district personnel most familiar with the projects.

The five-member panel used data and information from the interview guides to select the following six variables or factors as the most important characteristics affecting quality of pre-construction plans: (a) completeness of plans or drawings, specifications, general and special provisions (simply called "completeness"), (b) clarity of drawings, measuring the overall legibility of plans with respect to work required (simply called "clarity"), (c) constructability of plans measuring the practicality and ability to understand and use of the plans, (d) accuracy of computations, quantities and measurements on or from the plans, (e) timeliness measuring the ability of designers to adhere to schedule, and (f) coordination and communication measuring the communication, responsiveness, thoroughness and degree of communication between the SDHPT, consultants, other governmental, public and private entities. In addition, the Advisory Panel assigned weights to each variable or factor in accordance with how much they consider the variable or factor to contribute to quality in general or how those factors affect the quality of a project being evaluated.

Quality Evaluation

The TTI Advisory Panel, after determining the quality characteristics and weights, was asked to assess or evaluate the quality of each of the forty-eight projects **using the data provided in the interview guide from each of the seven districts.** Evaluation forms (presented in Appendix 2) were designed for use by the panel to evaluate the projects.

Comparison of In-House and Consultants' Quality of Work

Statistically based procedures were used to analyze the data used by the Advisory Panel. The input and all output data from the statistically-based procedures used are as found in Appendix 2. Tables 3 and 4 summarize the correlation factors and standard deviations for the quality characteristics identified by the panel using the procedure previously described. Tables 5 and 6 provide correlation factors as well as the means and F-ratio, respectively for the same characteristics using an analysis of variance procedure. Incidentally, the correlation factors produced by both procedures are the same. Close observation and evaluation of the outputs in Tables 4-6 in Appendix 2 yield the following evaluations:

(a) The quality variables or characteristics by themselves for both in-house and consultant outputs perfectly correlate positively (i.e. the existence or increase of one entails the existence or increase of the others);

(b) Correlation between timeliness and clarity, completeness and clarity, as well as constructability and timeliness for the SDHPT project analysis produce correlation factors of .39, .39 and .48 respectively - lowest among the group and less than .5;

(c) Correlation between accuracy and timeliness for the consultants' analysis produces a factor of .59, the lowest among that group;

(d) Quality characteristics for the consultants' are slightly higher correlated than the SDHPT's;

(e) The quality of work by both in-house and consultants are <u>approximately</u> <u>the</u> <u>same</u> both in total and by districts; and

(f) Mean values for timeliness and communication are slightly lower than the remaining quality characteristics.

Synthesis of the above evaluations produces the following general observations:

(1) the variables or factors chosen by the panel actually contribute to quality;

(2) the SDHPT, on the whole, is generally pleased with the quality of the consultant's work since most of consultants' work favorably compares with that of the SDHPT; and

(3) in general, the quality of consultants' work is considered good but lack of communication, coordination or responsiveness and the performance to schedule caused some concern and influenced the overall evaluation of the consultant's quality performance.

Contractors' Opinions on Quality

To broaden the quality assessment, members of the study staff decided to interview three highway building firms in the Houston area. At a later time, at the suggestion of SDHPT, a fourth contractor located in San Antonio was interviewed. The three contractors in Houston were directly contacted and interviewed in person. The fourth contractor was contacted by telephone and interviewed by a member of the study staff. The primary objective of these interviews was to obtain from the contractors' objective appraisals of the quality of SDHPT preliminary engineering work and consultant preliminary engineering work. All of the contractors were candid; generally, their thoughts on the quality issue were fairly uniform, with some minor differences.

Overall, the contractors said that whenever there were any problems with consultants' work it was not because of incompetence or low quality work but usually attributable to a lack of familiarity by the consultant with SDHPT procedures and specifications. Communication problems between consultants and SDHPT were commonly cited as a source of problems. The contractors said that working with consultants who had good rapport, knowledge of what they were supposed to do, and experience with SDHPT procedures was indistinguishable from working with SDHPT.

Conclusions on Quality

The following are the conclusions drawn from the analysis, synthesis, evaluations of the data obtained from study:

1. most of the responding districts indicated that the use of consultants was seen as desirable in handling (a) peak work loads to meet programmed schedules, and (b) specialized or complex jobs that the department cannot handle in-house.

2. consultants seem to be doing good quality work and favorably compare with the SDHPT's work.

3. coordination, communication, responsiveness and timeliness between the SDHPT and the consultants could be improved.

4. in general, the use of consultants is relatively new with the department and the SDHPT is going through the "learning curve" with the usage of consultants.

5. with time, when the "learning curve" is over, the problems with coordination, communication, responsiveness and timeliness between the SDHPT and the consultants will improve.

POLICY

The SDHPT's policy of using consultants during periods of peak work loads and to do specialty jobs is not unique to Texas. The Transportation Research Board surveyed the fifty states' departments in 1984 and determined that the two primary reasons given by states for hiring private firms were:

> **"to respond to increased or peak work loads" and "to obtain specially trained professionals and specialized equipment."**

The remaining five reasons (in order of importance) for obtaining contracted services were:

- to replace mandated staff reductions;
- to make use of all available funds;
- to reduce costs;
- to provide opportunities for private firms; and
- to improve agency credibility with the public and to respond to a desire for less government.

The responses of the consulting engineering representatives in the present study included all of the above reasons for SDHPT using private services. Their emphasis, though, was on the ability of the private firms to reduce costs, improve efficiencies, and boost productivity--all of which were thought to result from the private sector's inherent incentives to keep costs down and profits up.

There was general agreement that the risk-bearing nature of the private sector was ideally suited to accomodate swings in the amount of highway work done in the State. Private firms can acquire and release personnel and other resources more rapidly than does the public sector. This characteristic of the private sector works in support of the SDHPT's policy to use the consulting firms more extensively during upswings of activity and less extensively during level or downward movements of workloads.

The SDHPT policy of using consultants only to help with peak loads of design work was generally opposed by the consulting engineering respondents. The question "What is the peak?" was frequently raised. Beyond that, though, there was an overriding concern that the health of the consulting industry in Texas would be seriously impaired if the private sector was used only in peak periods.

While no detailed analysis of capacity (either of SDHPT or the private sector) was undertaken, there are some salient inferences about this "peak load" policy that are possible. Consultants (though not unanimously) generally expressed the thought that SDHPT should rely more and more on the private sector to do the design and planwork for the Department. Support for this position included the boundary view that: SDHPT cadres of engineers should be used exclusively to manage programs of design work done by private consultants (much as is done in some other states, e.g., Arizona, Florida, Virginia). However, at the opposite boundary, California, with a program comparable to Texas, has consistently used in-house personnel for nearly all highway design and currently less than 5% of such work is being handled by consultants. Also, the State of New York utilizes consultants only for peak loads and specialty work, which presently combined, is about 15% of the design work.

If consultant engineers were assigned to do all of the preliminary engineering and design, the SDHPT's engineering staff would be needed to manage and direct the private sector in producing plans. While this could probably be done without jeopardy during the short run ahead (2-5 years), in a long run context, two self-limiting factors would become crucial:

(1) the career development of SDHPT's engineering staff would be shaped differently, due to its more limited role in highway planning and design; and

(2) the decentralized structure of the SDHPT would become a liability to the efficient management of consulting engineering.

In the first instance, the SDHPT would ultimately have to rely on management personnel who did not have extensive experience and training in design work --traditionally, the primary source of SDHPT's senior managers. This concern was also a major finding in the 1984 nationwide survey of highway departments conducted by TRB, to wit: "the increased usage of consultants might result in the loss of staff engineering and design skills and the (departmental) staff would become planning and management oriented, depending on consultants for technical services."

Secondly, the ability to supervise successfully an engineering program produced by consultants presupposes strong centralized organization and control -- just the opposite of the much-admired strength of SDHPT's decentralized 24-district structure. Extensive use of consultants seems to be more prevalent in states which have a strong, centralized departmental organization. This is certainly not the case in Texas.

Thus, while it would be possible to use consultants exclusively to perform engineering services, to do so, however, would require an approach to organization and management vastly different from the two markedly successful traits of the Texas SDHPT: (1) top management personnel who have been highly trained and experienced in highway design; and (2) decentralized organizational structure.

Peak Load Concept

The peak workload that is a candidate for assignment to consultants has two important aspects:

1) relativity--What is the peak relative to?

2) size and duration--How big is the peak and how long will it last?

First the notion of peak activity has meaning only relative to the surrounding levels of activity. In the present context, the surrounding levels of preliminary engineering are derived from the demands generated for the production of plans to be let to contract. In Texas, increased highway funding has driven construction lettings from $750 million in FY 82 to $1.9 billion in FY 86.

In terms of the current workload analysis, SDHPT expects that a $1.4-$1.5 billion level of construction can be accommodated by in-house design forces beginning in 1989 and continuing indefinitely. Presently, SDHPT is conducting detailed manpower and workload assignment analyses to produce a plan for augmenting in-house design capabilities to meet projected design requirements.

In Figure 4, the expected contract amounts are shown for the next 7 years in which the construction program begins to level out in 1989. From these data, the new plateau, when extended back to 1985, helps define the peak in construction as defined by SDHPT. It is the period from 1985-89 and comprises the shaded area in Figure 4.

The peaking that occurs in preliminary engineering will, given the nature of the design and construction process, occur 12-18 months prior to the peaking in construction lettings. Using a 12-month lag, the data represented in Figure 5 show a similar concept of the peak load in preliminary engineering. Although the relative amounts are sufficient to describe the concept, the actual data are derived directly from the construction data in Figure 4. The construction data was multiplied by 4.0%--the amount that preliminary engineering expenses are as a percentage of the value of construction. This factor was calculated from the study's project data.

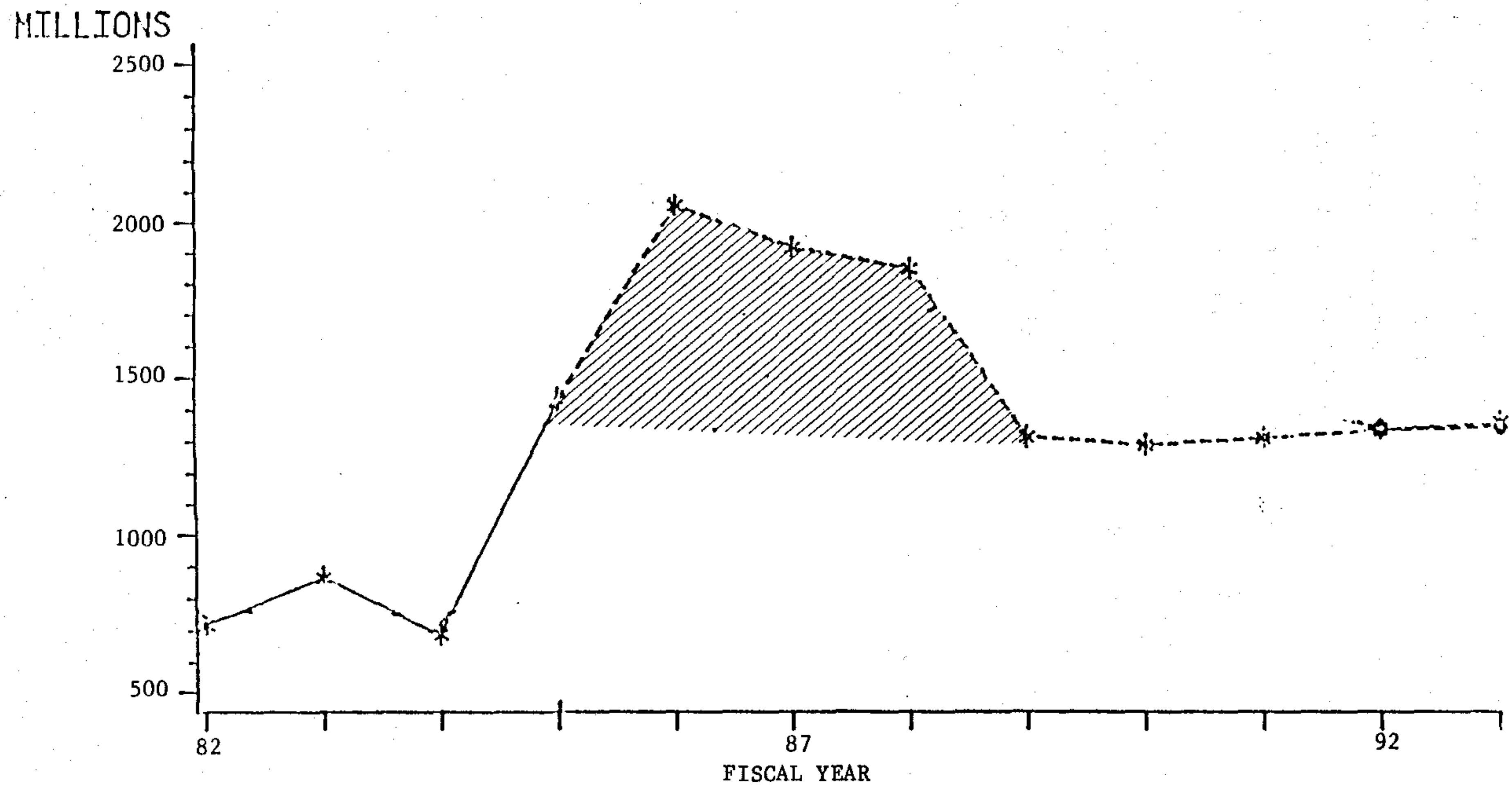

Figure 4. SDHPT Highway Construction Letting

Figure 5 shows that the preliminary engineering peak period extends from 1984 through 1987. Beginning in 1988, the effects of the expansion are expected to be dissipated such that normal work loads will be re-established by SDHPT at the new plateau levels. Future peaks will occur as departures from the plateau level and will occur when new financing is injected, either as Federal or State taxes, into the highway program.

The amounts of money being spent for consulting engineering are shown in Figure 6 for the period 1981-1986. Based on these data, the peak in expenditures for consultant services occurred in 1986, not in 1985 as suggested in Figure 5. It is likely that the FY 87 amounts for consulting preliminary engineering will be less than in FY 86, thus signaling the movement downward as shown in Figure 5.

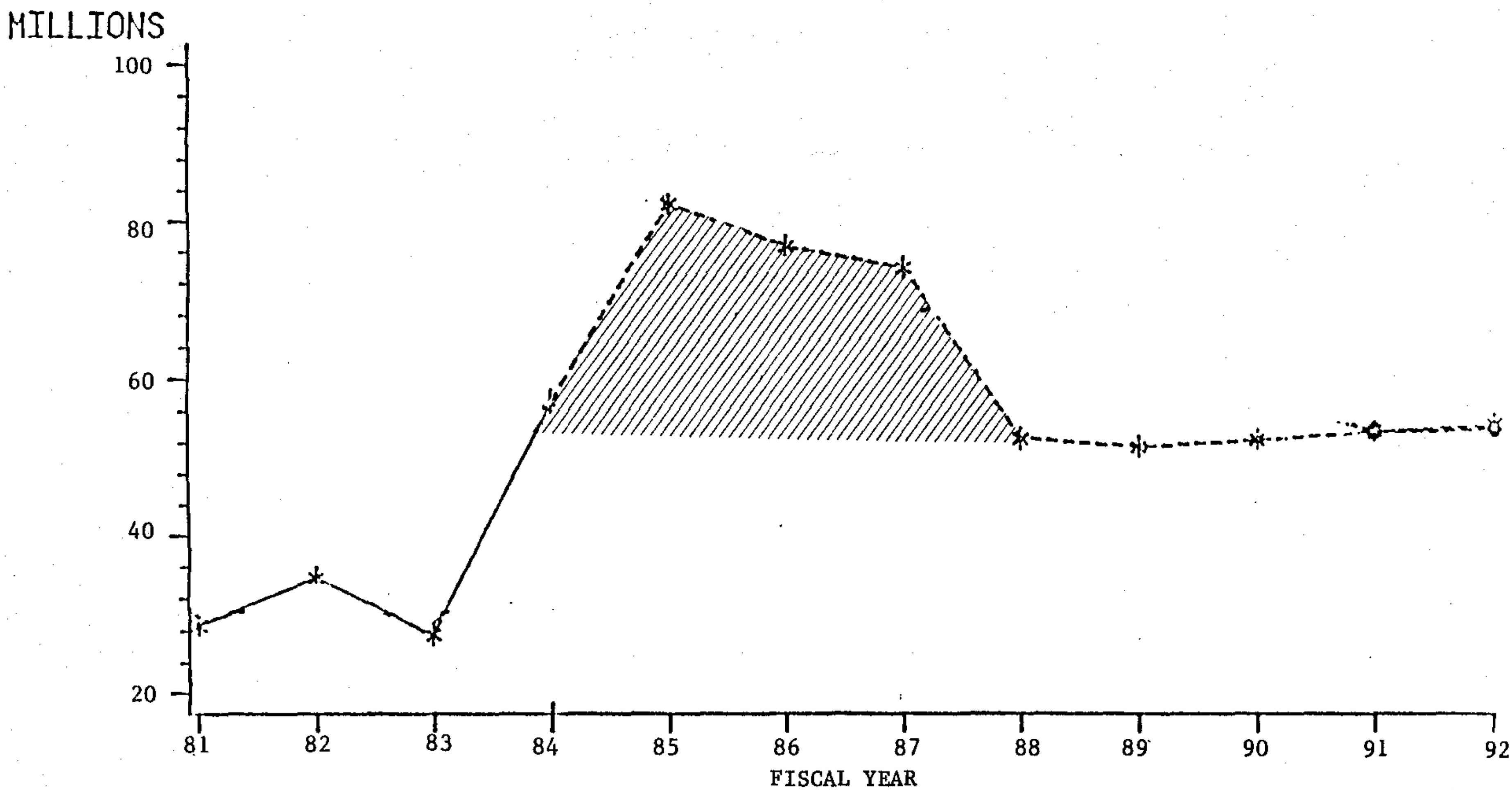

Figure 5. Preliminary Engineering Peak, 1984-1988.
Lagged-one year behind contract letting schedule

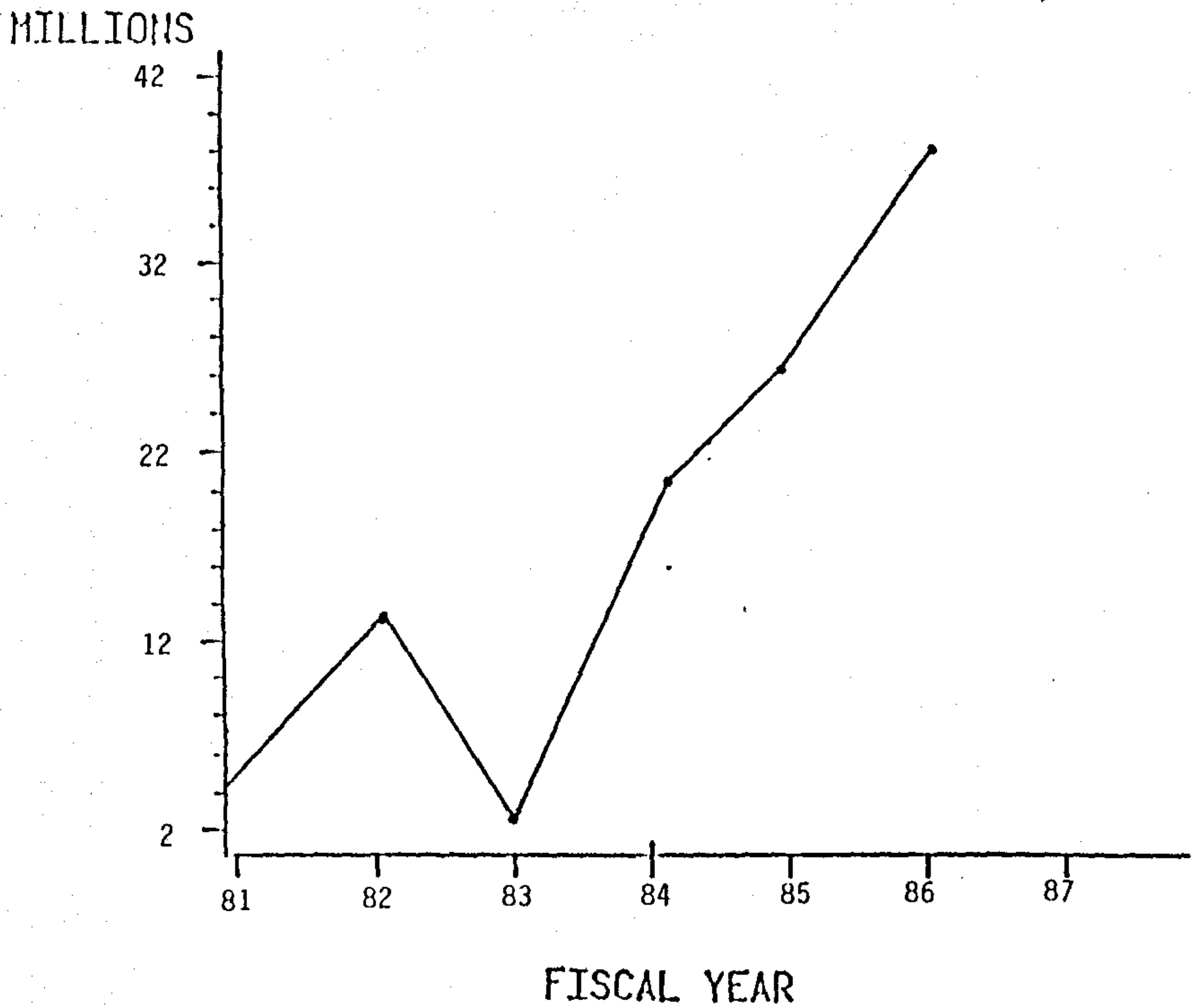

Figure 6. Consulting Contract Amounts for Preliminary Engineering, 1981-1986

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APPENDIX 1

Project Comparability

The purpose of this section is to perform a statistical analysis of the degree of comparability between in-house and consultant projects. This issue of project comparability is important in this study. For this reason, it was decided to attempt to quantify the degree of comparibility to examine the reliability of the original grouping of projects into pairs on the basis of engineering judgement.

The statistical procedure to verify if two projects are or are not comparable is based on a few independent (or relatively independent) project characteristics. These "independent" (statistically independent) characteristics were obtained by performing a correlation analysis of 19 project characteristics provided in the interview guide. After a correlation matrix was obtained for these 19 characteristics, those least related to any of the other 18 characteristics were deemed statistically independent. The characteristics meeting the requirements of independence are:

- Length
- Nonstandard plansheets
- Number of bid items
- ADT

The above project characteristics can be measured for each project of the data base developed in this study. For any pair of projects, let x_1, x_2, x_3, x_4 be the numerical values associated with the in-house project, and let y_1, y_2, y_3, y_4 be the values associated with the consultant project.

It is possible to prove that if the project characteristics are independent, the two projects being considered are totally comparable. The quantity

$$\chi_0^2 \sum_{i=1}^{4} \frac{(x_i - y_i)^2}{\sigma_{x_i}^2 + \sigma_{y_i}^2}$$

follows a chi-square distribution with three degrees of freedom. In the above mathematical expression, it is assumed that $x_i \sim N(\mu_{ix}, \sigma_{x_i}^2)$ and $y_i \sim N(\mu_{iy}, \sigma_{y_i}^2)$. In statistical terms, the project comparison study is actually the testing of the hypothesis

H_0: $\mu_{x_i} = \mu_{y_i}$, $i = 1, 2, 3$

against the alternative hypothesis

H_1: $\mu_{x_i} = \mu_{y_i}$

for at least one value of $i = 1, 2, 3$.

Given a critical value χ_c^2 corresponding to a level of significance and four degrees of freedom, it is possible to check if the numerical value of

$$\chi_0^2 = \sum_{i=1}^{4} \frac{(x_i - y_i)^2}{\sigma_{xi}^2 + \sigma_{yi}^2} < \chi_c^2$$

In case that the above relationship is satisfied, it is concluded that the in-house and consultant projects are comparable at a 100 % level of significance. Otherwise, the projects are not considered to be comparable.

The comparison methodology was conducted using the critical value $\chi_c^2 = 9.487$, obtained from a chi-square significance table with $\alpha = 0.05$. used on available project data, the variance of each of the three project characteristics was found to be equal to:

(a) For in-house projects:

$\sigma^2_{x_1} = 6.09$

$\sigma^2_{x2} = 17513.4$

$\sigma^2_{x3} = 2463.9$

$\sigma^2_{x4} = 1636380$

(b) For consultant projects:

$\sigma^2_{y_1} = 7.74$

$\sigma^2_{y2} = 30565.2$

$\sigma^2_{y3} = 2852.7$

$\sigma^2_{y4} = 1344446$

The application of the statistical test for comparing the projects is summarized in the following table. In this table two projects would be perfectly comparable (from a statistical point of view) if the χ^2_0/χ^2_c ratio were equal to zero; within the range of values between 0 and 1, this ratio can still be used to conclude that two projects are comparable, assuming a maximum probability of 5% that a wrong conclusion is reached. Outside the range [0,1] increasing values of the ratio χ^2_0/χ^2_c would indicate that two projects are more statistically different. According to the above statistical criterion, Pair #8 contains the most comparable projects, while Pair #10 contains the most different projects.

Understandably, this procedure tends to select the projects that, by nature, are less complex in their characteristics. Thus, the seven pairs of statistically comparable projects are seven of the simplest, ordinary projects in the data set and are not very representative of the full range of work being done by SDHPT or consultants. On these 7 pairs, however the average % PE for the state projects was lower (4.6%) than for the consultants projects (5.2%).

This statistical analysis identifies Projects 10-10A as the least statistically comparable in the data set.

Table A-1. Project Comparison Results

PAIR ID	X2	COMPARABLE	X2/X2
1-1A	N/A	N/A	N/A
2-2A	N/A	N/A	N/A
5-5A	N/A	N/A	N/A
12-12A	40.12	NO	4.22
6-6A	6.35	YES	0.7
7-7A	28.54	NO	3.0
8-8A	0.74	YES	0.078
10-10A	1,090.32	NO	114.9
17-17A	0.9142	YES	0.096
16-16A	0.9318	YES	0.098
25-25A	45.94	NO	4.84
26-26A	435.81	NO	45.85
27-27A	326.10	NO	34.37
25-25B	45.71	NO	4.81
22-22A	30.86	NO	3.25
21-21A	3.623	YES	0.381
23-23A	6.56	YES	0.69
24-24A	4.41	YES	0.46
13-13A	N/A	N/A	N/A
14-14A	N/A	N/A	N/A
15-15A	N/A	N/A	N/A
18-18A	460.12	NO	48.5
19-19A	317.01	NO	33.41
20-20A	56.81	NO	5.98

Table A-2. Cost Deflators
(1979=100)

Year	Construction[1]	Engineering[2]
1971	34.15*	53.95
1972	36.68	57.43
1973	40.97	61.14
1974	61.01	67.55
1975	63.00	73.69
1976	57.45	78.99
1977	64.69	84.98
1978	83.84	91.77
1979	100.00	100.00
1980	122.64	109.67
1981	113.80	120.61
1982	120.15	127.93
1983	120.33	135.24
1984	109.23	142.44
1985	120.91	149.52
1986	131.72	157.64

[1]SDHPT, Highway Cost Index, Construction Component

[2]U.S. Department of Commerce, State Government Price Deflator

*Estimates

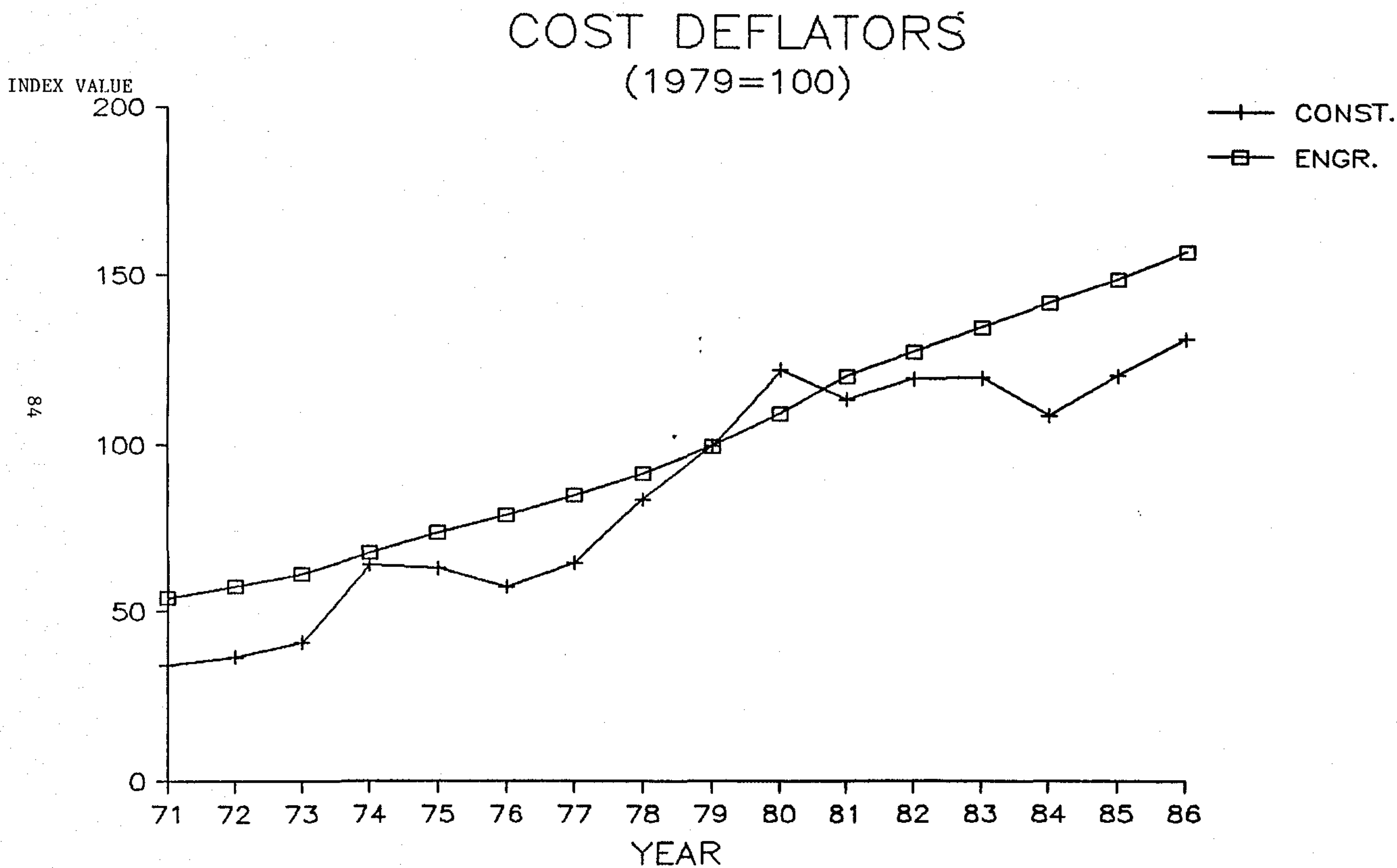
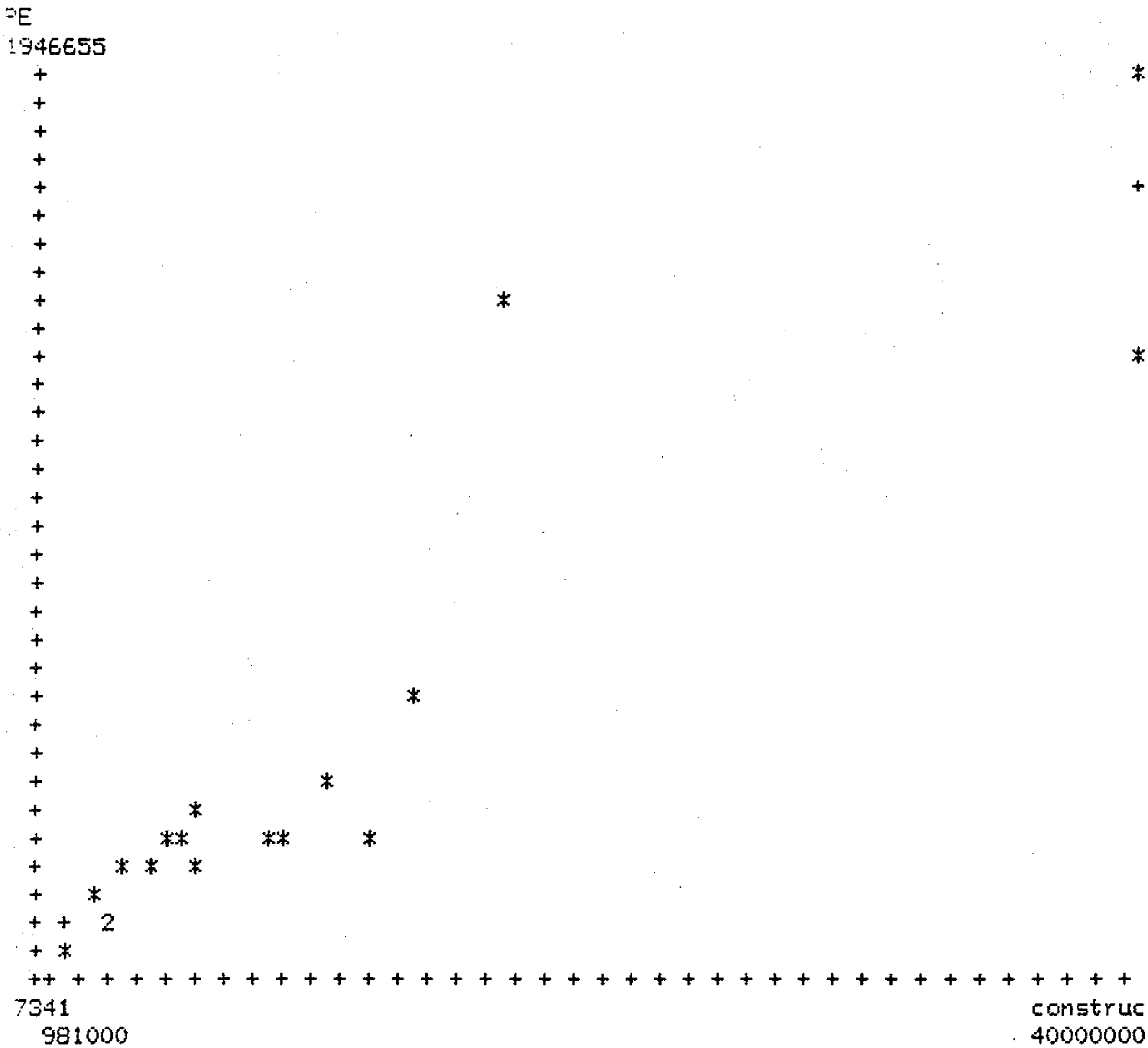


FIGURE A-1. COST DEFLATORS (1979=100)



CONSULTANT PROJECTS

EADER DATA FOR: A:CONSULTA   LABEL: consultant
UMBER OF CASES: 18   NUMBER OF VARIABLES: 2

REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 82520.08099645   SLOPE= 4.0885905805127E-02

r = .9036   r squared = .8165

Figure A-2

-------------------- DESCRIPTIVE STATISTICS --------------------

HEADER DATA FOR: A:CONSULTA LABEL: consultant
NUMBER OF CASES: 18 NUMBER OF VARIABLES: 2

CONSULTANT PROJECTS

NO.	NAME	N	MEAN	STD. DEV.	MINIMUM	MAXIMUM
1	construc	18	10434378.8333	11569239.4072	981000.0000	40000000.0000
2	PE	18	509139.1111	523473.0806	77341.0000	1946655.0000

-------------------- REGRESSION ANALYSIS --------------------

HEADER DATA FOR: A:CONSULTA LABEL: consultant
NUMBER OF CASES: 18 NUMBER OF VARIABLES: 2

CONSULTNAT

INDEX	NAME	MEAN	STD.DEV.
1	PE	509139.1111	523473.0806
DEP. VAR.:	construc	10434378.8333	11569239.4072

DEPENDENT VARIABLE: construc

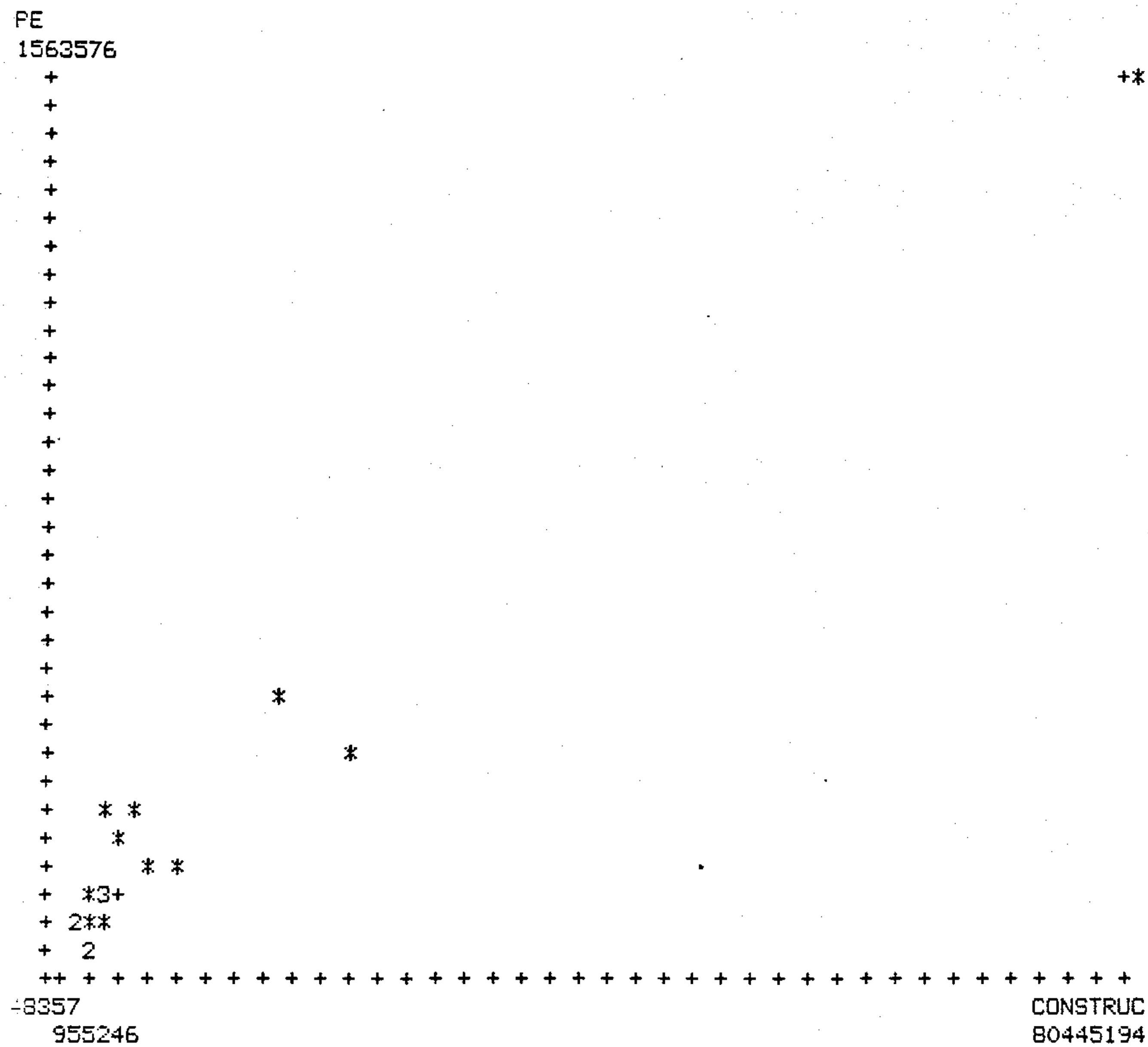
VAR.	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 16)	PROB.
PE	19.9708	2.3667	8.438	.00000
CONSTANT	266485.2137			

STD. ERROR OF EST. = 5108115.1924

r SQUARED = .8165
r = .9036

ANALYSIS OF VARIANCE TABLE

SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
REGRESSION	1.85792E+15	1	1.85792E+15	71.204	2.757E-07
RESIDUAL	4.17485E+14	16	2.60928E+13		
TOTAL	2.27540E+15	17			



STATE PROJECTS

HEADER DATA FOR: A:STATE   LABEL: STATE
NUMBER OF CASES: 18   NUMBER OF VARIABLES: 2

REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 89794.13054372   SLOPE= 1.8285156385395E-02

r = .9794   r squared = .9593

Figure A-3

-------------------- DESCRIPTIVE STATISTICS --------------------

HEADER DATA FOR: A:STATE LABEL: STATE
NUMBER OF CASES: 18 NUMBER OF VARIABLES: 2

STATE PROJECTS

NO.	NAME	N	MEAN	STD. DEV.	MINIMUM	MAXIMUM
1	CONSTRUC	18	9406250.3333	18552913.3075	955246.0000	80445194.0000
2	PE	18	261788.8889	346368.4247	48357.0000	1563576.0000

--------------------- REGRESSION ANALYSIS ---------------------

HEADER DATA FOR: A:STATE LABEL: STATE
NUMBER OF CASES: 18 NUMBER OF VARIABLES: 2

STATE PROJECTS

INDEX	NAME	MEAN	STD.DEV.
1	PE	261788.8889	346368.4247
DEP. VAR.:	CONSTRUC	9406250.3333	18552913.3075

DEPENDENT VARIABLE: CONSTRUC

VAR.	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 16)	PROB.
PE	52.4622	2.7022	19.414	.00000
CONSTANT	-4327765.0784			

STD. ERROR OF EST. = 3859091.4243

r SQUARED = .9593
r = .9794

ANALYSIS OF VARIANCE TABLE

SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
REGRESSION	5.61330E+15	1	5.61330E+15	376.919	1.610E-12
RESIDUAL	2.38281E+14	16	1.48926E+13		
TOTAL	5.85158E+15	17			

APPENDIX 2

Procedure to Assign Quality Assessments of Projects

A statistical procedure was developed to identify meaningful factors and scales in a point project quality evaluation plan by examining factor overlapping, capability of factors to be quality indicators, and their ability to discriminate among projects. A computer program was written to facilitate the execution of the statistical procedure.

The validity of the factors and factor scales can only be judged by the validity of the project quality relationships emanating from their application. The factors are generally selected and weighed on the basis of past experience. The selection of the factors should be made by giving due consideration to the following: (1) acceptability, (2) applicability, (3) ratability, (4) distinctive nature, (5) number of factors, and (6) ease and economy of administration.

Too many factors or factor levels will produce results which are ambiguous and overlapping. On the other hand, if too few factors or levels are selected the evaluation process will rather become generalized. Consequently, the factors and factor scales should be selected carefully and deliberately.

The main objective of this section is to describe the statistical procedure for selecting factors and designing factor scales in an evaluation plan so that the overall reliability and accuracy of the plan can be improved. Emphasis is placed on the methodology that was especially employed to conduct a systematic and relatively objective analysis of a particular choice of factors and scales given a sample of key projects (both for consultants and in-house).

For the application of the project quality evaluation methodology, TTI's panel carefully examined the scope and content of each project from considering the following factors: completeness, clarity, constructability, accuracy, timeliness, and coordination/communication. For each of these six factors, a five-level scale was designed in order to cover a range that reflected all possible quality ratings for a given project.

The factor screening methodology is based on 23 in-house and 23 consultant projects. The statistical procedure developed in this can be used to eliminate undesirable factors or to modify irregular factor scales, according to a collection of four tests. A summary of each test is given in Appendix 3.

Table 1. Advisory Panel Quality Evaluation Form

Project#________________________ District #__________________________

Quality Characteristic	Hierarchic[1] Weighting (%)	Scale[2] A B C D E	Remarks[3]
1. Completeness			
2. Clarity			
3. Constructibility			
4. Accuracy			
5. Timeliness			
6. Coordination & Communication			
Sum of 1-6	100%		
7. Complexity[4]	Low, Medium, High		
8. Comparability[4]	Yes, No		

1: Assign the proportionate weight (in %) to each of the quality characteristics. The weight you assign should reflect how this particular characteristic affects quality in general or how it affects the quality of the project you are evaluating.

2: See the attached sheet for the definition of the scaling system.

3: Comment or express any observation, judgement or opinion you might have, based on the data in the interview guide.

4: Circle appropriate ones please.

Name of Panel Advisor______________________________________

Table 2. Definition of Scaling System for Quality Characteristics

Scaling System (A, B, C, D, E) is Defined for Each Quality Characteristic as Follows:

Quality Characteristic	A	B	C	D	E
Completeness	Very good plans; no omissions; no conflicts between plans and spec.; below average errors; plans maintain all the necessary elements; no changes during construction.	Good plans with below average omissions, conflicts and errors; plans contain all the necessary elements; no changes during construction.	Good plans with below average errors, omissions, conflicts and changes; plans contain most of the necessary elements.	Satisfactory plans with average omissions, errors, conflicts; plans contain more of the necessary elements.	Satisfactory plans above average omissions, errors, conflicts and changes; plans contain essentially more of the necessary elements.
Clarity	Very neat; very legible; very neat to produce; no errors, omissions and misspelled words.	Very neat; legible; easy to reproduce; below average errors, omissions and misspelled words.	Legible and neat; average errors, omissions and misspelled words; easy to produce.	Legible but not so neat; above average errors, omissions and misspelled words; can reproduce.	Barely legible; not so neat; above average errors, omissions and misspelled words; barely reproducible.
Constructibility	Very good plans; no omissions, conflicts, errors, changes or claims; design/plans are very practical.	Good plans with below average errors, omissions, or conflicts; below average changes and no claims; plans/design very practical.	Good plans with average errors, omissions, conflicts, or changes; plans/design practical, below average claims.	Satisfactory plans with above average omissions, conflicts or changes; average claims; plans/design practical.	Satisfactory plans with above average errors, conflicts, changes; plans/design fairly practical.
Accuracy	Plans are free from errors; plans conform exactly to requirements; no omissions or conflicts; very good plans.	Plans have below average errors, conflicts, omissions; plans conform exactly to requirements; good plans.	Plans have average errors, conflicts, and/or omissions; plans conform requirements; good plans.	Plans have above average errors, conflicts, and/or omissions; plans conform to requirements; satisfactory plans.	Plans have above average errors, conflicts, and/or omissions; plans barely conform to requirements; satisfactory plans.
Timeliness	Adhered very closely to original project schedule; met all deadlines; performed within schedule.	Adhered closely to original project schedules; met most of deadlines; performed within schedule.	Deviated from original schedule by 60 days; met most deadlines; overrun was not designers' fault.	Deviated from original schedule by 120 days; met some of deadlines; both department and consultant contributed to overrun(s).	Deviated from original schedule by more than 120 days; designer defaulted.
Communication and Coordination	Excellent communication and coordination; both department and consultant were very responsive; review was below normal to normal.	Good to very good communication and coordination; department and consultant were very responsive; normal review.	Good or average communication and coordination; responsiveness from one or both parties was just normal; just above average review.	Satisfactory communication, coordination, and responsiveness; above average review.	Poor communication, coordination, and responsiveness; excessive review.

Table 3. Correlation Factors & Standard Deviations for the Consultant's Data

Correlation Between Factor and Quality

Factor	Correlation	Description
1.000	0.935	Completeness
2.000	0.775	Clarity
3.000	0.898	Constructibility
4.000	0.798	Accuracy
5.000	0.888	Timeliness
6.000	0.805	Coord./Commun.

Correlation Between Factors

Factors	Correlation
1 and 2	0.693
1 and 3	0.856
1 and 4	0.739
1 and 5	0.834
1 and 6	0.699
2 and 3	0.605
2 and 4	0.667
2 and 5	0.614
2 and 6	0.655
3 and 4	0.695
3 and 5	0.739
3 and 6	0.727
4 and 5	0.594
4 and 6	0.634
5 and 6	0.658

Factor	Std. Dev.
1	1.132
2	0.778
3	0.920
4	0.972
5	1.231
6	1.102

Table 4. Correlation Factors & Standard Deviations for the Department's Data

Correlation Between Factor and Quality

Factor	Correlation	Description
1.000	0.843	Completeness
2.000	0.754	Clarity
3.000	0.862	Constructibility
4.000	0.921	Accuracy
5.000	0.685	Timeliness
6.000	0.904	Coord./Commun.

Correlation Between Factors

Factors	Correlation
1 and 2	0.603
1 and 3	0.692
1 and 4	0.799
1 and 5	0.385
1 and 6	0.649
2 and 3	0.522
2 and 4	0.673
2 and 5	0.390
2 and 6	0.728
3 and 4	0.785
3 and 5	0.476
3 and 6	0.767
4 and 5	0.542
4 and 6	0.763
5 and 6	0.613

Factor	Std. Dev.
1	0.928
2	0.550
3	0.751
4	0.792
5	1.216
6	0.991

Table 5. Means and F-Ratios for the Quality Characteristics for both In-House and Consultant Data

		Completeness	Clarity	Constructibility	Accuracy	Timeliness	Communication	Total
D12	Dept.	16.1	12.4	14.3	12.9	8.7	11.9	76.3
	Consul.	16.2	12.2	15.2	14.7	11.8	16.2	86.1
	F-Ratio	.76 E-04	0.02	0.9	0.7	1.0	1.6	0.8
D14	Dept.	17.7	12.0	16.5	16.8	9.5	13.9	86.4
	Consul.	7.9	8.4	8.3	9.2	5.6	10.2	49.6
	F-Ratio	17.8	3.9	15.9	7.0	2.9	2.7	10.0
D15	Dept.	18.3	12.0	19.7	14.4	9.8	14.3	88.5
	Consul.	17.9	13.0	16.5	13.2	11.3	10.7	82.3
	F-Ratio	0.05	1.0	6.0	1.0	1.0	2.6	0.8
D16	Dept.	11.4	9.6	13.0	13.2	12.1	11.4	70.7
	Consul.	13.3	12.0	13.3	10.8	9.1	17.5	76.0
	F-Ratio	1.0	0.4	0.01	4.0	3.6	2.6	0.16
D18	Dept.	11.4	10.0	10.1	8.4	6.9	9.6	56.5
	Consul.	10.1	9.7	8.7	8.2	3.5	8.8	49.1
	F-Ratio	0.3	0.05	0.6	0.02	0.8	0.09	0.9
D20	Dept.	16.2	13.2	15.2	14.4	13.3	15.4	87.5
	Consul.	16.2	12.0	12.4	14.2	9.8	12.8	77.5
	F-Ratio	0.0	0.7	2.5	0.02	7.6	1.2	1.3
D24	Dept.	16.2	12.0	16.2	14.4	12.4	14.4	85.5
	Consul.	14.3	11.3	14.3	15.3	9.8	12.8	77.6
	F-Ratio	2.0	1.0	2.0	1.0	3.4	1.0	1.3

Table 6. ANOVA Means and F-Ratios for Both Department and Consultants

Correlation Matrix

Header Data For: A:1100DEPT Label: Department Analysis
Number of Cases: 23 Number of Variables: 7

Department Analysis

	Complete	Clarity	Construt	Accuracy	Timely	Coor/Com	Qualvalu
Complete	1.00000						
Clarity	.60346	1.00000					
Construt	.69175	.52208	1.00000				
Accuracy	.79930	.67252	.78527	1.00000			
Timely	.38716	.39014	.47645	.54167	1.00000		
Coor/Com	.64894	.72804	.76718	.76294	.61316	1.00000	
Qualvalu	.84325	.75393	.86125	.92146	.68420	.90327	1.00000

Critical Value (1-Tail, .05) = + or - .35214
Critical Value (2-Tail, .05) = + or - .41228

N = 23

Correlation Matrix

Header Data For: A:1100CONS Label: Consultants' Analysis
Number of Cases: 23 Number of Variables: 7

Consultant Analysis

	Complete	Clarity	Construt	Accuracy	Timely	Coor/Com	Qualvalu
Complete	1.00000						
Clarity	.69345	1.00000					
Construt	.85642	.60481	1.00000				
Accuracy	.73853	.66750	.69514	1.00000			
Timely	.83401	.61390	.73906	.59377	1.00000		
Coor/Com	.69874	.65526	.72721	.63364	.65779	1.00000	
Qualvalu	.93514	.77524	.89813	.79754	.88828	.80520	1.00000

Critical Value (1-Tail, .05) = + or - .35214
Critical Value (2-Tail, .05) = + or - .41228

N = 23

APPENDIX 3

Statistical Quality Evaluation Procedure

A. Basic Purpose of Statistical Tests

The factor screening methodology is based on a sample of key projects. The computerized statistical procedure developed in this study can be used to eliminate undesirable factors or to modify irregular factor scales, according to a collection of four tests. A summary of each test is given below:

Test 1. Analysis of the degree of field super-position for all factors. Find the correlation coefficient for any two factors and compare it with a specified value. If the correlation coefficient is larger than the specified value, it is suggested that the two factors, to a significant extent, are measuring the same field or requirement. In this case, one of the factors may be eliminated.

Test 2. Analysis of the capability of each factor to be a quality rate indicator. Find the correlation coefficient of every factor and quality rate. If the coefficient is larger than a specified value, or less than another specified value, then the factor is a good quality indicator. Otherwise, the factor may be eliminated because its poor power to measure quality.

Test 3. Analysis of the ability of each factor scale to discriminate among projects. Determine the standard deviation of each factor. The standard deviation is a measure of the ability of a factor to discriminate among the projects under consideration. Factors with a good discriminative power are very desirable.

Test 4. Analysis of the degree of utilization of the midpoints of each factor scale. Determine the absolute different between the observed mean degree and the midpoint of the scale. The scale of a given factor can be redefined on the basis of this analysis.

B. Description of Statistical Tests

Consider the following notation:

P = number of key project

N_i = number of degrees in the scale of factor i

X_{ij}= number of key project assigned to the j_{th} degree of the scale of factor i

Y_k = Salary of the kth key project

J_{ik}= degree of the scale of factor i to which key project. is assigned

The observed mean degree of factor i is defined by

$$\overline{X}_i = \sum_{j=i}^{N_i} j\ X_{ij}/P \qquad (2)$$

The observed standard deviation of the degrees of factor i is given by

$$S_i = \sqrt{\sum_{j=1}^{N_i} j^2\ X_{ij}/P - (\overline{X}_i)^2} \qquad (3)$$

Test 1. Find the correlation coefficient for any two factors and compare it with a specified value. If the correlation coefficient is larger than the specified value, it is suggested that the two factors, to a significant extent, are measuring the same field or requirement. In this case, one of the factors may be eliminated.

Consider the factors i and ℓ; the correlation coefficient for these factors is defined as $\rho_{i\ell} = \text{cov}\ (i,\ell)/S_i S_\ell$, where

$$\text{cov}\ (i,\ell) = \frac{1}{P}\sum_{k=1}^{P}(J_{ik} - \overline{X}_i)\ (J_{\ell k} - \overline{X}_\ell) \qquad (4)$$

and $-1 \leq \rho_{i\ell} \leq 1$. If v_1 is the specified value, then $\rho_{i\ell} > V_1$ implies that one factor may be eliminated.

The assessment of v_1, v_2, v_3, and v_4 is a subjective activity which presents some difficulty because such parameters reflect to the extent of any acceptable degree of superposition between any two factors.

Test 2. Find the correlation coefficient of every factor and project quality. If this coefficient is larger than a specified positive value, or less than another specified negative value, then the factor is a good tool to measure quality. Otherwise, the factor may be eliminated because its power to measure quality is poor. In other words, the purpose of this test is to identify those factors that show a high negative or positive correlation with project quality. The correlation coefficient between factor i and quality y is given by

$$\rho_i y = \text{cov}\ (i,y)\ /\ S_i S_y\ ,$$

where cov (i,y) indicates the covariance of i and y; this covariance is defined as

$$\text{cov}\ (i,y) = \frac{1}{P}\sum_{k=1}^{P}(J_{ik} - \overline{X}_i)\ (Y_k - \overline{Y}),$$

where $Y = \sum_{k=1}^{P} Y_k/P$; in all cases $-1 \leq \rho i\, y \leq 1$.

If v_2 is a specified value against which ρ_{iy} can be compared, then $|\rho_{iy}| < v_2$ implies that factor i may be eliminated.

Test 3. The standard deviation is a measure of the ability of a factor to discriminate among the projects under consideration. Factors with a good discriminative power are very desirable.

As an alternative measure of discrimination among jobs (dispersion) the coefficient of variation may be used; this is defined as the standard deviation divided by the mean, i.e., $c_i = S_i/\bar{X}_i$. If v_3 is a specified value for the minimal acceptable standard deviation or for the coefficient of variation, whichever quality is chosen, then $c_i < v_3$ implies that factor i may be eliminated.

Test 4. Let μ_i be the midpoint of the scale of the factor i. Then $|\bar{X}_i - \mu_i|$ measures the deviation of the observed mean degree with respect to the midpoint of the scale. Obviously, factors with a low $|\bar{X}_i - \mu_i|$ value are of major interest. Therefore, if v_4 is a specified upper bound for the lack of symmetry of the distribution of factor i, this factor should be eliminated if $|\bar{X}_i - \mu_i| > v_4$.