

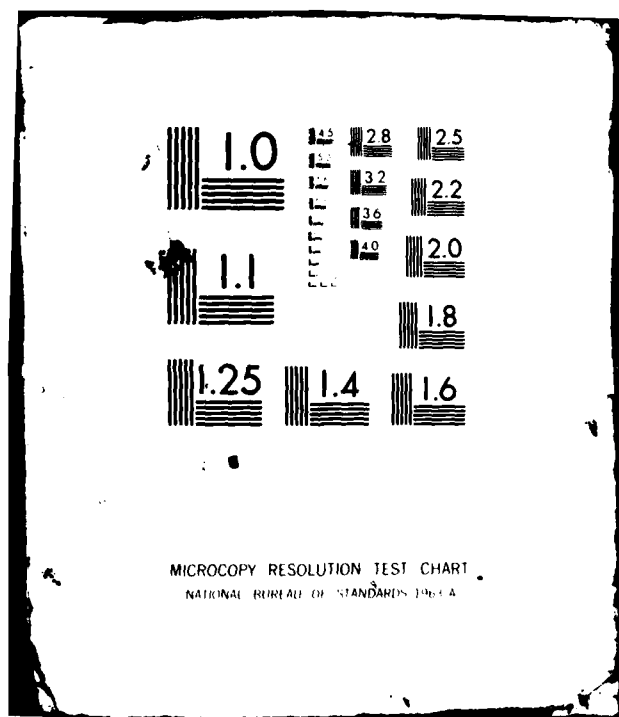
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Potential construction productivity improvement through the use of technological factors is assessed. Data was gathered through solicitation of information from top, corporate level construction managers among the important owner companies and the largest 400 American contractors and design firms. Technological factors covered consisted of construction categories and construction indicators of potential productivity improvement.		

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CONSTRUCTION PRODUCTIVITY IMPROVEMENT THROUGH TECHNOLOGICAL FACTORS

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Final Report 15 Dec 1981

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A Masters Report (Thesis) submitted to the University of Texas at Austin
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Science in Civil Engineering

CONSTRUCTION PRODUCTIVITY IMPROVEMENT
THROUGH TECHNOLOGICAL FACTORS

APPROVED:

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John D. Berchard



CONSTRUCTION PRODUCTIVITY IMPROVEMENT
THROUGH TECHNOLOGICAL FACTORS

BY

STEPHEN MICHAEL SHEPPARD, M.S.B.A.

REPORT

Presented to the Faculty of the Graduate School of
The University of Texas at Austin
in Partial Fulfillment
of the Requirements
for the Degree of

MASTERS OF SCIENCE IN ENGINEERING

THE UNIVERSITY OF TEXAS AT AUSTIN

December, 1981

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CHAPTER 1. RELATED CONSTRUCTION TECHNOLOGY STUDIES

1.1. Former Questionnaire Efforts

A survey of knowledgeable owners, contractors, and designers is a rapid, efficient tool for gathering construction information. In the past, the survey format has been used successfully in related construction information endeavors.

The Associated General Contractors of America, through its Education and Research Foundation, mailed questionnaires to 1200 contractor members to assess research needs in the construction industry and to identify appropriate procedures for research initiation. The 1975 questionnaire had 148 responses which contributed greatly to AGC's efforts. The responses were analyzed at the University of Texas at Austin (6).

A survey of the top 400 Engineering News Record contractors was conducted in 1979 by the Illinois Institute of Technology Research Institute to assess areas of productivity improvement in construction. Ninety-nine of 400 surveys were returned, providing contractor input on productivity improvement potential and contractor willingness to support improvement activities (3).

1.2. CICE

Prominent project owners and contractors agree that one of the basic factors contributing to ever increasing construction expense is the low rate of U.S. technological advance. Evidence also exists that American technological advance is not as progressive as that of foreign construction competitors. Technological advance could be the most important contributor to future construction productivity increase.

The Construction Industry Cost Effectiveness Project (CICE) is a ten year work/research program designed to modernize and upgrade the U.S. construction industry. CICE recognizes the importance of technological advance and wishes to make the U.S. competitive in construction progress. Once significant advance is realized, CICE wants to sustain the rate of advance.

1.3. Construction Technology Study Area

Within the framework of the CICE effort to achieve technological advancement exists the Construction Technology Study Area. The members of the study area initially assessed current conditions and causes for deficient technological development. The members concluded the assessment in 1980 by recommending a study program with three main parts (2):

1. Formation of a task force to be taken from experts active in modern construction with the mission of developing a formal survey of construction technology needs.

2. Execution of a series of detailed studies to formulate research and development programs and future efforts of the study group.

3. Critique and finalization of results of the other parts at a construction technology conference.

Currently, two teams are working on part 2 studies. Team 1 is studying the integration of planning, design, and construction. Team 2 is investigating construction research and development.

1.4. University of Texas Endeavors

The University of Texas research team was a subdivision of Team 2. The research team was contracted by CICE to determine areas of technological need and advancement potential (5). Its efforts were organized into two parts. Part 1 involved a questionnaire which solicits identification of specific problem areas from contractors, project owners, and design firms. Part 1 questionnaires also provided guidance for a subsequent, more detailed second part which was conducted at construction project level. Part 2's purpose was to obtain information from people close to actual construction activities and also to explore technology transfer opportunities.

The ensuing report describes and analyzes the efforts of the research team in part 1 efforts.

1.4.1. Scope of Studies

The technological research team concentrated on technological aspects of the modern construction effort. Hardware, building materials, tools, systems, and mechanical improvements were within the limits of the research. The part 1 study utilized expert opinions of modern construction managers to identify areas of construction effort which would most benefit from further technological research.

The part 1 questionnaire also collected data concerning uses of integrated construction technology. The results were sent to another CICE study and are not included in this report.

1.4.2. Objectives of Part 1 Research

The main objective of part 1 research was to prioritize potential technological areas for subsequent detailed research by the research team which would follow in part 2 studies. Opinions of corporate level construction managers were solicited through the use of mailed questionnaires. Owner companies, contractors, and design firms were asked to provide input. Selection criteria included:

1. Listing of contractors in the current ENR 400.
2. Representative contractors with expertise in Buildings, Light and Heavy Industrial projects, and Power Generation construction.
3. Design firms working in all divisions of construction covered in the study.
4. National geographic distribution.

In addition to technological potential data, added information from the part 1 questionnaire included:

1. Current use of integrated construction technology data (to be used by another CICE study group).
2. Solicitation of construction sites available during July-October, 1981, for part 2 investigations.
3. Other relevant comments helpful to the research being performed.

CHAPTER 2. QUESTIONNAIRE AND RESEARCH

2.1. Selection of the Research Instrument

The University of Texas research team used a questionnaire similar in concept to the previously employed surveys. The target audience was expanded to include prominent project owners with engineering staffs and design firms as well as ENR 400 contractors. A wealth of construction information existed in owner and design firms which was of great value to the research efforts.

The research team felt that a short, succinct questionnaire designed to be time efficient was the best information tool to use under current conditions in the construction environment. During the part 1 research period, the construction world was flooded with questionnaires, work studies, interview sessions, and other information efforts. With such an avalanche of activity, the information collecting done by the research group needed to be done quickly and efficiently. The survey was designed to require 20 minutes to complete. Each section of the questionnaire was clearly explained in a brief, concise manner. Instructions were supplemented with telephonic explanations. Coordination was made with company representatives prior to distribution.

The questionnaire developed is Appendix A.

Corporate level constructors were selected to complete the questionnaires for two reasons:

1. Corporate constructors maintain contact with the full gamut of projects handled by their companies.
2. Corporate constructors have experience in their backgrounds which was reflected in their answers.

2.2. Questionnaire Design

The questionnaire was not designed as a statistical study. Its purpose was to obtain information and opinions representative of expertise present in modern construction.

The first three questions asked individual addresses, background experience, and questions which would categorize and adjust raw answers given in question 5.

Question 2 described the project used as a frame of reference for further answers. The question described the project in terms of type of construction division, cost, labor force size and composition, and union affiliation of labor used.

Question 3 gave cost breakdowns of the construction categories used in question 5.

Question 4 was the integrated construction technology question used by the other study group.

Question 5 was the central question of the survey. It asked the questionnaire recipient to rate the named construction categories to determine their potential for technological improvement based on selected indicators of construction category effectiveness.

Detailed Description

Question 2 solicited background information on projects used by the questionnaire respondents as frames of reference for answers in the rest of the questionnaire. The respondent was asked to:

1. Classify the projects as most typically (1) Buildings (2) Light Industrial (3) Heavy Industrial or (4) Power.
2. Give the typical project construction cost.
3. List the maximum size of the typical project's work force.
4. Give the percentage of projects that were union.
5. List the craft makeup of the work force as a percentage of the total workers used. The following crafts were submitted for respondent consideration.

- | | |
|------------------------|---|
| a. Boilermakers | j. Millwrights |
| b. Carpenters | k. Laborers/Helpers |
| c. Cement Finishers | l. Painters |
| d. Electricians | m. Pipefitters |
| e. Equipment Operators | n. Riggers |
| f. Insulators | o. Roofers |
| g. Instruments | p. Teamsters |
| h. Ironworkers | q. Welders |
| i. Masons | r. Other crafts as given
by respondent |

The cost question, question 3, asked for costs associated with the typical projects described in the background question. The respondent was asked to estimate the direct construction costs that were associated with construction categories given. The costs were expressed as a percentage of the total typical project cost.

The construction categories consisted of the following construction work processes:

1. Civil categories subdivided into earthwork, foundations, structure, enclosure skin, interior finishing, and roofing
2. Mechanical categories, subdivided into piping, plumbing, vessels, hvac, and mechanical equipment
3. Special equipment installation
4. Electrical
5. Instrumentation
6. Insulation
7. Coatings and paintings
8. Fireproofing/fire protection

The selected construction categories were designed to account for all direct construction costs in commonly accepted, clear cut cost centers, enabling respondents to divide and list costs accurately.

Question 5 was the technological improvement question central to the questionnaire. Each category of construction was rated on a scale of 1 through 10 with 10 indicating the highest priority area for technological improvement. The ratings were based on construction indicators. The ratings resulted in exact data reduction for relative comparisons between construction categories and construction indicators.

The indicators were chosen for conciseness, ease of understanding and response brevity. The indicators were focal points of technological improvement potential within the scope of the study. An attempt was made to cover every aspect of improvement potential for a project with clearly understood and commonly accepted terms.

The construction indicators used were:

1. Difficulty in estimating costs.
2. Sensitivity to timeliness and quality of design.
3. Necessary lead time for scheduling.
4. Problems in obtaining proper materials.
5. Unplanned rework on typical projects.
6. Requirement for the most communications between engineering and construction teams.
7. Problems in handling materials and their distribution.
8. Sensitivity of prefabrication tolerances and accuracy.
9. Number of different crafts required.
10. Dependence on foreman competence.
11. Craftsman skill needed to perform operation.
12. Required specialized tools and equipment for construction.
13. Necessary coordination with support crafts.
14. Most wasted time among craftsmen.
15. Wasted time waiting for inspections.

Question 6 asked for sites available for part 2 investigations. When suitable sites were listed by the respondents, the research team contacted the site managers to arrange visits. Question 6 also solicited any added information or helpful suggestions to the research being conducted.

2.3. Data Reduction

2.3.1. Background Information

The research group divided questionnaires returned into four construction divisions according to the respondent answer to part A of the background question. If more than one answer was selected in part A, the research team used intuitive judgment in selecting the division in which the respondent's job experience indicated he was most familiar. His answers would most typify that construction division. The construction divisions were:

- | | |
|---------------------|---------------------|
| 1. Buildings | 3. Heavy Industrial |
| 2. Light Industrial | 4. Power |

In determining typical project costs within each division, the researchers averaged all answers given to determine one typical project cost for each division. Answer choices listed a range of values for each selection. The research group used the following discrete values during project cost determinations:

<u>Choice</u>	<u>Discrete Assumed Cost</u>
1. Less than \$10 million	\$8 million
2. 10 - 50 million	\$30 million
3. 50 - 100 million	\$70 million
4. 100 - 500 million	\$300 million
5. Greater than 500 million	\$700 million

The procedure was inaccurate for construction divisions with very few returned surveys. Wide ranges of potential error were associated with each assumed discrete value.

Similiarly, the size of the peak work force for each construction division was averaged using discrete values for each work force range given.

<u>Choice</u>	<u>Discrete Assumed Number</u>
1. Less than 100	70
2. 100 - 500	300
3. 500 - 1000	700
4. Greater than 1000	2000

The typical percentages of projects which were union were also calculated with average percentages. Assumed discrete values were needed in two of the choices.

<u>Choice</u>	<u>Discrete Assumed Percentage</u>
1. 0%	0%
2. 1 - 50%	25%
3. 50 - 99%	75%
4. 100%	100%

The labor makeup of the typical project within each division was profiled by averaging the figures for each craft and showing the average values obtained as the typical project labor makeup. Any craft with no answer was counted as zero in the overall averaging. As with the other parts of the background question, craft profiles were calculated for each of the construction divisions. If other crafts were written in addition to the standard selections available, the write-ins were included in the averaging process.

2.3.2. Cost Information

A procedure identical to that used for craft profiles was used in cost profiles for the typical project in each construction division. Intuitive judgment was used in cases where civil or mechanical costs were not divided between the subdivisions, or where costs listed separately by the respondent as not included in the given categories, were in fact, part of the categories listed. As with the labor profiles, a cost profile was calculated for each of the four construction divisions.

2.3.3. Technological Improvement

Basic Averages

On each questionnaire, each category of construction had listed for it in a vertical direction 15 answers ranging in value from 1 through 10. All blanks were to be answered unless the category of construction did not apply to the typical project used as a frame of reference for that particular questionnaire.

Each of the answers for each of the 17 categories was averaged from all answers given for a particular construction division. If the answer spaces were blank, they were not included in the averaging process.

Individual Construction Category Potential

The 15 vertical average numbers associated with each construction category were then summed and an average value was calculated from the summation. Each resultant double average number for each category represented the potential of that construction category for improvement with respect to the construction indicators. Results were kept separate for each construction division.

Individual Construction Indicator Potential

The same calculations took place in the horizontal direction. The 17 average numbers associated with each construction indicator were summed and an average was taken from the summation. The resultant number for each indicator represented the potential of that construction indicator for improvement with respect to each category.

CHAPTER 3. QUESTIONNAIRE RESULTS

3.1. Questionnaires Returned

A total of 133 questionnaires were returned representing input from 36 different companies. Major contributors included Daniel Construction Company, Dow Chemical, and Texaco Petroleum.

The questionnaires were grouped according to type of company represented.

1. Contractor Firms - 68 surveys.
2. Owner Firms - 54 surveys.
3. Design Firms - 11 surveys.

The questionnaires were also grouped according to the construction division to which the answers pertained. The number of surveys for each division comprised the data base from which further analysis was performed. The totals returned by construction division (size of data base) are summarized:

1. Buildings - 8 surveys.
2. Light Industrial - 16 surveys.
3. Heavy Industrial - 68 surveys.
4. Power - 36 surveys.
5. Composite - 5 surveys.

Information in the composite surveys was applied where relevant to the other construction divisions. The composite surveys themselves did not constitute another data group.

3.2. Project Profiles and Costs

The background information and cost information from questions 2 and 3 of the survey are outlined in Table 111-1.

The table lists for each division:

1. Number of surveys in the data base.
2. Average project cost.
3. Average peak work force.
4. Average percentage of projects that were union.
5. Average labor percentage makeup by craft.
6. Average percent of direct construction costs associated with each construction category.

3.3. Technological Improvement Ratings

The basic average numbers for each answer in question 5 are listed in Table 111-2. Also listed are potential numbers of each construction category for improvement with respect to the construction indicators. They are the vertical double averages at the bottom of each page of Table 111-2.

Finally, the potential numbers of each construction indicator for improvement with respect to the construction categories are included. They are the double horizontal averages in the vertical right hand margins of each page of Table 111-2.

Table III-1a

Typical Project Profile - Buildings - Based on 8 surveys returned.

1. Average Project Cost - \$25.2 million
2. Average Peak Work Force - 300
3. Average Percent of Projects that are union - 61%
4. Average Labor Percentage Makeup by Craft

Boilermakers	1%	Millwrights	1%
Carpenters	16%	Labors/Helpers	17%
Cement Finishers	7%	Painters	4%
Electricians	11%	Pipefitters	9%
Equipment Operators	4%	Riggers	1%
Insulators	1%	Roofers	2%
Instrument	1%	Teamsters	1%
Ironworkers	14%	Welders	1%
Masons	4%	Others	5%
5. Average percent of direct construction costs associated with each construction category.

Civil

Earthwork	4.8%
Foundations	3.3%
Structure	26.9%
Enclosure Skin	15.2%
Interior Finishing	11.6%

Mechanical

Roofing	2.1%
Piping	3.4%
Plumbing	2.2%
Vessels	2.0%
HVAC	6.5%
Mechanical Equip.	5.4%

Special Equipment Installation 1.4%Electrical 8.5%Instrumentation 1.6%Insulation .8%Coatings and Painting 2.0%Fireproofing/Fire Protection 2.0%

Table III-1b

Typical Project Profile - Light Industrial - Based on 16 surveys rnd.

1. Average Project Cost - \$118.6 million
2. Average Peak Work Force - 600
3. Average Percent of Projects that are union - 69%
4. Average Labor Percentage Makeup by Craft

Boilermakers	1%	Millwrights	3%
Carpenters	14%	Labors/Helpers	14%
Cement Finishers	4%	Painters	3%
Electricians	10%	Pipefitters	14%
Equipment Operators	5%	Riggers	1%
Insulators	2%	Roofers	3%
Instrument	3%	Teamsters	3%
Ironworkers	9%	Welders	2%
Masons	6%	Others	3%
5. Average percent of direct construction costs associated with each construction category.

Civil

Earthwork	4.3%
Foundations	7.2%
Structure	17.2%
Enclosure Skin	7.0%
Interior Finishing	8.5%

Mechanical

Roofing	3.9%
Piping	11.6%
Plumbing	3.7%
Vessels	1.4%
HVAC	8.4%
Mechanical Equip.	6.0%

Special Equipment Installation 5.7%

Electrical 11.3%

Instrumentation 2.1%

Insulation .9%

Coatings and Painting 1.9%

Fireproofing/Fire Protection 2.5%

Table III-1c

Typical Project Profile - Heavy Industrial - Based on 68 surveys rtnd.

1. Average Project Cost - \$188.1 million
2. Average Peak Work Force - 896
3. Average Percent of Projects that are union - 50.9%
4. Average Labor Percentage Makeup by Craft

Boilermakers	2%	Millwrights	4%
Carpenters	8%	Labors/Helpers	10%
Cement Finishers	2%	Painters	2%
Electricians	18%	Pipefitters	22%
Equipment Operators	5%	Riggers	2%
Insulators	4%	Roofers	1%
Instrument	5%	Teamsters	2%
Ironworkers	7%	Welders	4%
Masons	1%	Others	1%
5. Average percent of direct construction costs associated with each construction category.

Civil

Earthwork	3.3%
Foundations	7.5%
Structure	8.2%
Enclosure Skin	1.7%
Interior Finishing	1.6%

Mechanical

Roofing	1.1%
Piping	23.9%
Plumbing	1.5%
Vessels	7.3%
HVAC	2.3%
Mechanical Equip.	9.9%

Special Equipment Installation 3.0%Electrical 15.0%Instrumentation 6.4%Insulation 3.8%Coatings and Painting 2.1%Fireproofing/Fire Protection 1.4%

Table III-1d

Typical Project Profile - Power - Based on 36 surveys returned.

1. Average Project Cost - \$466.6 million
2. Average Peak Work Force - 1635
3. Average Percent of Projects that are union - 81.3%
4. Average Labor Percentage Makeup by Craft

Boilermakers	11%	Millwrights	3%
Carpenters	9%	Labors/Helpers	13%
Cement Finishers	1%	Painters	2%
Electricians	15%	Pipefitters	18%
Equipment Operators	7%	Riggers	0% (.3%)
Insulators	2%	Roofers	1%
Instrument	1%	Teamsters	2%
Ironworkers	10%	Welders	1%
Masons	1%	Others	3%
5. Average percent of direct construction costs associated with each construction category.

Civil

Earthwork	6.2%
Foundations	10.4%
Structure	9.7%
Enclosure Skin	1.8%
Interior Finishing	2.2%

Mechanical

Roofing	.8%
Piping	16.1%
Plumbing	1.4%
Vessels	3.9%
HVAC	2.9%
Mechanical Equip.	18.5%

Special Equipment Installation 5.3%

Electrical 14.1%

Instrumentation 2.9%

Insulation 1.6%

Coatings and Painting 1.6%

Fireproofing/Fire Protection .6%

TABLE III- 2a Buildings Data Base

Question 5 Results

CONSTRUCTION CATEGORY

CIVIL	MECHANICAL					OTHERS										
	Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Pumping	Vessels	HVAC	Mechanical Equipment	Special Equip. Instal	Electrical	Instrumentation	Insulation	Coatings and Painting

- Rate the work categories in terms of:
- DIFFICULTY IN ESTIMATING COSTS
 - SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN
 - NECESSARY LEAD TIME FOR SCHEDULING
 - PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT - NOT DESIGN)
 - UNPLANNED REWORK ON YOUR TYPICAL PROJECTS
 - WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS
 - PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION
 - SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY
 - NUMBER OF DIFFERENT CRAFTS REQUIRED
 - DEPENDENCE ON FOREMEN COMPETENCE
 - CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION
 - REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION
 - NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)
 - MOST WASTED TIME AMONG CRAFTSMEN
 - WASTED TIME WAITING FOR INSPECTIONS

56	23	38	45	45	45	48	45	43	43	38	40	43	45	45	45	53	48
53	48	63	75	80	64	88	78	93	75	80	80	85	83	70	73	65	
30	40	40	73	68	36	58	60	80	60	60	60	73	75	83	43	43	
38	23	30	55	28	54	45	43	73	70	73	60	50	60	53	43	40	
47	40	33	37	40	43	63	67	65	43	53	55	53	63	63	73	37	
43	48	50	70	58	52	65	53	67	60	65	73	68	70	45	53	38	
43	13	40	67	60	57	67	64	77	57	73	87	70	70	73	53	77	
35	33	48	65	65	40	68	55	83	58	73	70	63	78	53	68	43	
23	38	30	20	28	25	33	30	37	40	45	67	40	60	38	45	28	
68	63	60	70	58	68	63	60	40	73	70	67	73	73	63	68	63	
85	65	80	84	73	42	78	78	80	78	70	73	63	73	73	85	70	
45	33	50	48	63	58	55	55	63	53	63	57	70	73	53	53	58	
43	43	50	58	68	30	43	45	33	50	60	47	50	55	58	65	50	
43	28	65	65	53	33	48	43	40	45	68	70	40	65	50	50	48	
48	38	35	23	35	40	45	50	50	53	50	73	65	50	48	48	33	
46	38	46	57	54	49	57	55	62	57	63	66	61	66	55	58	48	

TABLE III-2b Light Industrial Data Base

Question 5 Results

CONSTRUCTION CATEGORY

CIVIL	MECHANICAL					OTHERS										
	Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Plumbing	Vessels	HVAC	Mechanical Equipment	Special Equip. Instal	Electrical	Instrumentation	Insulation	Coatings and Painting

Rate the work categories in terms of:

- DIFFICULTY IN ESTIMATING COSTS
- SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN
- NECESSARY LEAD TIME FOR SCHEDULING
- PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT—NOT DESIGN)
- UNPLANNED REWORK ON YOUR TYPICAL PROJECTS
- WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS
- PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION
- SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY
- NUMBER OF DIFFERENT CRAFTS REQUIRED
- DEPENDENCE ON FOREMEN COMPETENCE
- CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION
- REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION
- NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)
- MOST WASTED TIME AMONG CRAFTSMEN
- WASTED TIME WAITING FOR INSPECTIONS

39	31	33	27	34	31	55	35	44	49	59	76	65	74	39	41	34	4.5
36	44	49	40	46	47	54	34	48	53	59	73	63	72	36	41	36	4.9
47	49	61	45	45	43	59	47	58	55	70	76	66	68	34	32	39	5.2
18	19	33	34	36	38	44	32	46	44	60	65	51	60	34	29	29	4.0
24	24	29	24	36	34	47	31	25	48	48	49	46	52	28	26	21	3.5
29	45	48	34	48	33	55	36	40	59	57	76	61	59	35	36	29	4.6
13	25	39	28	34	31	44	29	40	50	56	61	49	49	35	20	21	3.7
16	28	59	51	38	29	65	39	63	58	69	79	48	51	23	21	25	4.5
16	31	31	26	44	22	24	19	24	31	35	48	23	31	15	16	16	2.7
38	59	58	56	61	66	71	57	55	66	69	79	72	78	48	48	46	6.0
31	45	50	53	49	48	61	47	54	54	59	66	63	75	42	46	40	5.2
43	32	40	38	36	38	45	38	48	48	55	65	47	52	25	27	31	4.2
22	31	41	42	46	39	57	46	45	51	47	59	55	59	42	39	35	4.4
18	36	34	36	43	38	62	49	42	49	55	55	51	49	35	36	28	4.2
24	31	27	22	26	38	48	44	40	44	49	51	48	55	23	24	24	3.6
28	35	42	17	41	38	53	39	45	51	57	65	54	59	33	32	30	

TABLE III-2c Heavy Industrial Data Base

Question 5 Results

CONSTRUCTION CATEGORY

ation 5 Results

	CIVIL						MECHANICAL						OTHERS					
	Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Plumbing	Vessels	HVAC	Mechanical Equipment	Special Equip. Instal	Electrical	Instrumentation	Insulation	Coatings and Painting	Fireproofing/Protection	

32	26	32	29	39	26	40	39	36	46	50	65	55	60	39	37	37	4.2
34	42	47	34	36	31	70	42	54	51	64	62	67	73	39	34	34	4.8
28	38	45	37	31	34	64	44	62	52	65	64	61	66	38	31	32	4.7
17	21	33	34	32	26	56	30	44	38	51	51	51	56	29	25	22	3.6
19	24	37	22	25	24	63	27	29	32	37	43	46	51	27	23	20	3.2
23	38	43	26	28	22	70	29	38	40	54	63	65	64	26	26	27	4.0
15	21	34	30	25	22	61	30	37	30	43	44	47	49	32	23	21	3.3
13	26	50	29	23	19	70	30	58	34	62	65	35	40	23	18	22	3.6
17	32	26	21	33	19	35	22	31	27	41	46	26	33	18	17	18	2.7
33	51	51	42	44	43	73	48	49	50	65	70	70	74	43	39	38	5.2
33	39	44	40	44	35	69	52	51	50	63	64	66	71	38	38	38	4.9
41	31	36	36	29	29	51	34	42	36	50	62	46	51	30	29	31	3.9
17	29	34	30	30	26	45	38	44	41	51	54	51	52	45	35	33	4.0
18	36	31	28	33	28	66	42	38	35	52	59	54	52	38	29	29	3.9
25	31	28	19	20	23	49	37	36	31	46	45	39	45	25	22	27	3.2
24	32	38	30	32	27	61	36	43	40	53	57	52	56	33	28	29	

Rate the work categories in terms of:

- a. DIFFICULTY IN ESTIMATING COSTS
- b. SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN
- c. NECESSARY LEAD TIME FOR SCHEDULING
- d. PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT -- NOT DESIGN)
- e. UNPLANNED REWORK ON YOUR TYPICAL PROJECTS
- f. WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS
- g. PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION
- h. SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY
- i. NUMBER OF DIFFERENT CRAFTS REQUIRED
- j. DEPENDENCE ON FOREMEN COMPETENCE
- k. CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION
- l. REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION
- m. NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)
- n. MOST WASTED TIME AMONG CRAFTSMEN
- o. WASTED TIME WAITING FOR INSPECTIONS

Rate the work categories in terms of:

- DIFFICULTY IN ESTIMATING COSTS
- SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN
- NECESSARY LEAD TIME FOR SCHEDULING
- PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT - NOT DESIGN)
- UNPLANNED REWORK ON YOUR TYPICAL PROJECTS
- WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS
- PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION
- SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY
- NUMBER OF DIFFERENT CRAFTS REQUIRED
- DEPENDENCE ON FOREMEN COMPETENCE
- CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION
- REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION
- NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)
- MOST WASTED TIME AMONG CRAFTSMEN
- WASTED TIME WAITING FOR INSPECTIONS

TABLE III- 2d Power Data Base

Question 5 Results

CONSTRUCTION CATEGORY

ation 5 Results

CIVIL					MECHANICAL							OTHERS						
Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Pumping	Vessels	HVAC	Mechanical Equipment	Special Equip. Install	Electrical	Instrumentation	Insulation	Coatings and Painting	Fireproofing/Protection		

a. DIFFICULTY IN ESTIMATING COSTS	33	25	25	17	29	22	58	37	32	42	47	56	54	53	40	38	38	3.8
b. SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN	38	52	42	33	31	30	74	54	52	62	65	70	72	72	41	35	34	5.0
c. NECESSARY LEAD TIME FOR SCHEDULING	31	43	45	34	33	25	67	43	52	59	63	67	62	70	37	27	26	4.6
d. PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT -- NOT DESIGN)	19	18	24	28	27	20	53	34	43	44	52	52	47	60	33	28	30	3.6
e. UNPLANNED REWORK ON YOUR TYPICAL PROJECTS	25	36	30	27	26	30	62	37	28	48	38	33	56	58	34	26	29	3.7
f. WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS	27	35	28	21	28	38	68	40	43	58	52	52	66	71	33	25	28	4.2
g. PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION	21	27	29	24	28	23	57	35	36	44	45	47	52	49	29	32	25	3.5
h. SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY	13	30	46	29	33	25	68	31	52	44	62	56	42	45	26	26	22	3.8
i. NUMBER OF DIFFERENT CRAFTS REQUIRED	19	43	28	18	35	21	34	25	27	32	37	41	29	34	27	18	20	2.9
j. DEPENDENCE ON FOREMEN COMPETENCE	43	52	50	42	42	39	65	50	49	58	60	53	59	57	43	47	42	5.0
k. CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION	31	43	48	35	36	28	62	45	43	45	57	52	53	55	38	38	33	4.4
l. REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION	37	29	34	22	25	21	45	31	34	29	47	56	37	36	20	28	30	3.3
m. NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)	14	38	32	28	33	25	63	49	40	53	48	43	53	48	43	39	37	4.0
n. MOST WASTED TIME AMONG CRAFTSMEN	18	28	25	22	30	22	72	44	33	35	47	40	70	55	38	25	25	3.7
o. WASTED TIME WAITING FOR INSPECTIONS	25	30	31	19	19	17	46	32	28	28	36	33	33	41	19	19	22	2.8
	26	35	34	27	30	26	60	39	40	45	50	50	52	54	33	30	29	

Rate the work categories in terms of:

- DIFFICULTY IN ESTIMATING COSTS
- SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN
- NECESSARY LEAD TIME FOR SCHEDULING
- PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT - NOT DESIGN)
- UNPLANNED REWORK ON YOUR TYPICAL PROJECTS
- WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS
- PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION
- SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY
- NUMBER OF DIFFERENT CRAFTS REQUIRED
- DEPENDENCE ON FOREMEN COMPETENCE
- CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION
- REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION
- NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)
- MOST WASTED TIME AMONG CRAFTSMEN
- WASTED TIME WAITING FOR INSPECTIONS

CHAPTER 4. CONSTRUCTION IMPROVEMENT ANALYSIS

4.1. Data Bases

4.1.1. Buildings

The total of 8 questionnaires as a data base made the Buildings data questionable. The addition of a few more Building questionnaires not previously analyzed could completely change the overall results.

Ratings from Buildings respondents used in the potential improvement question were generally much higher answers and were not as varied in magnitude as other construction divisions. The appearances of 4's, 5's, and 6's predominated.

4.1.2. Light Industrial

The total of 16 questionnaires as a data base made the Light Industrial data base not as suspect as Buildings, but much less reliable than Heavy Industrial or Power. Similarities in many of the problem areas indicate the Light Industrial results are reliable.

4.1.3. Heavy Industrial

By far, the best data base, Heavy Industrial questionnaire results also correlated with each other more than any other intra-division results. More of the same things were said in Heavy Industrial questionnaire results than in other divisions.

4.1.4. Power

Power had the second largest data base and strong, reasonable results. The existence of key problem areas such as piping, electrical, and mechanical equipment on many of the questionnaires signified high reliability in Power answers.

4.2. Project Profiles and Costs

Average project costs differed from \$25.2 million for Buildings to a high of \$466.6 million for Power projects. Light and Heavy Industrial were middle values with price tags of \$118.6 and \$188.1 million respectively.

Peak work forces were similiarly distributed with Buildings low at 300 workers, Power high at 1635 workers, and Light and Heavy Industrial at 600 and 896 respectively.

Power projects were heavily union, 81.3%. Heavy Industrial had more open shop projects with only 50.9% union participation. Buildings and Light Industrial were similar in union composition with 61% and 69% respectively.

Significant crafts involved in construction included carpenters, electricians, and laborers for Buildings and Light Industrial. Pipefitters, electricians, and laborers were important crafts in Heavy Industrial and Power. Boilermakers were also significant in Power.

The more expensive construction categories for Buildings and Light Industrial included structure and electrical. Piping was of high value in Light Industrial, Heavy Industrial and Power. Electrical and mechanical equipment also accounted for significant costs in Heavy Industrial and Power.

4.3. Technological Improvement Ratings

4.3.1. Buildings and Light Industrial

High potential categories included special equipment installation, mechanical equipment, and electrical. Vessels were also important in Buildings.

Buildings' high potential indicators included craftsman skill, time and design sensitivity, foreman competence, and problems in material handling. Light Industrial high potential indicators included foreman competence, lead time for scheduling, and craftsman skill.

4.3.2. Heavy Industrial and Power

Piping, special equipment installation, electrical, and mechanical equipment were high potential categories.

High potential indicators included foreman competence, craftsman skill, time and design sensitivity, and lead time for scheduling. Different crafts required were also significant in Power.

4.4. Construction Category Cost Adjustments

To determine potential improvement impact on a construction process, costs must be considered. Cost information by construction category provided the necessary weighting to determine that impact.

4.4.1. Adjusted Construction Categories

Each vertical average indicator number (Table 111-2, bottom margin) was weighted according to the percentage of total construction costs associated with each of the construction categories. The weight factors were taken from the average percent of direct construction costs shown in Table 111-1.

The vertical double average number was multiplied by the weight factor directly to obtain the construction cost adjustments shown in Figure IV-1. The adjustments were relative factors of potential only.

Sample calculation for Earthwork, Buildings division:

$$4.6 \quad \times \quad 4.8 \quad = \quad 22$$

Table 111-2

Table 111-1

Figure IV-1

Table IV-1 summarizes the information shown in Figure IV-1. The table divided the construction categories into high potential improvement impact, intermediate potential, and low potential.

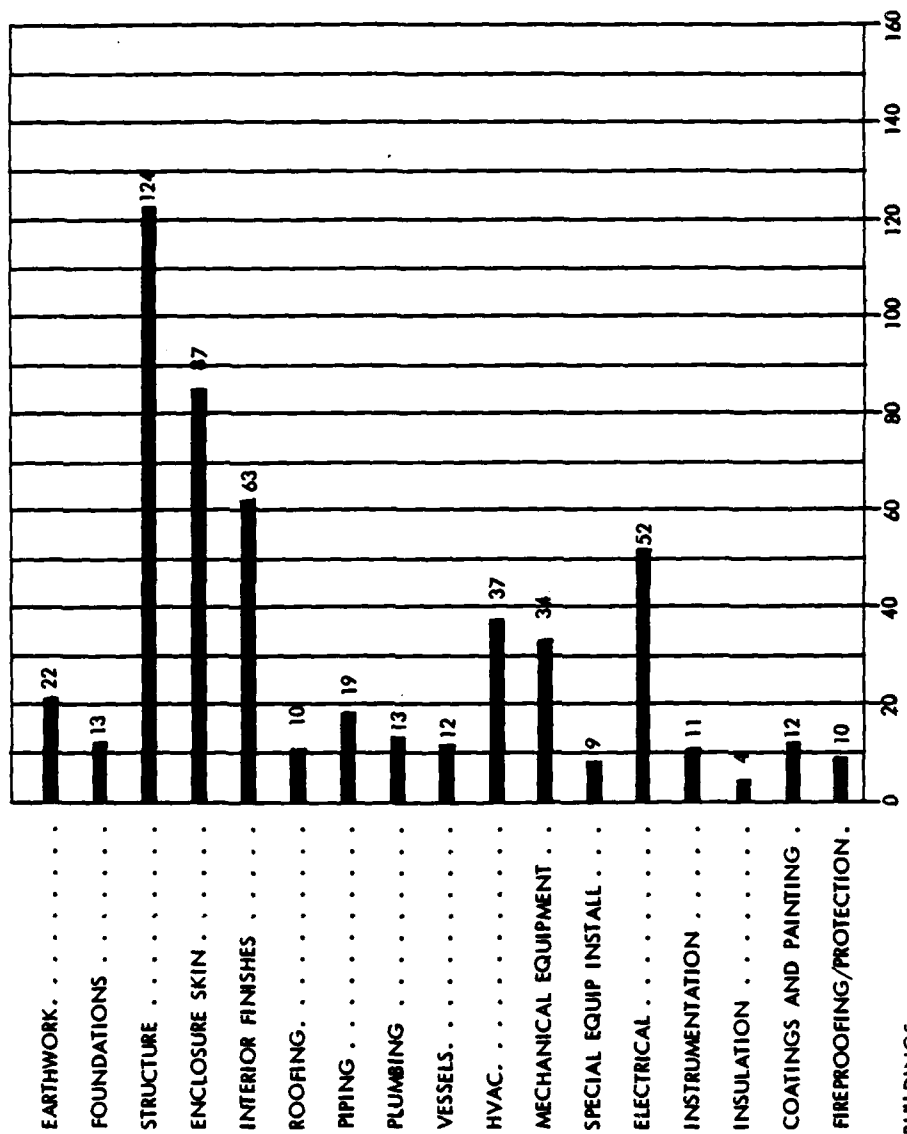


Figure IV -1a Construction Category Cost Adjustments
(Weight Factors from Table III-1, Average Indicators from Table III-2)

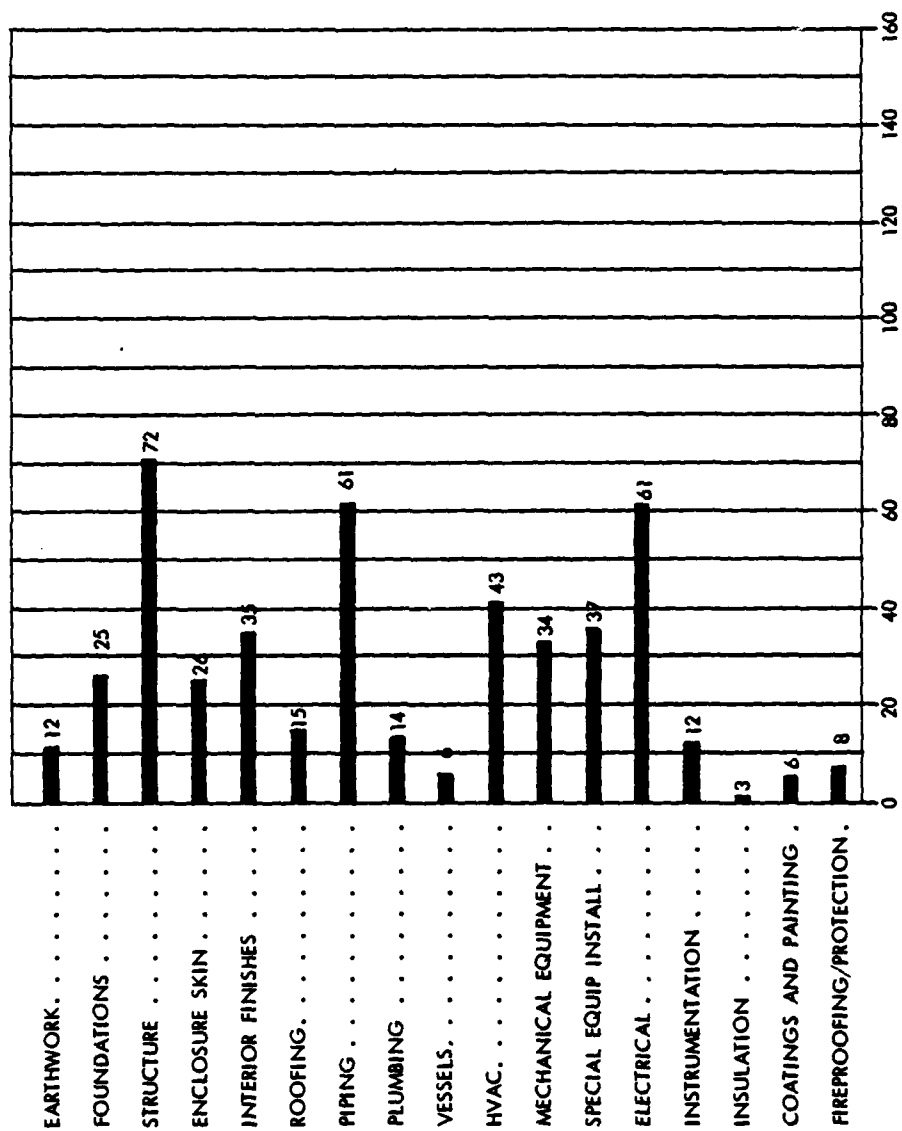


Figure IV-1b Construction Category Cost Adjustments
(Weight Factors from Table III-1, Average Indicators from Table III-2)

LIGHT INDUSTRIAL

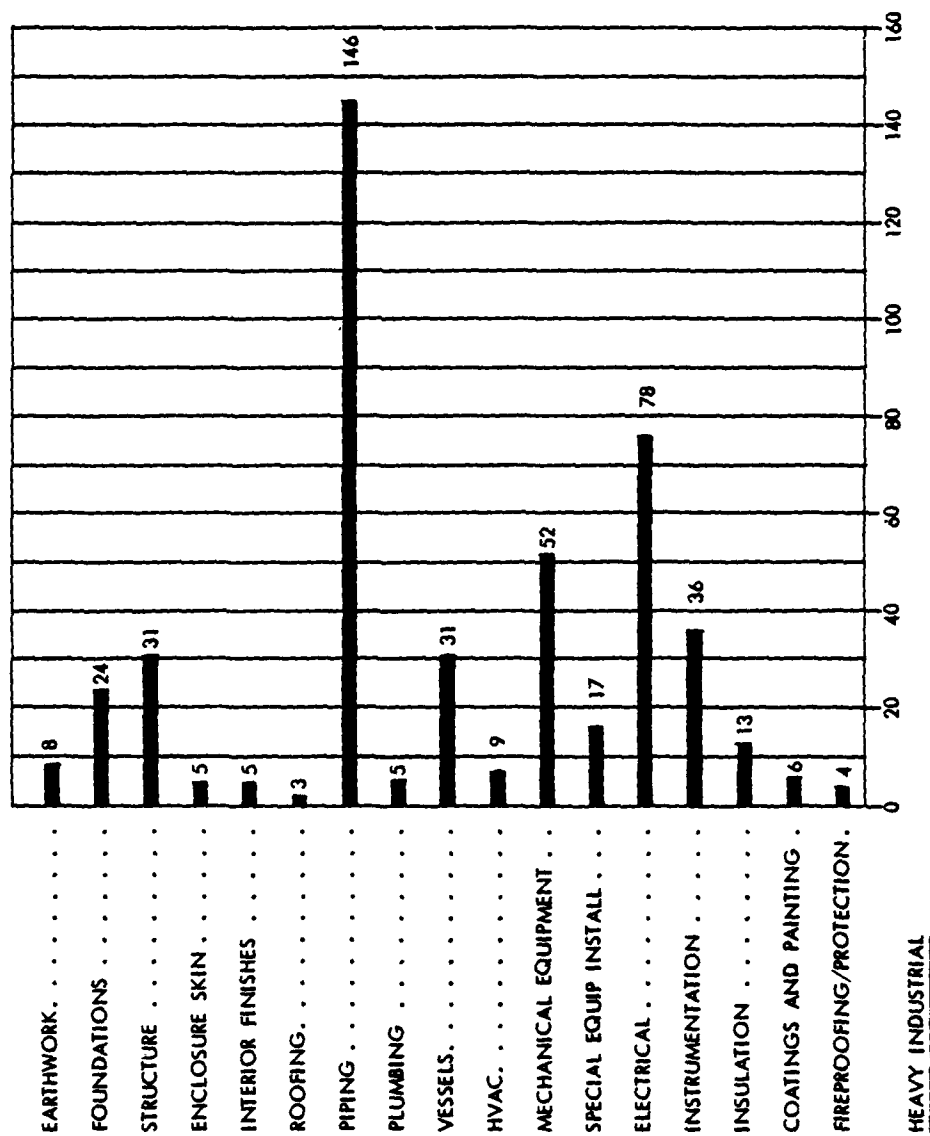


Figure IV-1c Construction Category Cost Adjustments
(Weight Factors from Table III-1, Average Indicators from Table III-2)

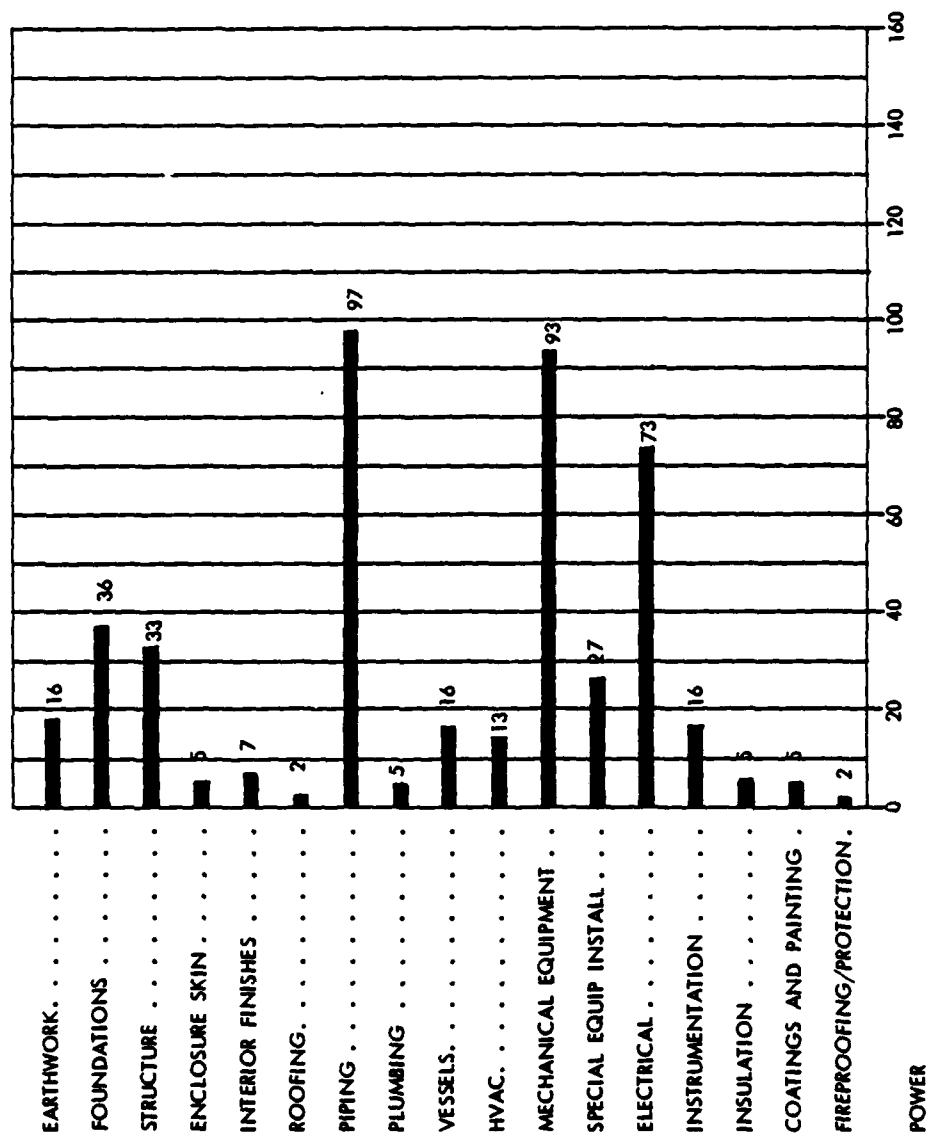


Figure IV-1d Construction Category Cost Adjustments
(Average Indicators from Table III-2, Weight Factors from Table III-1)

POWER

TABLE IV-1 CONSTRUCTION CATEGORY TECHNOLOGICAL IMPROVEMENT POTENTIAL
(Potential Number Adjusted for Cost in Parenthesis)

	<u>Buildings</u>	<u>Light Industrial</u>
High Potential	Structure (124) Enclosure Skin (87) Interior Finishes (63) Electrical (52)	Structure (72) Piping (61) Electrical (61)
Intermediate Potential	HVAC (37) Mech. Equip. (34) Earthwork (22)	HVAC (43) Spec. Equip. Inst. (37) Interior Finishes (35) Mech Equip. (34) Enclosure Skin (26) Foundations (25)
Low Potential	Piping (19) Plumbing (13) Foundations (13) Coatings & Paintings (12) Vessels (12) Instrumentation (11) Fire Proofing/Protec. (10) Roofing (10) Spec. Equip. Inst. (9) Insulation (4)	Roofing (15) Plumbing (14) Earthwork (12) Instrumentation (12) Fire Proofing/Protec. (8) Vessels (6) Coatings & Paintings (6) Insulation (3)

(Continued) Table IV-1 CONSTRUCTION CATEGORY TECHNOLOGICAL IMPROVEMENT POTENTIAL

	<u>Heavy Industrial</u>	<u>Power</u>
High Potential	Piping (146) Electrical (78) Mech. Equip. (52)	Piping (97) Mech. Equip. (93) Electrical (73)
Intermediate Potential	Instrumentation (36) Structure (31) Vessels (31) Foundations (24)	Foundations (36) Structure (33) Spec. Equip. Inst. (27)
Low Potential	Spec. Equip. Inst. (17) Insulation (13) HVAC (9) Earthwork (8) Coatings & Paintings (6) Enclosure Skin (5) Interior Finishes Plumbing (5) Fire Proofing/Protec. (4) Roofing (3)	Earthwork (16) Vessels (16) Instrumentation (16) HVAC (13) Interior Finishes (7) Enclosure Skin (5) Plumbing (5) Insulation (5) Coatings & Paintings (5) Roofing (2) Fire Proofing/Protec. (2)

Structure and electrical were dominant in Buildings and Light Industrial. Both categories were heavily influenced by the category costs.

Enclosure skin and interior finishes were high potential areas unique to Buildings.

Piping and electrical were important categories in the other three divisions.

Mechanical equipment surfaced as a high potential area in Heavy Industrial and Power.

4.4.2. Adjusted Construction Indicators

In Table 111-2, the 17 average numbers associated with each construction indicator were summed and an average value was taken from the summations. The double average numbers did not take into account the costs of each construction category but treated them instead as equal in weight. The following sample calculation shows how each horizontal double average number became a weighted average. The average was weighted according to the percent construction costs associated with each construction category.

Sample calculation for weighted average for cost
estimating, Buildings division:

<u>Category</u>	<u>Rating (Table 111-2)</u>	<u>% Cost (Table 111-1)</u>		
Earthwork	5.6	4.8	=	.269
Foundations	2.3	3.3	=	.076
Structure	3.8	26.9	=	1.022
Enclosure	4.5	15.2	=	.684
Interior Finish	4.5	11.6	=	.522
Roofing	4.8	2.1	=	.101
Piping	4.5	3.4	=	.153
Plumbing	4.3	2.2	=	.095
Vessels	4.3	2.0	=	.086
HVAC	3.8	6.5	=	.247
Mech Equipment	4.0	5.4	=	.216
Spec Equip Install	3.3	1.4	=	.046
Electrical	4.5	8.5	=	.383
Instrumentation	3.5	1.6	=	.056
Insulation	4.5	.8	=	.036
Coatings & Painting	5.3	2.0	=	.106
Fireproofing/ Protect	4.8	2.0	=	.096
				4.194 =

Table IV-2 4.2

Table IV-2 shows the old horizontal double averages and the new weighted construction indicator improvement potential ratings. The old ratings are listed first. The changes were directly attributed to heavy cost weighting or light cost weighting.

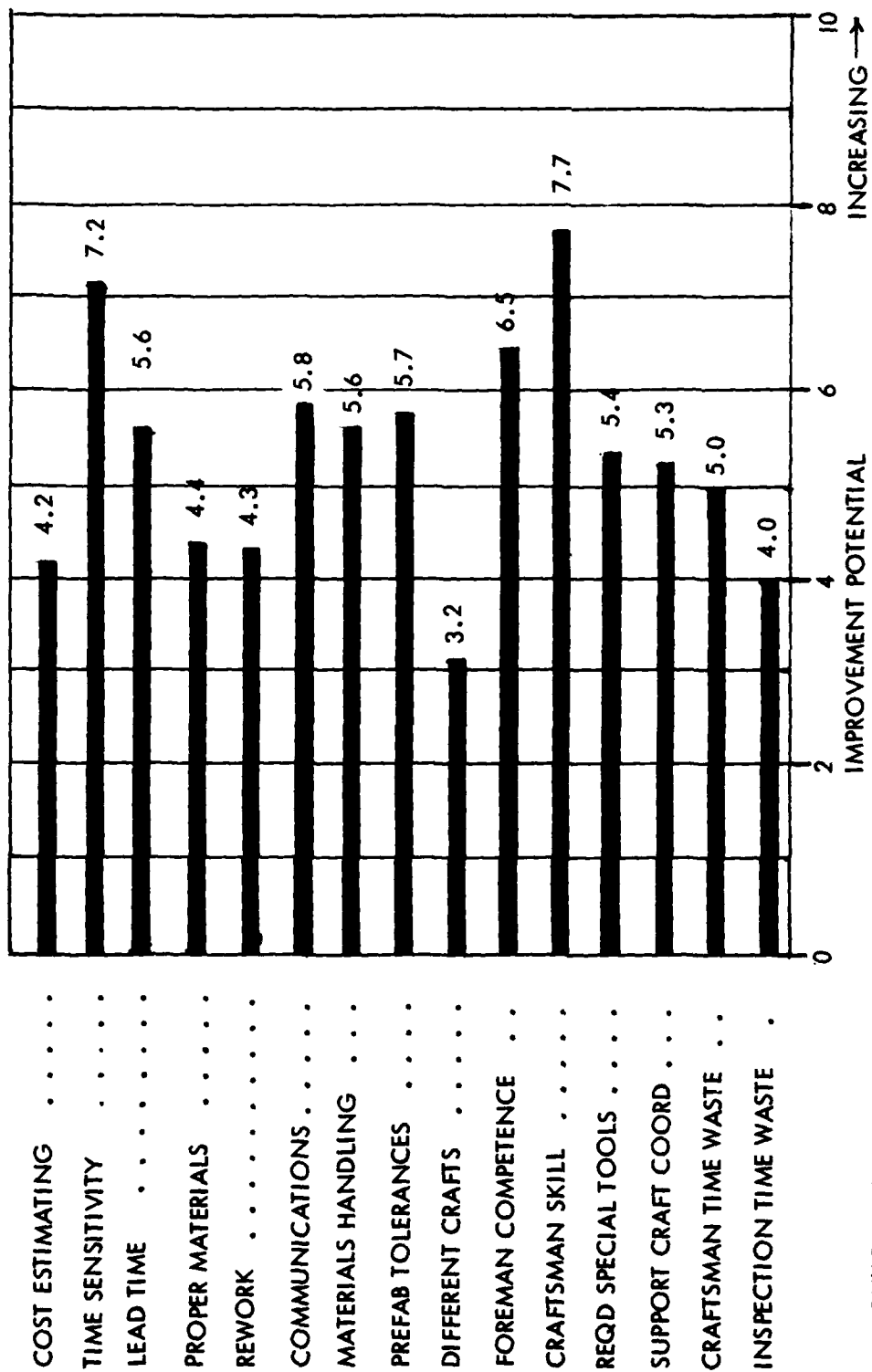
Table IV-2 Construction Indicator Improvement Ratings

	<u>Buildings</u>		<u>Light Industrial</u>		<u>Heavy Industrial</u>		<u>Power</u>	
	<u>Old</u>	<u>New</u>	<u>Old</u>	<u>New</u>	<u>Old</u>	<u>New</u>	<u>Old</u>	<u>New</u>
Cost Estimating	4.2-4.2		4.5-4.0		4.2-3.8		3.8-3.2	
Time Sensitivity	7.4-7.2		4.9-4.8		4.8-4.6		5.0-4.1	
Lead Time	5.6-5.6		5.2-5.5		4.7-4.5		4.6-4.4	
Proper Materials	4.9-4.4		4.0-3.8		3.6-3.6		3.6-3.2	
Rework	5.2-4.3		3.5-3.4		3.2-2.8		3.7-3.4	
Communications	5.7-5.8		4.6-4.7		4.0-4.0		4.2-3.7	
Materials								
Handling	6.2-5.6		3.7-3.7		3.3-3.3		3.5-3.3	
Prefab								
Tolerances	5.8-5.7		4.5-5.8		3.6-3.8		3.8-3.9	
Different								
Crafts	3.7-3.2		2.7-2.9		2.7-2.7		2.9-2.8	
Foremen								
Competence	6.4-6.5		6.0-6.0		5.2-5.1		5.0-4.9	
Craftsman Skill	7.6-7.7		5.2-5.2		4.9-4.8		4.4-4.4	
Required Spec								
Tools	5.6-5.4		4.2-4.1		3.9-3.8		3.3-3.2	
Spt Craft Coord	5.0-5.3		4.4-4.4		4.0-3.7		4.0-3.7	
Craftsman Time								
Waste	4.9-4.9		4.2-4.0		3.9-3.6		3.7-3.3	
Inspection								
Time Waste	4.6-4.0		3.6-3.2		3.2-2.9		2.8-2.7	

The new construction improvement potential ratings are also shown graphically in Figure IV-2.

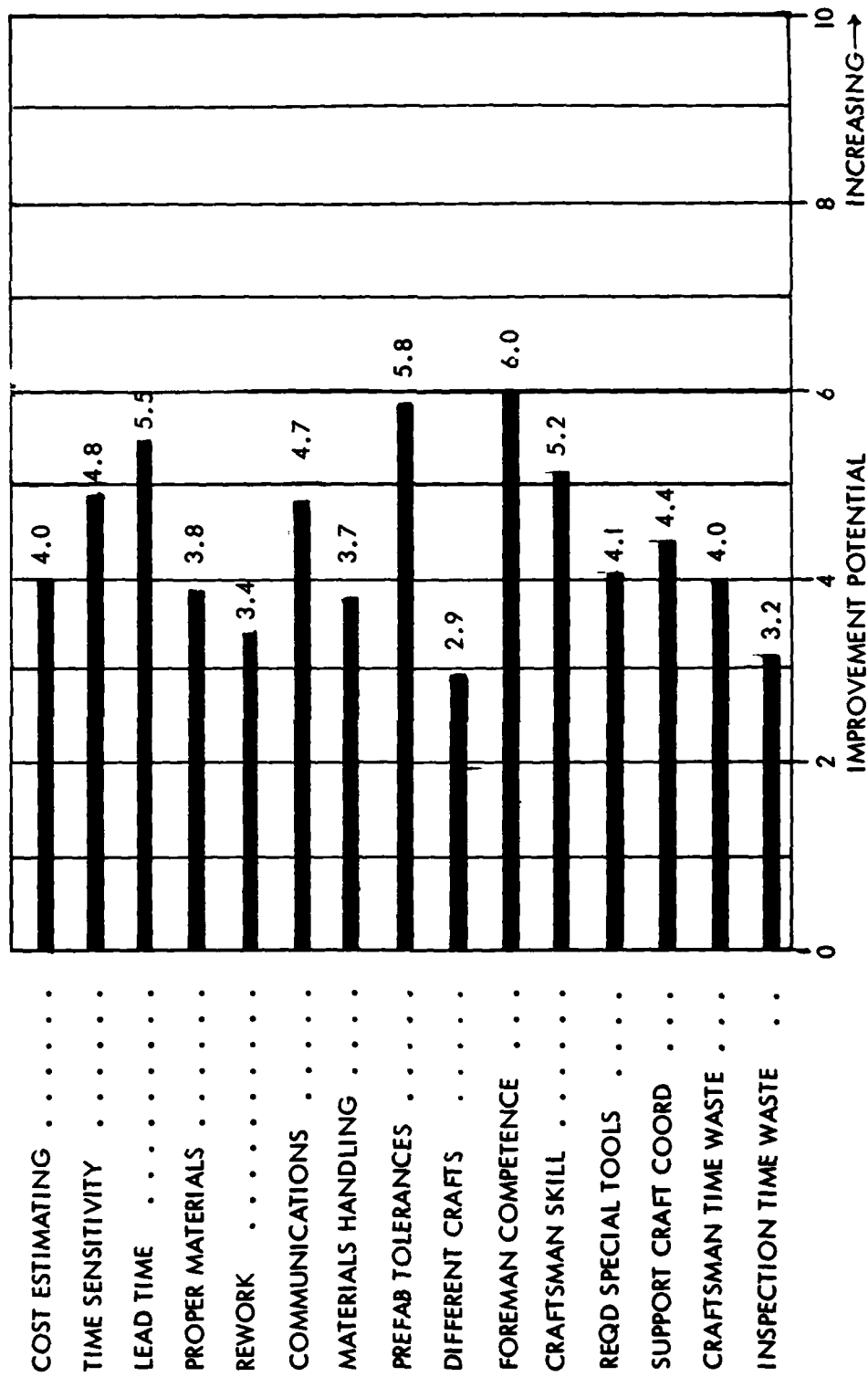
Table IV-3 summarizes the information shown in Table IV-2 and Figure IV-2. The table divides the construction indicators into high potential improvement impact, intermediate potential, and low potential.

Craftsman skill and foreman competence were high priority indicators common to all four divisions.



BUILDINGS

Figure IV-2a Construction Indicator Improvement Potential
(Ratings from Table IV-2, % Cost from Table IV-1)



LIGHT INDUSTRIAL

Figure IV-2b Construction Indicator Improvement Potential
(Ratings from Table IV-2, % Cost from Table IV-1)

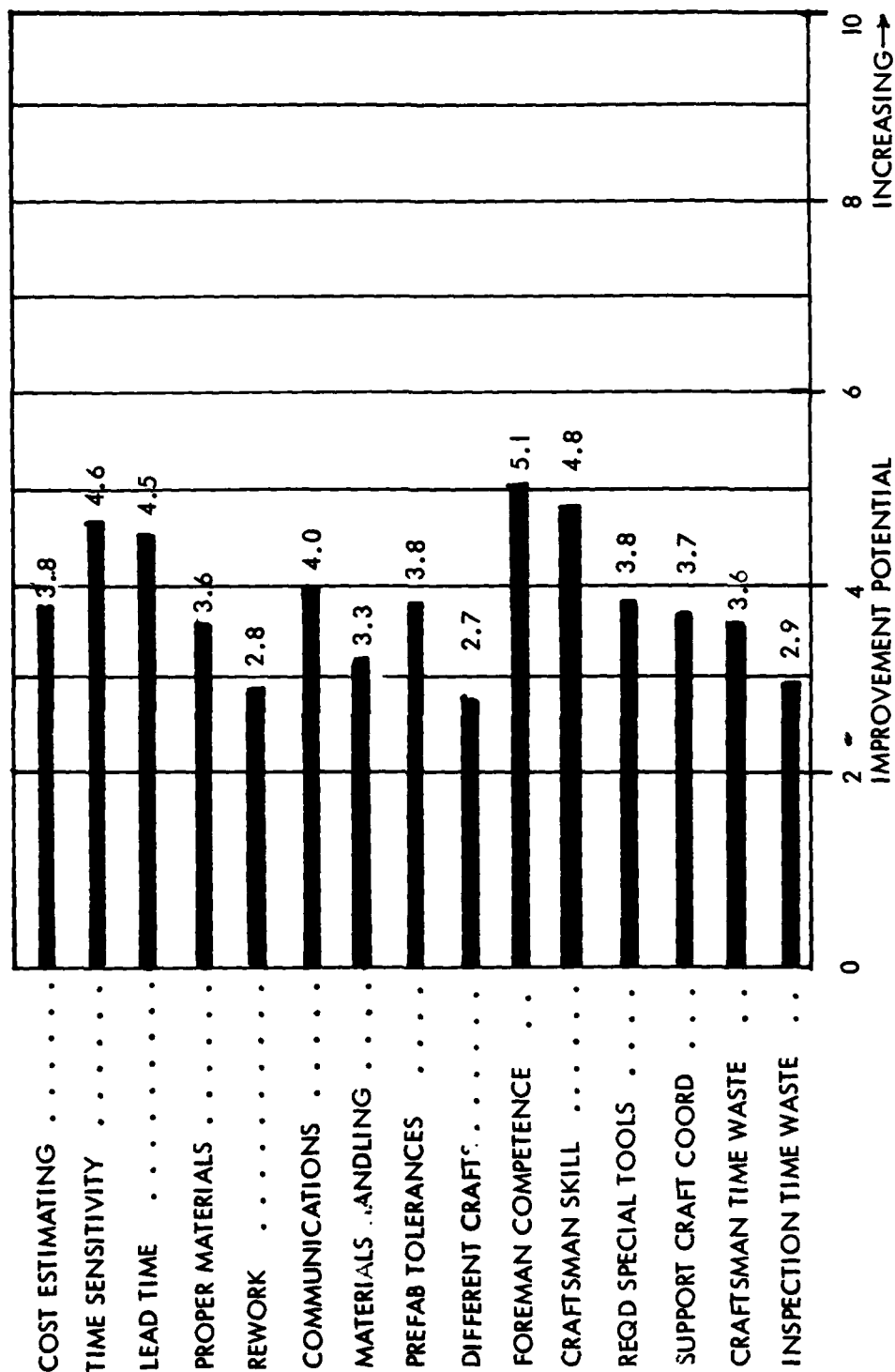
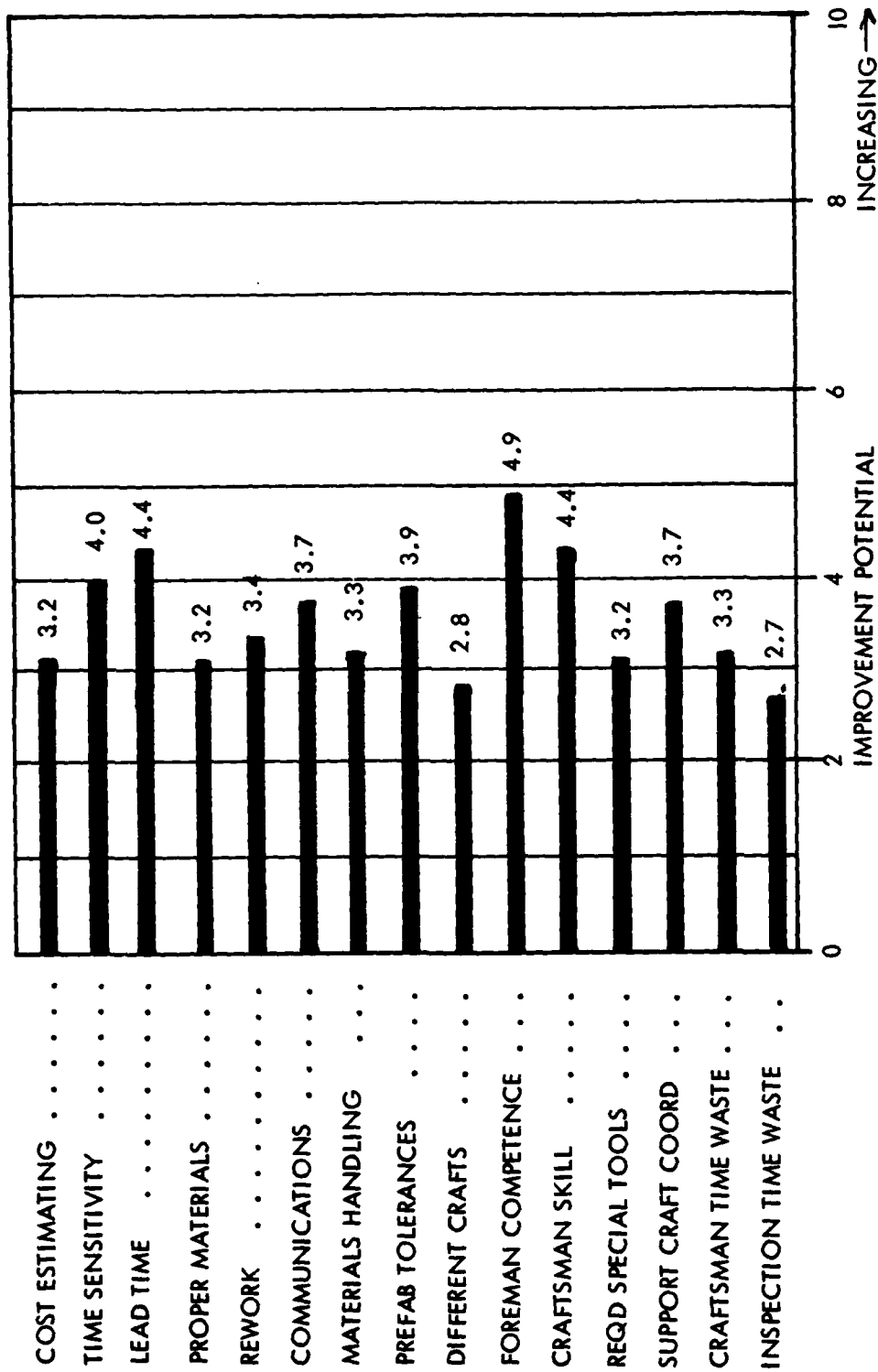


Figure IV-2c Construction Indicator Improvement Potential
(Ratings from Table IV-2, % Cost from Table IV-1)

HEAVY INDUSTRIAL



POWER

Figure IV-2d Construction Indicator Improvement Potential
(Ratings from Table IV-2, % Cost from Table IV-1)

TABLE IV-3 CONSTRUCTION INDICATOR IMPROVEMENT POTENTIAL
(Potential number from Figure IV-4 shown in parentheses)

	<u>Buildings</u>	<u>Light Industrial</u>
High Potential	Craftsman Skill (7.7) Time Sensitivity (7.2) Foreman Competence (6.5)	Foreman Competence (6.0) Prefab Tolerances (5.8) Lead Time (5.5) Craftsman Skill (5.2)
Intermediate Potential	Communications (5.8) Prefab Tolerances (5.7) Materials Handling (5.6) Lead Time (5.6) Required Spec Tools (5.4) Support Craft Coord (5.3) Craftsman Time Waste (5.0)	Time Sensitivity (4.8) Communications (4.7) Support Craft Coord (4.4) Required Spec Tools (4.1) Cost Estimating (4.0) Craftsman Time Waste (4.0)
Low Potential	Proper Materials (4.4) Rework (4.3) Cost Estimating (4.2) Inspection Time Waste (4.0) Different Crafts (3.2)	Proper Materials (3.8) Materials Handling (3.7) Rework (3.4) Inspection Time Waste (3.2) Different Crafts (2.9)

(Continued) TABLE IV-3 CONSTRUCTION INDICATOR IMPROVEMENT POTENTIAL

	<u>Heavy Industrial</u>	<u>Power</u>
High Potential	Foreman Competence (5.1) Craftsman Skill (4.8) Time Sensitivity (4.6) Lead Time (4.5)	Foreman Competence (4.9) Lead Time (4.4) Craftsman Skill (4.4) Time Sensitivity (4.0)
Intermediate Potential	Communications (4.0) Cost Estimating (3.8) Prefab Tolerances (3.8) Required Spec Tools (3.8) Support Craft Coord (3.7) Proper Materials (3.6) Craftsman Time Waste (3.6)	Prefab Tolerances (3.9) Communications (3.7) Support Craft Coord (3.7) Rework (3.4) Materials Handling (3.3) Craftsman Time Waste (3.3)
Low Potential	Materials Handling (3.3) Inspection Time Waste (2.9) Rework (2.8) Different Crafts (2.7)	Proper Materials (3.2) Required Spec Tools (3.2) Cost Estimating (3.2) Different Crafts (2.8) Inspection Time Waste (2.7)

Time sensitivity was important to Buildings, Heavy Industrial, and Power.

Lead time was important to Light and Heavy Industrial and Power.

Prefab tolerances were high priority in Light Industrial and intermediate potential in the other three divisions.

4.5. Further Refinements for Analysis of Construction Categories

4.5.1. Project Size Impact

The research group attempted to show impact potential on individual project size by assuming larger projects had more to be gained individually from technological improvement than smaller projects. The average project cost for each construction division determined the size of the project. The savings gained by a large project due to technological improvement was proportional to its average cost. The smaller savings from a smaller project were also proportional to its average cost. The relative factors used to adjust construction categories for project size influence (based on average project cost) are listed in Table IV-4.

Table IV-4 Project Size Adjustments

<u>Construction Division</u>	<u>Average Project Size (Table IV-1)</u>	<u>Adjustment Factors (Relative Ratios Only)</u>
Buildings	\$ 25.2 million	.032
Light Industrial	118.6	.146
Heavy Industrial	188.1	.236
Power	466.6	.584

Construction categories multiplied by project size influence gave project size impact factors shown in Figure IV-3.

Sample calculation for Earthwork, Buildings division:

$$22 \quad \times \quad .032 \quad = \quad .7$$

Figure IV-1 Adjustment Factor Figure IV-3

Power construction categories were more heavily weighted than the other divisions because the average project cost was 2.5 times as expensive as the next most expensive division's average project cost. Buildings were weighted much less due to relatively inexpensive average project costs. Heavy and Light Industrial costs were mid-range in weight. A comparison of the construction categories within each construction division has shown that Power has four of the top five potential categories. Heavy Industrial has the other top potential category.

The top 10 categories adjusted for project size are shown in Table IV-5.

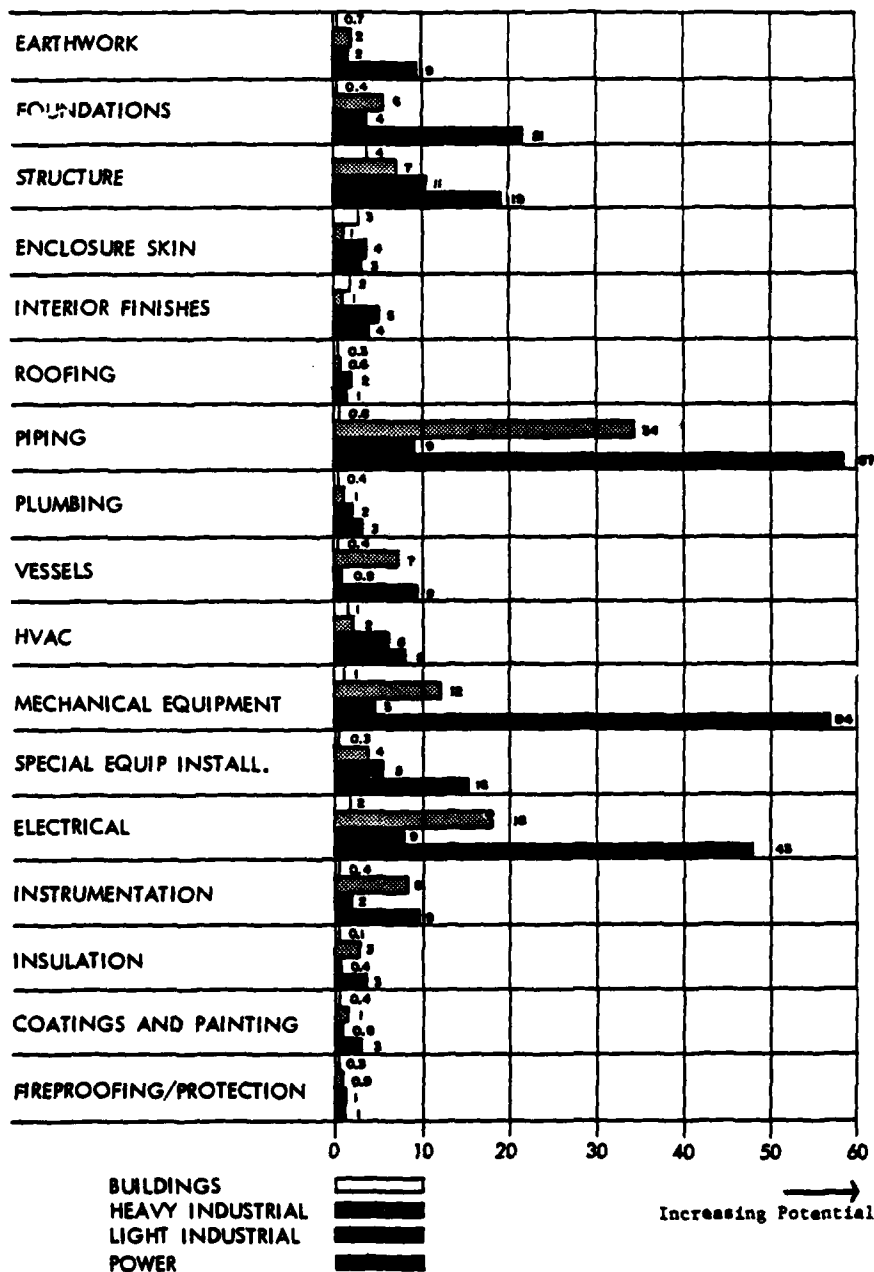


Figure IV-3. Construction Technology Improvement Potential based on Project Size

Table IV-5 Project Size Influence

	<u>Category</u>	<u>Division</u>
Highest Potential	Piping	Power
	Mech Equip	Power
	Electrical	Power
	Piping	Hvy Industrial
	Foundations	Power
	Structure	Power
	Electrical	Hvy Industrial
	Spec Equip	Power
	Mech Equip	Hvy Industrial
High Potential	Structure	Lt Industrial

4.5.2. Gross Industry Influence

The values of all Buildings, Light Industrial, Heavy Industrial, and Power construction for 1979 were taken from another CICE project study (5). The total value of each division was expressed as a percentage of the whole. This allowed each division to be compared to the other in terms of relative value. Since the values of Light and Heavy Industrial were not separated in the source information, both divisions were assumed equal.

The basic premise behind gross industry influence assumed construction divisions with more GNP value were indicative of higher total financial savings from increased productivity. The increased productivity would result from technological improvement.

GNP adjustment factors are shown in Table IV-6.

Table IV-6 Gross Industry Adjustments

<u>Construction Division</u>	<u>GNP (\$Billion)</u>	<u>Adjustment Factor</u>
Buildings	69	.407
Light Industrial		.213
Heavy Industrial	66	.213
Power	27	.167
		<u>1.000</u>

Construction category cost adjustments (Figure IV-1) were multiplied by gross industry influence adjustments to obtain values for construction technological improvement potential with respect to gross industry influence. The relative weights are shown in Figure IV-4.

Sample calculation for Earthwork, Buildings division:

$$22 \quad \times \quad .407 \quad = \quad 9$$

Figure IV-1

Table IV-5

Figure IV-4

Buildings were weighted more heavily than the other three divisions. Buildings represented more than 40% of the total GNP value of all four categories combined. Power was weighted the least with a 16.7% market share. Heavy and Light Industrial were again mid-range in weight.

A comparison of the construction categories within each construction division have shown Buildings to have four of the top five construction categories. Heavy Industrial has the other high priority category.

The top 10 categories adjusted for gross industry influence are shown in Table IV-7.

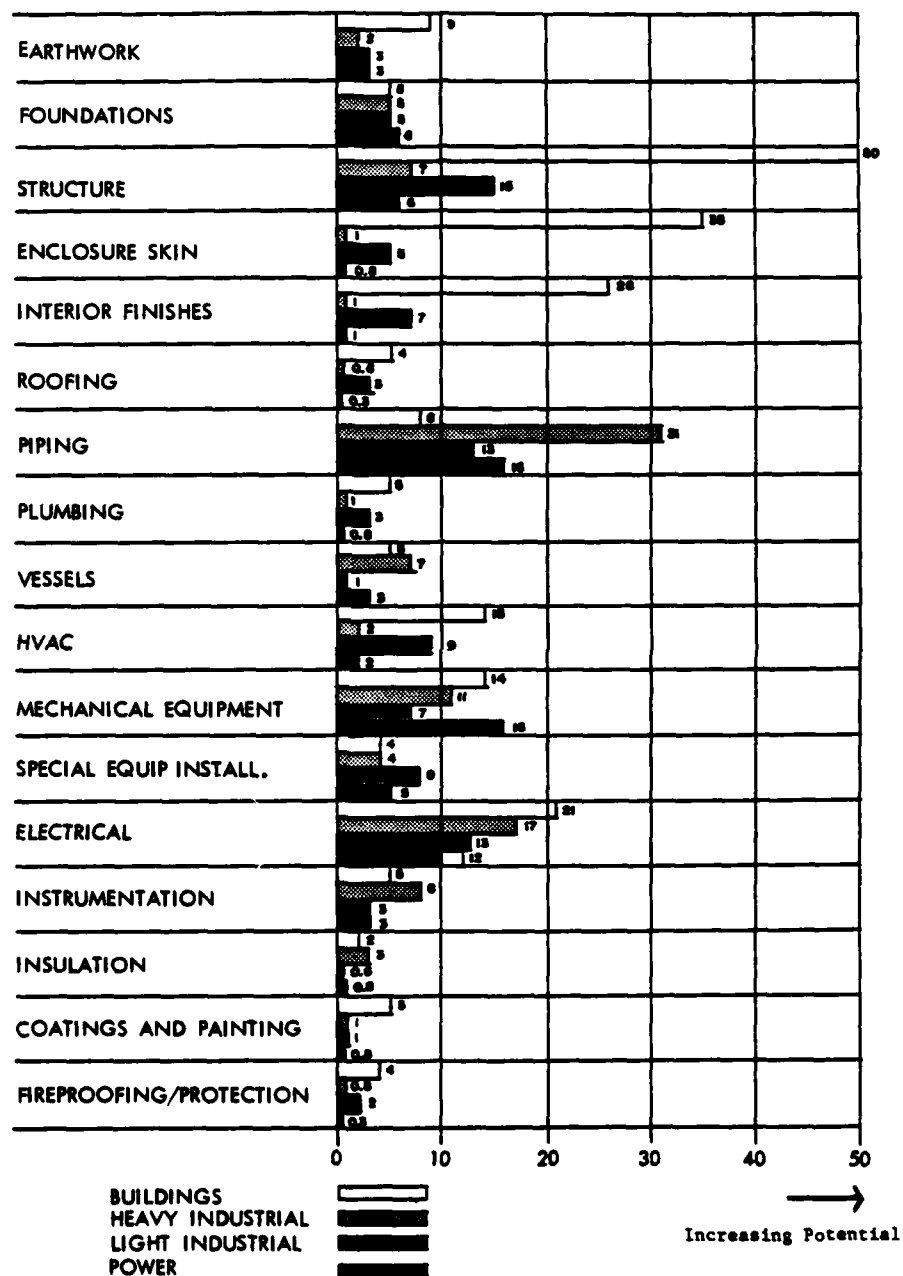


Figure IV-4 Construction Technology Improvement Potential based on Gross Industry Influence

" a IV-7 Gross Industry Influence

	<u>Category</u>	<u>Division</u>
Highest Potential	Structure	Buildings
	Enclosure Skin	Buildings
	Piping	Hvy Industrial
	Interior Finishes	Buildings
	Electrical	Buildings
	Electrical	Hvy Industrial
	Piping	Power
	Mech Equip	Power
	Structure	Lt Industrial
High Potential	HVAC	Buildings

4.6 Further Refinements for Analysis of Construction

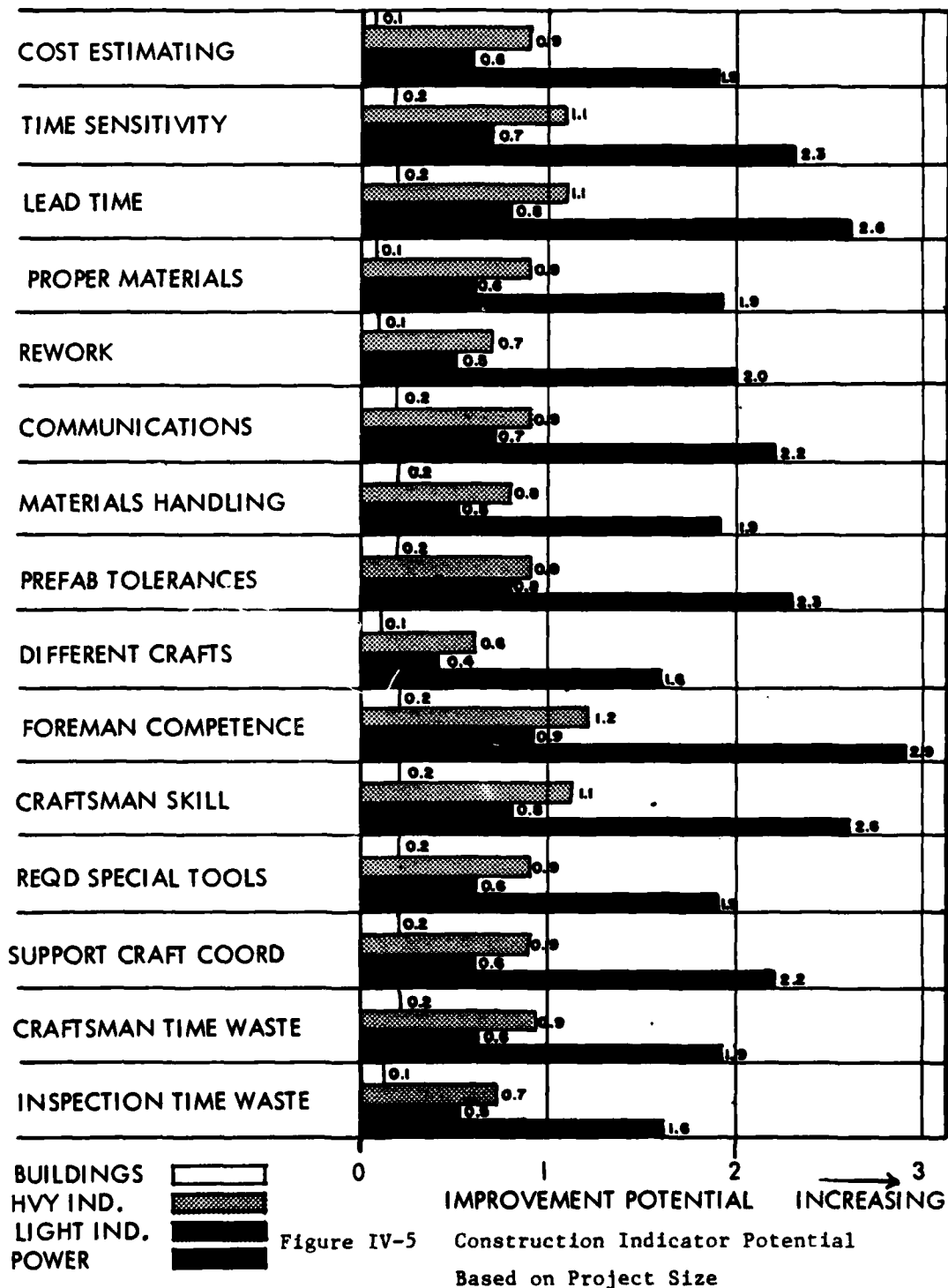
Indicators

The construction indicators, previously rank ordered by improvement potential ratings which were weighted by construction category costs, were then prioritized with respect to individual project size and gross industry influence.

The purposes of project size adjustments and gross industry influence were identical to the purposes used for adjustment of construction category prioritization.

Values used to adjust the indicator potential ratings were also the same as the values used for construction category prioritization.

The relative potential ratings with respect to project size are shown in Figure IV-5.



In project size influence comparisons, each of the Power division indicators were high priority indicators. Heavy and Light Industrial indicators were mid-range while Buildings indicators were very low.

The relative potential ratings with respect to gross industry influence are shown in Figure IV-6.

Sample calculation for cost estimating, Buildings
division:

In gross industry influence comparisons, each of the Buildings division indicators were high priority indicators. The other three divisions were mid-range to low potential.

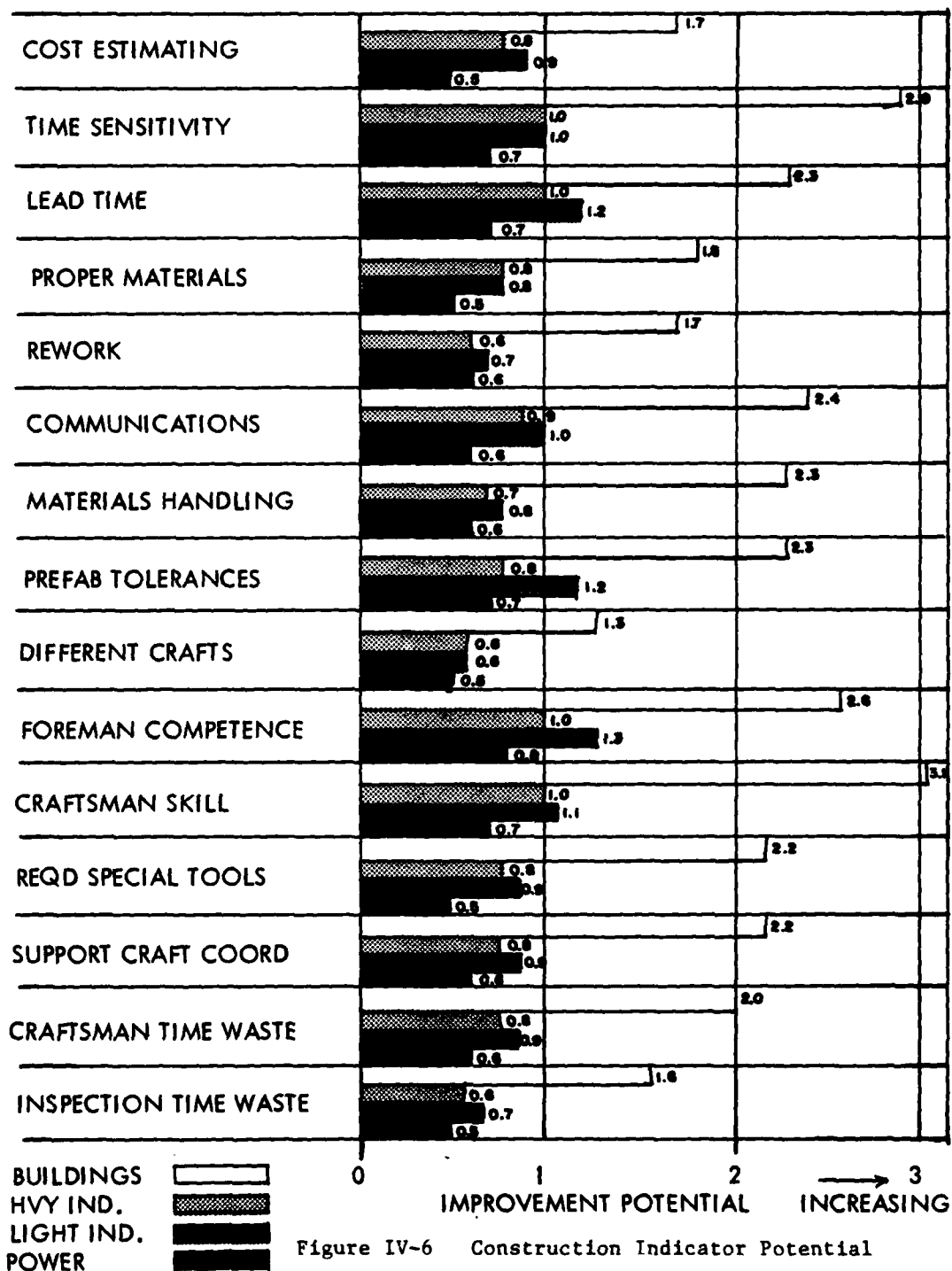


Figure IV-6 Construction Indicator Potential
Based on Gross Industry Influence

CHAPTER 5. CONCLUSIONS

5.1. Construction Categories

5.1.1. Construction Category Improvement Potential

Piping and electrical emerged as the common high potential categories. Structure was important to Buildings and Light Industrial. Mechanical Equipment was important to Heavy Industrial and Power. High potential categories are summarized in Table V-1.

Table V-1 High Potential Categories

<u>Buildings</u>	<u>Light Industrial</u>	<u>Heavy Industrial</u>	<u>Power</u>
Structure	Structure	Piping	Piping
Enclosure Skin	Piping	Electrical	Mech Equip
Interior Finishes	Electrical	Mech Equip	Electrical
Electrical			

5.1.2. Impact Potential due to Project Size and Gross Industry Influence

In order to compare overall high priority areas among the divisions, project size influence and gross industry influence were applied to the high potential categories. The results are summarized in Table V-2.

Table V-2 Impact Potential of Categories

	<u>Project Influence</u>	<u>Gross Industry Influence</u>
Highest Potential	Piping-Power	Structure-Buildings
	Mech Equip-Power	Enclosure Skin-Buildings
	Electrical-Power	Piping-Hvy Industrial
	Piping-Hvy Industrial	Interior Finishes-Bldgs
	Foundations-Power	Electrical-Buildings
	Structure-Power	Electrical-Hvy Industrial
	Electrical	
	Hvy Industrial	Piping-Power
	Spec Equip-Power	Mech Equip-Power
	Mech Equip	
	Hvy Industrial	Structure-Lt Industrial
High Potential	Structure	
	Lt Industrial	HVAC-Buildings

5.2. Construction Indicators5.2.1. Construction Indicator Improvement Potential

Craftsman skill and foreman competence were the high potential indicators common to all divisions. High potential indicators were summarized in Table V-3.

Table V-3 High Potential Indicators

	<u>Buildings</u>	<u>Light Industrial</u>
Highest	Craftsman Skill	Foreman Competence
	Time Sensitivity	Prefab Tolerances
	Foreman Competence	Lead Time
High		Craftsman Skill
	<u>Heavy Industrial</u>	<u>Power</u>
Highest	Foreman Competence	Foreman Competence
	Craftsman Skill	Lead Time
	Time Sensitivity	Craftsman Skill
High	Lead Time	Time Sensitivity

5.2.2. Impact Potential Due to Project Size and Gross
Industry Influence

In project size influence comparisons, the high potential indicators were all power division indicators.

In gross industry influence comparisons, the high potential indicators were all Building division indicators.

CHAPTER 6. RECOMMENDATIONS FOR FURTHER STUDY

6.1. Detailed Investigation of Areas with High Improvement Potential

6.1.1. Investigation Methods - Phase 2

High potential categories of construction and indicators of construction effectiveness were identified in the phase 1 research questionnaire. The data was obtained from corporate level executives with broad experience and varied backgrounds.

Phase 2 studies utilize the high priority categories/indicators identified to narrow the subject matter for further funded research.

The best sources of more detailed construction information are personnel actively engaged in current construction efforts, either working on sites, or supporting from home offices. Their proximity to construction activity makes their information very relevant.

The limited amount of time available and fiscal resource limitations will restrain the efforts of the research team in gathering information. The limited research resources can best be utilized by investigating only the high priority areas in an organized manner.

The research group should endeavor to obtain a national cross section of sites within each construction division investigated to lend legitimacy to the Phase 2 studies.

Information collection through combinations of interviews and questionnaires has proven successful in past construction research studies. That successful precedent should be applied to the present study.

Selection of persons to be interviewed must depend on subject material in two different methods. The results of question 5 lend themselves to organization of the subject material in two different methods.

METHOD ONE:

Each interview session would focus on one high potential category of construction such as piping, electrical work, and structural assembly. The questions would use high potential indicators of construction effectiveness to deal with specific aspects of the category investigated.

The one category of focus of each interview session would enable researchers to interview foremen, general foremen, and craft superintendents as well as field engineers. Those individuals are easily accessible on construction sites and have experience in their backgrounds that would be of use in their answers. Since the crafts are organized along

category of construction lines, one person could give complete information at an interview. With one hour interviews, researchers could research at least eight different crafts in a normal working day. The interviews could be conducted with minimal interference of work on the site. Only one supervisor would be absent from his place of duty in a time period.

METHOD TWO:

Each interview session would focus on one high potential indicator of construction effectiveness such as craftsman skill, foreman competence, necessary lead time, or time sensitivity to design. The questions would use the categories of construction to deal with specific aspects of the indicator examined.

The indicator investigated would necessitate group interviews with several crafts present, or would require audience with senior field engineers, project managers, and profit center managers in home offices. Such upper level managers would supervise activities associated with each indicator. The activities span several crafts and would be very broad in scope.

6.1.2. Advantages of Method One

1. Method one involves one on one interviews with personnel readily accessible for interviews. Similar studies have been conducted in the past with success.
2. Foremen and craft superintendents are closest to the actual construction activity and can give timely information very exacting in nature.
3. Categories of construction as opposed to indicators of effectiveness are better differentiated and serve as understandable subdivisions for research data organization and presentation.
4. The research team believes the categories of construction are complete and accurate. The indicators were intuitively derived without prior extensive research and are assumed complete.

6.1.3. Advantages of Method Two

1. Interviews with groups are effective at times. The group members stimulate each other with ideas that build upon themselves.
2. Similarities from indicator impact on different crafts could more easily be detected in group interviews.
3. Interviews with higher level managers produce information based on broad perspectives and experience in related areas. Often, the information is multifaceted and interfaced.

4. The thrust of each indicator lends itself to improvement suggestions. The interview purpose is more easily satisfied.

6.1.4. Method Recommended: Method One

Principle reasons:

1. The interviews are more easily controlled.
2. Interviews are more easily scheduled with minimal job interference on the sites.
3. Interview questions are more easily formulated and understood.
4. Results are better analyzed and presented.

6.2. Indicator Accuracy and Completeness

The 15 indicators on construction effectiveness used in the phase 1 questionnaire were intuitively formulated by the research team without prior extensive investigation. They were assumed to be complete for purposes of the study.

Much understanding of the construction process could be gained by evaluating the "best guess" indicators for accuracy of completeness. Possible problem areas of construction ineffectiveness could be combinations of the postulated indicators or results of criteria not yet formally recognized.

Possible also would be efforts to canvas other CICE results in areas such as Labor Effectiveness, Labor Supply and Training, and other construction technology studies to check the indicators used in question 5.

6.3. Similar studies in Other Construction Divisions

The methods of research applied in phase 1 could be easily modified for other construction divisions such as highways, seaport construction, dams, or other large, civil engineering works. Most of the other divisions fall in the public sector of construction.

APPENDICES

APPENDIX A. CONSTRUCTION TECHNOLOGY SURVEY



CONSTRUCTION TECHNOLOGY SURVEY

The Business Roundtable is conducting a major effort to improve construction through the Construction Industry Cost Effectiveness (CICE) Project. The Business Roundtable has given our group the opportunity to conduct a study to identify areas of potential construction improvement through technology.

Our approach is to conduct two surveys. The first uses a questionnaire (enclosed) to provide information for areas of future specific investigation. The questionnaire is being sent to knowledgeable, corporate level managers who can provide that information. The second survey, which will be done this summer, will be at the project level on actual sites, and will involve both questionnaires and interviews. Your answers to this questionnaire will help us to identify and prioritize those areas for this summer's activities.

The questionnaire is divided into four parts. The first part asks your background, experience, and your name, should we need to contact you for explanation of your answers. The next part asks about your present use of integrated construction technology. The third part asks you to rate different work categories per the instructions at the beginning of that part. The last question solicits your help in our summer investigations.

The questionnaire is designed to be simple and time effective. We realize you have probably been involved in other CICE studies and appreciate your giving us your best efforts in our project also.

Please return the questionnaire to your designated company representative and contact him if you have any problems. If he can not help, we would be glad to assist you. Contact one of us at The University of Texas at Austin: Dr. Richard Tucker, Stephen Sheppard, or Bryan Tucker at (512) 471-1733.

Cordially yours,

A handwritten signature in cursive script, appearing to read "Richard L. Tucker".

Richard L. Tucker, P.E.
Professor

CONSTRUCTION TECHNOLOGY SURVEY**1. Give your name, title, address, *brief* description of experience****Name** _____**Title** _____**Address** _____

Phone _____**Experience** _____

Is your firm owner or contractor? (circle)

CONSTRUCTION TECHNOLOGY SURVEY

2. Select factors that describe typical construction projects with which you have been involved in the past five years.

A. Category of Construction:

- ☐ Buildings (non-residential)
- ☐ Heavy Industrial (basic industry, chemical plants, etc.)
- ☐ Light Industrial (food plants, assembly plants, etc.)
- ☐ Power Generating

B. Project Construction Cost:

- ☐ less than 10 million
- ☐ 10-50 million
- ☐ 50-100 million
- ☐ 100-500 million
- ☐ greater than 500 million

C. Size of Peak Work Force (Manual):

- ☐ less than 100
- ☐ 100-500
- ☐ 500-1000
- ☐ greater than 1000

D. Give the percentage of projects which are union:

- ☐ 0%
- ☐ 1-50%
- ☐ 50-99%
- ☐ 100% Union

E. Identify the crafts listed below which represent the labor makeup on your typical projects:

% Craft

- ___ Boilermakers
- ___ Carpenters
- ___ Cement Finishers
- ___ Electricians
- ___ Equipment Operators
- ___ Insulators
- ___ Instrument
- ___ Ironworkers
- ___ Masons
- ___ Millwrights

% Craft

- ___ Laborers/Helpers
- ___ Painters
- ___ Pipefitters
- ___ Riggers
- ___ Roofers
- ___ Teamsters
- ___ Welders
- ___ List Others: _____

100% Total

CONSTRUCTION TECHNOLOGY SURVEY

3. Estimate the relative percentages of direct construction costs (at the site) of your typical projects which are associated with the following categories (ignore the costs of special equipment; this question relates to labor and materials associated with installation and erection):

Category	Approximate % Cost
Civil	
Earthwork	_____
Foundations	_____
Structure	_____
Enclosure Skin	_____
Interior Finishing	_____
Roofing	_____
Mechanical	
Piping	_____
Plumbing	_____
Vessels	_____
HVAC	_____
Mechanical Equipment	_____
Special Equipment Installation	_____
Electrical	_____
Instrumentation	_____
Insulation	_____
Coatings and Painting	_____
Fireproofing/Fire Protection	_____
TOTAL:	100%

CONSTRUCTION TECHNOLOGY SURVEY

4. The term INTEGRATED CONSTRUCTION TECHNOLOGY refers to the practice of having construction personnel work closely with the design team during the development and design phases of a project. The purpose of this interface is to integrate the construction team's knowledge into the design effort. The project will then be more efficient to construct.

Analyze your firm's use of integrated construction technology and answer the following:

	ALWAYS	FREQUENTLY	OCCASIONALLY	SELDOM	NOT USED
A. Do you integrate construction technology in planning and project design.	☐	☐	☐	☐	☐
B. Does your company have a formalized/standardized system to integrate construction in the project process.	☐	☐	☐	☐	☐
C. How often does your company save planning costs through use of integrated planning.	☐	☐	☐	☐	☐
D. How often does your company save construction costs and time through use of integrated planning and design.	☐	☐	☐	☐	☐
E. Does your firm separate engineering from construction during project development.	☐	☐	☐	☐	☐
F. Do you use integrated processes on a fixed price project.	☐	☐	☐	☐	☐
G. What percentage of project hard dollar costs are saved by utilizing integrated processes.	greater than 20 ☐	20-15 ☐	15-10 ☐	10-5 ☐	less than 5 ☐
H. List other benefits derived from using integrated construction technology.					
I. What commercial contracting methods do you use for design, engineering, and construction.					

CONSTRUCTION TECHNOLOGY SURVEY

6. The next phase of this survey will likely be conducted at the project level and will include interviews with Project Managers and their key assistants. Will you please identify below those projects in your company which you feel would provide useful information and be available for interviews in the July–August, 1981, time frame?

PROJECT A Name of Project _____
Address _____
Project Manager _____
Phone Number _____

PROJECT B Name of Project _____
Address _____
Project Manager _____
Phone Number _____

PROJECT C Name of Project _____
Address _____
Project Manager _____
Phone Number _____

We welcome your comments as necessary. If applicable, refer to the specific question concerned:

END OF SURVEY

APPENDIX B. COMPANIES CONTRIBUTING INFORMATION

1. Contractors

Austin Company (Cleveland)	Ebasco (New York)
Barton Malow	Fluor Constructors
Bechtel Petroleum	Frank J. Rooney
Bechtel Power	J. A. Jones
Bellows Construction	Morrison-Knudsen
Burns and Roe	Ortloff Co.
Daniel Construction	Pankow (Hawaii)
Dravo Corporation	Ray McDermott
Ebasco (Houston)	Voss, Intl.

2. Owners/Power

ALCOA	Georgia Power
American Electric Power	Monsanto
Amoco	Owens Corning Ware
Caterpillar	Phillips Petroleum
Commonwealth Electric	Proctor and Gamble
Dow Chemical	Texaco
Dupont Chemical	Union Carbide

3. Designers

Black and Veatch	J. E. Sirrine
CH2M Hill	Sargeant and Lundy

APPENDIX C. TIME SCHEDULE

Outline of Research by U. of Tex.,

Investigation by CICE	October-December 1980
Background Research	January-February 1981
Preparation of Part 1	
Questionnaire	March-May 1981
Distribution/Collection of Part	
1 Questionnaires	June-August 1981
1st Estimate of Questionnaire	
Results	July 1981
Data Reduction/Interim Reports	
for Part 1 Results	September-November 1981
Final Report	December 1981

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VITA

Stephen Michael Sheppard was born in Tulsa, Oklahoma on February 5, 1950, the son of Hazel Ledgerwood Sheppard and Robert Daniel Sheppard, Jr. In 1968 he entered the United States Military Academy and graduated with a Bachelor of Science in June, 1972. He has served as a field commander and staff officer with the United States Army beginning in 1972 and is still on active duty. He obtained a Masters of Science in Business Administration from Boston University in May, 1980. In June, 1980, he entered the Graduate School of the University of Texas at Austin.

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This report was typed by Dianne Howard Sheppard

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2. DD Form 1473 (Report Documentation Page) - 1 copy. Instructions for completion of form are attached as Incl 1. *10/15*
3. Cover Sheet - 1 copy attached to each copy of thesis. Cover sheet will be typed on plain paper with information and in format shown at Incl 2. *10/15*
4. DTIC Form 50 - 1 copy. Instructions for completion of form are attached as Incl 3. (Note that submission is optional rather than a requirement of the Defense Technical Information Center). *10/15*

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