6 Construction Technologies Richard L. Tucker

Richard L. Tucker

I'm not sure I agree with some statements made in previous papers. Rather than disagree with them, I'll just discuss the fact that there is a concerted interest and concern, particularly among the private community in this country, over the cost of construction itself. This is probably evidenced most closely by the Business Roundtable. The Business Roundtable is now right in the middle of Phase Three of a rather massive effort to look at the whole issue of growing costs in construction projects.

As you know, the Business Roundtable is made up of chief executive officers of the nation's largest corporations. They've put several million dollars of direct funding into this program, just trying to get a handle on the cost of construction and on what can be done to improve it. I would encourage you to write to them and get a copy of their reports. They have 23 separate reports that have been published. The reports are free, including a summary report entitled "More Construction for the Money."

They're now into Phase Three with an effort to try to educate the nation about all of the different factors relating to construction costs and about what should be done to improve these factors.

I have a different classification of construction than what John Eberhard presented, My classification results from a purely technological perspective. My four major categories include: residential buildings; non-residential buildings; engineered construction; and industrial construction. I would claim to you that these four categories are very distinct in terms of the types of workers that are involved in them, in terms of the types of construction companies, and in terms of the types of designers that participate in the projects.

Residential construction is dominated principally by architects, if there are any professionals at all. There are many house designers in the world that don't have any type of degree. The people that work in residential construction are relatively unskilled, compared to those that work in the other types of construction.

MR. EBERHARD: Did you say residential is dominated by architects?

MR. TUCKER: I say if there are any professionals, it's dominated by architects. It's really dominated by the people that push and develop them as far as the technical aspects of it are concerned.

Now, I'm not talking about the land development, John, I'm talking from the standpoint of the structural design, the components that go into it. All of this is a technical classification rather than a marketing classification.

Non-residental buildings are certainly dominated by architects. The engineering component in buildings is relatively small compared to the architectural component.

The engineered construction probably should be classified as civil engineered construction. That is, it is dominated by the civil engineering community: highways, dams, bridges, those kinds of things.

Industrial construction is dominated by other types of engineers: chemical, mechanical and electrical engineers. These projects include power plants, process plants, and other similar areas.

The size of the industry is one of the problems that we have. We don't know how to measure the size. Figure 1 came out of the Business Roundtable study in which they tried to compare the Census Bureau's numbers and their own estimates. On the left, it shows the total industry in the United States comprised $229 billion for 1979. The Business Roundtable went back and took data that they had from their own companies and showed some rather major changes in it and put the size at a round number of $300 billion a year.

This also shows, if you believe these numbers on the right, the relative magnitude of the different components of the industry, and it shows perhaps a different set of numbers than what John gave us yesterday in his presentation. Any way you look at it, the industry is very large and the opportunities for change are significant.

Similar data from the Roundtable show the construction cost index and that it is, at best, subject to dispute. It's part of the problem we have; we can't measure anything we agree on. Nonetheless, the construction cost index, as you look at numbers from back at 1967, shows that over the past fifteen years or so construction costs have gone up approximately 50 percent more than the rate of inflation as a whole for the nation.

The productivity index is just as controversial. I could show a variety of statistics. They all show the same kinds of trends, and that is that over the past fifteen or twenty years or so, construction productivity has dropped, again about 50 percent, compared to the rest of the economy.

Now, the Roundtable is very concerned about this. In contrast to some of the things that we were discussing yesterday, what these companies are saying is they're only going to put a certain amount of money into construction, and unless the productivity goes up, they're not going to build as much. Indeed, the nation's larger companies have quit building as much as they have. It's a crisis as far as they're concerned.

One of the unique characteristics of construction is that it's very heavily dependent upon job site labor, and productivity almost translates to the productivity of the craftman's time. You're not going to find the numbers in Figure 2 in the literature because I made them up,

(Laughter.)

MR. TUCKER: But I made them up with a certain amount of background, and you can find a lot of numbers in the literature that are compatible with these. I've shown these figures all over the world and to many of the companies in the United States, and what they tell me is that if anything the top number, showing 40 percent productive labor time, is a little bit high, and they feel that perhaps it realistically should be lower than that.

That doesn't mean that craftsmen aren't busy more than 40 percent of the time. It means that their time is not necessarily spent productively.

Figure 1

TYPICAL CONSTRUCTION WORKER TIME

PRODUCTIVE	40%
UNPRODUCTIVE	
Personal	5%
Jurisdictional	15%
Poor Methods	**20%**
Administrative Delays	**20%**

Figure 2

U S CONSTRUCTION INDUSTRY SIZE

	1979 Government Figures (billions)	Study Team Estimate (1979) (billions)
Industrial	$ 1495	$ 6 9 0
Office Buildings	9 4 6	14 .2
Commercial Buildings	I 546	232
Other Private Business	2 9 9	4 5
Farm and Private Institutional	11 59	146
Public Utilities	26.47	265
Residential	9903	990
Government	**4900**	**490**
TOTAL NEW CONSTRUCTION	$22895	$3000

However, we have a lot of work sampling studies and other data that show — I guess the particular extreme is the nuclear power plants — that 30 percent is about all of the time that they're busy at all on some projects.

If you look at the sources of the other 60 percent of craftsman time, then some of it perhaps is personal. I put five percent down there. Some people might claim that it's higher. Ten percent is about as high as you can find anyone that would realistically claim that it is on the average.

Jurisdictional problems may be due to unions, but not necessarily so. Even the merit shop companies have a kind of artificial jurisdiction that they've established where one craft does one thing and one craft another thing. Carpenters don't put in conduit, for example, even though they're quite capable of putting in conduit. There are lots of jurisdictional problems. Operators can't unload the truck, It takes a particular craft that has the stuff on the truck to unload their stuff. Perhaps that's some wastage of time.

Perhaps the ones that we should focus on are mostly the bottom two, the poor methods and the administrative delays. The methods themselves are the things that relate specifically to technology and the technology of putting the work into place, that of physically making the attachments.

Administrative delays relate pretty closely to the computer issues that Harry was talking about yesterday. These projects have many parties participating in them, and the communications are very tough. I could show you some other figures that would show you magnitude, but I won't because of time.

If we want to see the opportunities for improvement from a technological standpoint, then we probably should look at the different areas of a project as they take place. These are shown in Figure 3, as well as indicators of inefficiency.

Then if you look at the sources of inefficiency, and the things that might be indicators of inefficiency, how difficult is it to estimate costs for an area, how sensitive is that area to design, what's the lead time for schedule in the area, how much rework takes place, and so forth, then you can begin to get some kind of a feel for it. The numbers in Figures 4-7 represent the opportunities for technological improvement. The manner in which we developed quantitative numbers was to survey rather knowledgeable people in some of the nation's largest companies and ask them to rate these on a scale of one to ten. The number one meant that it was very easy to do something, a ten meant that there was a lot of difficulty and had a lot of inefficiency associated with it.

Then we took those average ratings and multiplied them by the percentage costs of a total project and broke them into four sectors. The power sector is one, and if you look at that sector (Figure 7), then it's obvious that the length of the bar, which is a combination of the relative cost impact and the difficulty on a project, it falls into the piping and mechanical equip ment installation and electrical category.

Heavy industrial projects (Figure 6), such as process plants and steel mills, show the same major areas: piping, mechanical equipment, installation, electrical. Piping shows up much more dominantly. As a matter of fact, piping is not only the largest portion of those projects, but also the most inefficient element of those projects, and so the length of that bar is rather obvious.

Now, remember this is a $60 billion per year industry. So it's not something to sneeze at. It is comparable to the size of the housing industry.

Light industrial plants are more building oriented, and as a result, the things that relate to buildings and some other things begin to become prominent. The structure, for example, begins to be a prominent area in light industrial buildings.

Then the structure, the enclosure skin and the interior finishes, are all very prominent, and as you can see, electrical is relatively more important in buildings than you would think. From the presentations we heard yesterday, electrical is going to be increasingly important in buildings.

Well, these are where we should probably be putting our attention. If you look at the areas of highest technology potential, then in buildings it falls into the structure, enclosure skin, interior finishes and electrical; in the other sectors, into these other three areas.

Even in buildings, I might advise you that plumbing, piping, those things are not insignificant. They're areas that justify attention.

If you look at an industry-wide basis and try to focus on the areas that have the greatest potential for this $300 billion a year industry, strictly from a technological improvement opportunity, then the piping, mechanical equipment, installation, electrical are the highest areas of potential. This is a weighted scale. The high areas of potential involve the structure and setting of vessels in the HVAC systems, installing special equipment and instrumentation, and are not incompatible with the things that we heard yesterday.

Some areas have lower potential, We complain a lot about roofing in buildings, and it certainly has an impact from a long-range operation standpoint. It has very little impact from the standpoint of efficiency of installing the project itself. The same thing is true with insulation and painting. Those are relatively

Figure 3

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

small portions of projects, and they're relatively efficient compared to the other aspects of the projects.

We went through some number systems and tried to take just those three areas of highest potential and estimate the savings on a nationwide basis per year, if you could just make those three areas no more inefficient than the average of the rest as a whole. So this isn't the potential that we could improve those, but just bringing them down to the same level of inefficiency as everything else, and as you can see in Figure 8, the potential savings are significant.

If you're wondering what the average cost of these projects is, this is based on a $25 million building because that was what was reported by the companies, and it shows an average savings of $91,000, even though those three areas aren't the highest potentials for buildings.

Incidentally, the structure is only an area of potential because of its relative magnitude in the project. It's a relatively efficient area of a project compared to the other areas of a building project.

I think the average cost of light industrial projects was about $120 million, and the heavy industrial, about $200 million, and power plants, about $500 million. On a nationwide basis for the gross industry then, the figures show that we could save about two billion dollars a year by just improving those three areas, not to say the other areas that are of higher potential in buildings.

Then you can go back and look at the activities that go into each of these areas. We picked six of these areas: electrical, instrumentation, piping, equipment installation, and then we broke the structure into two areas because concrete and steel construction have distinctly different characteristics.

We've investigated them pretty carefully. (Figures 9-14). We took the activities involved in steel construction, for example, setting the columns, setting the beams, making the connections as shown in Figure 14. The temporary connections and the final connections, putting in shims and cleaning the anchor bolts seem to be the major things in steel construction. We determined how much time each of these takes. Setting the column takes about 35 percent of the time in the cycle; setting the beams, 25 percent; final connections, 20 percent; temporary connections, 15 percent. I wouldn't claim to want to bet a lot of money on the accuracy of these numbers, but they're as good as I've seen.

Then we asked the people in the field, the superintendents in charge of these operations, to rate each of these areas on the basis of how complicated it is, the complexity of that particular activity, how much skill, the level of skill required for that activity, and then the dependence on accurate technical information for that activity because of this interface between design and construction that takes place, and that's what the ratings here indicate.

Invariably, what we find is that the ones that take the most time are also the ones that rate highest on all three of these areas. So it's possible to determine which kinds of activities tend to lend themselves to this inefficiency. It is somewhat subjective, but about as quantitative as we can make it at this stage.

Figure 13 is for concrete; constructing the form, setting the reinforcement, locating the forms, placing the concrete, aligning the forms, removing the forms after you've got the concrete placed, and so forth.

From this we focused on six activities and examined technological improvements that would lend themselves to major changes.

What we find in concrete work is that the designers, the structural engineers, architects, and so forth, tend to design the concrete structure as it's going to be in the final building. They don't tend to put much detail in design on how it gets in place. They will show where the reinforcement is located. They don't say anything about imbeds. Architects love to put a lot of imbeds in places for electrical boxes and those sorts of things, and those just play havoc with the construction crews because those imbeds somehow are supposed to be there when it's finished, but they're not designed on how they're attached to the forms while you place the concrete in them. When you put some kind of electrical box into the concrete form, and you depend on the workers in the field to somehow hold it in exact position while you place the concrete around it and push it around, it causes a lot of difficulties.

The lack of communication between designers and the people physically constructing these things causes lots of problems. Well, in the cost of concrete structures, the cost of the concrete form work itself is roughly equivalent to the cost of the concrete, the cost of the concrete and the steel. The cost of just the form work is roughly half the total cost, and it's the most volatile thing. If you talk to a construction company, they'll always tell you that they could care less about how much concrete it takes because they can figure that up pretty good, but they put all of their attention on figuring out how to design the form work and how to reuse the forms.

If you look at all of the other elements of construction, whether it's electrical, instrumentation, equipment setting or anything else, you'll find that the common thing is making connections; that is the common problem that wastes all of the time in the construction industry: making any kind of connection, whether it's a beam to a column, a beam to a beam, electrical wire that you're putting terminations in, whatever. The connections are the things that have the very high level of inefficiency. We haven't yet learned how to do that with robotics or any other kinds of machines. It still takes people and is a very inefficient operation, a lot of standing around all the time they're doing it.

Now, I want to talk about the breakdown between design and construction. I spent a lot of time studying a large precast erection project a few years ago in Houston. It had about 2,500 beams and columns and double-Ts that had to be put in place. We were studying the efficiency of the erection operation rather carefully. The vertical scale on Figure 15 is the number of pieces that were erected each day. The horizontal scale is time. As you can see, the

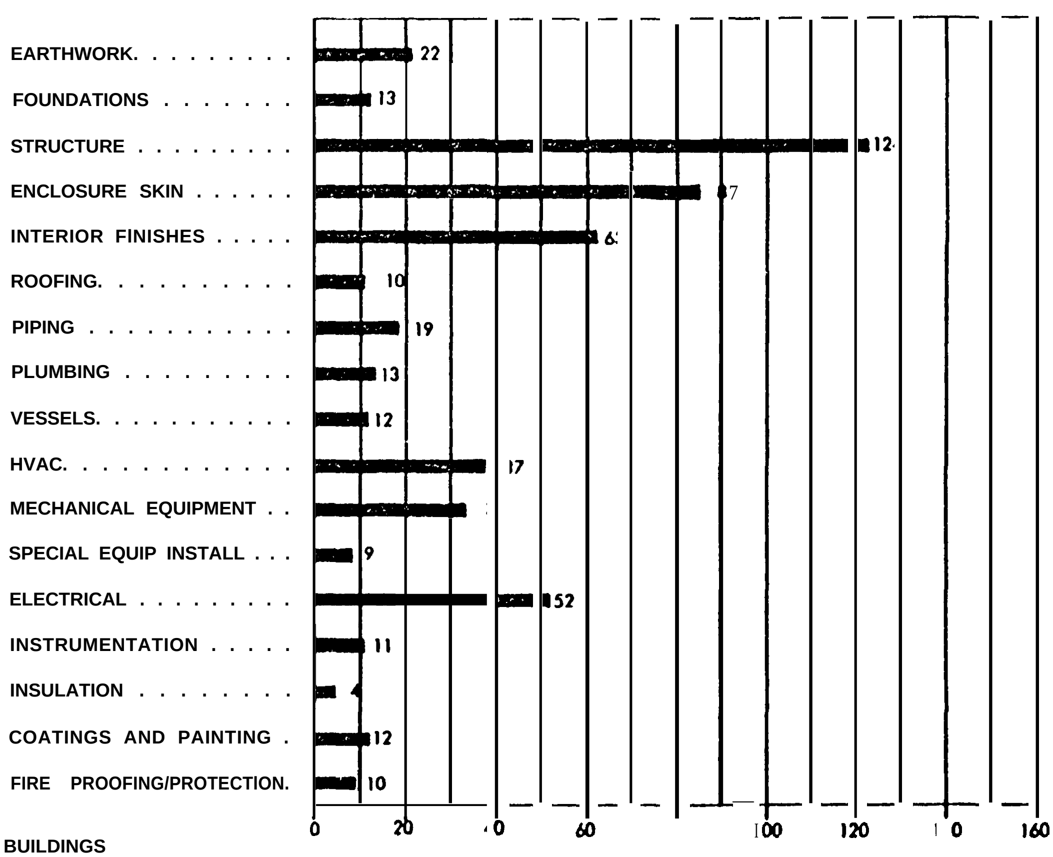

Figure 4

pieces/day varies all over the place. The factors that cost time are fit-up problems.

Figure 16 illustrates that if you put a double-T on a ledger beam that you have some tolerance. One inch is typical. We took several structures and compared them. The one-inch tolerance that these were designed for resulted in a five-inch bearing area plus or minus a half inch. You can see the range shown in about seven thousand measurements. What this says is that we need to integrate the design, definition, construction sequence much more and have a lot more interaction between the designers and the others. This is the potential impact of that integration. I've also put this on the handout.

In terms of combined impact of all of these things, I suggest to you that we're going to see some rather major changes. I'm claiming that technological changes are going to be made in the construction aspect of the industry, regardless of whether there's a Government program or not. The climate is here, We're going to have to have more integration of the design and construction. We're even going to get the owners into these things. We're going to find more machine-driven construction processes instead of people-driven construction processes, and we're going to find some major revisions in contract strategies. Instead of completing a design and putting the thing out for competitive bids, we're going to have to get the contractors in on it at an earlier stage. We'll have to have contracts that will speak to that point.

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Figure 5

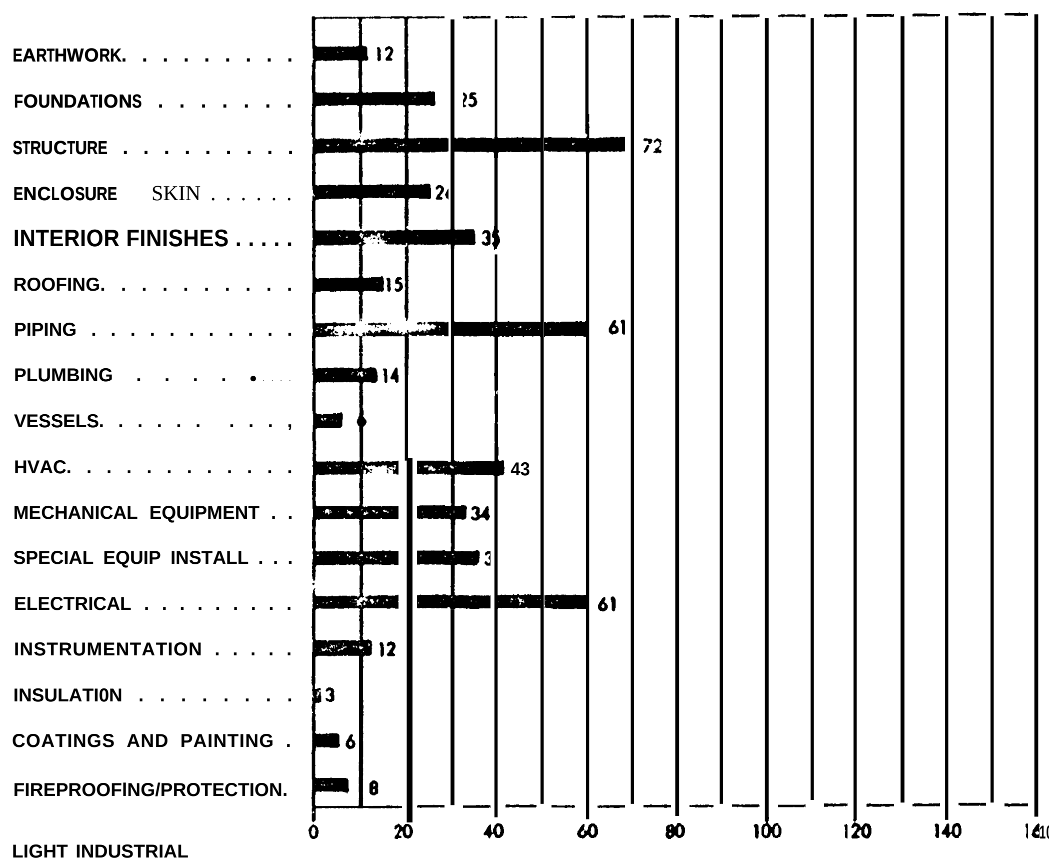


Figure 6

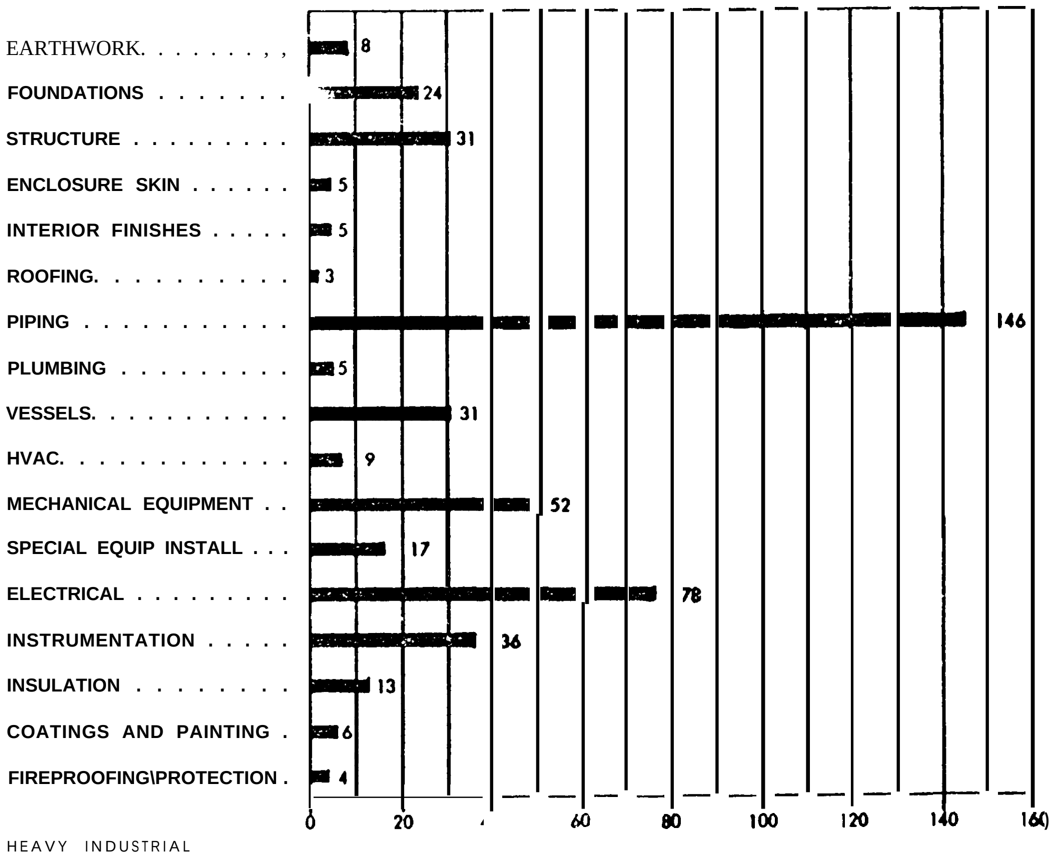
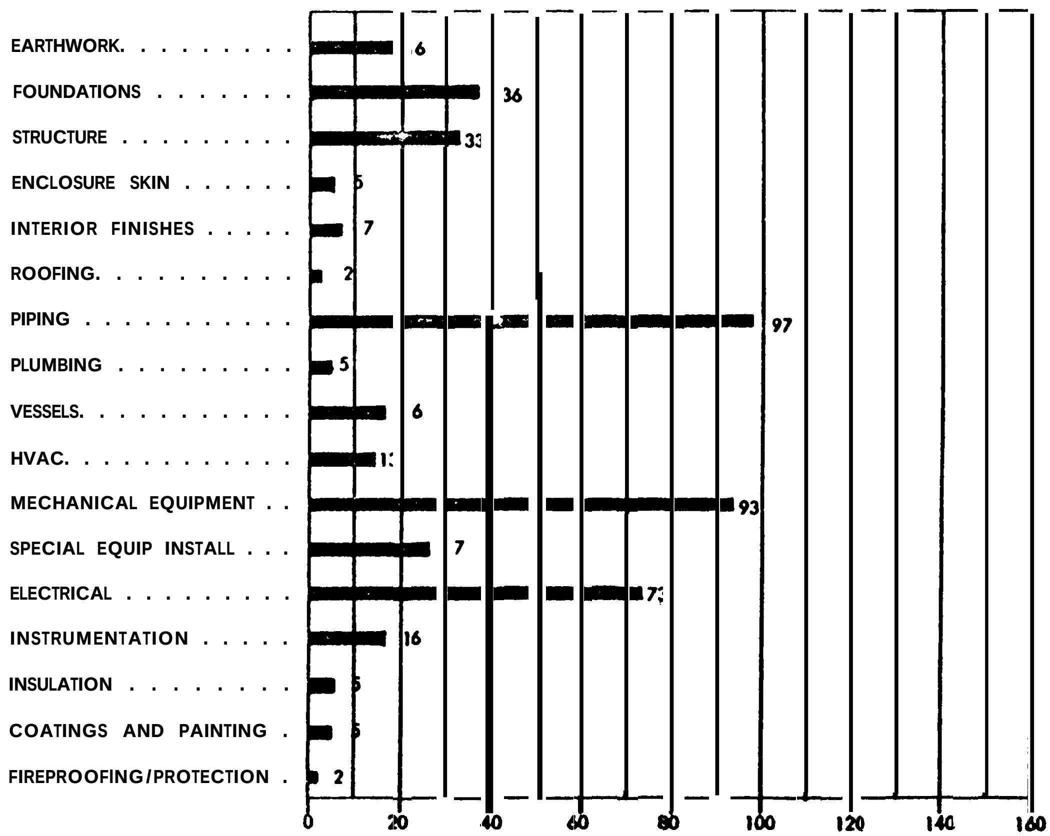

EARTHWORK. . . . . , ,
8
FOUNDATIONS . . . .
24
STRUCTURE . . . .
31
ENCLOSURE SKIN . . . . . .
5
INTERIOR FINISHES . . . . .
5
ROOFING. . . . .
3
PIPING . . . .
146
PLUMBING . . . .
5
VESSELS. . . . .
31
HVAC. . . . .
9
MECHANICAL EQUIPMENT . .
52
SPECIAL EQUIP INSTALL . . .
17
ELECTRICAL . . . .
78
INSTRUMENTATION . . . . .
36
INSULATION . . . .
13
COATINGS AND PAINTING .
6
FIREPROOFING\PROTECTION .
4
0
20
60
80
100
120
140
160
HEAVY INDUSTRIAL

Figure 7



POWER

Figure 8

Individual Project Basis ($ millions)	Piping	Mechanical Equipment	Electrical	Total
Buildings (25 million)	.006	.039	.046	$ .091 million
Light Industrial ($120 million)	.241	.174	.258	$ 0.673 million
Heavy Industrial ($190 million)	**3.802**	**1.002**	**1.410**	**$ 6.214** million
Power ($470 million)	**5.060**	**3.046**	**2.744**	$10.850 million
Gross Industry Basis ($ billions)				
Buildings ($69 billion)	.017	.108	.128	$ .253 billion
Light Industrial ($33 billion)	.067	.048	.071	$ .186 billion
Heavy Industrial ($33 billion)	.667	.176	.247	$ 1.090 billion
Power ($27 billion)	.292	.176	.158	$ .626 billion
Total ($162 billion)	1.043	.508	.604	$ 2.155 billion

***Assumptions**

1. Labor component is 25% of a project.
2. Improvement would allow Piping, Mechanical Equipment and Electrical to achieve average indicator ratings.
3. Numbers in parentheses are total project costs.

Figure 9

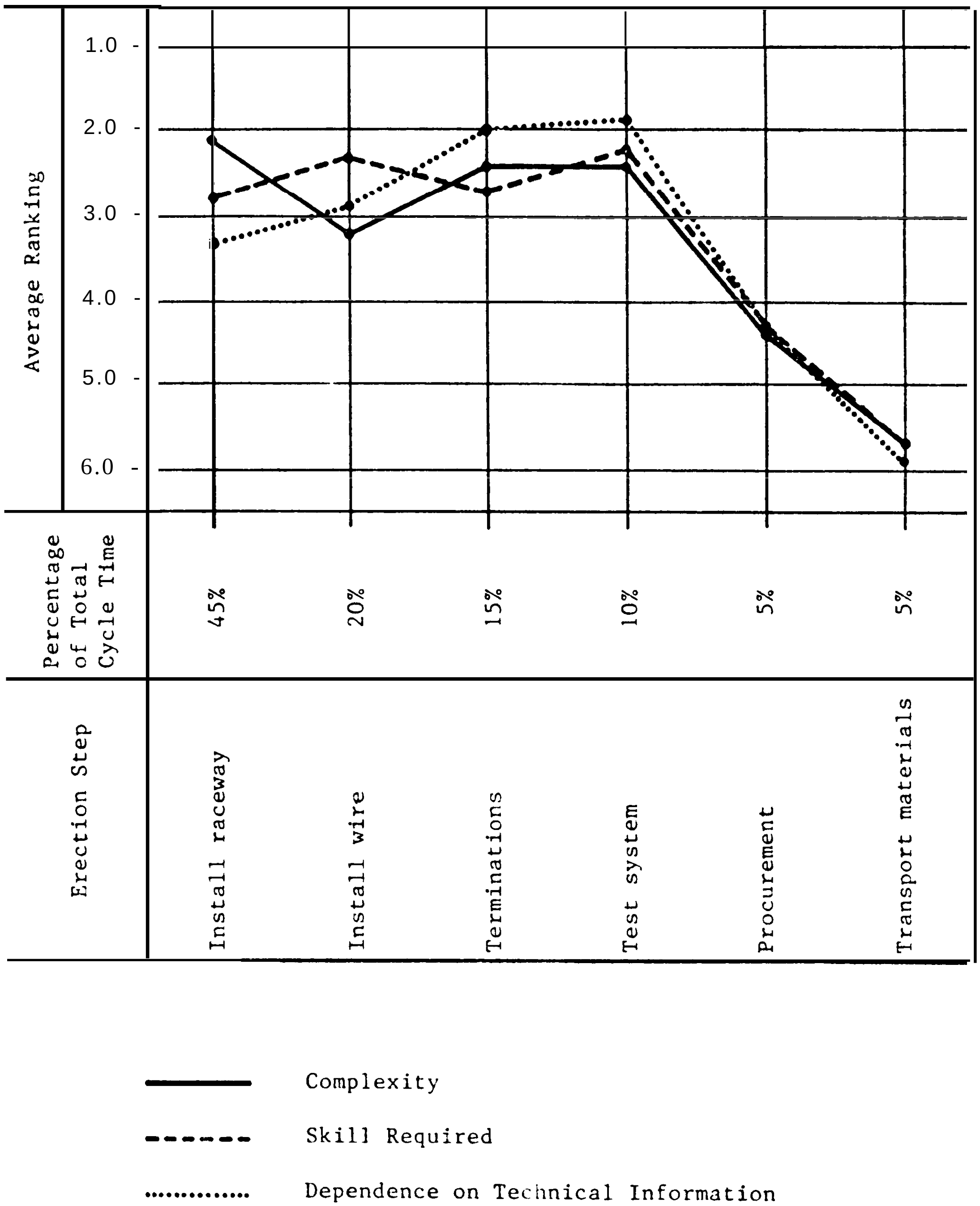

Average Ranking
1.0
2.0
3.0
4.0
5.0
6.0
Percentage of Total Cycle Time
45%
20%
15%
10%
5%
5%
Erection Step
Install raceway
Install wire
Terminations
Test system
Procurement
Transport materials
Complexity
Skill Required
Dependence on Technical Information

Figure 10

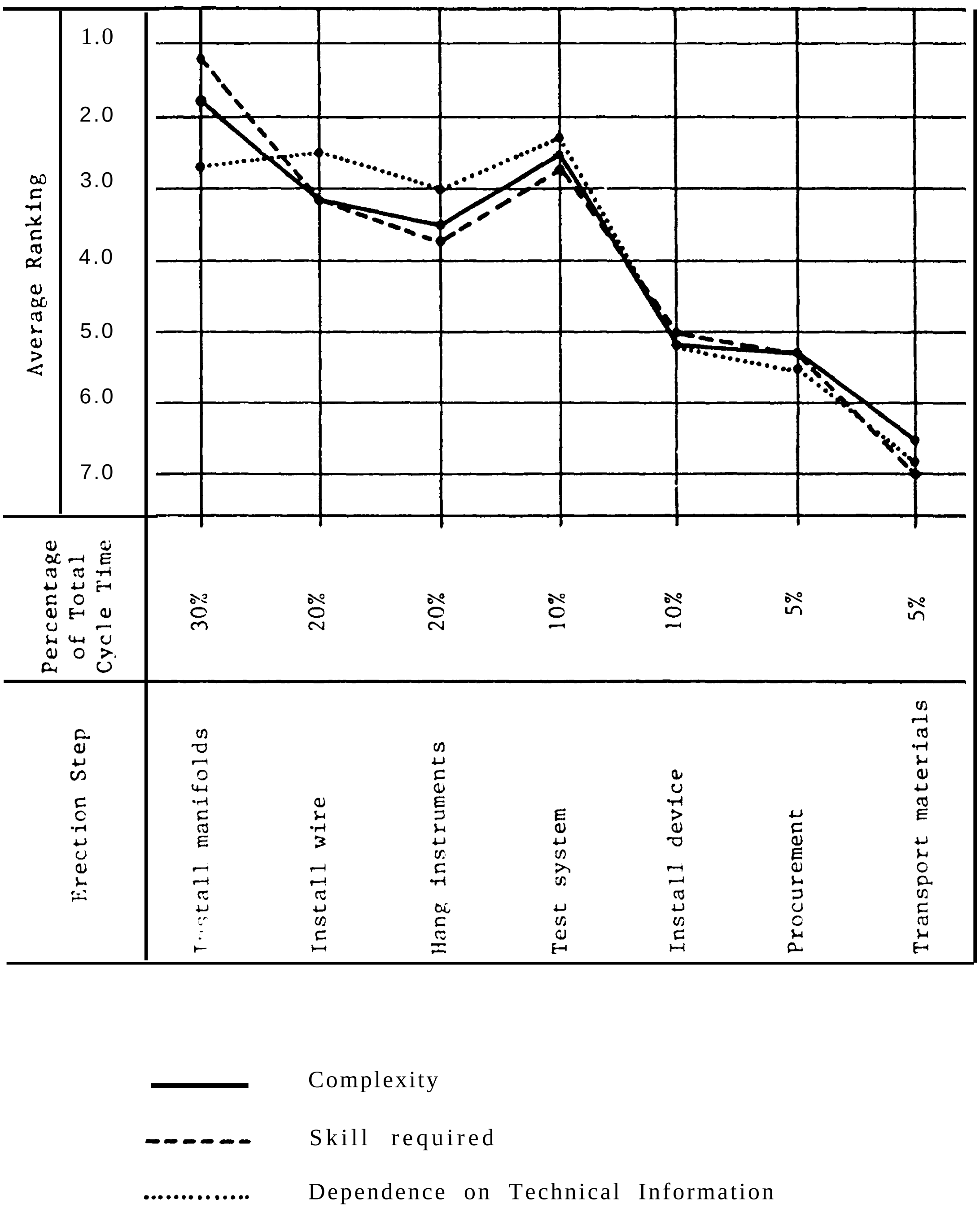
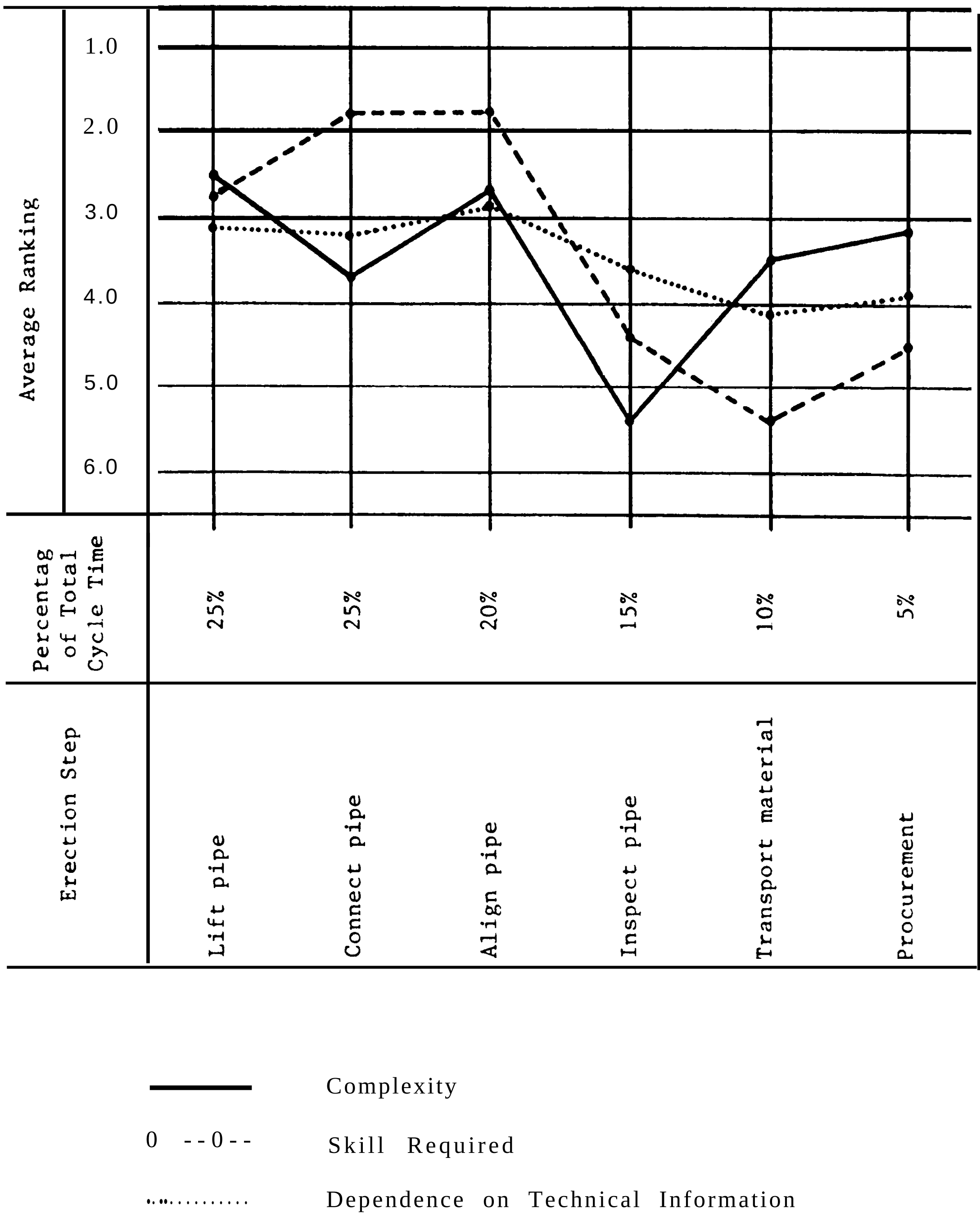

Average Ranking
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Percentage of Total Cycle Time
30%
20%
20%
10%
10%
5%
5%
Erection Step
Install manifolds
Install wire
Hang instruments
Test system
Install device
Procurement
Transport materials
Complexity
Skill required
Dependence on Technical Information

Figure 11


Average Ranking
1.0
2.0
3.0
4.0
5.0
6.0
Percentag of Total Cycle Time
25%
25%
20%
15%
10%
5%
Erection Step
Lift pipe
Connect pipe
Align pipe
Inspect pipe
Transport material
Procurement
Complexity
0 --0-- Skill Required
Dependence on Technical Information

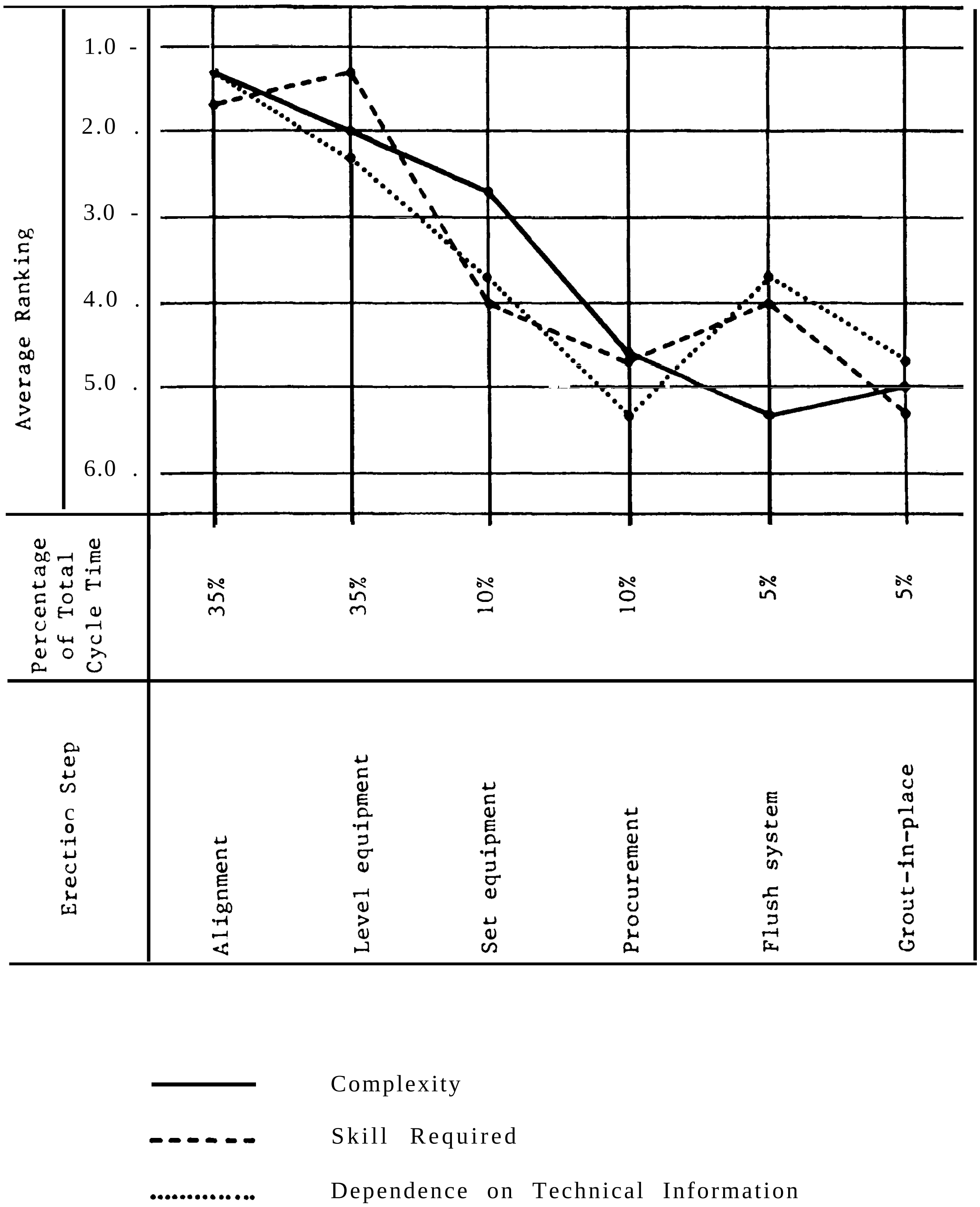
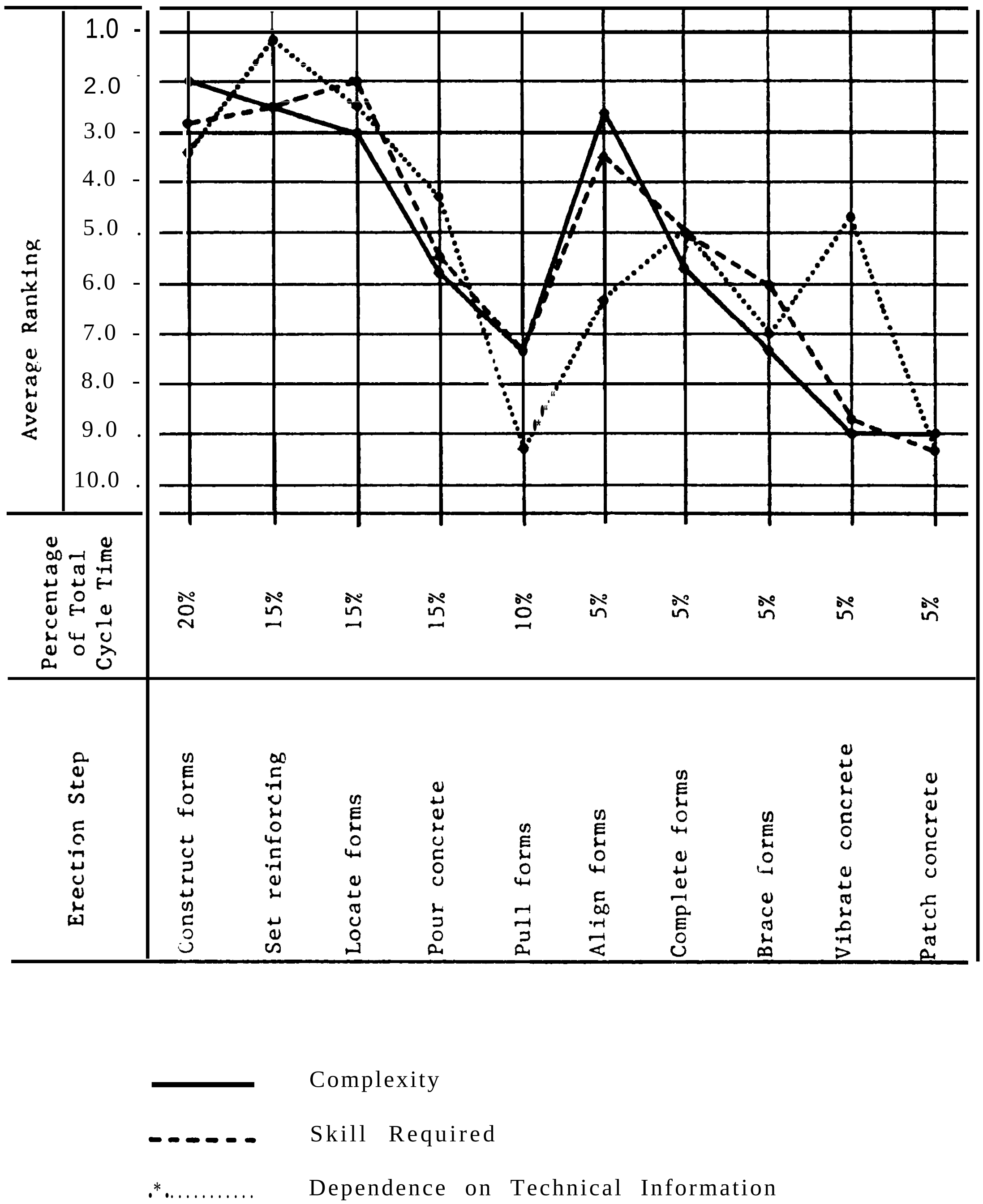

Average Ranking
1.0
2.0
3.0
4.0
5.0
6.0
Percentage of Total Cycle Time
35%
35%
10%
10%
5%
5%
Erection Step
Alignment
Level equipment
Set equipment
Procurement
Flush system
Grout-in-place
Complexity
Skill Required
Dependence on Technical Information

Figure 12

Figure 13



Average Ranking
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Percentage of Total Cycle Time
20%
15%
15%
15%
10%
5%
5%
5%
5%
5%
Erection Step
Construct forms
Set reinforcing
Locate forms
Pour concrete
Pull forms
Align forms
Complete forms
Brace forms
Vibrate concrete
Patch concrete
Complexity
Skill Required
Dependence on Technical Information

Figure 14

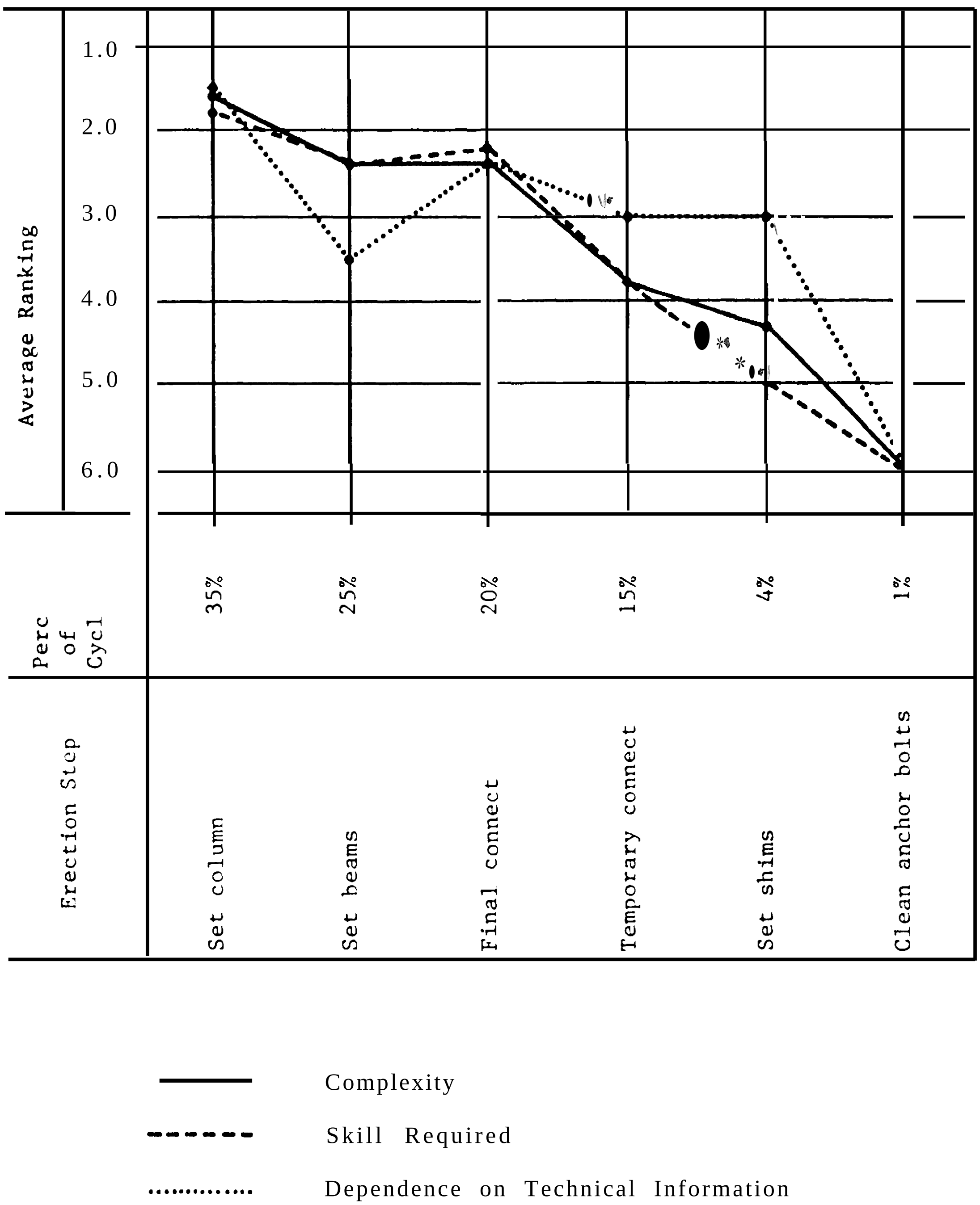

Average Ranking
1.0
2.0
3.0
4.0
5.0
6.0
Perc of Cycl
35%
25%
20%
15%
4%
1%
Erection Step
Set column
Set beams
Final connect
Temporary connect
Set shims
Clean anchor bolts
Complexity
Skill Required
Dependence on Technical Information

Figure 15

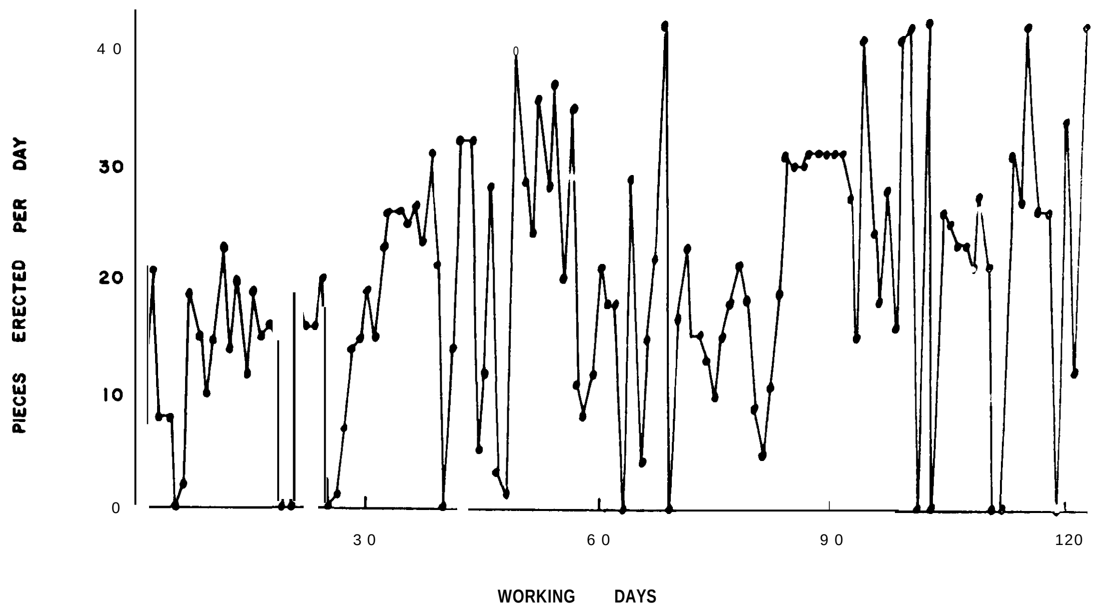


Figure 16

Bearing length in inches (1)	Frequency For Parking Garages				
	NS (2)	SS (3)	DP (4)	BH (5)	CB (6)
2 - 2/4		2			
2 - 3/4	2	1			
3	13	9			
3 - 1/4	26	15	1		
3 - 2/4	64	39	1		
3 - 3/4	109	64	5	1	
4	162	180	6	1	6
4 - 1/4	217	240	13	6	15
4 - 2/4	240	301	16	9	49
4 - 3/4	256	368	45	26	89
5	266	324	59	66	166
5 - 1/4	208	248	108	110	187
5 - 2/4	135	147	128	200	175
5 - 3/4	82	73	182	314	89
6	28	41	180	335	35
6 - 1/4			191	294	2
6 - 2/4			174	144	
6 - 3/4			128	66	
7			96	15	
7 - 1/4			42		
7 - 2/4			6		
Total	1,808	2,052	1,381	1,587	813

Note: 1 in. = 25.4 mm