



Room 14-0551
77 Massachusetts Avenue
Cambridge, MA 02139
Ph: 617.253.5668 Fax: 617.253.1690
Email: docs@mit.edu
<http://libraries.mit.edu/docs>

DISCLAIMER OF QUALITY

Due to the condition of the original material, there are unavoidable flaws in this reproduction. We have made every effort possible to provide you with the best copy available. If you are dissatisfied with this product and find it unusable, please contact Document Services as soon as possible.

Thank you.

Some pages in the original document contain pictures, graphics, or text that is illegible.

COORDINATION PROBLEMS IN FAST TRACK COMMERCIAL
CONSTRUCTION

by

Andrea Dickenson White

S.B.C.E. Massachusetts Institute of Technology
(1980)

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF

MASTER OF SCIENCE IN
CIVIL ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May 1980

© Andrea Dickenson White

The author hereby grants to M.I.T. permission to reproduce and
distribute copies of this thesis document in whole or in part.

Signature of Author

[Handwritten Signature]
Department of Civil Engineering

May 21, 1980

Certified by

[Handwritten Signature]
Raymond E. Levitt
Thesis Supervisor

Accepted by

[Handwritten Signature]
ARCHIVES
MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

[Handwritten Signature]
C. Allin Cornell
Chairman, Department Committee

JUL 18 1980

LIBRARIES

Coordination Problems in Fast Track
Commercial Construction

by

Andrea Dickenson White

Submitted to the Department of Civil Engineering on
May 23, 1980 in partial fulfillment of the requirements for
the Degree of Master of Science in Civil Engineering.

ABSTRACT

Fast track or overlapped construction is employed in place of the conventional design-bid-construct approach for a variety of reasons, among them, reducing the total duration of the design-build activities. This allows an Owner to experience a smaller time lag between initial capital expenditures and return on investment.

This study analyses a fast track case study project and a conventional construction case, which has been hypothetically extrapolated from it.

The fast track and conventional construction cases are then compared using an analysis technique called "TREND" which uses precedences, variability of activity durations, and actors involved in activities to discover coordination problem areas.

The final chapter critiques the results of the "TREND" analysis and draws some more general conclusions which can be applied to a wider variety of fast track projects. The results indicate that very careful attention must be given to scheduling and controlling design activities in the fast track case. Furthermore, it appears that a "TREND" analysis may be particularly useful on large, complex projects.

Thesis Supervisor: Dr. Raymond E. Levitt
Title: Associate Professor of Civil Engineering

ACKNOWLEDGEMENT

I wish to thank my thesis supervisor, Professor Raymond E. Levitt, for his advice, ideas and encouragement throughout this study. His guidance and friendship have made a truly positive impression on me.

The case study project which this study deals with was provided by Mr. James Wakefield of Carlson Corporation who was ever friendly and helpful as questions arose throughout the length of the study.

The contribution of Mr. Joe Morog in giving insight into the Architect's views along with invaluable moral support is greatly appreciated.

Special thanks go to Ellen Sebring whose typing contributed to the quality and timely completion of this study.

Finally, acknowledgement of the patience and understanding of my dog, Thunder, and my cats, Big Wig and O'Keefe. Throughout the length of this study they have relinquished my affection in deference to higher education.

TABLE OF CONTENTS

	Page
ABSTRACT . . . . .	.ii
ACKNOWLEDGEMENT.	iii
TABLE OF CONTENTS. . . . .	.iv
LIST OF TABLES	v
LIST OF FIGURES. . . . .	.vi
I. INTRODUCTION	7
OBJECTIVES . . . . .	.11
II. RESEARCH METHODOLOGY . . . . .	.12
Sources of Data. . . . .	.12
"TREND" Analysis . . . . .	.13
III. ACTIVITIES, ACTORS & INTERDEPENDENCIES . . . . .	.16
Description of Carlson Corporation . . . . .	.16
Description of Case Study Project. . . . .	.17
IV. ANALYSIS OF DATA . . . . .	.67
V. CONCLUSIONS. . . . .	.79
BIBLIOGRAPHY . . . . .	.84

LIST OF TABLES

I.	People Involved in Activities	26
II.	Fast Track Activity Precedences	34
III.	Conventional Activity Precedences	40
IV.	Activity Duration and Float	47
V.	Number of Activities Performed by Actors.	54
VI.	Fast Track: Actors Depended On	57
VII.	Conventional: Actors Depended On	62
VIII.	Percent Breakdown of Construction Cost.	66

LIST OF FIGURES

1. Contractual Relationships 9

1A. Fast track vs. Conventional Construction . .10

2. Fast Track Design-Construction Precedence . .22

3. Pre-Construction Activities Conventional. . .23
Construction

4. Fast Track Critical Path.24

5. Conventional Critical Path.25

6. Fast Track Design-Construction Actors74

7. Actor Interdependencies75

Chapter I

INTRODUCTION

This study will look at coordination problems in fast track construction. Fast tracking is the process by which design and construction processes overlap. Unlike the conventional approach, the design phase is finalized before construction begins, when a project is fast tracked, construction is started early on in the design phase. A fast track project is under the direction of a Construction Manager (CM) or a Project Manager (PM). Construction contracts may be let at various stages in the design by the CM or PM. These contracts may consist of a number of fixed price contracts which define the project. The contracts need not, however, be fixed price. In the event the job is given to a General Contractor (GC) or a Trade Contractor (TC) before the particular phase being bid is finalized, the contract may be let by unit pricing or under a cost reimbursable arrangement.

When a GC is in charge of the construction phase a PM is in charge of subcontracting the work. If a CM is hired as the Owner's representative, s/he will most likely not have in-house labour forces and will contract the work out to Trade Contractors. This study will deal only with the situation where the GC is under contract with the Owner and the subcontractors are under contract with the GC. The GC's function is described in greater detail in a later section. See figure 1 for clarification of contractual relations.

Fast track construction can be, and is, employed for a wide variety of reasons. It may be used when site conditions are unknown or variable, as in tunnel construction. The design in this case cannot be finalized before construction begins.

Tunnel construction is an ideal candidate for overlapping design and construction; Europeans and Japanese construct tunnels in this manner. Because of competitive bidding laws and traditions, however, U.S. tunnel projects are seldom fast tracked.

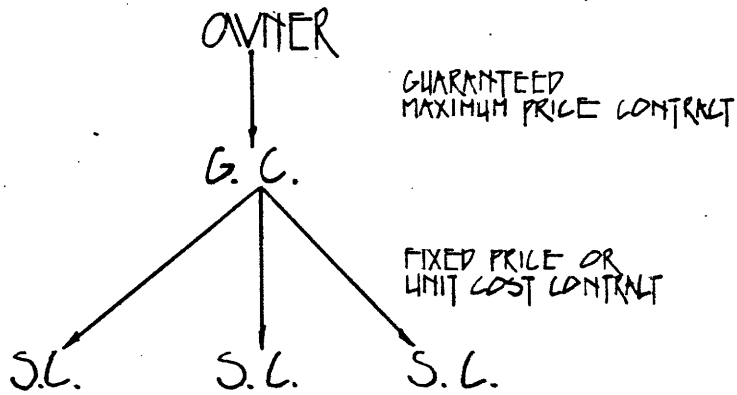
Fast tracking is also used when speed is the primary objective. By overlapping design and construction, the overall length of the project can be reduced thus reducing the time lag between initial capital expenditures and return on the Owner's investment. Speed of construction is very important in these times of double digit inflation. If a project Owner is operating on a fixed budget the size and/or quality of the project could vary substantially due only to an increase in the construction time. This is one obvious way in which time may constrain a project. See Figure 1.A.

In certain cases time is the main consideration. Design-construction costs become secondary to direct reductions in completion time. Coordination becomes a major concern on such projects, since the design and construction teams perform closely related activities which must be carefully managed.

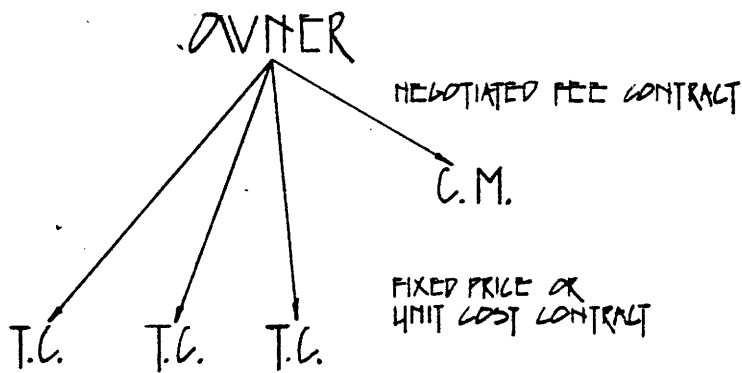
CONTRACTUAL RELATIONSHIPS

FIGURE - 1

1.1



1.2

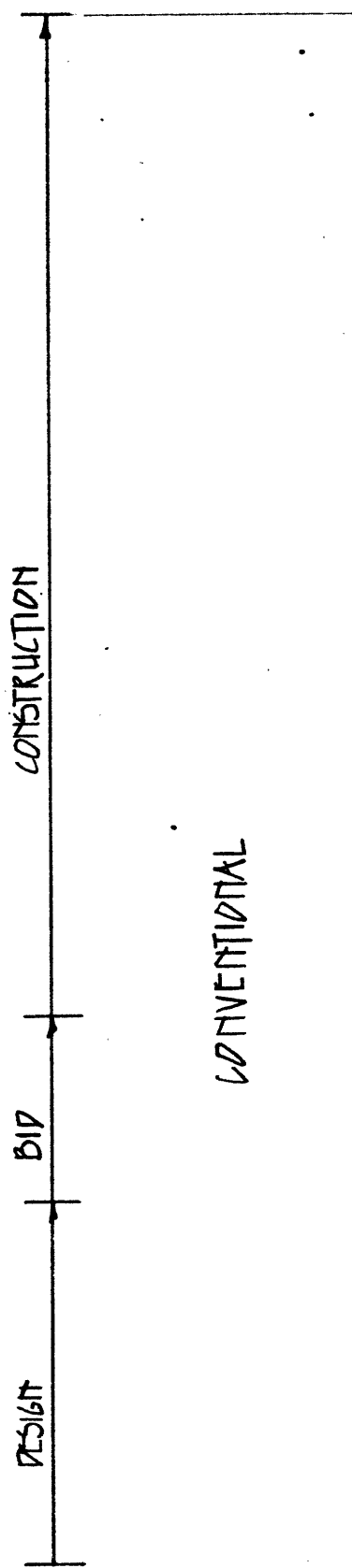


KEY:

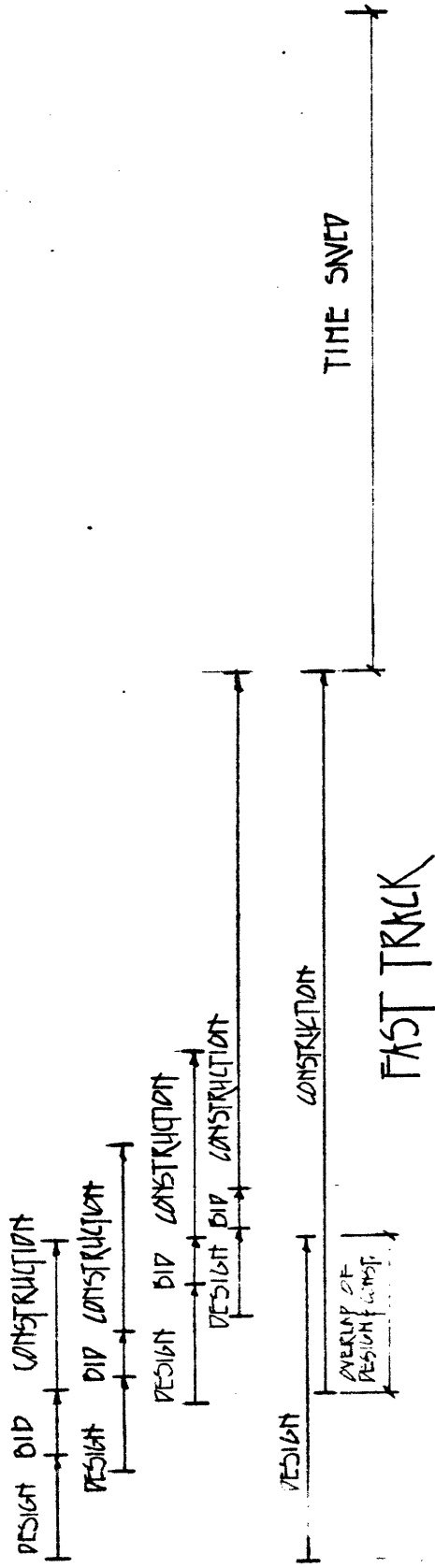
- G.C. - GENERAL CONTRACTOR
- S.C. - SUBCONTRACTOR
- C.M. - CONSTRUCTION MANAGER
- T.C. - TRADE CONTRACTOR

FIGURE - 1.A

FAST TRACK VS CONVENTIONAL CONSTRUCTION



CONVENTIONAL



FAST TRACK

OBJECTIVES

A quantitative approach will be taken to the comparison of coordination requirements on a fast track construction project and a conventional construction project.

The theory for this study will be taken from various contemporary management courses, notably "TREND: New Management Information from Networks," Proceedings, Third International Congress on Project Planning by Network Techniques, Lawrence A. Benningson, Stockholm, pp. 44-60. The analysis will also employ some basic management concepts. The project which will be used as an indepth case study is a manufacturing plant in Pennsylvania. This project is now under construction using fast track design-build methods.

The activities involved in design and construction of the same building have been hypothetically rearranged to depict the conventional case. In this case it will be assumed that contract documents are complete before the job is put out to bid by a General Contractor. The General Contractor will then employ the same subcontractors as are employed in the fast track case.

A precedence network will be constructed for each case which will show precedence, activity duration and float. From these networks critical paths can be determined.

These precedence networks will then be used to perform a "Trend Analysis" whereby coordination and scheduling problems can be pinpointed. This is more fully explained in Chapter 2.

Chapter II

RESEARCH METHODOLOGY

Sources of Data

The major portion of the hard data for this study was provided by Carlson Corporation in the form of a detailed CPM network. This network represented the scheduling of the project, as of April, 1980, using fast track construction methods. The hypothetical conventional construction case was derived from this network.

In deriving the conventional case from this network we have assumed no change in activity durations from the fast track case to the conventional case. We have also assumed the same construction activity precedences. There may be some subtle differences which have been neglected in this simplified model. We have proceeded in this vain, however, since it is our assumption that these differences are in fact subtle and more insight can be gained in the comparison of one project performed using two different methods than in comparing two distinctly different projects. In using the same project, design-construction actors are the same and a direct time savings can be projected. We can thereby examine the relationships of the actors to each other in both cases and make direct comparisons.

Insight into the Architect's views of fast track design and construction were provided by Joe Morog, a practicing Architect and fellow student. He also provided the major

portion of the data in Table VIII which he collected from various sources.

The information in Table VIII encompasses a wide variety of project types and sizes. The percentages for major contract items vary by project type and project size. These percentages do, however, show which items are major contract items. Their purpose is to give a rough idea of the weight these items should be given in determining the guaranteed maximum price and at what point in the design this price can realistically be determined.

Explanation of "TREND" Analysis Technique

Information on the "TREND" analysis technique was taken directly from an unpublished paper by Raymond E. Levitt, entitled, "Two New Project Coordination Techniques for Construction Manager," 1977. Levitt's paper is based on Lawrence Benningson's paper entitled, "TREND: New Management Information from Networks."¹ Levitt's paper focuses on the specific applications of "TREND" to construction.

Much of the following description of "TREND" is taken, with permission, directly from Levitt's paper:

"The TREND model draws upon three independent theories in analyzing the coordination requirements of groups. These theories involve the concepts of:

- Interdependence
- Uncertainty
- Prestige.

¹"Two New Project Coordination Techniques for Construction Managers," Raymond E. Levitt. 1977. Unpublished.

Interdependence

The mechanism required to coordinate two groups in a project depends upon the task-related relationship between them. Three types of relationship exist:

- "pooled" - neither interacts directly with the other,
- "sequential" - one group depends on the other,
- "reciprocal" - each group depends on the other.

Uncertainty

Individuals and groups that must cope with a high degree of uncertainty in their jobs are different from their counterparts who do work involving a low degree of uncertainty. Where large differences exist between the degrees of uncertainty to be coped with by two groups, their organisational orientation will be different. In this case a third party is required to translate and integrate for them. Also, as the degree of uncertainty increases, more complex integrating mechanisms are needed."

In the case study uncertainty in activity duration was unknown. It was assumed that the relative level of uncertainty for all of the activities was approximately the same.

"Prestige

A third important characteristic in the interaction of groups is their relative prestige in the project hierarchy. The authors suggest that where a group with a relatively high level of prestige in the organisation depends heavily (as defined under interdependence) upon a group with a lower level of prestige, conflict is likely to occur.

The analysis now proceeds as follows:

- A precedence diagram is constructed to show relationships between activities in the project.
- Sequential dependence of the group performing a successor activity on the group/s performing preceding activity/ies is inferred from the precedence diagram.
- Estimates of the variability of activity durations are assumed to represent degrees of task uncertainty.
- The relative prestige of groups is inferred from contracts, organisational charts, and background."

Activity precedence is shown in Tables II and III. The actors involved in each activity are listed in Table I. From these tables the number of activities for each actor was determined and listed in Table V. The actors depended on by each actor are listed in Tables VI & VII. A graphic representation of this data is given in Figures 6 and 7.

Chapter III

ACTIVITIES, ACTORS & INTERDEPENDENCIES

In evaluating the coordination problems inherent in the interlacing of design and construction activities in a fast tracked construction project, this study will look at one particular project in great detail. This project will be rearranged hypothetically to depict the design-construction activities of a building being designed and built by conventional methods (ie. lump sum bid by a General Contractor after a completed design).

Construction activity precedences will be shown in tabular form. Critical activities and design-construction overlap will be shown in precedence diagrams. All activity precedences and durations are taken directly from Carlson Corporation's CPM network of the actual case study project. The conventional construction case was then hypothetically extrapolated from this network for the purpose of this study.

DESCRIPTION OF CARLSON CORPORATION

The Carlson Corporation is a design build firm with offices located in Natick, Massachusetts in addition to offices in other areas throughout the United States. Carlson Corporation has a full range of in-house design capabilities and some of the construction trades, including steel erection, masonry, drywall and painting. The company does not typically bid jobs,

but deals with repeat clients and new clients through Carlson's sales office. A project begins in the planning stage with the Owner and the Carlson design team. A design proposal is then prepared in conjunction with a guaranteed maximum price. If this is acceptable to the Owner a contract is awarded to Carlson Corporation.

The contractual relationship between the parties is shown in figure 1.1

DESCRIPTION OF CASE STUDY PROJECT

The building is constructed of structural steel bearing on concrete foundations. The floor is structural concrete with various finishes. Several wall systems are employed: interior, gypsum board on metal studs and masonry walls. Exterior: precast concrete, masonry and metal wall systems.

The roof is built-up on a metal deck resting on steel joists. Stairways are prefabricated steel.

On-site is a drainage, sewer and water system. Sidewalks are concrete and parking lots are bituminous concrete paving. Curbing is precast and patios are cast-in-place.

The building is fully sprinkled, smoke vented, heated and air-conditioned.

The case study project is a 120,000 square foot manufacturing plant located in Pennsylvania. The project start-up (contract award) was in November, 1979 and the expected completion date is February, 1980.

On this project the Carlson Corporation of Natick, Massachusetts is the Structural, Mechanical, Electrical, Soils and Foundation Engineer. Carlson Corporation also handles the Architectural and Interior Decorating services. Due to a wide range in project localities Carlson Corporation normally hires outside surveyors; they have done so in this case.

All of the trades are subcontracted on this project. The Project Manager (PM) and design team are off-site and Carlson's Superintendent is on-site.

The project analyzed consists of 142 activities in the fast track case and 143 activities in the conventional case. These are to be performed by eight designers and twenty-one subcontractors in both cases. In reality there are more than twenty-one subs as the sitework need not be performed by one sub, and various other work items could be further broken down as was in fact done by Carlson Corporation. These items have been combined for simplicity as the design-construct relationships are not affected by this condensation. There are of course inherent coordination problems which have thereby been artificially eliminated, but these do not differ substantially from the fast track to the conventional construction case. Thus consistency is maintained.

Table I lists all of the activities, the actors involved in each activity and the duration of the activity. Tables II and III list the activities which are depended on for each

activity for the fast track and conventional cases respectively. Table IV shows floats associated with each activity.

Table V, VI and VII list all of the actors, the number of activities each actor is involved in and the actors whom they depend on with the frequency of occurrence taken into account.

In the fast track case the design begins with the Project Architectural Definition, Owner and Architect working together. A design proposal is prepared and a Guaranteed Maximum Price is given to the Owner. This is done by a joint effort of the design team and the Project Manager.

The Civil and Structural Engineers then come into the picture. The Civil Engineer prepares working drawings towards the goal of site plan approval by Regulating Agencies. The Structural Engineer designs the structural components of the building and prepares a set of contract drawings which can be put out to bid by fabricators and erectors.

In the interim the Architect prepares preliminary floor plans which are subject to approval by the Owner. The preliminary floor plans are turned over to the Environmental Engineer who obtains environmental approval from the associated Regulating Agencies.

The Architect continues working on the design, preparing finish schedule, details and evaluations while the Mechanical and Electrical Engineer work on the plumbing, HVAC and electrical design.

As soon as a set of drawings for a particular work package

is completed that package is put out for lump sum bid by subcontractors. Thus long lead time items such as steel, glass, masonry, precast, doors, hardware and electrical components can be set into motion before the overall design is complete. See figure 2.

Construction can begin anytime after the sitework contract is awarded and the site plan and environmental approval have been obtained.

In the conventional case a complete set of bid documents is prepared by the Architect and Engineers. A quantity surveyor will give advice on costs and the project will be put out to bid by a General Contractor (GC).

The General Contractor's Project Manager will put the project out to bid by subcontractors and prepare an estimate of the cost of the project. This process will take as long as the longest bid item in the fast track case and an estimated five days for bid and award of contract by the GC. It can of course be argued that it will take longer but it is herein assumed that because of the early stage in the total design subcontractors in the fast track case may actually take longer to prepare a bid than in the conventional case. The difference in time would in any case be negligible when compared to total project length.

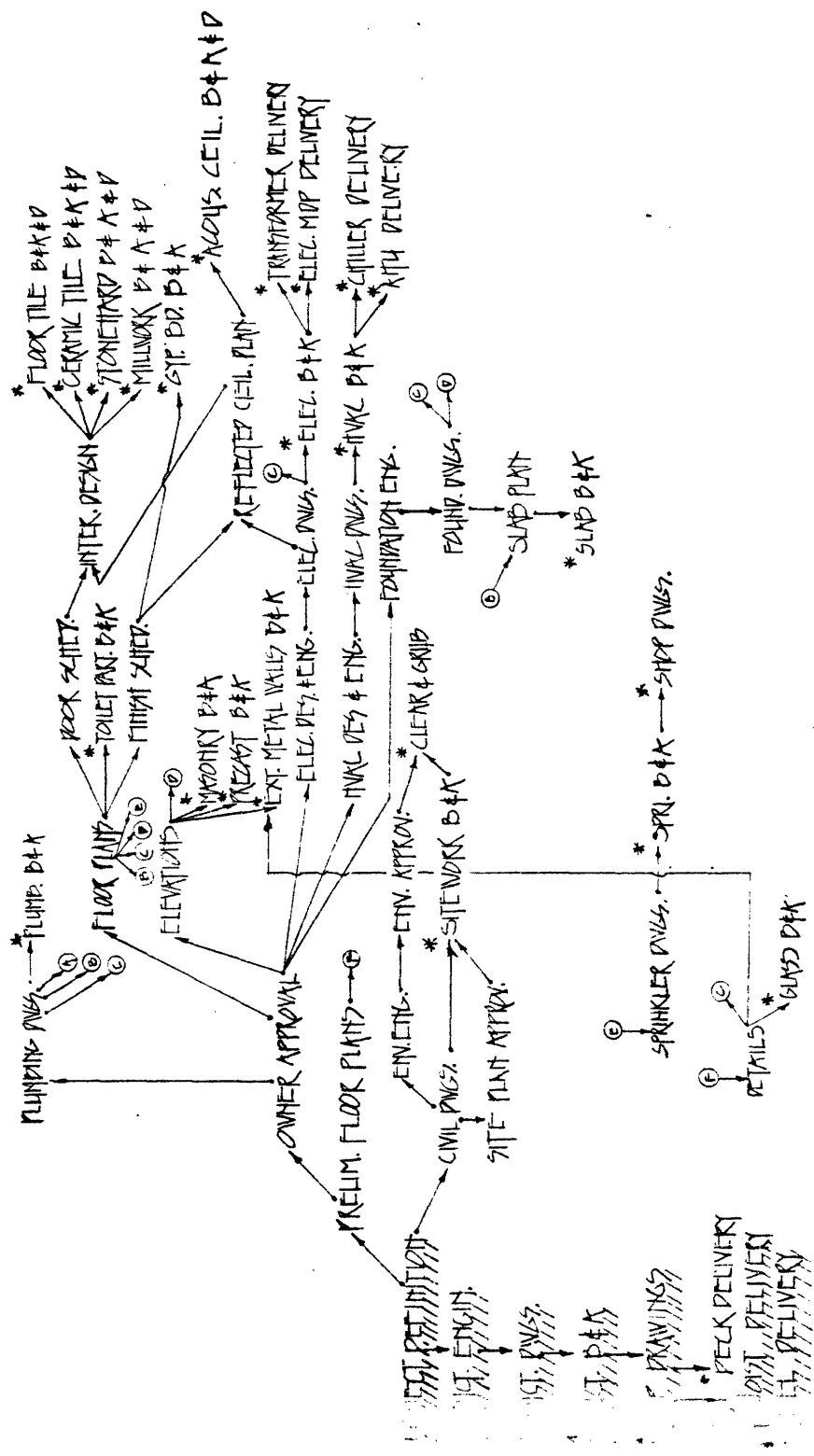
A contract is awarded to the GC, the GC in turn awards contracts to the subcontractor, and construction begins. At this point all plans have been approved by the Owner and any

associated Regulating Agencies, and all building permits have been obtained. See figure 3.

Construction activity precedence and duration is the same in both cases, the difference lying in the interlacing of the design process in the fast track case. Critical paths for both cases are shown in figure 4 and figure 5.

FAST TRACK - DESIGN - CONSTRUCTION PRECEDENCE

FIGURE-2

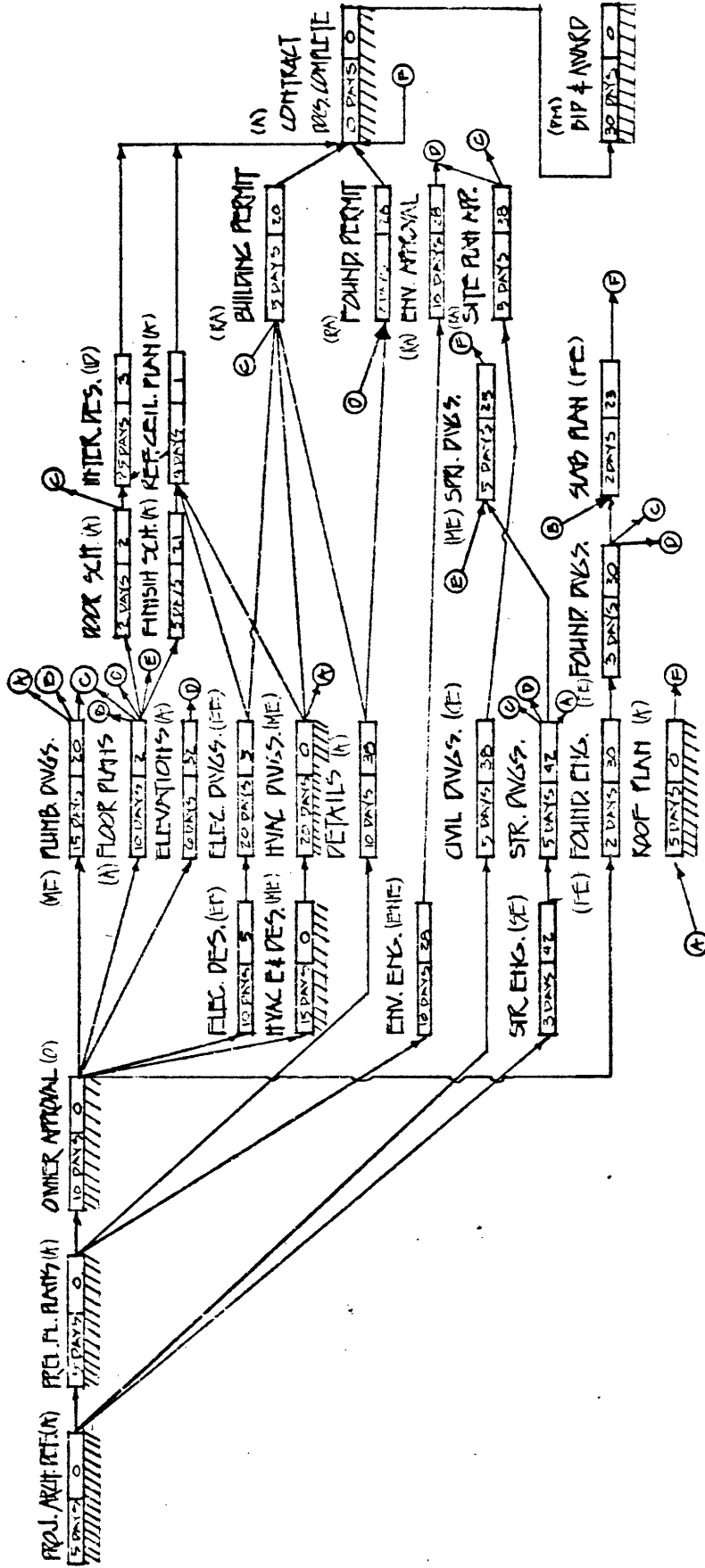


KEY: X → Y X PRECEDES Y
 * CONSTRUCTION ACTIVITIES
 /// CRITICAL

FIGURE - 3

CONVENTIONAL CONSTRUCTION

PRE-CONSTRUCTION ACTIVITIES



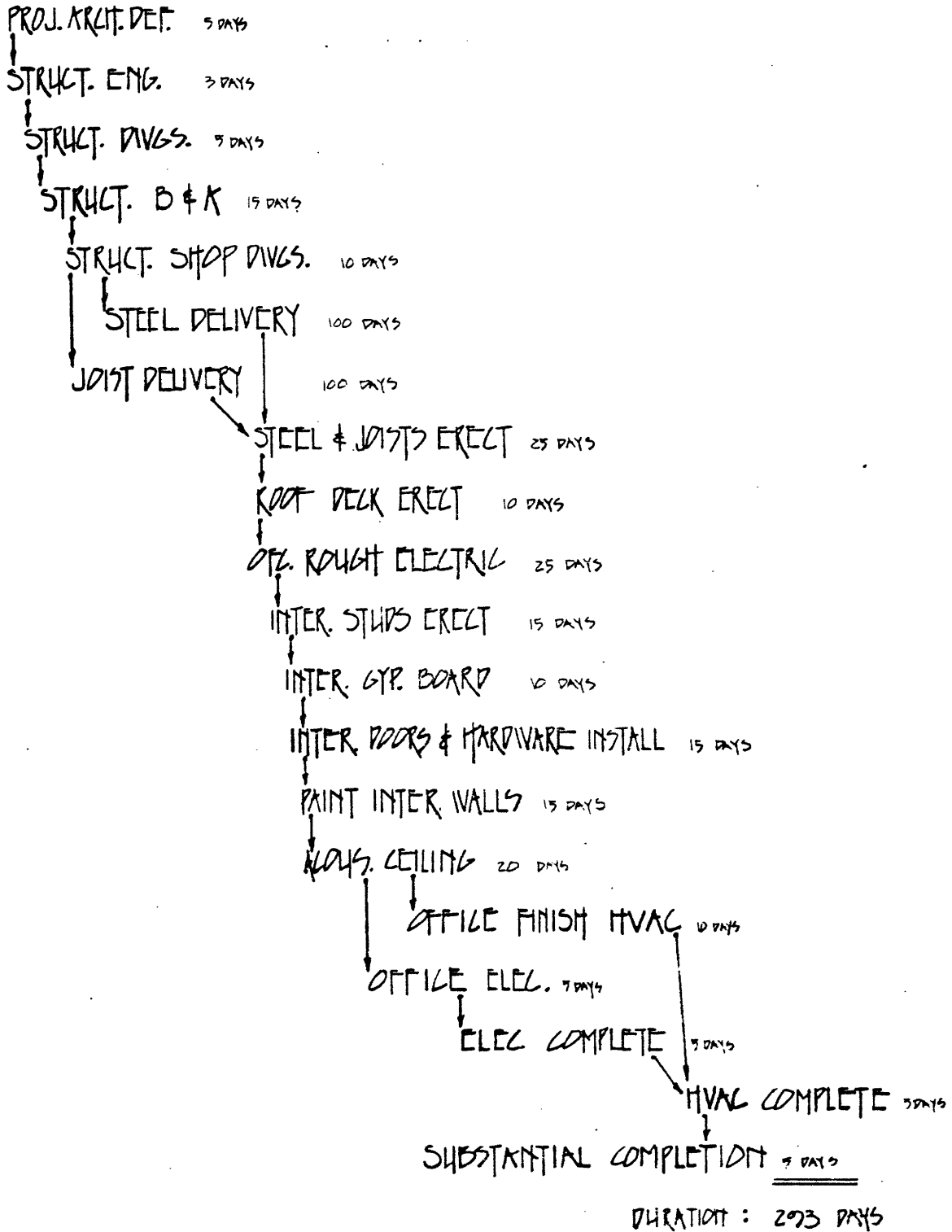
- (PM) - PROJECT MANAGER
- (A) - ARCHITECT
- (SE) - STRUCTURAL ENGINEER (OF OWNER)
- (FE) - FOUNDATION ENGINEER
- (ME) - MECHANICAL ENGINEER
- (IP) - INTERIOR DESIGNER
- (CE) - CIVIL ENGINEER
- (ME) - ENVIRONMENTAL ENGINEER

KEY: DURATION PLAN
 /// CRITICAL

PLANNING → SKETCH DESIGN → DETAIL DESIGN → CONTRACT DRAWINGS → PROJECT PLANNING → BID & AWARD

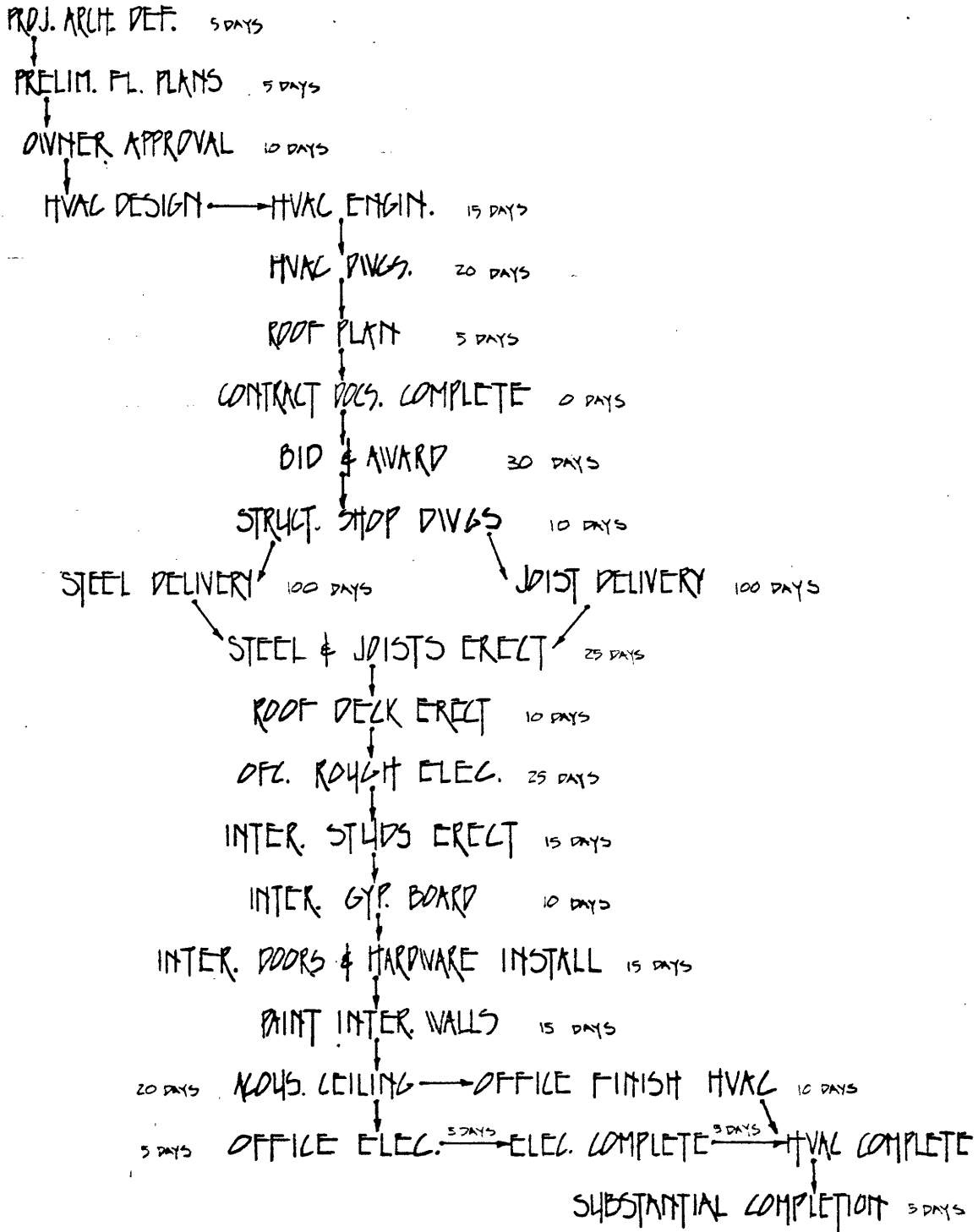
FAST TRACK CRITICAL PATH

FIGURE - 4



CONVENTIONAL CRITICAL PATH

FIGURE - 5



DURATION : 355 DAYS

TABLE I

KEY:

Duration in days

List shows actors involved in each activity

- O - Owner
- A - Architect
- SE - Structural Engineer
- ME - Mechanical Engineer
- EE - Electrical Engineer
- ENE - Environmental Engineer
- CE - Civil Engineer
- FE - Foundation Engineer
- ID - Interior Designer
- RA - Regulating Agencies
- PM - Project Manager
- Sub - Subcontractor
- Supp - Supplier

PEOPLE INVOLVED IN ACTIVITIES

TABLE I

Activity #	Name	Duration	People Involved
1	Project Architectural Definition	5	O,A
2	Structural Engineering	3	SE
3	Structural Working Drawings	5	SE
4	Structural Bidding and Award	15	Fab,Erec, PM
5	Structural Shop Drawings	10	SE, Fab
6	Steel Delivery	100	Fab
7	Joist Delivery	100	Fab
8	Steel & Joists Erect	25	Erec
9	Roof Deck Erect	10	Erec
10	Office Rough Electrical	25	Sub
11	Interior Studs Erect	15	Sub
12	Interior Gypsum Board	10	Sub
13	Interior Doors & Hardware Install	15	Sub
14	Paint Interior Walls	15	Sub
15	Acoustical Ceiling	20	Sub
16	Office Finish HVAC	10	Sub
17	Office Electrical	5	Sub
18	Complete Electrical	5	Sub
19	Substantial Completion	5	-
20	HVAC Completion	5	Sub
21	Civil Working Drawings	5	CE
22	Preliminary Floor Plans	5	A
23	Site Plan Approval	5	CE, RA
24	Environmental Engineering	5	ENE

TABLE I Contd.

Activity #	Name	Duration	People Involved
25	Owner Floor Plan Approval	10	O
26	Details	10	A
27	Environmental Approval	10	RA
28	Glass Bidding & Award	15	PM, Manuf, Sub
29	Glass Delivery	60	Manuf
30	Floor Plans	10	A
31	Elevations	5	A
32	Electrical Design	10	EE
33	HVAC Design	5	ME
34	Plumbing Working Drawings	15	ME
35	Precast Concrete B&A	15	PM, Supp, Sub
36	Precast Delivery	45	Supp
37	Masonry B&A	15	PM, Supp, Sub
38	HVAC Engineering	10	ME
39	HVAC Working Drawings	20	ME
40	Finish Schedule	5	A
41	Door Schedule	2	A
42	Electrical Engineering	10	EE
43	Electrical Working Drawings	20	EE
44	Exterior Doors & Hardware B&A	15	PM, Supp, Sub
45	Exterior Doors & Hardware Del.	44	Supp
46	Interior Doors & Hardware B&A	15	PM, Supp, Sub
47	Interior Doors & Hardware Del.	50	Supp
48	Plumbing B&A	25	PM, Sub
49	Reflected Ceiling Plan	4	A

TABLE I Contd.

Activity #	Name	Duration	People Involved
50	Electrical B&A	25	PM, Supp, Sub
51	Acoustical Ceiling B&A&D	30	PM, Supp, Sub
52	Interior Design	25	ID
53	Electrical MDP Delivery	120	Supp
54	Floor Tiles B&A&D	50	PM, Supp, Sub
55	Ceramic Tile B&A&D	50	PM, Supp, Sub
56	Stonehard B&A&D	60	PM, Manuf, Sub
57	Millwork B&A	15	PM, Supp, Sub
58	Millwork Delivery	30	Supp
59	Transformer Delivery	120	Supp
60	Office Rough Plumbing	25	Sub
61	Plumbing Fixtures Install	15	Sub
62	Underslab Fine Grade	2	Sub
63	Exterior Doors & Hard. Install	5	Sub
64	Millwork Install	5	Sub
65	Underslab Electric	15	Sub
66	Ceramic Tile Install	10	Sub
67	Interior Finish Painting	10	Sub
68	Underslab Plumbing	30	Sub
69	Stonehard Install	25	Sub
70	Floor Tile Install	15	Sub
71	Transformer Install	15	Sub
72	Building Gravel	5	Sub
73	Plant Plumbing	75	Sub
74	Air Handler Delivery	86	Manuf

TABLE I Contd.

Activity #	Name	Duration	People Involved
75	Paint Exterior Walls	10	Sub
76	Gyp Bd. Systems B&A	15	PM,Manuf, Sub
77	Toilet Partitions B&A	35	PM,Manuf, Sub
78	Electrical MDP Install	25	Sub
79	Toilet Partitions Install	5	Sub
80	Brick Delivery	60	Supp
81	Masonry Exterior Walls	10	Sub
82	HVAC B&A	25	PM,Sub
83	Chiller Delivery	90	Manuf
84	Relocate Oil Tank	5	Sub
85	Exterior Metal Wall Erect	50	Sub
86	Air Handlers Install	60	Sub
87	Slab On Grade Place & Finish	15	Sub
88	Exterior Metal Walls B&A	15	PM,Sub
89	Exterior Metal Walls Del.	60	Manuf
90	Outside Light Foundations	5	Sub
91	Patios	5	Sub
92	Precast Erection	8	Sub
93	Paint Plant	25	Sub
94	Masonry Interior Walls	35	Sub
95	Site B&A	15	PM,Sub
96	Foundation Excavate & Backfill	2	Sub
97	Curb Set In Place	10	Sub
98	Glass & Glazing	15	Sub
99	Slab Placement B&A	15	PM,Sub

TABLE I Contd.

Activity #	Name	Duration	People Involved
100	Foundation Engineering	2	FE
101	Slab Placement Plan	2	FE
102	Building Permit	5	A, RA
103	Foundation Working Drawings	3	FE
104	Foundation Permit	5	RA
105	Smoke Vent B&A&D	40	PM, Sub, Manuf
106	Roof Plan	5	A
107	Roofing B&A	15	PM, Sub
108	Sprinkler Bid Documents	5	ME
109	Sprinkler B&A	15	PM, Sub
110	Sprinkler Shop Drawings	25	ME, Sub
111	Clear & Grub	2	Sub
112	Strip Loam	5	Sub
113	Earthwork Cut	5	Sub
114	Fill Spread & Compact	20	Sub
115	Building Foundations	26	Sub
116	Waterproofing	5	Sub
117	Drainage System	10	Sub
118	Sewer System	5	Sub
119	Exterior Water System	15	Sub
120	Drainage Structures	2	Sub
121	Site Gravel Spread And Compact	10	Sub
122	Sidewalks	10	Sub
123	Railroad Track	20	Sub
124	Site Fine Grade	2	Sub

TABLE I Contd.

Activity #	Name	Duration	People Involved
125	Bituminous Concrete Paving	10	Sub
126	Misc. Iron Erection	10	Sub
127	Office Rough HVAC	30	Sub
128	Plant HVAC	90	Sub
129	Plant Electrical	60	Sub
130	Smoke Vents	2	Sub
131	Office Rough Sprinkler	5	Sub
132	Plant Sprinkler	30	Sub
133	Compressed Air Piping	20	Sub
134	Loam & Seed	10	Sub
135	Outside Light Poles	5	Sub
136	Plantings	25	Sub
137	Roof Drains & Piping	10	Sub
138	Roofing	20	Sub
139	Chiller Install	45	Sub
140	Office Finish Sprinkler	5	Sub
141	Plumbing Completion	2	Sub
142	Deck Delivery	100	Manuf

TABLES II & III

KEY: Duration in days

*critical activity

Activity on left depends on activity on right.

Activity on right given by activity number.

EAST TRACK ACTIVITY PRECEDENCES

TABLE II

Activity #	Name	Duration	Depends on
1	Project Architectural Definition	5	0
2	Structural Engineering	3	*1
3	Structural Working Drawings	5	*2
4	Structural Bidding and Award	15	*3
5	Structural Shop Drawings	10	*4
6	Steel Delivery	100	*5
7	Joist Delivery	100	*6
8	Steel & Joists Erect	25	*7
9	Roof Deck Erect	10	*8
10	Office Rough Electrical	25	129
11	Interior Studs Erect	15	*10
12	Interior Gypsum Board	10	*11
13	Interior Doors & Hardware Install	15	*12
14	Paint Interior Walls	15	*13
15	Acoustical Ceiling	20	*14
16	Office Finish HVAC	10	127
17	Office Electrical	5	*15, *10
18	Complete Electrical	5	*17, 129
19	Substantial Completion	5	*18
20	HVAC Completion	5	*19
21	Civil Working Drawings	5	*1
22	Preliminary Floor Plans	5	*1
23	Site Plan Approval	5	21
24	Environmental Engineering	5	22

TABLE II Contd.

Activity #	Name	Duration	Depends on
25	Owner Floor Plan Approval	10	22
26	Details	10	22
27	Environmental Approval	10	24
28	Glass Bidding & Award	15	26
29	Glass Delivery	60	28
30	Floor Plans	10	25
31	Elevations	5	25
32	Electrical Design	10	25
33	HAVC Design	5	25
34	Plumbing Working Drawings	15	25
35	Precast Concrete B&A	15	31
36	Precast Delivery	45	35
37	Masonry B&A	15	31
38	HVAC Engineering	10	26
39	HVAC Working Drawings	20	38
40	Finish Schedule	5	30
41	Door Schedule	2	30
42	Electrical Engineering	10	32
43	Electrical Working Drawings	20	42
44	Exterior Doors & Hardware B&A	15	41
45	Exterior Doors & Hardware Del.	44	44
46	Interior Doors & Hardware B&A	15	41
47	Interior Doors & Hardware Del.	50	46
48	Plumbing B&A	25	34
49	Reflected Ceiling Plan	4	43, 40, 39

TABLE II Contd.

Activity #	Name	Duration	Depends on
50	Electrical B&A	25	43
51	Acoustical Ceiling B&A&D	30	49
52	Interior Design	25	49, 41
53	Electrical MDP Delivery	120	50
54	Floor Tiles B&A&D	50	52
55	Ceramic Tile B&A&D	50	52
56	Stonehard B&A&D	60	52
57	Millwork B&A	15	52
58	Millwork Delivery	30	57
59	Transformer Delivery	120	50
60	Office Rough Plumbing	25	68, 9
61	Plumbing Fixtures Install	15	60, 66
62	Underslab Fine Grade	2	72
63	Exterior Doors & Hard. Install	5	72
64	Millwork Install	5	58, 14
65	Underslab Electric	15	115, 50
66	Ceramic Tile Install	10	55, 14
67	Interior Finish Painting	10	15, 52
68	Underslab Plumbing	30	50, 115
69	Stonehard Install	25	56, 93
70	Floor Tile Install	15	54, 14
71	Transformer Install	15	59, 78
72	Building Gravel	5	68, 65, 115
73	Plant Plumbing	75	68, 9
74	Air Handler Delivery	86	82

TABLE II Contd.

Activity #	Name	Duration	Depends on
75	Paint Exterior Walls	10	63, 81, 92
76	Gyp Bd. Systems B&A	15	40
77	Toilet Partitions B&A	35	30
78	Electrical MDP Install	25	53, 138
79	Toilet Partitions Install	5	60, 77
80	Brick Delivery	60	37
81	Masonry Exterior Walls	10	80
82	HVAC B&A	25	39
83	Chiller Delivery	90	82
84	Relocate Oil Tank	5	82
85	Exterior Metal Wall Erect	50	89
86	Air Handlers Install	60	81
87	Slab On Grade Place & Finish	15	99, 138, 62
88	Exterior Metal Walls B&A	15	26, 31
89	Exterior Metal Walls Del.	60	88
90	Outside Light Foundations	5	50, 114
91	Patios	5	121
92	Precast Erection	8	*8, 36
93	Paint Plant	25	94, 99, 40
94	Masonry Interior Walls	35	115, 37
95	Site B&A	15	21, 23
96	Foundation Excavate & Backfill	2	104, 113, 103
97	Curb Set In Place	10	121
98	Glass & Glazing	15	92, 29, 81
99	Slab Placement B&A	15	101

TABLE II Contd.

Activity #	Name	Duration	Depends on
100	Foundation Engineering	2	*2, 25
101	Slab Placement Plan	2	30, 34, 103
102	Building Permit	5	*3, 103, 23, 26, 27, 30, 34, 39, 41, 43
103	Foundation Working Drawings	3	100
104	Foundation Permit	5	*3, 103, 23, 26, 27, 30, 31
105	Smoke Vent B&A&D	40	*3
106	Roof Plan	5	34, 40,*3
107	Roofing B&A	15	106
108	Sprinkler Bid Documents	5	*3, 104, 30
109	Sprinkler B&A	15	108
110	Sprinkler Shop Drawings	25	109
111	Clear & Grub	2	95, 23, 27
112	Strip Loam	5	111
113	Earthwork Cut	5	112
114	Fill Spread & Compact	20	113
115	Building Foundations	26	96, 104
116	Waterproofing	5	115
117	Drainage System	10	114
118	Sewer System	5	114
119	Exterior Water System	15	114, 110
120	Drainage Structures	2	117
121	Site Gravel Spread and Compact	10	120, 118, 90, 119

TABLE II Contd.

Activity #	Name	Duration	Depends on
122	Sidewalks	10	121
123	Railroad Track	20	121
124	Site Fine Grade	2	122, 91, 116, 97, 84
125	Bituminous Concrete Paving	10	123, 124
126	Misc. Iron Erection	10	*8
127	Office Rough HVAC	30	*9
128	Plant HVAC	90	*9
129	Plant Electrical	60	*9
130	Smoke Vents	2	*9, 105
131	Office Rough Sprinkler	5	105,*9
132	Plant Sprinkler	30	*9, 110
133	Compressed Air Piping	20	*9
134	Loam & Seed	10	125
135	Outside Light Poles	5	125
136	Plantings	25	125
137	Roof Drains & Piping	10	*9, 68, 120
138	Roofing	20	126,*9, 107, 130 137, 92, 85, 81
139	Chiller Install	45	138, 83
140	Office Finish Sprinkler	5	131, 15
141	Plumbing Completion	2	18, 133, 73, 61
142	Deck Delivery	100	*5

CONVENTIONAL ACTIVITY PRECEDENCES

TABLE III

Activity #	Name	Duration	Depends on
0	Project Start-up	1	-
1	Project Architectural Definition	5	-
2	Structural Engineering	3	*1
3	Structural Working Drawings	5	2
4	Structural Bid and Award	15	143
5	Structural Shop Drawings	10	*4
6	Steel Delivery	100	*5
7	Joist Delivery	100	*5
8	Steel & Joists Erect	25	*7
9	Roof Deck Erect	10	*8
10	Office Rough Electrical	25	129
11	Interior Studs Erect	15	*10
12	Interior Gypsum Board	10	*11
13	Interior Doors & Hardware Install	15	*12
14	Paint Interior Walls	15	*13
15	Acoustical Ceiling	20	*14
16	Office Finish HVAC	10	127
17	Office Electrical	5	*15,*10
18	Complete Electrical	5	*17, 129
19	Substantial Completion	5	*18
20	HVAC Completion	5	*19
21	Civil Working Drawings	5	*1
22	Preliminary Floor Plans	5	*1

TABLE III Contd.

Activity #	Name	Duration	Depends on
23	Site Plan Approval	5	21
24	Environmental Engineering	5	*22
25	Owner Floor Plan Approval	10	*22
26	Details	10	*22
27	Environmental Approval	10	24
28	Glass Bid & Award	15	143
29	Glass Delivery	60	28
30	Floor Plans	10	*25
31	Elevations	5	*25
32	Electrical Design	10	*25
33	HVAC Design	5	*25
34	Plumbing Working Drawings	15	*25
35	Precast Concrete B&A	15	143
36	Precast Delivery	45	35
37	Masonry B&A	15	145
38	HVAC Engineering	10	*33
39	HVAC Working Drawings	20	*38
40	Finish Schedule	5	30
41	Door Schedule	2	30
42	Electrical Engineering	10	32
43	Electrical Working Drawings	20	42
44	Exterior Doors & Hardware B&A	15	143
45	Exterior Doors & Hardware Del.	44	44
46	Interior Doors & Hardware B&A	15	143
47	Interior Doors & Hardware Del.	50	*46

TABLE III Contd.

Activity #	Name	Duration	Depends on
48	Plumbing B&A	25	143
49	Reflected Ceiling Plan	4	40, 39, 43
50	Electrical B&A	25	143
51	Acoustical Ceiling B&A&D	30	143
52	Interior Design	25	41
53	Electrical MDP Delivery	120	*50
54	Floor Tiles B&A&D	50	143
55	Ceramic Tile B&A&D	50	143
56	Stonehard B&A&D	60	143
57	Millwork B&A	15	143
58	Millwork Delivery	30	57
59	Transformer Delivery	120	*50
60	Office Rough Plumbing	25	68,*9
61	Plumbing Fixtures Install	15	60, 66
62	Underslab Fine Grade	2	72
63	Exterior Doors & Hard. Install	5	72
64	Millwork Install	5	58, 14
65	Underslab Electric	15	115,*50
66	Ceramic Tile Install	10	55, 14
67	Interior Finish Painting	10	15, 52
68	Underslab Plumbing	30	*50, 115
69	Stonehard Install	25	56, 93
70	Floor Tile Install	15	14, 54
71	Transformer Install	15	59, 78
72	Building Gravel	5	65, 68, 115

TABLE III Dontd.

Activity #	Name	Duration	Depends on
73	Plant Plumbing	75	*9, 68
74	Air Handler Delivery	86	82
75	Paint Exterior Walls	10	63, 81, 92
76	Gyp Bd. Systems B&A	15	143
77	Toilet Partitions B&A	35	143
78	Electrical MDP Install	25	53, 138
79	Toilet Partitions Install	5	60, 77
80	Brick Delivery	60	37
81	Masonry Exterior Walls	10	80
82	HVAC B&A	25	143
83	Chiller Delivery	90	82
84	Relocate Oil Tank	5	82
85	Exterior Metal Wall Erect	50	89
86	Air Handlers Install	60	81
87	Slab On Grade Place & Finish	15	99, 62, 138
88	Exterior Metal Walls B&A	15	143
89	Exterior Metal Walls Del.	60	88
90	Outside Light Foundations	5	*50, 114
91	Patios	5	121
92	Precast Erection	8	*8, 36
93	Paint Plant	25	40, 94, 99
94	Masonry Interior Walls	35	115, 37
95	Site B&A	15	143
96	Foundation Excavate & Backfill	2	103, 104, 113

TABLE III Contd.

Activity #	Name	Duration	Depends on
97	Curb Set In Place	10	121
98	Glass & Glazing	15	29, 81, 92
99	Slab Placement B&A	15	143
100	Foundation Engineering	2	*25
101	Slab Placement Plan	2	30, 34, 103
102	Building Permit	5	26, *39, 43, 34, 30, *3, 103, 23, 41
103	Foundation Working Drawings	3	100
104	Foundation Permit	5	26, 30, 31, *3, 103, 27, 23
105	Smoke Vent B&A&D	40	143
106	Roof Plan	5	34, *39, *3
107	Roofing B&A	15	143
108	Sprinkler Bid Documents	5	*3, 30
109	Sprinkler B&A	15	143
110	Sprinkler Shop Drawings	25	109
111	Clear & Grub	2	23, 27, 95
112	Strip Loam	5	111
113	Earthwork Cut	5	112
114	Fill Spread & Compact	20	113
115	Building Foundations	26	96
116	Waterproofing	5	115
117	Drainage System	10	114

TABLE III Contd.

Activity #	Name	Duration	Depends on
118	Sewer System	5	114
119	Exterior Water System	15	110, 114
120	Drainage Structures	2	117
121	Site Gravel Spread and Compact	10	90, 118, 119, 120
122	Sidewalks	10	121
123	Railroad Track	20	121
124	Site Fine Grade	2	84, 91, 97, 116, 122
125	Bituminous Concrete Paving	10	123, 124
126	Misc. Iron Erection	10	*8
127	Office Rough HVAC	30	*9
128	Plant HVAC	90	*9
129	Plant Electrical	60	*9
130	Smoke Vents	2	*9, 105
131	Office Rough Sprinkler	5	*9, 105
132	Plant Sprinkler	30	*9, 110
133	Compressed Air Piping	20	*9
134	Loam & Seed	10	125
135	Outside Light Poles	5	125
136	Plantings	25	125
137	Roof Drains & Piping	10	*9, 68, 120
138	Roofing	20	*9, 81, 85, 92, 107, 126, 130, 137
139	Chiller Install	45	83, 138

TABLE III Contd.

Activity #	Name	Duration	Depends on
140	Office Finish Sprinkler	5	*15, 131
141	Plumbing Completion	2	*18, 61, 73, 133
142	Deck Delivery	100	*5
143	B&A By General Contractor	5	144
144	Contract Documents Complete	0	49, 52, 101, 102, 104, 106, *108, *82

TABLE IV

KEY:

Duration in days

Activity float given in days for both
fast track and conventional case.

ACTIVITY DURATION & FLOAT

TABLE IV

Activity #	Name	Duration	FLOAT	
			Fast Track	Conventional
1	Project Architectural Definition	5	0	0
2	Structural Engineering	3	0	42
3	Structural Working Drawings	5	0	0
4	Structural Bid and Awards	15	0	10
5	Structural Shop Drawings	10	0	0
6	Steel Delivery	100	0	0
7	Joist Delivery	100	0	0
8	Steel & Joists Erect	25	0	0
9	Roof Deck Erect	10	0	0
10	Office Rough Electrical	25	0	0
11	Interior Studs Erect	15	0	0
12	Interior Gypsum Board	10	0	0
13	Interior Doors & Hardware Install	15	0	0
14	Paint Interior Walls	15	0	0
15	Acoustical Ceiling	20	0	0
16	Office Finish HVAC	10	0	0
17	Office Electrical	5	0	0
18	Complete Electrical	5	0	0
19	Substantial Completion	5	0	0
20	HVAC Completion	5	0	0
21	Civil Working Drawings	5	69	38
22	Preliminary Floor Plans	5	38	0
23	Site Plan Approval	5	84	38

TABLE IV. Contd.

Activity #	Name	Duration	FLOAT	
			Fast Track	Conventional
24	Environmental Engineering	5	69	28
25	Owner Floor Plan Approval	10	36	0
26	Details	10	43	38
27	Environmental Approval	10	74	28
28	Glass Bidding & Award	15	138	10
29	Glass Delivery	60	138	138
30	Floor Plans	10	79	2
31	Elevations	5	38	32
32	Electrical Design	10	68	5
33	HVAC Design	5	78	0
34	Plumbing Working Drawings	15	98	20
35	Precast Concrete B&A	15	105	10
36	Precast Delivery	45	105	105
37	Masonry B&A	15	38	10
38	HVAC Engineering	10	78	0
39	HVAC Working Drawings	20	78	0
40	Finish Schedule	5	74	21
41	Door Schedule	2	101	2
42	Electrical Engineering	10	68	5
43	Electrical Working Drawings	20	68	5
44	Exterior Doors & Hardware B&A	15	211	10
45	Exterior Doors & Hardware Del.	44	211	211
46	Interior Doors & Hardware B&A	15	161	0
47	Interior Doors & Hardware Del.	50	161	161
48	Plumbing B&A	25	98	0

TABLE IV Contd.

Activity #	Name	Duration	FLOAT	
			Fast Track	Conven- tional
49	Reflected Ceiling Plan	4	149	1
50	Electrical B&A	25	68	0
51	Acoustical Ceiling B&A&D	30	194	194
52	Interior Design	25	149	3
53	Electrical MDP Delivery	120	68	68
54	Floor Tiles B&A&D	50	169	169
55	Ceramic Tile B&A&D	50	167	167
56	Stonehard B&A&D	60	149	149
57	Millwork B&A	15	184	10
58	Millwork Delivery	30	184	184
59	Transformer Delivery	120	93	93
60	Office Rough Plumbing	25	35	35
61	Plumbing Fixtures Install	15	8	8
62	Underslab Fine Grade	2	57	57
63	Exterior Doors & Hard. Install	5	148	148
64	Millwork Install	5	30	30
65	Underslab Electric	15	34	34
66	Ceramic Tile Install	10	6	6
67	Interior Finish Painting	10	5	5
68	Underslab Plumbing	30	34	34
69	Stonehard Install	25	70	70
70	Floor Tile Install	15	20	20
71	Transformer Install	15	68	68
72	Building Gravel	5	57	57
73	Plant Plumbing	75	73	73

TABLE IV Contd.

Activity #	Name	Duration	FLOAT	
			Fast Track	Conven- tional
74	Air Handler Delivery	86	88	88
75	Paint Exterior Walls	10	142	142
76	Gyp Bd. Systems B&A	15	183	10
77	Toilet Partitions B&A	35	253	253
78	Electrical MDP Install	25	68	68
79	Toilet Partitions Install	5	20	20
80	Brick Delivery	60	38	38
81	Masonry Exterior Walls	10	38	38
82	HVAC B&A	25	88	0
83	Chiller Delivery	90	103	103
84	Relocate Oil Tank	5	201	201
85	Exterior Metal Wall Erect	50	38	38
86	Air Handlers Install	60	55	55
87	Slab On Grade Place & Finish	15	15	15
88	Exterior Metal Walls B&A	15	48	48
89	Exterior Metal Walls Del.	60	48	48
90	Outside Light Foundations	5	136	136
91	Patios	5	139	139
92	Precast Erection	8	27	27
93	Paint Plant	25	70	70
94	Masonry Interior Walls	35	89	89
95	Site B&A	15	69	10
96	Foundation Excavate & Backfill	2	14	14
97	Curb Set In Place	10	134	134
98	Glass & Glazing	15	62	62

TABLE IV Contd.

Activity #	Name	Duration	FLOAT	
			Fast Track	Conven- tional
99	Slab Placement B&A	15	166	10
100	Foundation Engineering	2	84	30
101	Slab Placement Plan	2	168	23
102	Building Permit	5	73	20
103	Foundation Working Drawings	3	84	30
104	Foundation Permit	5	79	28
105	Smoke Vent B&A&D	40	148	148
106	Roof Plan	5	118	20
107	Roofing B&A	15	168	25
108	Sprinkler Bid Documents	5	168	0
109	Sprinkler B&A	15	168	10
110	Sprinkler Shop Drawings	25	168	168
111	Clear & Grub	2	14	14
112	Strip Loam	5	14	14
113	Earthwork Cut	5	14	14
114	Fill Spread & Compact	20	59	59
115	Building Foundations	26	14	14
116	Waterproofing	5	157	157
117	Drainage System	10	59	59
118	Sewer System	5	136	136
119	Exterior Water System	15	126	126
120	Drainage Structures	2	59	59
121	Site Gravel Spread and Compact	10	126	126
122	Sidewalks	10	134	134
123	Railroad Track	20	125	125

TABLE IV Contd.

Activity #	Name	Duration	FLOAT	
			Fast Track	Conven- tional
124	Site Fine Grade	2	134	134
125	Bituminous Concrete Paving	10	125	125
126	Misc. Iron Erection	10	25	25
127	Office Rough HVAC	30	90	90
128	Plant HVAC	90	55	55
129	Plant Electrical	60	80	80
130	Smoke Vents	2	23	23
131	Office Rough Sprinkler	5	140	140
132	Plant Sprinkler	30	120	120
133	Compressed Air Piping	20	128	128
134	Loam & Seed	10	141	141
135	Outside Light Poles	5	146	146
136	Plantings	25	126	126
137	Roof Drains & Piping	10	15	15
138	Roofing	20	15	15
139	Chiller Install	45	70	70
140	Office Finish Sprinkler	5	10	10
141	Plumbing Completion	2	3	3
142	Deck Delivery	100	25	25

TABLE V

KEY:

Table lists the number of activities each actor is involved in and how many of these activities are critical for both the fast track and conventional case.

NUMBER OF ACTIVITIES PERFORMED
BY ACTORS

TABLE V

Subcontractors	FAST TRACK		CONVENTIONAL	
	# of Activities	# Critical	# of Activities	# Critical
Mechanical	9	1	9	1
Electrical	8	3	8	4
Plumbing	7	0	7	1
Erection	6	2	6	2
Sprinkler	4	0	4	0
Precast Erector	2	0	2	0
Glazing	2	0	2	0
Millwork	2	0	2	0
Flooring	4	0	4	0
Doors & Hardware	4	1	4	1
Masonry	3	0	3	0
Drywall & Partitions	3	0	3	0
Formwork	2	0	2	0
Finish Concrete	4	0	4	0
Waterproofing	1	0	1	0
Roofing	2	0	2	0
Sitework	20	0	20	0
Toilet Partitions	2	0	2	0
Ceiling	2	1	2	1
Painting	4	0	4	0
Railroad	1	0	1	0
<u>Designers</u>				
Architect	12	1	12	3

TABLE V (CONTD.)

	FAST TRACK		CONVENTIONAL	
	# of Activities	# Critical	# of Activities	# Critical
Structural Engineer	3	3	3	1
Mechanical Engineer	6	0	6	3
Electrical Engineer	3	0	3	0
Civil Engineer	2	0	2	0
Foundation Engineer	4	0	4	0
Environmental Engineer	1	0	1	0
Interior Designer	1	0	1	0
Project Manager	22	1	22	4
Owner	3	1	3	2
Regulating Agencies	4	0	4	0
<u>Suppliers</u>				
Fabricator, Steel	4	4	4	4
Mechanical Manufacturer	4	0	4	1
Electrical	3	0	3	1
Masonry	2	0	2	0
Precast Concrete	2	0	2	0
Glazing	2	0	2	0
Millwork	2	0	2	0
Flooring	3	0	3	0
Toilet Partitions	1	0	1	0
Ceiling	1	0	1	0
Doors & Hardware	4	0	4	0
Miscellaneous Iron	1	0	1	0
Metal Walls	2	0	2	0

TABLES VI & VII

KEY:

Tables list the actors which each actor depends on. Derived from tables I, II, & III. Frequency of dependency is to the left of the actor.

FAST TRACK: ACTORS DEPENDENT ON

TABLE VI

ACTOR Subcontractors	Depends on			
	Management	Designers	Subcontractors	Suppliers
Mechanical	1) PM	1) ME 1) SE	1) *Ceil 1) Spri 2) Roof 2) Erect	2) Mech
Electrical	1) PM	1) EE	1) Formwork 1) Roof 1) Erect	2) Elect
Plumbing	1) PM	1) ME	4) Erector 1) Floor 1) Formwork	
Erection	1) *PM	1) A 1) *SE	1) Formwork 1) Mason	1) Metal Wall 2) *Fabri- cator
Sprinkler	1) PM	1) ME	2) Erector 1) Ceiling sub	
Precast Erector	1) PM	1) A	1) Erector	1) Precast
Glazing	1) PM	1) A	1) Mason 1) Precast	1) Glazing
Millwork	1) PM	1) FD	1) Paint	1) Mill- work
Flooring	3) PM	3) ID	3) Paint	3) Floor- ing
Doors & Hardware	2) PM	1) A	1) Erector 1) Gyp 1) Mason	2) Door & Hard
Masonry	1) PM	1) A	1) Formwork	2) Masonry
Drywall & Partitions	1) PM	1) A	1) Glazing 1) Roof 1) Finish Conc 1) *Elec 1) Mech 1) Plumb	1) Drywall

ACTOR	DEPENDS ON			
	Management	Designers	Subcontractors	Suppliers
Formwork	1) RM 1) PM		2) Site 1) Elec	
Finish Concrete	1) PM	1) FE	3) Site 1) Finish Conc	
Waterproofing	1) PM		1) Formwork	
Roofing	1) PM	1) A	1) Mason 1) Mechanical 3) *Erector 1) Plumb 1) Precast	
Sitework	4) RA 1) PM	1) FE 2) Surveyor 2) CE 1) ENE	1) Waterproof 1) Fin Conc 1) Rail 1) Mech 1) Elec 2) Formwork 1) Spri	
Toilet Partitions	1) PM	1) A	1) Floor	1) Partit
Ceiling	1) PM	1) A	1) *Paint	1) Ceil
Painting	1) PM	1) A 1) FD	1) Precast 1) Roof 2) *Door 1) Dwl 1) Ceil 2) Mason	
Railroad	1) PM		1) Site	
Designers	Management	Designers	Suppliers	
Architect	3) 0	1) CE 1) Surveyor 2) EE 5) ME 2) SE 1) FE		
Structural Engineer		1) *A	1) *Fabricator	

TABLE VI Contd.

ACTOR	DEPENDS ON		
	Management	Designers	Suppliers
Mechanical Engineer	2) O	1) SE 1) A	1) Spri
Electrical Engineer	1) O		
Civil Engineer		1) A	
Foundation Engineer		2) A 1) ME 1) SE	
Environmental Engineer		1) A	
Interior Designer		2) A	
Project Manager		1) CE 1) FE 1) RA 1) Surveyor 2) *SE 9) A 4) ME 1) EE 4) ID	
Owner		1) A	
Surveyor		1) CE	
Regulating Agencies		1) ME 1) EE 2) SE 1) CE 1) ENE 2) FE 4) K	
<u>Suppliers</u>			
Fabricator, Steel	1) *PM	1) *SE	
Mechanical Manufacturer	1) PM	1) ME	
Electrical	1) PM	1) EE	

TABLE VI Contd.

ACTOR	DEFENDS ON Management - Designers	
Masonry	1) PM	1) A
Precast Concrete	1) PM	1) A
Glazing	1) PM	1) A
Millwork	1) PM	1) ID
Flooring	3) PM	3) ID
Toilet Partitions	1) PM	1) A
Ceiling	1) PM	1) A
Doors & Hardware	2) PM	2) A
Miscellaneous Iron	1) PM	
Metal Walls	1) PM	1) A

CONVENTIONAL : ACTORS DEPENDENT ON

TABLE VII

ACTOR	DEPENDS ON		
	Subcontractors	Management	Subcontractors Suppliers
Mechanical	1) PM	1) *Ceil 1) Spri 2) Roof 2) Erect	2) Mech
Electrical	1) PM	1) Formwork 1) Roof 1) Erect	2) Electrical
Plumbing	1) PM	4) Erect 1) Floor 1) Formwork	
Erection	1) PM	1) Formwork 1) Mason	1) Metal wall 2) **Fabricator
Sprinkler	1) PM	2) Erect 1) Ceiling	
Precast Erector	1) PM	1) Erect	1) Precast
Glazing	1) PM	1) Mason 1) Precast Erect	1) Glazing
Millwork	1) PM	1) Paint	1) Millwork
Flooring	3) PM	3) Paint	3) Flooring
Doors & Hardware	2) PM	1) Erect 1) Gyp bd 1) Mason	2) Doors & Hardware
Masonry	1) PM	1) Formwork	2) Masonry
Drywall & Partitions	1) PM	1) Glazing 1) Roof 1) Finish Conc 1) *Elec 1) Mech 1) Plumb	1) Drywall
Formwork	1) PM	2) Site 1) Elec	

TABLE VII Contd.

ACTOR	DEPENDS ON		
	Management	Subcontractors	Suppliers
Finish Concrete	1) PM	3) Site 1) Finish Conc	
Waterproofing	1) PM	1) Formwork	
Roofing	1) PM	1) Mason 1) Mech 3) *Erect 1) Plumb 1) Precast Erect	
Sitework	1) PM	1) Waterproof 1) Finish Conc 1) Rail 1) Mech 1) Elec 2) Formwork 1) Spri	
Toilet Partitions	1) PM	1) Floor	1) Partition
Ceiling	1) PM	1) *Paint	1) Ceiling
Painting	1) PM	2) Mason 1) Precast 1) Roof 2) *Door 1) Gyp Board 1) Ceil	
Railroad	1) PM	1) Site	
Designers	Management	Designers	Suppliers
Architect	2) RA 2) O	1) EE 1) *FE 1) *ID 3) **ME 1) *SE	
Structural Engineer		1) A	1) *Fabricator
Mechanical Engineer	2) O	1) SE 1) A	1) Sprinkler

TABLE VII Contd.

ACTOR	DEPENDS ON		
	Management	Designers	Suppliers
Electrical Engineer	1) 0		
Civil Engineer		1) A	
Foundation Engineer		2) A 1) ME 1) SE	
Environmental Engineer		1) A	
Interior Designer		2) A	
Surveyor		1) CE	
Project Manager		1) A	
Owner		1) A	
Regulating Agencies		1) EE 1) ME 4) A 1) ENE 1) CE 2) FE 2) SE	

Suppliers	Management
Fabricator, Steel	1) PM
Mechanical Manufacturer	1) PM
Electrical	1) PM
Masonry	1) PM
Precast Concrete	1) PM
Glazing	1) PM
Millwork	1) PM
Flooring	3) PM
Toilet Partitions	1) PM

ACTOR	DEPENDS ON Management
Ceiling	1) PM
Doors & Hardware	2) PM
Miscellaneous Iron	1) PM
Metal Walls	1) PM

PERCENT BREAKDOWN OF CONSTRUCTION COST TABLE - VIII

BUILDER	FLOORS	SQUARE FEET	SUBURBAN OFFICE BUILDING									
			EXTERIORS & FOUNDATIONS	STRUCTURE & INTERIORS	MECHANICAL & ELECTRICAL	PLUMBING & PIPING	ELECTRICAL	SPRINKLER	HVAC	ELECTRICAL	PLUMBING	SITE
TURNER	1	40,000	16.8%	22.6%	7.5%	2.3%	1.6%	1.6%	19.2%	10.7%	11.1%	1.2%
TURNER	13	234,000	6.2%	15.5%	10.1%	14.6%	3.4%	1.9%	11.5%	9.3%	1.7%	.75%
	3	19,200	12.3%	11.9%	1.1%	9.1%	1.4%	12.4%	12.4%	6.1%	1.7%	10.1%
TURNER	65	300,000		30%			1.6%		16%	8%	4%	
CONCRETE	10	-					6%	1%	12%	12%	3%	
CONCRETE	40	-					8%	2%	17%	12%	9%	
CONCRETE	60	-					9%	2%	12%	12%	5%	
CLAF			8.4%	21.2%	15.4%	3.3%	7.9%	2.7%	12%	12%	2.4%	26%
TURNER			6.6%	12.6%	11.2%	10.4%	3.1%	1.4%	9.2%	6.2%	4.6%	.3%
AVERAGE			10%	20.3%	10.4%	9.2%	4.9%	1.6%	13.1%	8.8%	3.7%	15.2%

SOURCES: N.E.M.B., C.C.F. - SOME POSSIBLE INNOVATIONS IN THE DESIGN, FABRICATION & CONSTRUCTION OF HIGH-RISE STEEL-FRAME BUILDINGS, MIT DEPT. OF ARCHITECTURE & CIVIL ENGINEERING, NOV. 1967

ALL OTHERS COMPILED BY JOE MOROS

Chapter IV

ANALYSIS OF DATA

We have now shown the relationship between all the actors in both the fast track construction case and the conventional construction case. Precedences and floats were used in each case to determine critical and non-critical relationships between actors.

In this chapter we will discuss these relationships in greater detail and show how they might impact the overall project in both cases.

Fast track, sequential interdependencies between designers and construction actors are shown in figure 5. With the exception of interactions with the PM, none of these interdependencies occurs in the conventional case. The information for these relationships was taken from Table VI.

In the conventional case all design-construction interdependencies are eliminated using the General Contractor (GC) as an interface. Construction only depends on contract awards which in turn depend on completion of the contract documents. There are no dependencies on designers or regulating agencies by the subcontractors or manufacturers. The subcontractors still depend on designers for shop drawing approval. This occurs in the case study for sprinkler and steel shop drawings. Structural shop drawings still remain on the critical path in the conventional case. Shop drawing approval has been considered a sequential construction activity in this study. It must be scheduled in both conventional and fast track construction cases.

No interlacing is present. The Project Manager (PM) cannot let any contracts and does not in fact even receive any contract documents until the final completion of the

documents. All contracts are then simultaneously let after the GC is awarded the overall construction contract. There is still some float associated with some of the contract awards to subcontractors which may or may not be used at the discretion of the PM.

Figure 6 shows the relationships between all of the actors for both cases. Actors involved and number of interactions are shown.

In the fast track case subcontractors and suppliers cannot be awarded contracts by the PM until the related designer has finished his/her work package. In this case one designer can impact the entire job once the float associated with their work package is exceeded. Construction is already underway and equipment and/or workers may be forced to remain idle while design problems are resolved.

In the conventional case the only costs associated with design delays are costs incurred due to the project finish date being extended. These would be costs such as reduced value of money due to inflation and a delay on the return on investment. These costs would be suffered in the fast track case in addition to construction delay costs.

In the conventional case the project is carried to completion in two distinct phases: design and construction.

Designers, who are on relatively equal footing with respect to professional prestige interact to formulate a completed design which is ready for construction. The architect coordinates this process and is in the end, at the "completion of contract documents," responsible to the Owner

for the bid documents for the entire project.

The bid documents are turned by the Architect over to a General Contractor (or several GC's) whose Project Manager separates them into work packages to be bid by selected subcontractors. The PM then compiles a bid for the entire project. The Owner awards the contract to a General Contractor who in turn awards the associated subcontracts.

The PM has only to depend on the Architect to turn over the completed bid documents and the subcontractors and suppliers depend only on the PM to subdivide their particular work package from the aggregate project and award the subcontract. Subcontractors then depend on suppliers for their materials and on other subcontractors whose work precedes theirs. As in the design phase, actors in the construction phase have about the same professional prestige in most cases. Subcontractors are familiar with the existing precedences, ie. underslab plumbing must be completed before the slab is poured.

In the fast track case the project cannot be divided into distinct phases. As soon as the design phase is completed on a work package the PM can award a contract on that item. In this particular case study this means construction can begin on the 28th day after environmental approval, approval of site plan and award of sitework subcontract. In the conventional case construction cannot begin until the 90th day. Total project duration is increased by 62 days or 12.4 weeks.

Interactions between designers and the Project Manager are substantially increased in the fast track case. PM-sub-contractor relationships are not impacted in frequency but timing is affected.

The graphic and tabular representations of the project only reveal the sequential relationships between the actors. Reciprocal relationships are ever present between the designers in both cases. Sequential relationships are linear in nature. In a sequential relationship one actor depends on another. ie. $x \rightarrow y$, y depends on x . In a reciprocal relationship actors depends on each other, ie. $x \leftrightarrow y$, x depends on y and y depends on x .

The activities in the construction phase are primarily sequential. In these sequential relationships an assembly line approach can be adopted. This type of a relationship can be controlled by planning and scheduling.¹

The design process consists of both sequential and reciprocal relationships. Reciprocal relationships are more difficult to control. Control mechanisms include mutual adjustment and feedback.¹ Mutual adjustment is the process by which the people involved in the relationship work together to coordinate their effort.²

In the conventional case the coordinating mechanisms are clear. The design phase, marked by reciprocal interdependencies

¹Organizations in Action, James D. Thompson, 1967, McGraw Hill, Inc.

²The Structure of Organizations, Henry Mintzberg, 1979, Prentice-Hall, Inc.

can be controlled by mutual adjustment and feedback between the designers. All of the actors in this phase are dealing with the project on the same intellectual plane. Sequential relationships in the design phase can be handled with scheduling by the Architect. Construction is almost entirely composed of sequential relationships. These can be handled with scheduling and planning by the PM. Every work package is clearly defined and any of a number of scheduling techniques can be employed.

The fast track case is, however, not as clear cut. A reciprocal relationship still exists between designers, but it is now interlaced with the sequential construction activities. Instead of one sequential relationship between the design phase and the construction phase there are now many such relationships. Coordination mechanisms for the design are still mutual adjustment and feedback between designers. Construction is still controlled by scheduling and planning. In the fast track case, however, the interface between design and construction takes on a critical nature. This necessitates the scheduling of the design process.

In the case of Carlson Corporation, the design and construction are all in-house. This provides a much closer link between the PM and the designers. In the general case this link would not be present as the design firm would be separate from the GC. In the general case someone would have to be present at the start of the project as the Owner's representative to coordinate the design and construction

efforts. The identity of this person is not the subject of this study, but rather the nature of this person's duties. The Owner's representative should be familiar with design and construction precedences and durations. This person should have the authority and responsibility to enforce all design and construction deadlines. This person should have the authority to identify and procure all long-lead time items.

In the case study long-lead time items are: steel delivery - 100 days, joist delivery - 100 days, deck delivery - 100 days, glass delivery - 60 days, precast delivery - 45 days, exterior doors and hardware delivery - 44 days, interior doors and hardware delivery - 50 days, electrical MDP delivery - 120 days, transformer delivery - 120 days, AHU delivery - 86 days, chiller delivery - 90 days, exterior metal walls delivery - 60 days and brick delivery - 60 days.

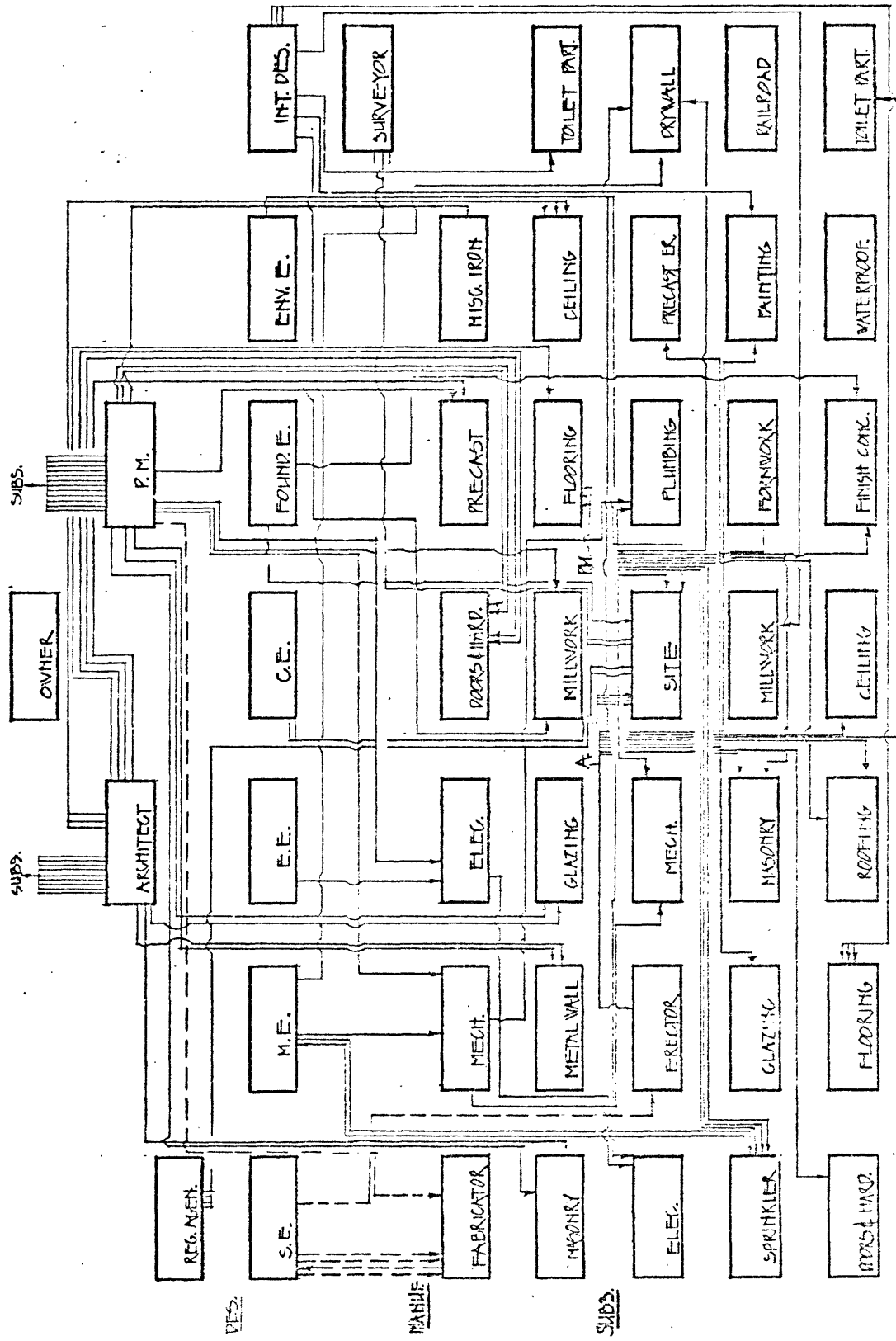
These items encompass the mechanical, electrical and structural systems, doors and hardware and the facade of the building. Table VIII represents the percentage breakdown of several projects of various sizes. As shown in this table these items represent a large portion of the total construction cost. Using the averaged figures, 61.8% for the case study.

By implementing the design of these long-lead time items early in the project total project cost can be projected by the Owner's representative with some certainty. It is also clear from the case study that many of these long-lead time items will find their way onto the critical path. They can

therefore substantially effect the project duration. These items must be identified by the Owner's representative before the project begins in order to determine the optimal sequencing of the project.

FIGURE -6

FAST TRACK: DESIGN-CONSTRUCTION ACTOR INTERDEPENDENCIES



KEY: X ———> Y Y - - - - -> X

FIGURE 7

KEY:

7.A CONVENTIONAL

7.B FAST TRACK

- ▼ ACTIVITY ON LEFT DEPENDS ON ACTIVITY ABOVE LESS THAN 3 TIMES
- ACTIVITY ON LEFT DEPENDS ON ACTIVITY ABOVE 3 OR MORE TIMES
- ⊙ ACTIVITY ON LEFT DEPENDS ON ACTIVITY ABOVE CRITICALLY

FIG. 7.B

CONTINUED

NO
SCHEDULE

SUPPLIERS

FABRICATION
 MECH.
 ELEC.
 MASONRY
 PRECAST
 CHASING
 MILLWORK
 FLOORING
 PAINT
 CEILING
 DOORS & HW
 MISC. IRON
 METAL WALL

ARCHITECT
 STR. ENG.
 MECH. ENG.
 ELEC. ENG.
 CIVIL ENG.
 ENV. ENG.
 INTERIOR

Chapter V

CONCLUSIONS

In this study we have analyzed design and construction precedences and total project durations for the construction of a building using fast track construction methods in one case, and design and lump sum bid in the other case. Interdependencies between the actors have been discussed and related coordination problems brought to light.

The "TREND" analysis has provided specific quantitative data on the case study. In the fast track case there is a heavy dependence of construction activities on design activities; 28 such cases, one critical. In the conventional case the PM depends on the Architect for the completion of the contract documents and the fabricator and sprinkler subcontractors depend on the structural engineer and mechanical engineer, respectively for shop drawing approvals. Thus construction activities depend on designers only 3 times.

With "TREND" the coordination problem area can be pinpointed. The results have been summarized in the following conclusions:

The "TREND" analysis has highlighted many potential problem areas in the fast track case. Although we have assumed that the uncertainty in the duration of design activities is relatively constant, and that uncertainty among construction activity durations is relatively constant,

design activities generally have more uncertainty associated with their duration than do construction activities. As pointed out by "TREND" this is a potential problem area. There are 28 such cases of interdependency from high to low uncertainty levels. One such interface is critical: structural steel design to steel bid and award. These interfaces can be seen in Figure 2, where construction activities depend on design activities. "TREND" suggests that a "third party is required to translate and integrate for them."¹ This third party was described in Chapter IV.

In the conventional case only 3 design-construction activities are present. Two of these are shop drawing approvals, which as explained earlier, are sequential activities which occur after the design is finalized and are therefore considered to act as construction activities in terms of uncertainty levels.

In the fast track case, "TREND" points out another problem with design-construction interfaces. The relative levels of prestige between design and construction actors can be quite substantial. Depending on the actors involved potential conflicts could evolve at any one of the interfaces. Where there is a greater amount of float associated with an activity the possibility of conflict lessens, which is the case with

¹"Two New Project Coordination Techniques for Construction Managers," Raymond E. Levitt. 1977. Unpublished.

all but one activity in the case study. This is the critical interface between the Structural Engineer and the fabricator and erector. It is unlikely that all of the parties involved here are of the same prestige level. The actual actors in the case study are unknown, but it is possible that any one of the permutations could actually exist; i.e. a very prestigious Structural Engineer with a "two bit" fabricator and erector, or a small time Structural Engineer with a very prestigious fabricator and "two bit" erector, and so on.

Conflicts are likely to occur when a high prestige actor depends on a low prestige actor, i.e. small time Structural Engineer with a prestigious fabricator and erector.

In the conventional case (again with the exception of shop drawing approvals) this critical interface is only between the Architect and the Project Manager. No other interfaces occur. This may still be a potential problem area, but it is a very obvious interaction unlike the fast track case where there can be more than one critical interface which can occur between many actors.

"TREND" has also pointed out the need for intensive scheduling and planning at the start of a project when fast tracking is employed due to the sequential interdependencies of construction on design. This necessitates the rigorous scheduling of design activities. Unlike the conventional case where design delays are much less important, fast track design delays adversely affect the entire project causing costly down-time on the construction site. Accurate schedules

must therefore be produced and adhered to.

By scheduling the design of long-lead time items at the start of a project, overall project duration can be reduced. In the case study the fast track duration was 293 days while the conventional duration was 355 days, a 62 day savings in time. Long-lead time items can be purchased as soon as the design is completed on that item. In the case study, steel and joist delivery were the critical items. Depending on the project, any one of the long-lead time items could fall on the critical path.

Another advantage of designing long-lead time items early in the project is that a realistic guaranteed maximum price can be projected at an early date in the design-construction phase.

In this study we have only looked at one project. When activity durations and precedences change, new critical paths are created and relationships between actors change. The specific results from project to project can vary substantially. We feel, however, that the basic underlying problems inherent in fast tracking will remain constant regardless of project size or duration. Design-construction over-lap is still present, therefore, the need for scheduling of the design process becomes strong.

In the case study, with the CPM network in hand, the Owner's representative would very likely be able to intuitively predict the potential problem areas without the use of "TREND" analysis. The case study project is small in scope and duration,

however, and with increasing project size and complexity, problem areas may become harder to detect intuitively. This would be particularly true in the case of nuclear power plant construction where the number of activities explodes to tremendous proportions and hence the number of actors involved and the number of design-construction interfaces increase substantially. By using "TREND" analysis the activities could be analyzed on an individual level without losing sight of the aggregate project.

We have shown that a "TREND" analysis can be performed on a project to pinpoint specific problem areas. On a small project these problems may be obvious, but as the complexity of the project increases the analysis becomes more valuable. The "TREND" analysis highlights the need for scheduling and control of design activities.

BIBLIOGRAPHY

- Benningson, Lawrence A., "TREND: New Management Information from Networks," Proceedings, Third International Congress on Project Planning by Network Techniques, 1972, Stockholm, pp. 44-60.
- Clough, Richard H., Construction Contracting, 3rd Edition, 1975, John Wiley & Sons, Inc. pp. 5-14.
- Irwig, Henry G., The Building Design Process: An Investigation into Productivity, Thesis submitted to the Faculty of Architecture, University of the Watwatersrand for the Degree of Doctor of Philosophy, 1977, Johannesburg.
- Levitt, Raymond E., "Two New Project Coordination Techniques for Construction Managers," 1977, Unpublished.
- Mintzberg, Henry, The Structuring of Organizations, 1979, Prentice-Hall, Inc.
- Thompson, James D., Organizations in Action, 1967, McGraw-Hill, Inc.