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KyTC 96-167

Development of a Critical Path Method Specification and a Training Program for use of CPM for KyTC

Research Report
KyTC 96-167

Development of a Critical Path Method Specification and a Training Program for use of CPM for KyTC

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In cooperation with Kentucky Transportation Cabinet
And
Federal Highway Administration
U.S. Department of Transportation

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16. Abstract

The Critical Path Method scheduling technique is outlined as it applies to KYTC projects. Special Provision 82 (94) and its requirements are outlined.

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1.0 Introduction

There are numerous project management techniques available that can be used to assist today's construction professional in the management of a construction project. The most widely accepted and successful of these project management techniques is Critical Path Method (CPM) scheduling.

Although it has been more widely used in the building construction industry, Critical Path Method (CPM) scheduling has also proven beneficial for the planning and monitoring of many highway construction projects in other states, as well as, the Commonwealth of Kentucky.

2.0 Background and Significance of Work

Currently, the Kentucky Transportation Cabinet uses the Critical Path Method (CPM) for scheduling very infrequently, and only on a very select number of their highway construction projects. These projects are the unusual, are typically very complicated, and are difficult to accomplish within the time available to perform the work. These are the projects which really need a project schedule to ensure the success of the project.

The project schedule is a very well developed detailed plan of the project, defining what the work is, just how and when it is to be accomplished. It also defines how all parties associated with the project need to coordinate their activities to ensure the successful on-time completion of the project. The project schedule also serves as a communications vehicle to all parties associated with the project, as well as, a documentation device of what was accomplished, as compared to the original plan.

When CPM scheduling is specified for a highway construction project, it is done through the current specification, Kentucky Transportation Cabinet, Department of Highways, Special Provision No. 82 (94), General Schedule Provisions.

This specification requires the contractor to prepare and submit a progress schedule. With its reference to progress schedule, versus project schedule, the specification is requesting something short of a detailed project plan. Perhaps the purpose of the progress schedule is for use in monitoring the project progress to support the progress payment process. Although this may be an important function of a project schedule, it is only one of the planning and communications functions the project schedule is to provide.

When KyTC specifies the use of CPM scheduling and incorporates it as a requirement into the contract documents, the contractor can by the specification request an alternative to CPM scheduling. The KyTC project management team normally has granted the contractor requests for an alternative scheduling method. Currently, most contractors performing highway construction projects for the Cabinet do not use a formal CPM scheduling technique for planning and communications with their KyTC representative counterparts.

It has been the KyTC's experience that contracts requiring the use of CPM scheduling for the project have often resulted in confusion and claims.

This is a strong indication of the need for a more clearly defined and functional specification for the project schedule with an elaboration on the use of CPM scheduling as a project management technique.

Also, this may indicate that both the contractor and the KyTC project management team require a better working knowledge and understanding of the purposes and uses of CPM as a project management tool for both parties.

Thus, this research project (KTC 96-167) was initiated by the KyTC Construction Division and the faculty and staff of the University of Kentucky's Civil Engineering Department, in conjunction with the Kentucky Transportation Center, to assist the KyTC with the resolution of these issues.

3.0 Research Project Objectives

The objectives of the research project were developed with the approval of the KyTC Division of Construction; they are:

1. To understand the needs of the KyTC for scheduling the construction of highway work and to learn as much as possible about current practices in Kentucky and elsewhere.
2. To develop a sample specification to use in the specification of the Critical Path Method (CPM) project management technique for highway construction in Kentucky that will clarify requirements for contractors and reduce the number of schedule-related claims.

3. To develop and implement a training program for KyTC personnel and highway contractors on how to better utilize CPM to plan and monitor highway construction projects, and to reduce the potential of claims.

4.0 Research Accomplishments

4.1 Literature Search

A literature search for the project management techniques that could be used to assist state agency construction professionals in the management of highway construction projects was conducted. The literature search disclosed several newly developed project management techniques, as well as, the tried and true "Industry Standards" project management techniques. Most of the new techniques that have yet to be validated by actual field application experience and were discounted. The project management planning tools selected for further investigation were Bar Chart scheduling, "I-J" Network scheduling, Precedence Diagram scheduling, and Line of Balance scheduling.

Each of these project management techniques has particular strengths when applied to highway construction projects. Each also has different levels of difficulty to prepare and modify. These characteristics were important considerations in selecting the types of techniques to incorporate into the highway construction contract specification.

4.2 Survey of Other State Transportation Departments

A survey of state Departments of Transportation was performed to determine which of the project management planning tools and techniques were currently being used successfully for highway construction projects. The extent to which each of these tools was being used was also determined.

The survey questionnaire was developed to obtain this information and it was sent to the other state Departments of Transportation. The questionnaire requested responses to include which project management techniques were they currently using, and how often they used each. Also requested was the criteria they used for the requirement of CPM scheduling for a project, plus information on other uses of CPM scheduling and any problems they were experiencing with the use of CPM scheduling.

The survey response was very good with forty-seven state agencies responding. The information supplied by these respondents was summarized and evaluated. The preliminary survey results were reported in the preliminary report of June 1996, previously submitted. The survey results are consistent with, and generally support the use Critical Path Method (CPM) project management technique as the technique of preference to assist the state highway construction professional in the management of complex highway construction projects. The questionnaire is included in the Appendix of this report.

Survey Results:

1. *Frequency of Use of CPM scheduling:* (7) Always, (10) Often, (13) seldom, (6) never. See Figure 1.
2. *Criteria for Using CPM scheduling:* (20) Time Constraints, (18) Degree of Complexity, (11) Dollar Amount, (3) Always Used, (3) Other Reasons. The other reasons were related to the expectation of claims. See Figure 2.
3. *Problems with CPM Usage:* (20) Schedule is not regularly updated, (18) Contractor does not know how to prepare CPM schedule, (9) Don't know how to follow-up the CPM schedule, (6) Not Applicable, (5) Other Problems, (1) No Problems. Some the other problems were: Using CPM scheduling on a project that does not need it, Contractor manipulation of logic or not following their own schedule, and not receiving CPM schedule at 'Notice-to-Proceed'. See Figure 3.
4. *Frequency of Up-Dating CPM Schedule:* (20) Regularly, (12) Upon a problem occurrence, (4) Occasionally, (1) Never. See Figure 4.
5. *Other Uses for CPM Schedules:* (22) Claims resolution, (6) Other reasons, (2) Cash flow preparation. Some of the other reasons indicated were: to allocate resources, to determine progress or problem occurrence, and to review the project. See Figure 5.
6. *Do You Have Trained Staff:* (20) No, (14) Yes. Some responding state transportation use consultants to review and recommend all dealings related to the use of CPM scheduling. See Figure 6.

7. *Do You offer Training for Your Staff:* (14) Yes, (19) No. Most state agencies use consultants for CPM scheduling training. See Figure 7.

4.3 CPM Training Seminar

4.3.1 Introduction to Scheduling

The researchers developed a training seminar on CPM scheduling as a project management technique applied to highway construction projects. KyTC District Construction personnel were the intended target audience for this seminar. The seminar was designed to provide the participants with an understanding of the basic fundamentals and essentials of project scheduling, and a confidence in their abilities to use CPM scheduling as a construction project management tool.

The seminar content included the following topics: the development of basic concepts of project scheduling; bar chart schedules; critical path methods; conceptual scheduling; "I-J" (activity-on-arrow) and precedence CPM logic diagrams; time calculations; calculations of activity starts, finishes, and floats; reading of the CPM diagram; CPM calendar to day conversion; and identifying the critical path. An agenda is included in the Appendix.

Specific highway construction example projects were used throughout the seminar. There were also real problem situations and examples contributed by KyTC construction participants. A special set of seminar notes was developed and is included in the Appendix.

4.3.2 Software Demonstration

A demonstration of Primavera's Suretrak scheduling software was included as part of the CPM scheduling seminar to introduce computerized scheduling to the participants, and to familiarize them with the process and ease of creating and updating a computerized bar chart and CPM types of schedule. Although this was a specific demonstration of bar chart scheduling, the computations and logic development are exactly the same as those performed for any CPM scheduling software. Since the seminars were conducted, Primavera has made improvements in the Suretrak software package and now includes the optional PERT graphical presentation of the bar chart logic diagram.

4.3.3 Seminar Implementation Plan

A total of four (4) CPM scheduling seminars were conducted for the KyTC construction personnel, including Frankfort Head Office and all District Offices. The seminars were held at various different locations throughout the Commonwealth for the convenience of the participants. The locations were UK's CE/KyTC facilities, Elizabethtown CC, again at UK's CE/KyTC facilities, and Prestonsburg CC. The dates of the seminars were February 11th, February 28th, March 14th, and 28th, 1997, respectively.

Invitations to each District Office were limited to four people from the construction division per district, to ensure a good representation from every district. Additional district construction people desiring to attend from the larger districts were also accommodated.

The attendance totaled (76) seventy-six construction people for the four seminars held, including representation from all twelve districts and from the Frankfort Construction Head Office. The attendance at each seminar is indicated in the following table.

Location	Date	Districts Represented	Number
UK's CE/KyTC	2/11/97	Head Office	8
Elizabethtown CC	2/28/97	1,2,3,4	20
UK's CE/KyTC	3/14/97	4,5,6,7,8	28
Prestonsburg CC	3/28/97	9,10,11,12	20
		Total	78

At the completion of each seminar session, the participant evaluations and comment was used for slight modifications and adjustments of the course content and presentation. This was to provide more focus on the real problem situations that occur in the project management of KyTC construction projects.

4.3.4 District Office Construction Personnel Survey

A follow up survey questionnaire was developed to gather additional project management practices information from the District Offices. The questionnaire was sent to the Construction Personnel in all twelve (12)

District Offices. This survey provided input to the development of the sample CPM scheduling specification. Also, this survey obtained feedback on the effectiveness of the use of CPM scheduling and gave an indication of further training needs. The survey questionnaire is included in the Appendix.

The District Office survey results are:

1. The number of projects per respondent ranged from a maximum of (10) to a minimum of (3) with an average of (6) active projects at any given time. See Figure 8.
2. The number of major activities of each project ranged from a maximum of (40) to a minimum of (3) with an average of (15) major activities per project. See Figure 8.
3. The project duration of the construction projects ranged from a maximum of (150) calendar days to a minimum of (10) calendar days with an average duration of (60) calendar days. See Figure 8.
4. The respondents considered their projects moderately complex, and that they have often encountered complex projects.
5. The respondents often encountered projects that were in the need of more effective project scheduling.
6. When a contractor was required to submit a project schedule, only 20% of the time would they receive a computer-generated CPM schedule. 16% of the time the contractor would submit a hand drawn CPM schedule. The rest of the time the contractor would

submit only a written explanation of what was to be done. See Figure 9.

7. When a computerized scheduling system was used, the computer generated CPM schedule of choice by the contractors is Primavera Project Planner, P3, with better than 66% of the computer generated schedules submitted are the P3 schedule format. Others schedule formats submitted include Primavera's Suretrak bar chart at approximately 24% and the rest balance being Microsoft's Project bar chart. The respondents indicated no other computerized schedule systems. See Figure 10.
8. There is a moderately strong agreement of the respondents that the project schedule should be used for monitoring project progress, and that they would use it for this purpose, if given the opportunity.
9. There is also moderately strong belief of the respondents that the contractor does not use his own schedule.
10. The respondents feel moderately comfortable and technically competent in using bar chart and precedence schedule techniques to monitor their construction projects.
11. The respondents were more than moderately in favor of the use of computerized project schedules and equally feel that they are in need additional training in the use of precedence CPM scheduling for project management.

The results of the survey of the District construction personnel were enlightening. All serious input and comments was taken into consideration in the development of the CPM Scheduling Specification.

4.3.5 Other Transportation Department's CPM Specifications

The specification and use of the CPM scheduling technique, as a project management tool, is more frequent in other states than Kentucky. Of the state agencies surveyed, almost a third of the responding state agencies require the contractor to submit a CPM schedule as part of every submittal of a bid.

The ranking of the selection criteria for use of the CPM schedule technique by other state Departments of Transportation is as follows: Time Constraints, Degree of Complexity, Dollar Amount, and Other Criteria. Only six of the responding state agencies never specify CPM scheduling.

Over two-thirds require updating of the CPM schedule on a regular, or at least, occasional basis.

Other uses for CPM scheduling are for Claims Resolution and Cash Flow Management.

Although, KyTC's use of CPM scheduling as a project management tool is not drastically different than some of the other states, there are overlooked benefits to the Commonwealth with a more comprehensive and consistent use of the CPM scheduling as a project management tool.

5.0 Sample CPM Specification Preparation

A sample specification for CPM scheduling was to be developed for recommendation to the KyTC as part of this study. With the review of several specifications from other state transportation agencies, an understanding of what was being used to specify CPM project scheduling was gained. It was determined that the intent and content of these other specifications was not appreciably different than what was currently used by the KyTC for construction projects, but problems resulting from the use of CPM scheduling was not as prominent. The current version of the KyTC specification does present known problems that needed addressing.

The additional input from the participants of the CPM scheduling seminars and then directly from all construction personnel of the District Offices through the follow-up survey questionnaire, lead to the development of a scheduling specification guideline system, as opposed to the current specification. The researchers think that being able to specify and use varying levels of schedule complexity would be of benefit in the management of the Cabinet's construction projects. The scheduling guideline system is to address all levels of complexity of highway construction projects.

The schedule level system would require a schedule for every KyTC highway construction project. The project schedule form would be specified from one of four complexity levels or types of schedules. Selection of the type of project schedule is to be done by considering the key project variables that indicate the level of complexity and sophistication of project schedule needed to successfully manage the specific project.

Schedule type selection guidelines are based on the key project variables: the Estimated Number of Activities on the Critical Path, the Estimated Contract Amount, the Estimated Project Duration, the degree of Time Constraints, the degree of Resources Constraints, and the degree of Project Complexity. The guidelines do require that every KyTC highway construction project have a project schedule, only the type and complexity of the project schedule will vary to match the needs of the specific project. The type and form of the project schedule for each project will also require an active endorsement by the KyTC project management team with inclusion into the contract documents.

A sample CPM specification document was drafted for submittal to KyTC for review and comment. Since the KyTC is currently in the process of updating all construction specifications, the form and format was not a priority. Any sample specification format that would be submitted would necessarily be modified and integrated to comply with the new standards currently under development. The substance and content was the main focus of the research effort. The definition of the roles and responsibilities of the parties using the project schedule are detailed.

It must be noted that for the sample specification to be of benefit, it must be integrated into the new specification system and also into the project management policies and practices.

6.0 Sample CPM Specification

KENTUCKY TRANSPORTATION CABINET

DEPARTMENT OF HIGHWAYS

SPECIAL PROVISION NO. xxx (xx)

SAMPLE SPECIFICATION

CRITICAL PATH METHOD (CPM)

PROJECT MANAGEMENT SCHEDULING

This Special Provision shall apply when indicated on the plans or in the proposal. Section references herein are the Department's 19xx Standard Specifications for Road and Bridge Construction.

I. PROJECT SCHEDULE

A. **General.** Every construction project performed for KyTC shall have a project schedule. The project schedule form shall vary in content and complexity to sufficiently meet the specific needs and requirements of the construction project as specified in contract documents.

AS A MINIMUM, A LEVEL 1 GANNT DIAGRAM WILL BE REQUIRED FOR EVERY KyTC CONSTRUCTION PROJECT.

B. **Purpose and Intent.** The purpose of this specification is to define the general and specific requirements for the project schedule for KyTC construction projects. It includes the details for schedule preparation, submission, acceptance, and revision. It also includes general guidelines on uses of the project schedule for the management of the project.

C. **Preparation.** The project schedule is prepared by the contractor and is the result of the contractor's detailed planning. It shall reflect the contractor's logical order and work sequence of all activities to be performed for the contractor to accomplish the Work of the Project within the Contract Time. The project schedule is to be the plan to successfully complete the construction project.

D. **Included.** The project schedule shall include a detailed listing of all major work activities. The estimated activity durations, and the relationships of these activities with each other shall also be included. The project shall also include all major milestones that define required actions of all parties involved in the execution of the project.

E. **Special Requirements.** The Project Schedule shall include all special project management requirements as specified by contract documents.

F. **Format.** The project schedule form and format shall vary depending on the specific requirements of the project. The project schedule format will range in complexity from a simple Gannt Diagram bar chart to a detailed precedence diagram CPM schedule.

G. **Uses.** The main function of the project schedule is for the contractor to successfully manage the project to completion. Additionally, the contractor is to use the project schedule for communication of the progress and performance. KyTC shall use the project schedule for project planning, communications, progress and performance measurements, coordinating of KyTC resources, evaluating change, evaluating effects of weather, and other project management type requirements of the specific construction project.

H. **Project Schedule Updates.** The project schedules shall be modified and revised by the contractor as necessary to accurately reflect the current status of the construction project and all contract modifications. The project schedule shall also be modified and revised by the contractor with any major change in the sequence of work, or at the request of the KyTC project management team.

I. **Progress.** Project progress shall be reported to KyTC on a periodic basis as specified in the contract documents.

J. **Intention.** The project schedule is to provide better planning and communication for the contractor and KyTC construction personnel. It is to provide a vehicle to focus discussion and resolution of differences in management of the project. It shall be used to indicate critical activities, the Critical Path, and their impact on the total project duration,.

II. ROLES & RESPONSIBILITIES

A. **Contractor.** The contractor shall develop the original project schedule to accurately reflect how the contract work is to be accomplished. It is the contractor's responsibility to maintain the project schedule to accurately reflect all updated project information. The contractor shall submit the required project schedule to the KyTC representative as specified in the contract documents.

B. **KyTC.** The KyTC representative shall acknowledge receipt of the project schedule as a contract document. This acknowledgement shall not be construed as approval, acceptance, or any modification of the contract, the scope of work, the contract time, or any other intention of the contract. The KyTC representative shall use the project schedule only for the specific intended purposes, for project evaluations, planning, communication, and measurement of the contractor's progress. The KyTC construction personnel shall review the project schedule to determine that it meets the requirements on the project and the contract. Any differences from contract requirements shall be presented to the contractor for formal resolution. Any questions or concerns of KyTC construction personnel other than the contractual requirements, i.e., preferred sequence of work activities, sufficient dedication of resources, etc., shall be informally resolved with the contractor and KyTC construction personnel.

III. SUBMISSION REQUIREMENTS

The contractor shall submit the original project schedule within ten (10) working days of Award of Contract, or at the time of Notice to Proceed. The project schedule shall be in the form and media type as specified in the contract documents.

IV. TYPES OF SCHEDULES:

A. **LEVEL ONE - GANNT DIAGRAM** (Bar Chart): **THE MINIMUM PROJECT SCHEDULE REQUIRED FOR KYTC CONSTRUCTION PROJECTS.**

(1) Electronic Data Disk with (4) Hard Copy Printouts.

(2) **Minimum Schedule Content**:

a. **Major Project Milestones**: Project Start, Mobilization, and Estimated Project Completion.

b. Activity Descriptions with Unique Activity ID, Activity Duration, and the Logical Sequencing of Activities.

c. **Estimated or Target Times**: Activity Start and Finish Times.

B. **LEVEL TWO - GANNT DIAGRAM** (Bar Chart): with Linking Logic of Activities.

(1) Electronic Data Disk with (4) Hard Copy Printouts.

(2) **Minimum Schedule Content**:

a. **Major Project Milestones:** Project Start, Mobilization, Estimated Project Completion.

b. Activity Descriptions with Unique Activity ID, Activity Durations, the Logical Sequencing of Activities, the Activity Links with Link Type Definition.

c. **Estimated or Target Dates:** Early/Late Start Times, Early/Late Finish Times.

d. Definition of Critical Path.

C. **LEVEL THREE - PRECEDENCE CPM SCHEDULE DIAGRAM**

(1) Electronic Data Disk with (4) Hard Copy Printout

(2) **Minimum Schedule Content:**

a. **Major Project Milestones:** Project Start, Mobilization, Estimated Project Completion

b. Activity Descriptions with Unique Activity ID, Activity Durations, the Logical Sequencing of Activities, the Activity Links with Link Type and Duration Definition.

c. **Estimated or Target Dates:** Early/Late Start Times, Early/Late Finish Times, Total/Free Floats.

d. Definition of Critical Path.

(3) A Project Schedule Baseline Report is required at the Start of Project.

D. **LEVEL FOUR - DETAILED PRECEDENCE CPM SCHEDULE DIAGRAM with Major Resource Allocation**

(1) Electronic Data Disk with (4) Hard Copy Printouts.

(2) **Minimum Schedule Content:**

a. **Major Project Milestones**: Project Start, Mobilization, Estimated Project Completion

b. Activity Descriptions with Unique Activity ID, Activity Durations, the Logical Sequencing of Activities, the Activity Links with Link Type and Duration Definition.

c. **Estimated or Target Dates:** Early/Late Start Times, Early/Late Finish Times, Total/Free Floats.

d. Definition of Major Resources, Resource Data (Min: Budgeted Qty & Usage Rate).

(3) Definition of Critical Path with Resource Analysis.

(4) A Project Schedule Baseline Report is required at the Start of Project.

V. GUIDELINES FOR PROJECT SCHEDULE LEVEL SELECTION:

A. GANNT DIAGRAM (Bar Chart)

1.) Minimum Bound:

Minimum is required for all KyTC construction projects.
Contract Amount, $ 0.00.
Project Duration: (0) Day.
Time Constraints: (None).
Resource Constraints: (None)
Project Complexity, (Simple).

2.) Upper Bound:

Estimated (5) Activities on Critical Path.
Contract Amount: $10,000.00.
Project Duration, (20) Days.
Time Constraints: (Moderate)
Resource Constraints: (Routine)
Project Complexity: (Simple)

B. Precedence Diagram

1.) Minimum Bound:

Contract Amount, $10,000.00.
Project Duration, (20) Days.
Time Constraints: (Moderate)
Resource Constraints: (Routine)Project Complexity: (Moderate)

2.) Upper Bound

(∞) Activities on Critical Path.
Contract Amount, (∞).
Project Duration, (∞) Days.
Time Constraints: (Difficult).
Resource Constraints: (Moderate)
Project Complexity, (Complex).

C. Detailed Precedence Diagram with Resource Allocation

1.) Minimum Bound:

Contract Amount, $1,000,000.00.
Project Duration, (20) Days.
Time Constraints: (Moderate).
Resource Constraints: (Moderate).
Project Complexity, (Moderate).

2.) Upper Bound: None

VI. MEASUREMENT AND PAYMENT

This is not a pay item.

Table of Figures

Figure 10. CPM Computer Software of Preference

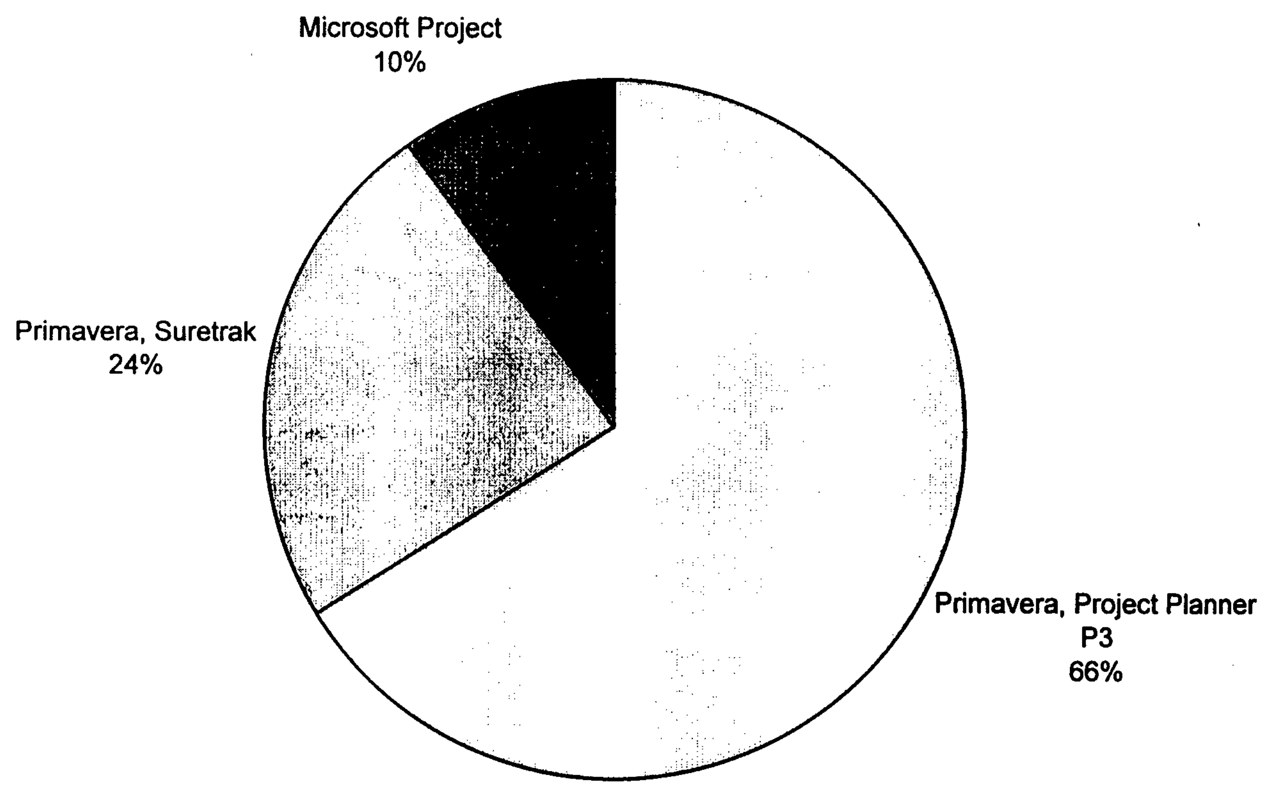


Figure 9. Project Schedule Submittal

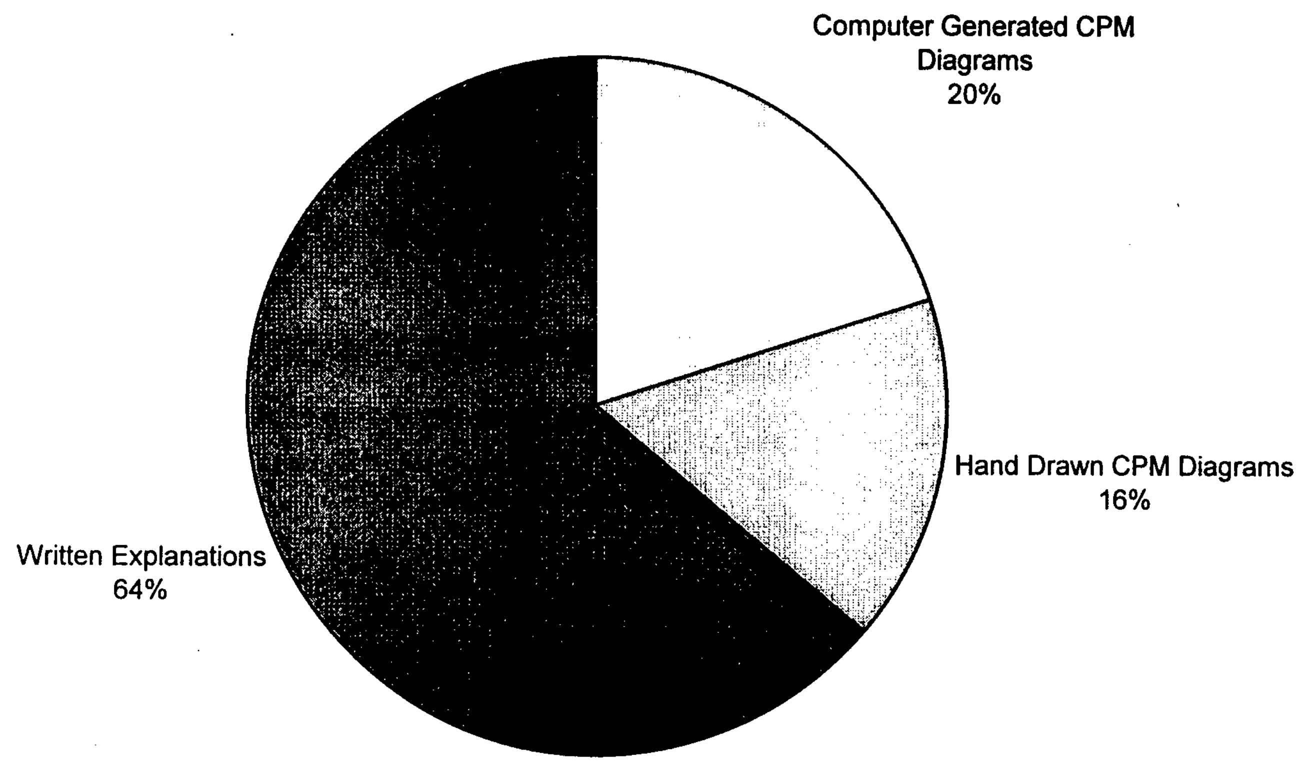


Figure1. Frequency of Use of CPM Scheduling

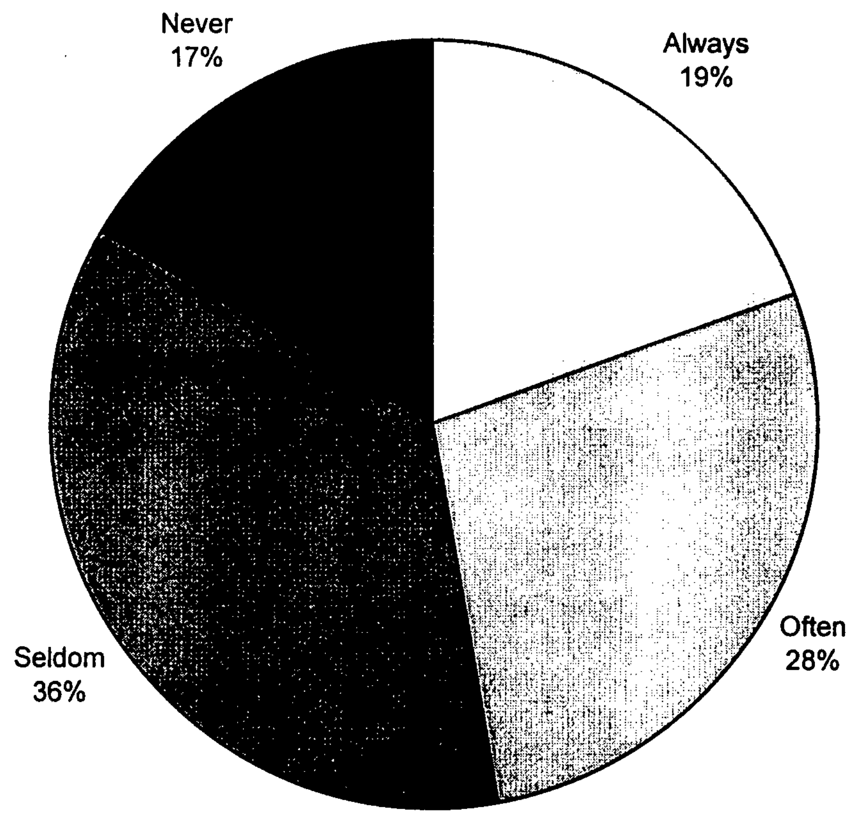


Figure 2. Criteria for Using CPM Scheduling

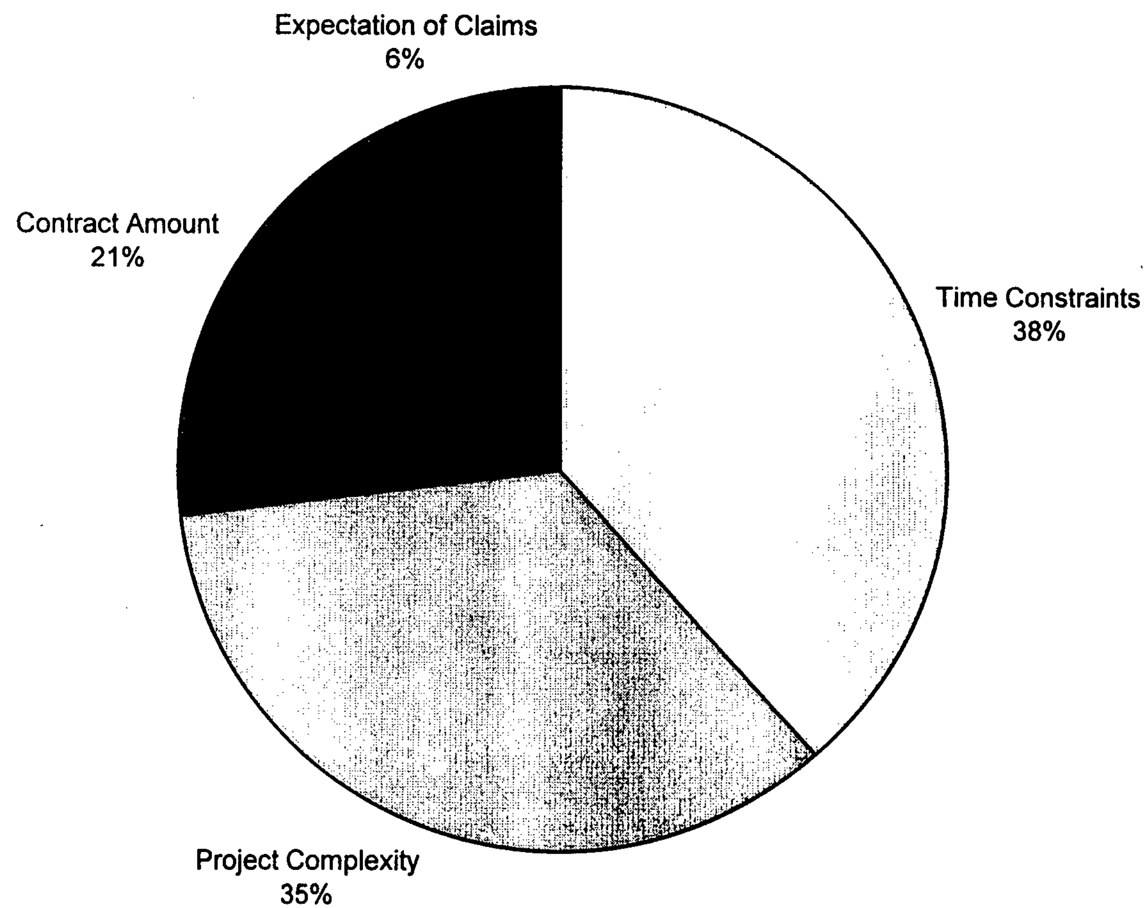


Figure 3. Problems Experienced with CPM Schedle Usage

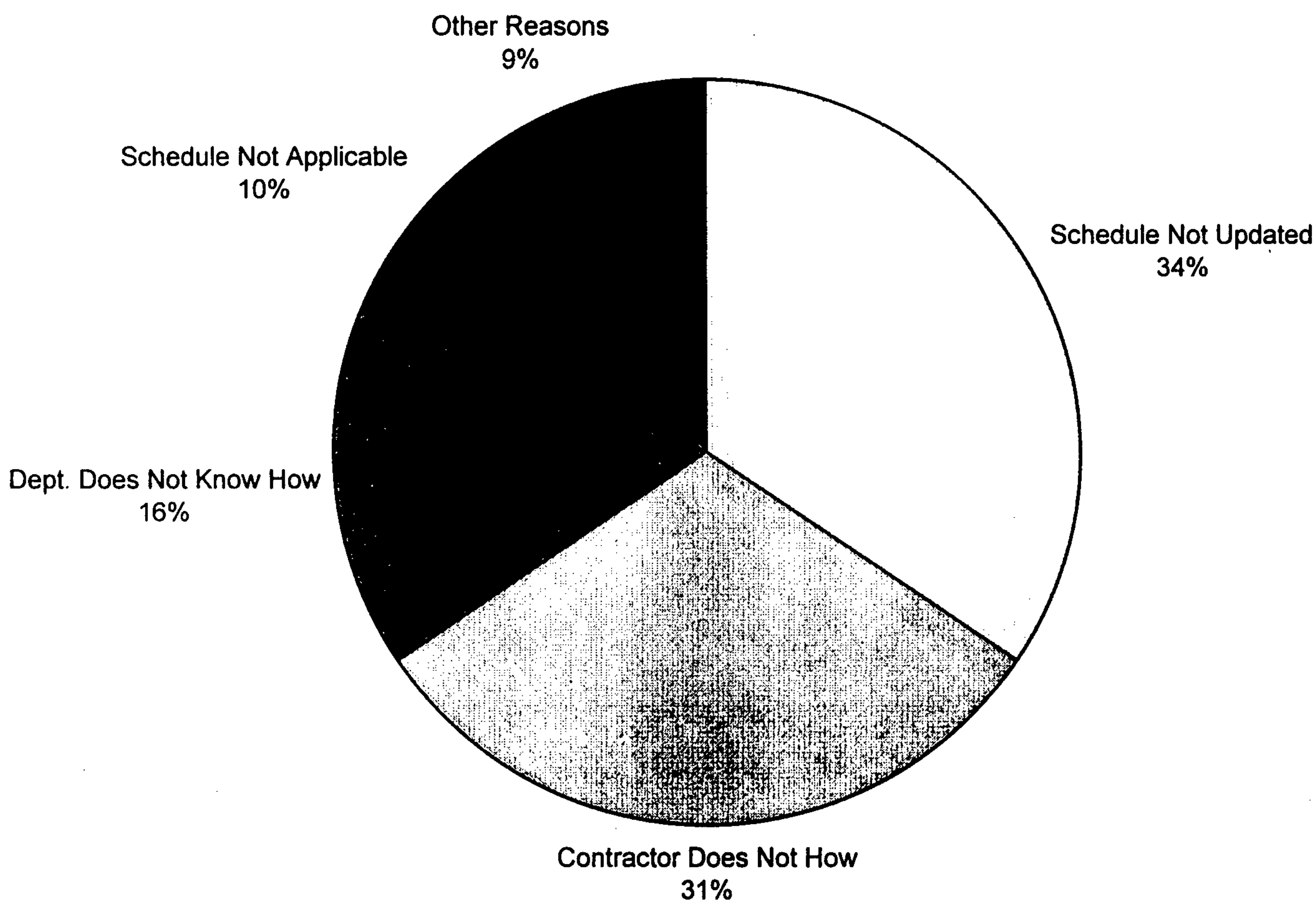


Figure 4. Frequency of Up-Dating CPM Schedules

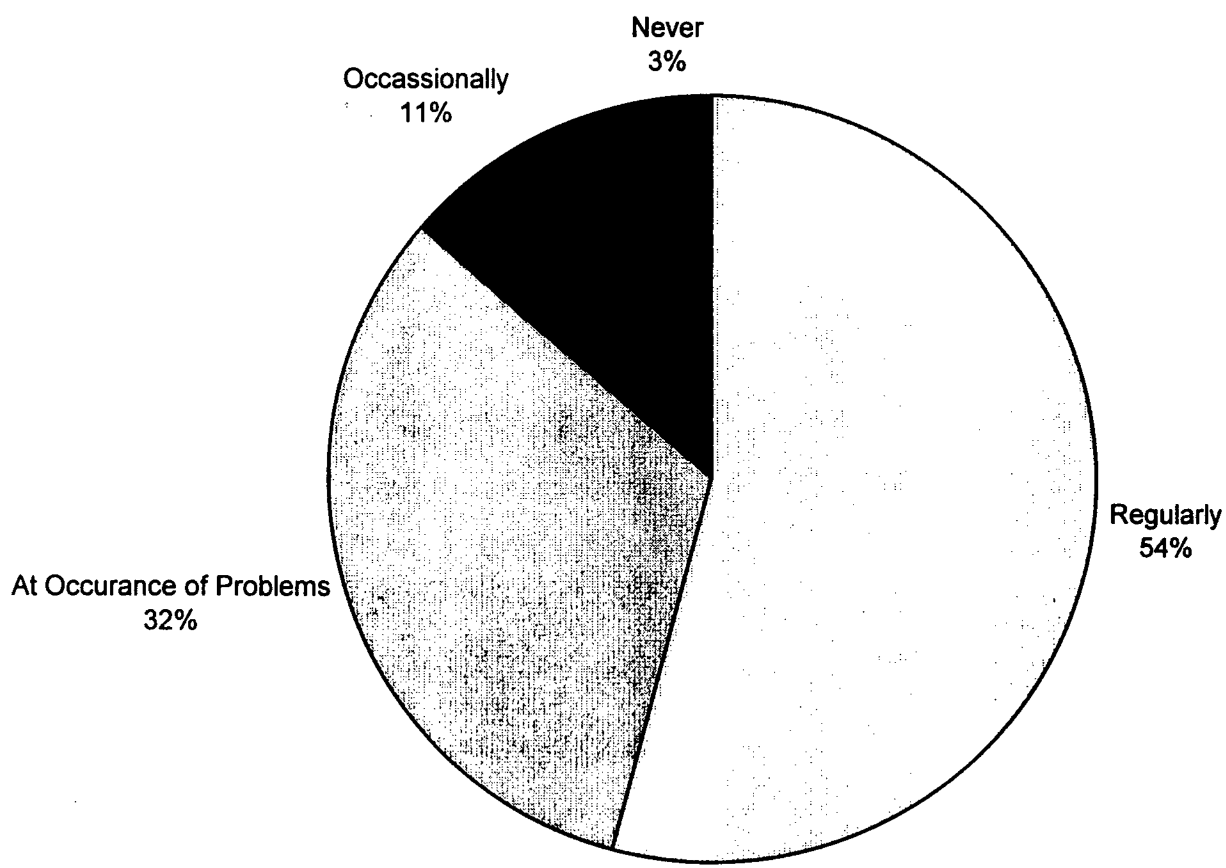


Figure 5. Other Uses of CPM Scheduling

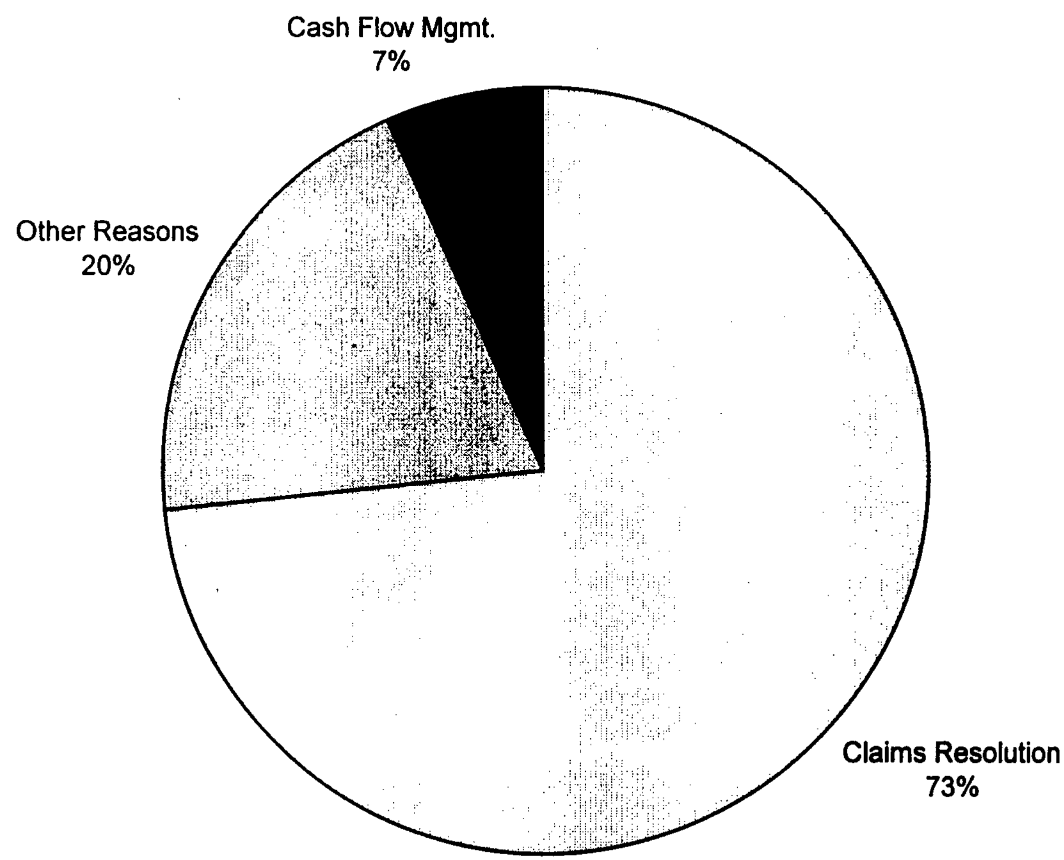


Figure 6. Does the Dept. Have Trained Staff?

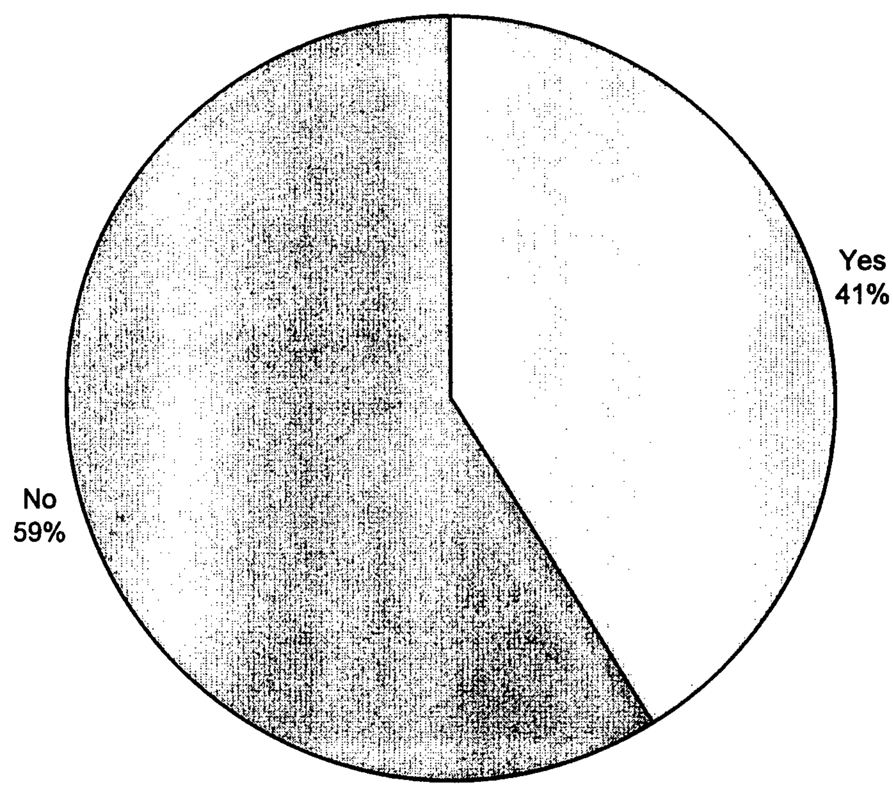


Figure 7. Does the Department Provide Training in CPM Scheduling?

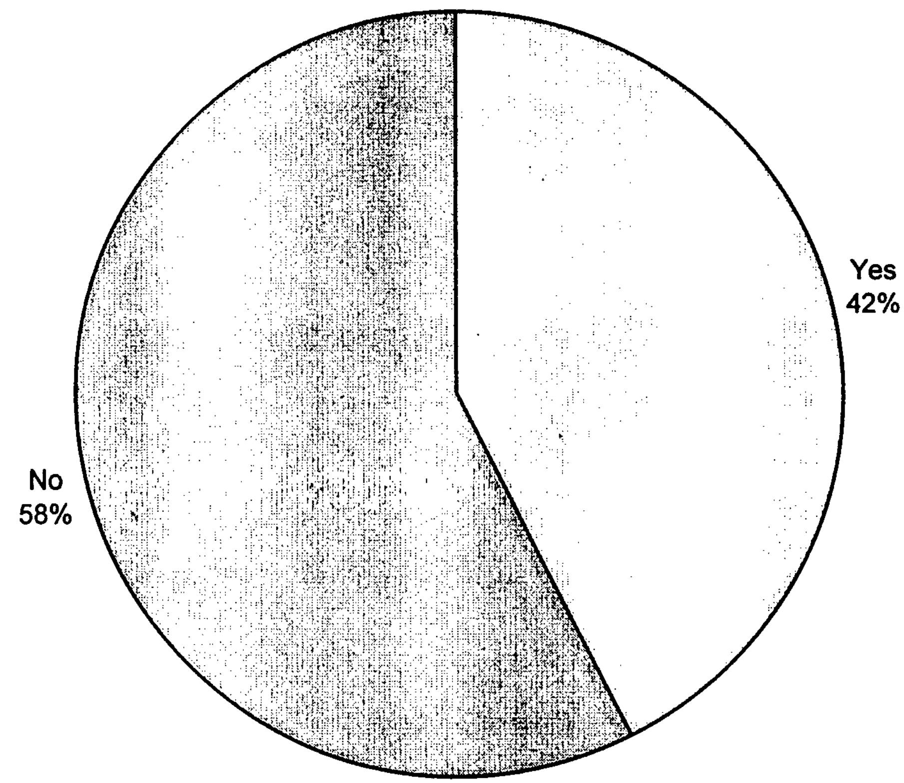
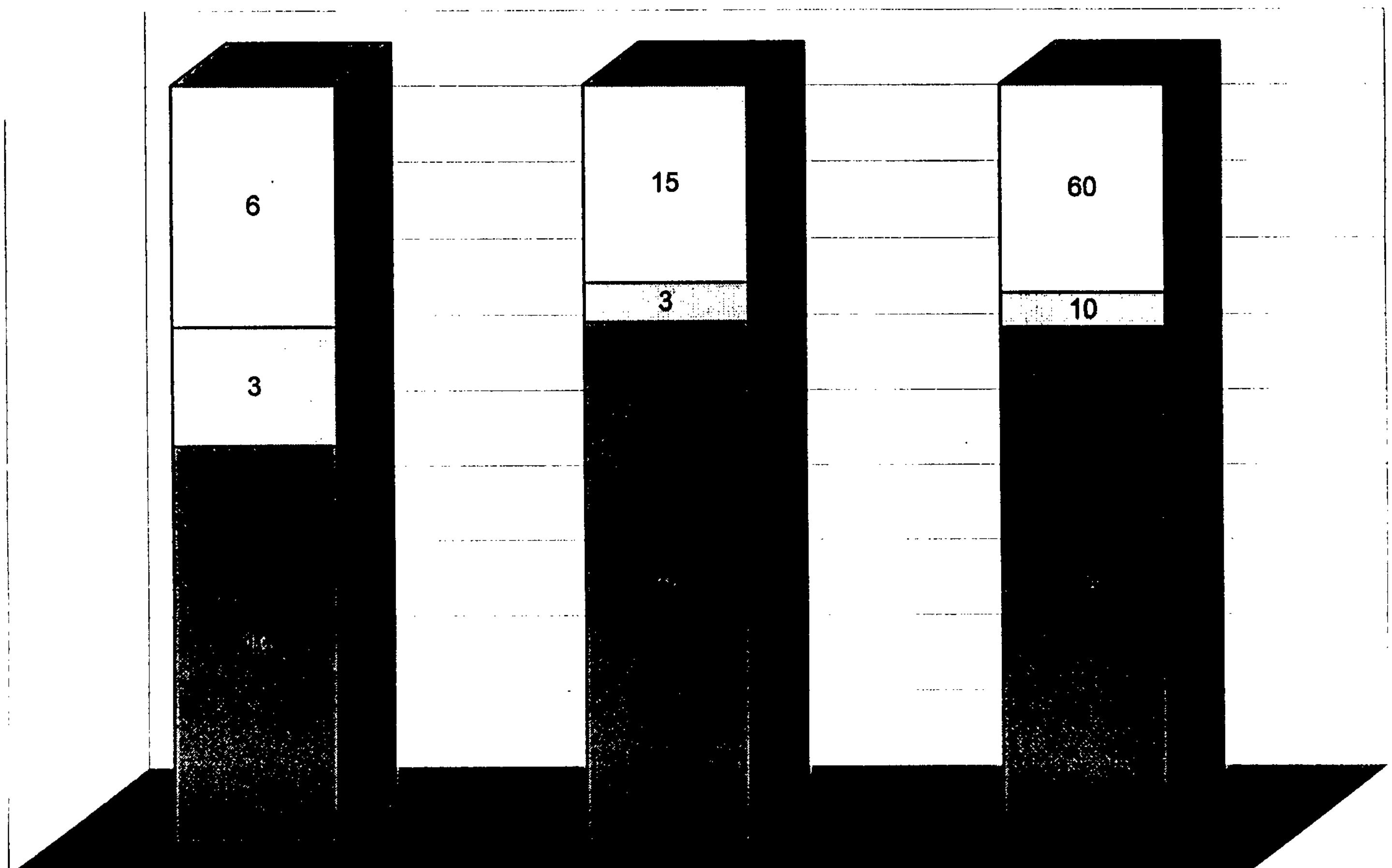


Figure 8. District Office Project Assignment Information



	Number of Projects per KyTC Representative	Major Activities per Project	Duration of Project, Cal Days
□ Average	6	15	60
□ Avg Min	3	3	10
■ Avg Max	10	40	150

Appendices

A. Questionnaire ~ Survey of Department of Transportation

B. CPM Scheduling Seminar Notes

C. Questionnaire ~ KyTC District Construction Personnel Survey

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Appendix A –

Questionnaire ~

Survey of Department of Transportation

UNIVERSITY OF KENTUCKY

KENTUCKY TRANSPORTATION CABINET

CPM USAGE IN U.S. HIGHWAY PROJECTS

*** General Information:**

- Department of Transportation: (State)
- Address:
- Phone/Fax:
- Name of respondent:
- Title:

*** Planning and scheduling information:**

- What planning techniques do you use to schedule your project during the pre-construction phases ?
  - Bar charts
  - I-J networks (Arrow diagrams)
  - Precedence diagrams
  - Line of balance
  - Other (please state)
  - None of the above

- How often do you use CPM (Critical Path Method) scheduling techniques in planning your projects (during the pre-construction phases) ?
  - Always
  - Often
  - Seldom
  - Never

- Do you provide a milestone schedule in the bid documents?
  - Yes - No

- Do you require the contractor to submit a construction CPM schedule with the bid?
  - Yes - No

- How often do your contract conditions include clauses for CPM schedule preparation and updating?
  - Always
  - Often
  - Seldom
  - Never

- In case your contract requires a CPM schedule, what criteria control the use of it?
  - Always used
  - Degree of complexity
  - Dollar amount
  - Time constraints
  - Other (Please state)

- What problems have you had monitoring and/or controlling the CPM construction schedule?
  - We don't know how to follow-up the CPM schedule
  - The contractor does not know how to prepare/update the schedule
  - The schedule is not regularly and/or timely updated
  - Other (please state)
  - No problems
  - Not applicable

- How often do you require the contractor to update the CPM schedule?
  - Regularly
  - Occasionally
  - Upon problem occurrence
  - Never

- For what purposes have you used the CPM other than scheduling ?
  - Claims resolution
  - Cash flow preparation
  - Other (Please state)

- Do you have trained staff for criticizing/checking and revising the contractor submitted CPM schedules?

  - Yes　　　　　　　　-No

- Do you provide this training for your staff ?

  -Yes　　　　　　　　-No

- Would you be willing to share information about your CPM usage?

  -Yes　　　　　　　　-No

- Who should we contact?

  Name:　　　　　　　　　　Title:

  Phone/Fax

Appendix B –

Questionnaire ~

KyTC District Construction Personnel Survey

In order to provide a better set of project specifications to be integrated with the new standard specifications, we would like for you to help us out and take the time and complete this survey. *Thank you,*

The University of Kentucky, Civil Engineering Dept.

Please Circle Your DISTRICT (circle only one) 1 2 3 4 5 6 7 8 9 10 11 12

	minimum	average	maximum
1 How many projects you coordinate at any one time?			
2 How many activities do your projects have?			
3 How many days do your projects take?			

4 What forms of schedule do you receive from contractors?

Computer Generated Schedules, % ________

Hand Drawn Schedules, % ________

Written Explanations, % ________

5 Of the computer generated schedules you have received, what software was used? (as a percentage)

Primavera Project Planner, (%) ________

Primavera Sure-Track, (%) ________

Open Plan, (%) ________

Microsoft Project, (%) ________

Other, (%) (please specify) ________________

	not at all (never)						very (always)
6 Rate the complexity of your typical projects.	1	2	3	4	5	6	7
7 How often do you encounter a complex project?	1	2	3	4	5	6	7
8 Do you think schedules should be used for monitoring progress?	1	2	3	4	5	6	7
9 When there is a project schedule, do the contractors use it to monitor their progress?	1	2	3	4	5	6	7
10 When there is a project schedule, do you use it to monitor progress?	1	2	3	4	5	6	7
11 How technically competent do you feel about using a:	-	-	-	-	-	-	-
Bar chart schedule to measure progress?	1	2	3	4	5	6	7
Precedence schedule to measure progress?	1	2	3	4	5	6	7
12 How comfortable do you feel monitoring a contractors progress with a:	-	-	-	-	-	-	-
Bar chart schedule?	1	2	3	4	5	6	7
Precedence schedule?	1	2	3	4	5	6	7
13 Are you in favor of using computer generated schedules?	1	2	3	4	5	6	7
14 Do you think that you need additional training in using Precedence CPM schedule	-	-	-	-	-	-	-
for project management?	1	2	3	4	5	6	7
15 How often do you encounter projects that need scheduling?	1	2	3	4	5	6	7

(More information in the back of the page)

Appendix C –

CPM Scheduling Seminar Notes

CRITICAL PATH METHODS SCHEDULING SEMINAR

for

The Kentucky Transportation Cabinet

by

The University of Kentucky
Civil Engineering Department
And
Kentucky Transportation Center

Donn E. Hancher, Ph.D., P.E.
Raymond F. Werkmeister, P.E.
Sion L. Tesone

CPM Scheduling Seminar for KyTC

University of Kentucky
Lexington, Kentucky

AGENDA

8:00 am	**Sign In - Coffee & Doughnuts**
8:30 am	**Introduction to Scheduling** **Bar Charts** **Critical Path Methods** **Conceptual Scheduling**
	Precedence CPM **Logic Diagram** **Time Calculations**
10:30 am	**Break**
	A CPM Example **Calculation of Float**
	Reading the CPM Diagram **CPM to Calendar Day Conversions** **The Critical Path**
12:00 noon	**Lunch**
	Introduction to Scheduling Software
	A Project Schedule Example Problem
1:30 pm	**Break**
	Summary Session
2:30 pm	**Departure**

CPM Scheduling Seminar for KyTC

University of Kentucky
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AGENDA

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8:30 am	**Introduction to Scheduling**
	    Bar Charts
	    Critical Path Methods
	    Conceptual Scheduling

	Precedence CPM
	    Logic Diagram
	    Time Calculations

10:30 am	**Break**
	A CPM Example **Calculation of Float**

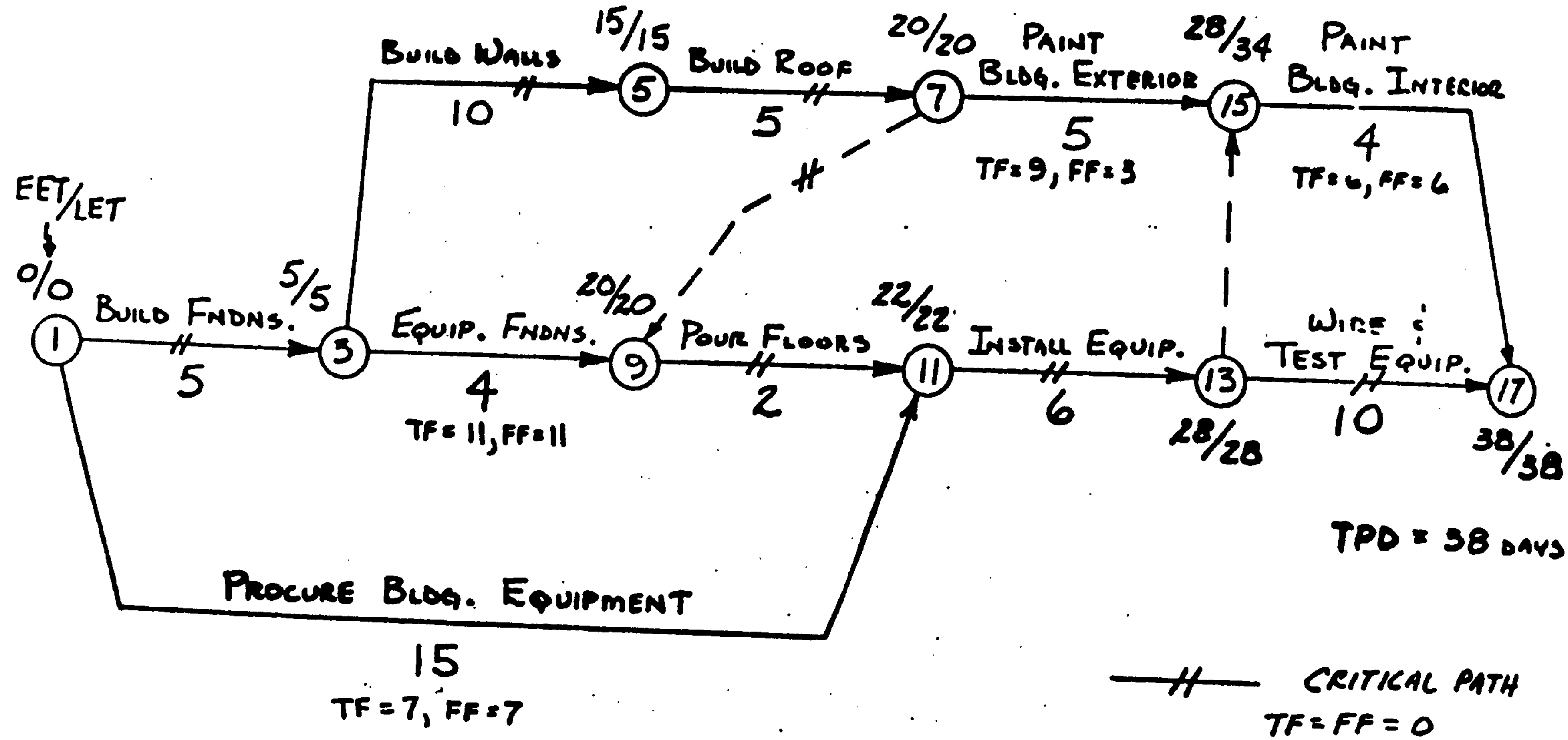
	Reading the CPM Diagram
	    CPM to Calendar Day Conversions
	    The Critical Path

12:00 noon	**Lunch**
	Introduction to Scheduling Software
	A Project Schedule Example Problem
1:30 pm	**Break**
	Summary Session
2:30 pm	**Departure**

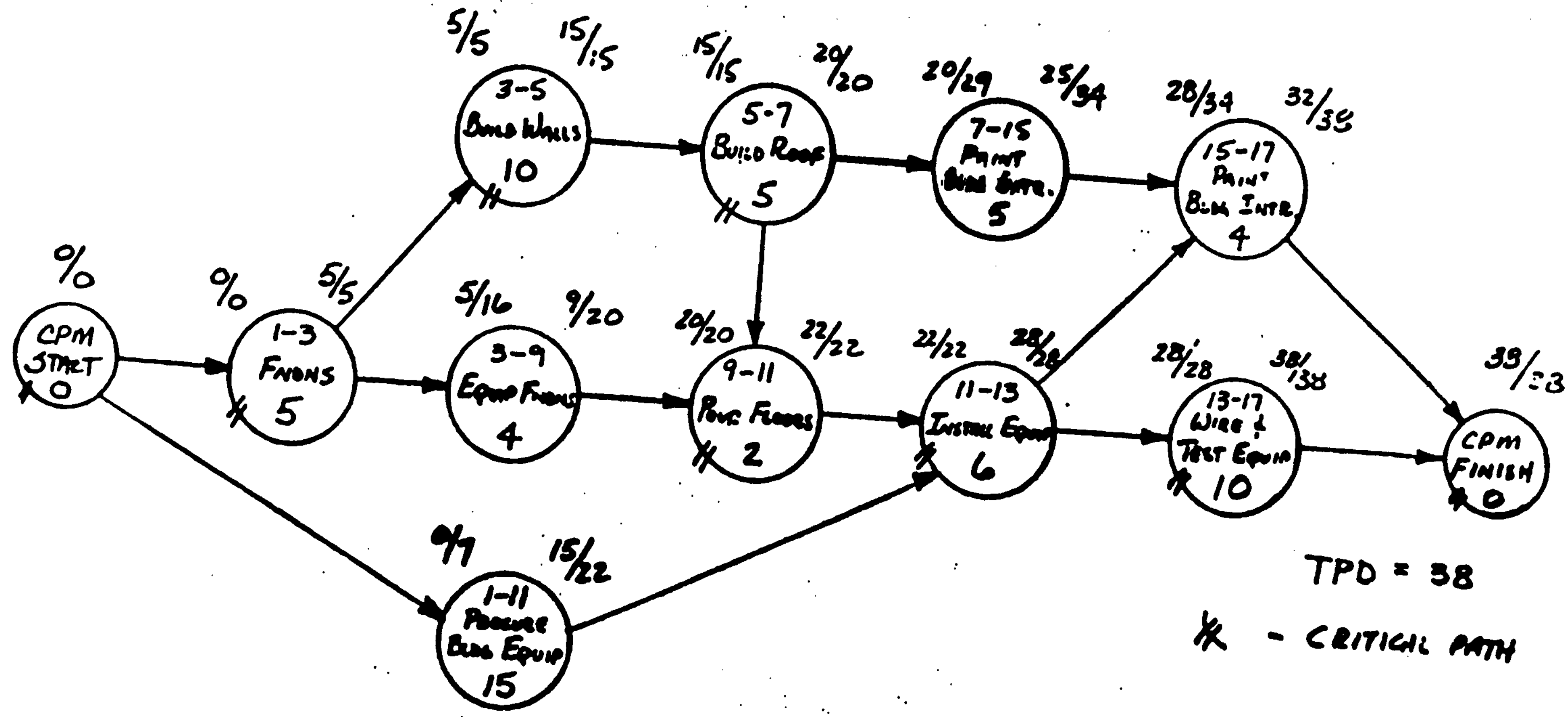
List of Overhead Figures

Construction Planning and Scheduling

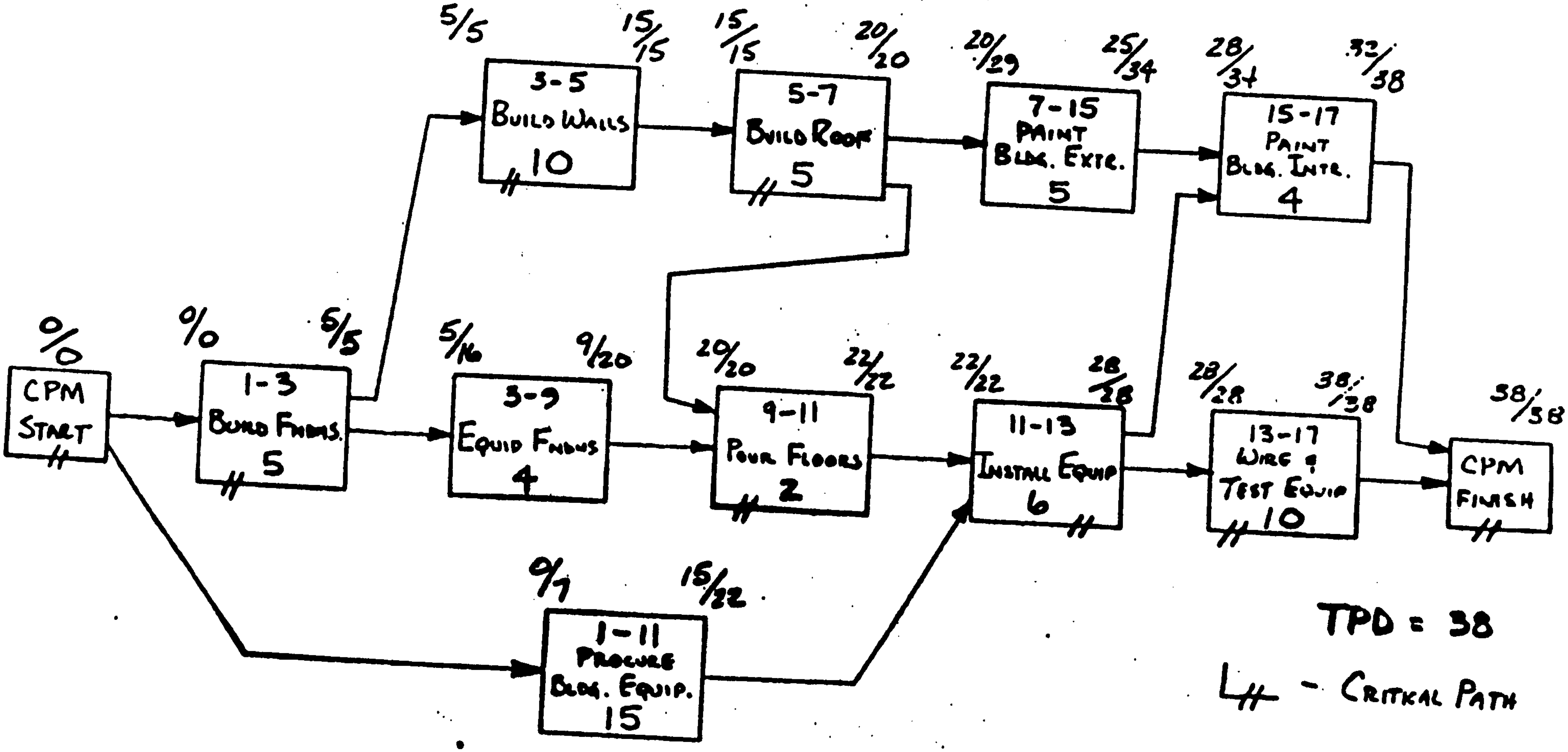
- Construction Projects - "Key to Profit"
- Construction Project Mgmt. - "Unique"
- Bar Charts
- Critical Path Methods



"I-J" CPM Diagram

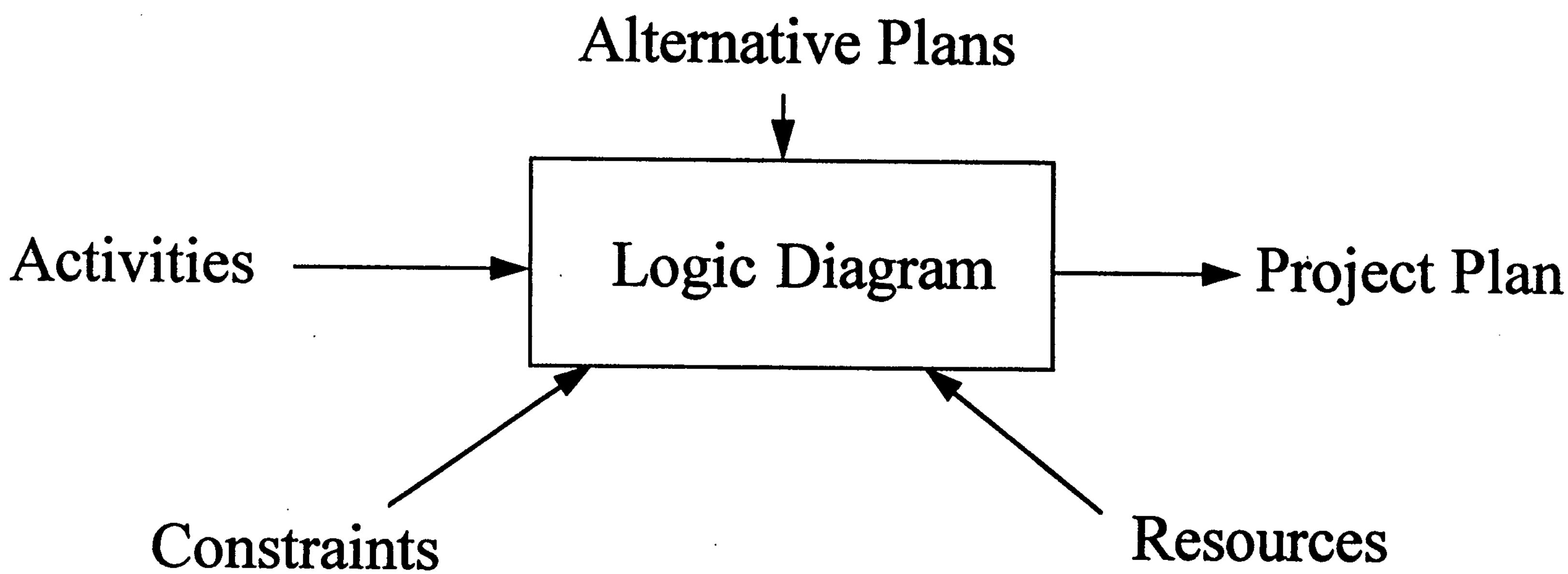


ACTVITY-ON-NODES CPM DIAGRAM



"PRECEDENCE" CPM DIAGRAM

Planning



- Level of Detail = ??
- Activity Ordering = ??
- Time Estimates = ??

Scheduling

- Time Calculations
  - Activity starting & finish times
  - Total project duration
  - Activity float times
  - Critical path or paths
- Other Project Scheduling
  - Financial funds flow
  - Resource scheduling and leveling
  - Inplement weather simulation
- Replanning and Scheduling
  - **Feasible construction schedule!!!**

Critical Path Techniques

<u>Deterministic</u>

- Activities-on-Arrows
  - I-J
- Activities-on-Nodes
  - Precedence

<u>Probabilistic</u>

- PERT

–Better suited to construction!

–Both do a good job!

–Should look at both thoroughly!

Advantages of Planning with CPM

1 CPM encourages a local discipline in the planning, scheduling, and control of projects.

2 CPM encourages more long-range and detailed planning of projects.

3 All project personnel get a complete overview of the total project.

4 CPM identifies the most critical elements in the plan, focusing management's attention to the 10 to 20 percent of the project that is most constraining on the schedule.

5 CPM provides an easy method for evaluating the effects on technical and procedural changes which occur on the overall project schedule.

Controlling or Monitoring

Time and Money - Compare to Budget

Deviations - Replanning and Rescheduling!

"MINIMIZE COSTS"

> Largest cause for unsuccessful applications of CPM in construction = Lack of monitoring!

Frequency of Updating CPM Schedules ???

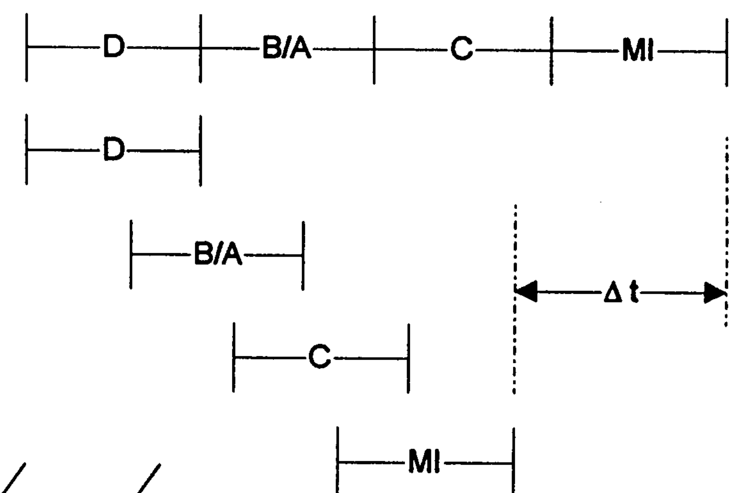
Types of Activities

- Planning and Approvals
- Design
- Contract Awards / Fabr. / Deliver
- Construction
- Commissioning
  - Move-in & Start up

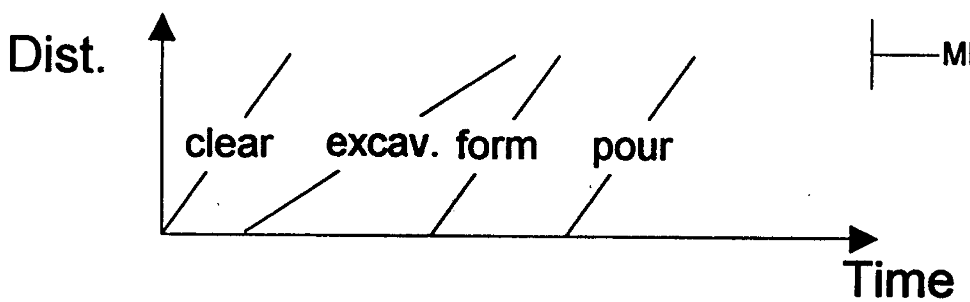
Types of Schedules

- Master Control - Major milestones & subnets

- Traditional →
- Fast Track →



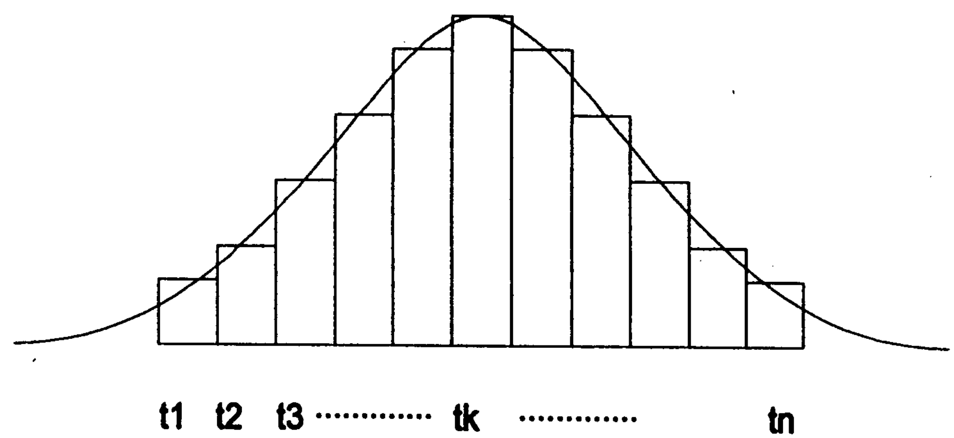
- Linear Schedules



Activity Durations

"From Experience"

$$X = \frac{\sum_{1}^{n} t_k}{n}$$



Critical Data Concerns ???

Factors Impacting Duration's ???

Activity Time Issues

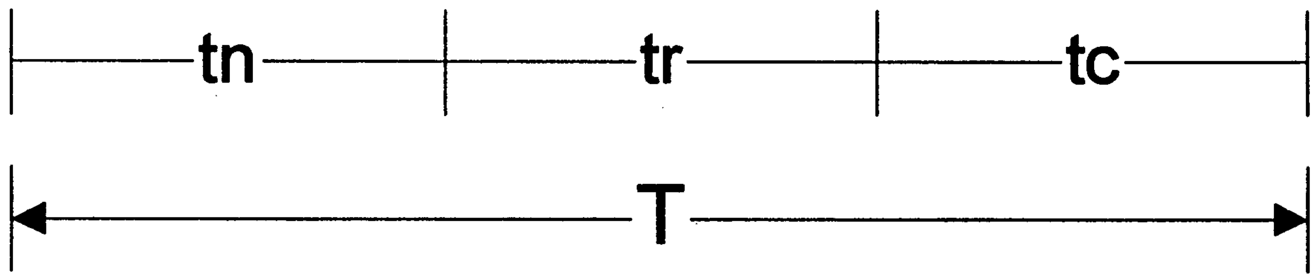
1 Workdays Vs. calendar days Vs. CPM days

2 Other time bases - months, weeks, hours

3 Efficiency - 100% production Vs. delays

- Routine delays - Job mgmt, job conditions
- Contingency delays - Predictable Vs. non-predictable

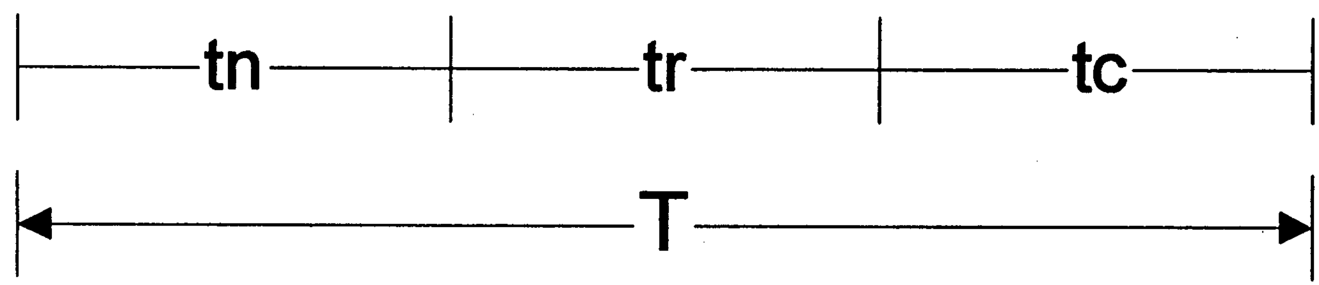
4 Basic time calculation $T = Q / P$



- $P_{peak} = Q / t_n$
- $P_{normal} = Q / (t_n + t_r)$
- $P_{average} = Q / (t_n + t_r + t_c) = Q / T$

<u>Definitions:</u>

t_n = normal, t_r = routine, t_c = contingency.

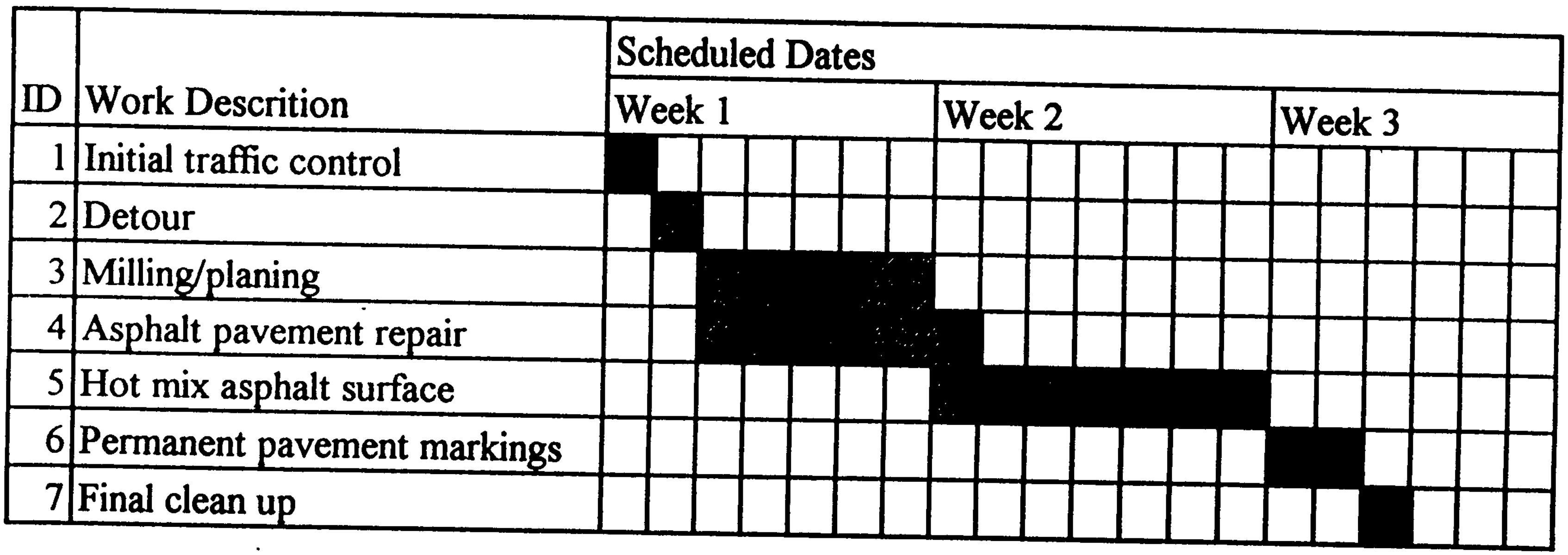


Contract Time ($t_{required}$) - Most often set by owner !!

- $P_{required} = Q / t_{reqd}$
- $P_{equip} = EIH / C$

"Contract Documents"

Gantt (bar) chart



CONCEPTUAL PROJECT PLANNING DATA FOR:

BRIDGE DECK OVERLAY PROJECTS

NO.	STANDARD ACTIVITY DESCRIPTION	UNITS FOR WORK QUANT	L.SUM DUR. OR DAILY PROD RATE
1	Move In	Lump Sum	3 Days
2	Concrete Scarification	Sq. Yds.	3000 Syds/Day
3	Bridge Deck Patching	Sq. Ft.	700 Sft/Day
4	Overlay Dams	Sq. Ft.	300 Sft/Day
5	Blast & Clean Deck	Lump Sum	1 Day
6	Place Overlay	Sq. Yds.	1000 Syds/Day
7	Cure Deck Overlay	Lump Sum	4 Days
8	Install B.S. Joints	Lin. Ft.	200 Lft/Day
9	Reset Bridge Rail	Lin. Ft.	400 Lft/Day
10	Place Bituminous Wedge	Lump Sum	2 Days
11	Epoxy Surface Seal	Lump Sum	1 Day
12	Clean & Paint Str. Steel	Lump Sum	10 Days
13	Guardrail	Lump Sum	2 Days
14	Incidentals & Clean Up	Lump Sum	10 Days

CONCEPTUAL PROJECT PLANNING DATA FOR:

STANDARD INTERSECTION/ROAD (ASPHALT) PROJECTS

Finish Time	STANDARD ACTIVITY NO.	DESCRIPTION	UNITS FOR WORK QUANT	L.SUM DUR. OR DAILY PROD RATE
	1	Utility Relocation	Lump Sum	Per Project
	2	Move In	Lump Sum	3 Days
3	3	Clearing R/W	Lump Sum	2 Days
	4	Retaining Walls	Lin. Ft.	8 Lft/Day
5	5	Removal Items (add all items collectively into single duration)		
		a) Concrete Curb	Lin. Ft.	500 Lft/Day
		b) Conc. Center Curb	Sq. Yds.	300 Syds/Day
		c) Retaining Wall	Lin. Ft.	100 Lft/Day
		d) Guardrail	Lin. Ft.	800 Lft/Day
		e) Bldg. Demolition	Lump Sum	4 Days
	6	Pavement Removal		
		a) Concrete Pvmt. Removal	Sq. Yds.	800 Syds/Day
		b) Asphalt Surface Removal	Sq. Yds.	1600 Syds/Day
8	7	Common Excavation	Cu. Yds.	800 Cyds/Day
	8	Borrow	Cu. Yds.	1200 Cyds/Day
33	9	Drainage Structures	Lin. Ft.	150 Lft/Day
	10	Underdrains a) Intersection	Lin. Ft.	100 Lft/Day
39		b) Road	Lin. Ft.	500 Lft/Day
	11	a) Curbs/Curbs & Gutter	Lin. Ft.	300 Lft/Day
38		b) Center Curbs	Sq. Yds.	300 Syds/Day
	12	Drives	Sq. Yds.	300 Syds/Day
	13	Sidewalks	Sq. Yds.	200 Syds/Day
	14	Sub-base	Tons	900 Tons/Day
	15	Base Course	Tons	700 Tons/Day
	16	Binder Course	Tons	700 Tons/Day
	17	Adjust Castings	Each	10/Day
	18	Seeding & Sodding	Lump Sum	2 Days
	19	Surface Course	Tons	500 Tons/Day
	20	Complete Traffic Signals	Lump Sum	1 Day
	21	Incidentals & Clean Up	Lump Sum	15 Days

CONCEPTUAL CONSTRUCTION SCHEDULE WORKSHEET

PROJECT: SAMPLE IDOT PROJECT **DATE:** / /

TYPE OF PROJECT: ASPHALT ROAD **BY:** DEH

No.	Work Item	Quantity	Daily Prod. Rate	Act. Dur.	Preceding Activity(s)	Start Time	Fin Tim
1	UTILITY RELOCATION	0	—	0	—	—	—
2	MOVE IN	L. Sum	—	3	—	1	3
3	CLEAR R/W	L. Sum	—	2	2	4	5
4	RETAINING WALLS	0	—	0	3	—	—
5	REMOVAL ITEMS	0	—	0	3	—	—
6	PAVEMENT REMOVAL	359 SYD 3765 SYD	800 SYD 1600 SYD	0.45 2.35			
"	"	TOTAL DUR	= 2.80 =	3	3	6	8
7	COMMON EXCAVATION	19,516 CYD	800 CYD	25	4,5,6	9	33
8	BORROW	7061 CYD	1200 CYD	6	7	34	39
9	DRAINAGE STRUCTURES	7351 LFT	150 LFT	49	8	40	88
"	GROUP D – 12" REINF CONC. – 6"	(64 LIN FT) (23 LFT)	DUCTILE IRON REINF CONC.	– 8" – 12"	(18 LFT) (2867 LFT)		
"	" " – 15" " " – 21"	(414 LFT) (517 LFT)	" " " "	– 18" – 24"	(188 LFT) (200 LFT)		
"	" " – 27" DRAINTILE – 6"	(217 LFT) (200 LFT)	" " BOX CULVERT –	– 30"	(932 LFT) (121 LFT)		
"	7351 LFT	TOTAL @ 150 LFT/DAY		= 49.01 DAY = 49			
10	UNDERDRAINS	10,753 LFT	500 LFT	22	8	40	61

CONCEPTUAL CONSTRUCTION SCHEDULE WORKSHEET

PROJECT: Sample IDOT Project (cont) **DATE:** / /

TYPE OF PROJECT: Asphalt Road **BY:** DEH

No.	Work Item	Quantity	Daily Prod. Rate	Act. Dur.	Preceding Activity(s)	Start Time	
11	CURBS	↓	↓	21	9,10	89	
"	a) Conc. Curb + Comb. Curb/Gutter	9848 LFT	300 LFT	32.83 days	Too CREWS	LONG, USE = 16.[illegible]	
"	b) Conc. Center Curb	1171 SYDS	300 SYD	3.90 days	[TOTAL	= 20.32 USE 21	
12	DRIVEWAYS	1900 SYDS	300 SYD	7	9,10	89	[illegible]
13	SIDEWALKS	3113 SYDS	200 SYD	16	11,12	110	1
14	SUB-BASE	760 TON	900 TON	1	11,12	126	1
15	BASE COURSE	16,346 TON	700 TON	24	14	127	1[illegible]
16	BINDER COURSE	3640 TON	700 TON	6	15	151	15
17	ADJUST CASTINGS	12 EA	10	1	16	157	15
18	SEEDING & SODDING	L. SUM	—	2	13	126	12
19	SURFACE COURSE	1820 TON	500 TON	4	17,18	158	16
20	COMPLETE TRAFFIC SIGNALS	L. SUM	—	1	19	162	16
21	INCIDENTALS & CLEAN UP	L. SUM	—	15	20	163	17
		" TOTAL PROJECT DURATION = 177 WORK DAYS "					

1. SEAL COAT

MAJOR WORK ITEMS	PRECEDING ACTIVITIES & RELATIO (% complete of predecessor)
1. Initial traffic control	-
2. Detour	1, 100%
3. Pavement repair	
A. Asphalt	2, 100%
B. Concrete	2, 100%
4. One-course surface treatment	3, 100%
5. Permanent pavement markings	4, 100%
6. Final clean up	5, 100%

2. OVERLAY

MAJOR WORK ITEMS	PRECEDING ACTIVITIES & RELATIONS (% complete of predecessor)
1. Initial traffic control	-
2. Detour	1, 100%
3. Milling/planing	2, 100%
4. Pavement repair	
A. Asphalt	2, 100%
B. Concrete	2, 100%
5. Concrete paving	3, 75% ; 4B, 75%
6. Hot mix asphalt surface	3, 75% ; 4A, 75%
7. Permanent pavement markings	5, 100% ; 6, 100%
8. Final clean up	7, 100%

3. REHABILITATE EXISTING ROAD

MAJOR WORK ITEMS	PRECEDING ACTIVITIES & RELATIONSHIP (% complete of predecessor)
1. Initial traffic control	-
2. Detour	1, 100%
3. ROW Preparations	2, 100%
A. Clear and grub	
B. Remove old structures (small)	
C. Remove old pavement	
D. Remove old curb & gutter	
E. Remove old sidewalks	
F. Remove old drainage/utility structur	
4. Excavation/embankment	
A. Earth excavation	3, 25%
B. Rock excavation	3, 25%
C. Embankment	3, 25%
5. Drainage structures/storm sewers	
A. Pipe	4A, 10% ; 4B, 10%
B. Box culverts	4A, 10% ; 4B, 10%
C. Inlets & Manholes	5A, 10%
6. Base preparations	
A. Lime stabilization	4A, 50% ; 4C, 50% ; 5A, 75% ; 5B, 75%
B. Flexible base material	6A, 75%
C. Cement treated base material	6A, 75%
7. New curb and gutter	6B, 75% ; 6C, 75%
8. Pavement repair	
A. Asphalt	3, 75%
B. Concrete	3, 75%
9. Milling/planing	3, 75%
10. Hot mix asphalt base	5C, 100% ; 7; 75%
11. Concrete paving	5C, 100% ; 6B, 100% ; 6C, 100% ; 9, 100%
12. One-course surface treatment	8A, 100%
13. Hot mix asphalt surface	8A, 100% ; 8B, 100% ; 9, 100% ; 10, 100%
14. Permanent pavement markings	11, 100% ; 12, 100% ; 13, 100%
15. Final clean up	14, 100%

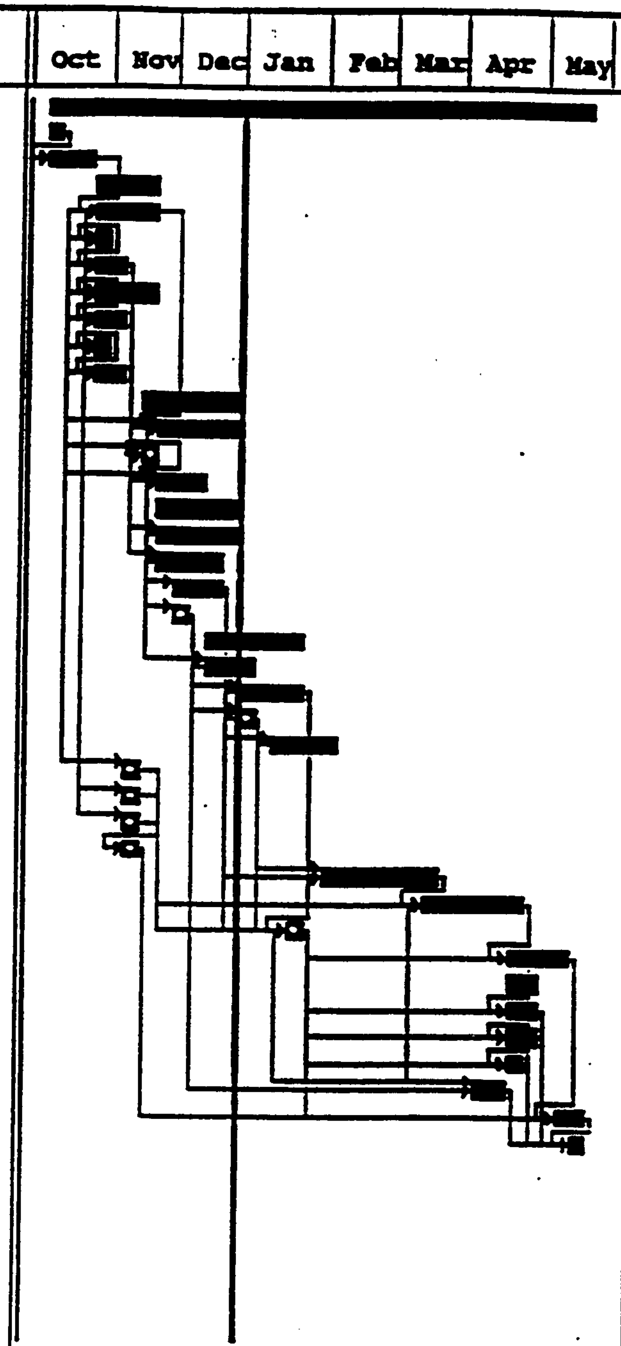
CONCEPTUAL CONSTRUCTION SCHEDULE WORKSHEET

Project: EXAMPLE OVERLAY PROJECT

Date.

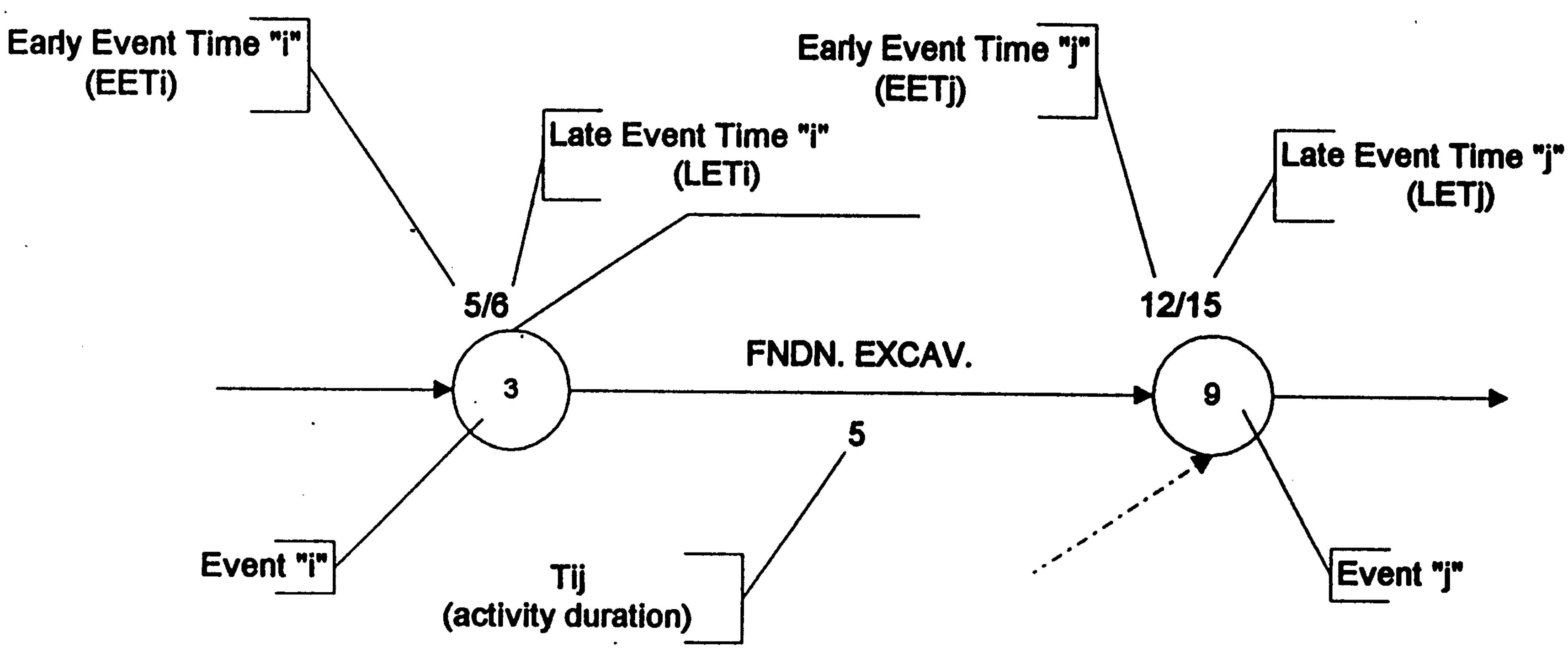
ID No	Work Item	Quantity & Unit	Daily Production Rate	Duration (days)	Preceding Activities & Relationships (% complete of pred)	Start Time	Finish Time	Workdays (0 5 10 15 20 25 30 35)
1	SET UP TRAFFIC CONTROL	L.S.		1	-	1	1	
2	DETOUR	L.S.		3	1, 100%	2	4	
3	REMOVE OLD PAVEMENT	6700 SY	700 SY	10	1, 100% ; 2, 100%	5	14	
4	PAVEMENT REPAIR	500 SY	100 SY	5	1, 100% ; 2, 100%	5	9	
5	CONCRETE PAVING	-		-				
6	HOT-MIX ASPHALT BASE	5000 t	500 t	10	3, 80% ; 4, 80%	13	22	
7	HOT-MIX ASPHALT SURFACE	4000 t	700 t	6	6, 100%	23	28	
8	PERMANENT PAVEMENT MARKINGS	22,000 LF	9000 LF	3	7, 100 %	29	31	
9	FINAL CLEAN-UP	L.S.		2	8, 100 %	32	33	

Heading/Task 7 Days Per Column	Schd Dur
CNF-PH1.PJ	164d
Initial Traf. Control	3d
Detour	12d
ROW Preparations	20d
Major struc. demoli'n	20d
Clear & Grub	4d
Rmv. old strc.(small)	10d
Rmv. old pavement	16d
Rmv old curb & gutter	9d
Rmv. old sidewalks	3d
Rmv old drai/util str	9d
Excavation/Embankment	23d
Earth Excavation	23d
Rock Excavation	0dy
Embankment	12dy
Drainage str/Storm sw	18dy
Pipe	18dy
Box Culverts	13dy
Inlets & Manholes	11dy
Retaining Walls	0dy
Base Preparations	26dy
Lime Stabilization	13dy
Flexible Base Mater'l	16dy
Cement Treated Base M	0dy
New Curb & Gutter	15dy
Asph. Pavement Repair	0dy
Conc. Pavement Repair	0dy
Milling/Planing	0dy
One-course Surf. Trmt	0dy
Hot-mix Asphalt Base	33dy
Hot-mix Asphalt Surf.	22dy
Concrete Paving	0dy
Precast Traf. Bar'ers	15dy
Signing/Traf. Signals	6dy
Small signs	6dy
Overhead signs	6dy
Major traffic signals	4dy
Seeding & Landscaping	10dy
Pavement Markings	5dy
Final Clean-up	3dy



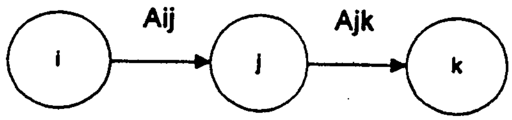
Unassigned
Critical
Interrupted
Milestone
Noncritical

Terminology for "I-J" CPM activities



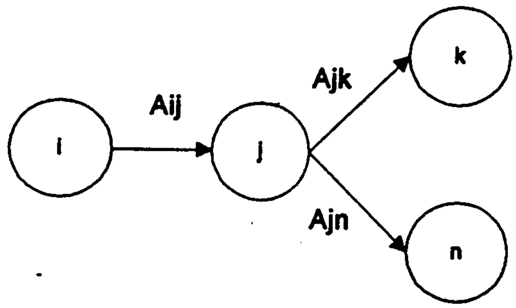
Typical Activity Relationship for Activities-on-arrows CPM

SEQUENTIAL



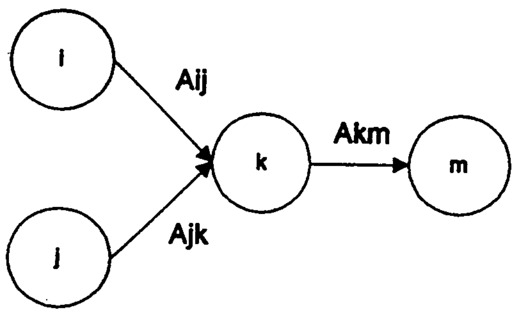
Activity Ajk can commence only after activity Aij is completed

DIVERGING
(Separating)



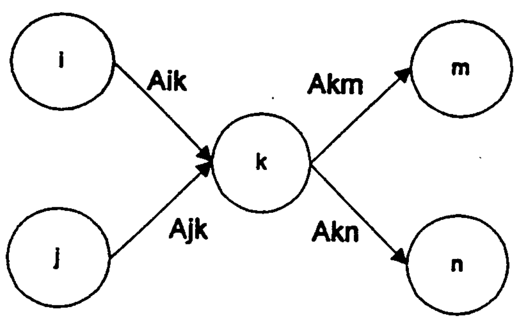
Activities Ajk and Ajn cannot begin until activity Aij is completed. However, activities Ajk and Ajn can then proceed concurrently

CONVERGING
(Combining)



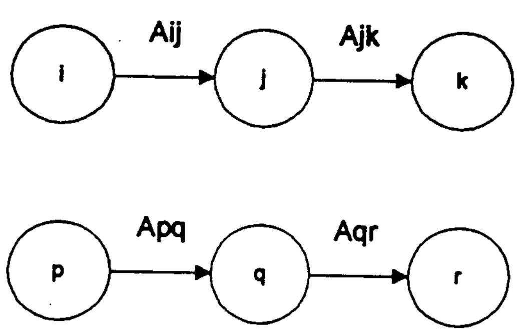
Activity Akm can commence only after activities Aik and Ajk are completed. Activity Aik can be begun independently of activity Ajk and vice versa

COMPLEX



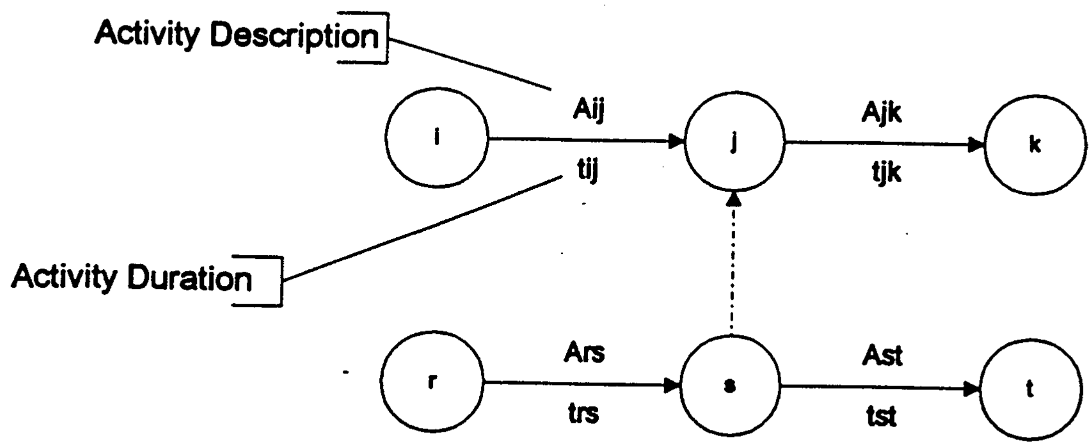
Neither activity Akm nor activity Akn can commence until activities Aik and Ajk are completed. Activity Aik can commence independently of activity Ajk, and vice versa

CONCURRENT

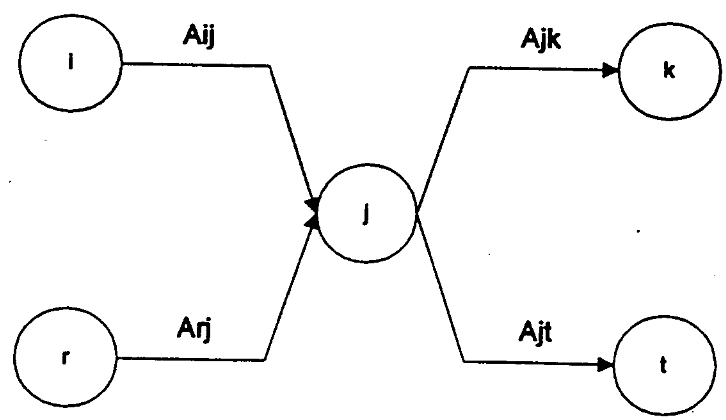


Activities Aij and Ajk are sequential, but independent of activities Apq and Aqr. Activities Apq and Aqr are sequential but independent of activities Aij and Ajk

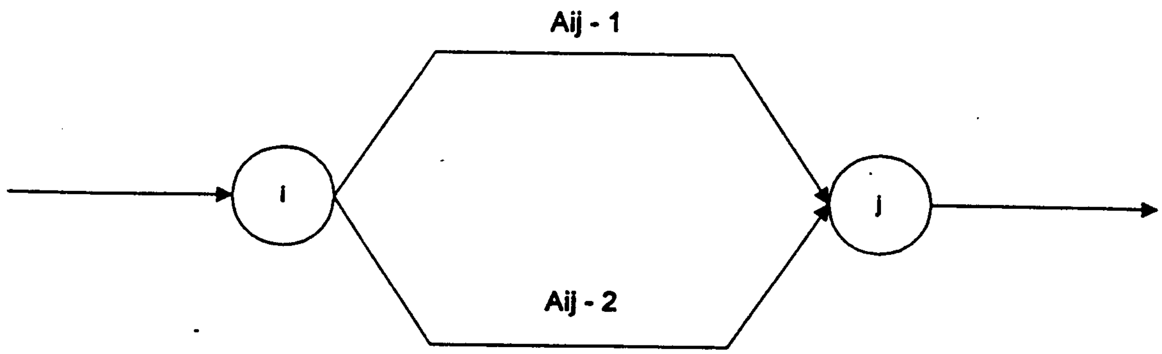
Correct Use of Dummy Activity



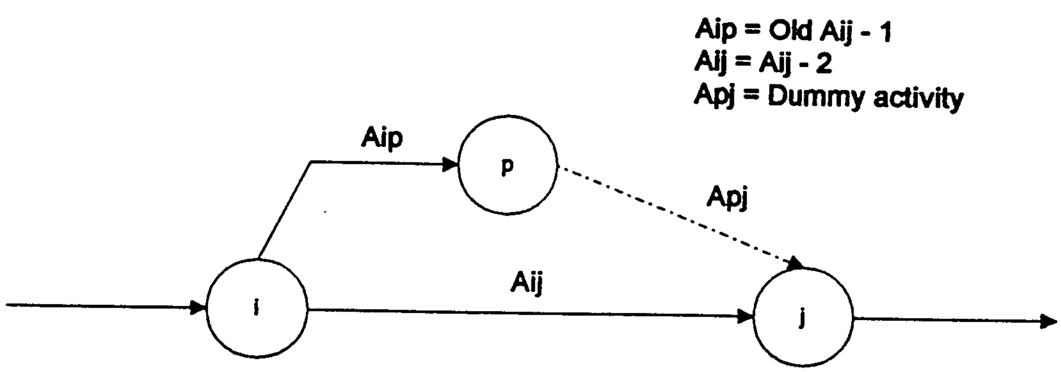
Incorrect Use of Dummy Activity



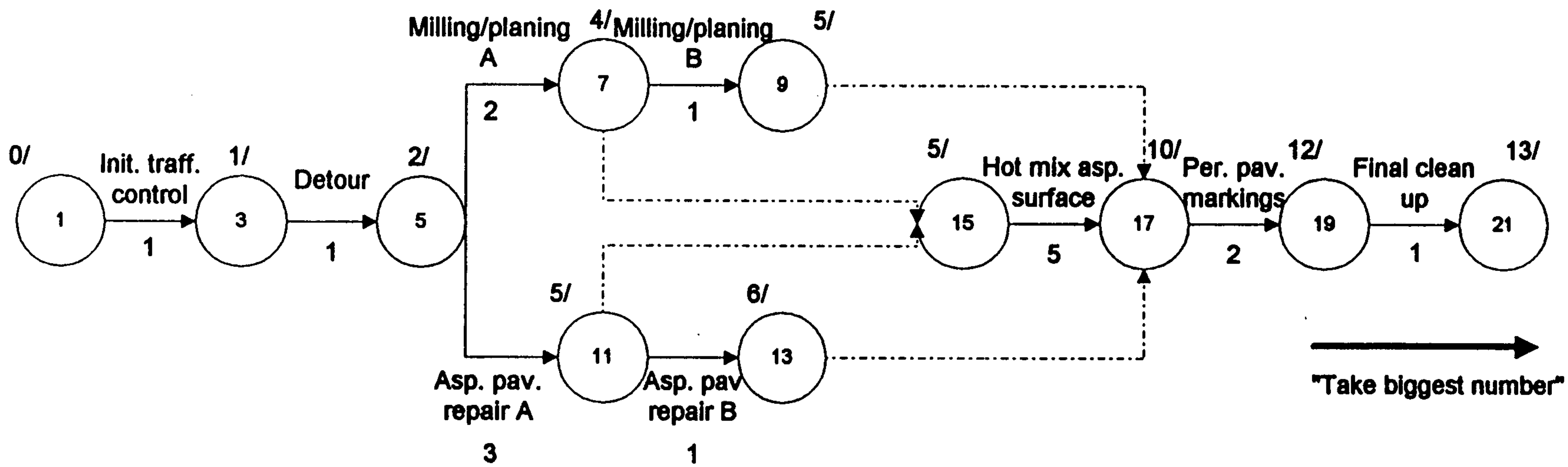
Incorrect Nodes for Parallel Activities



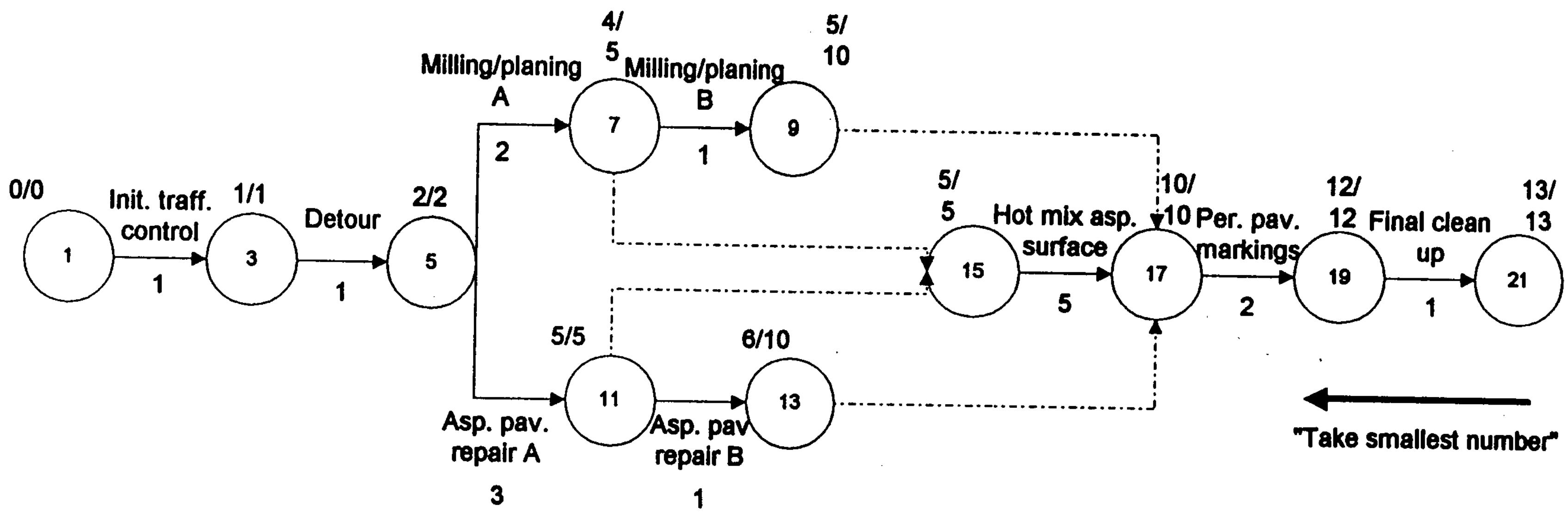
Correct Nodes for Parallel Activities



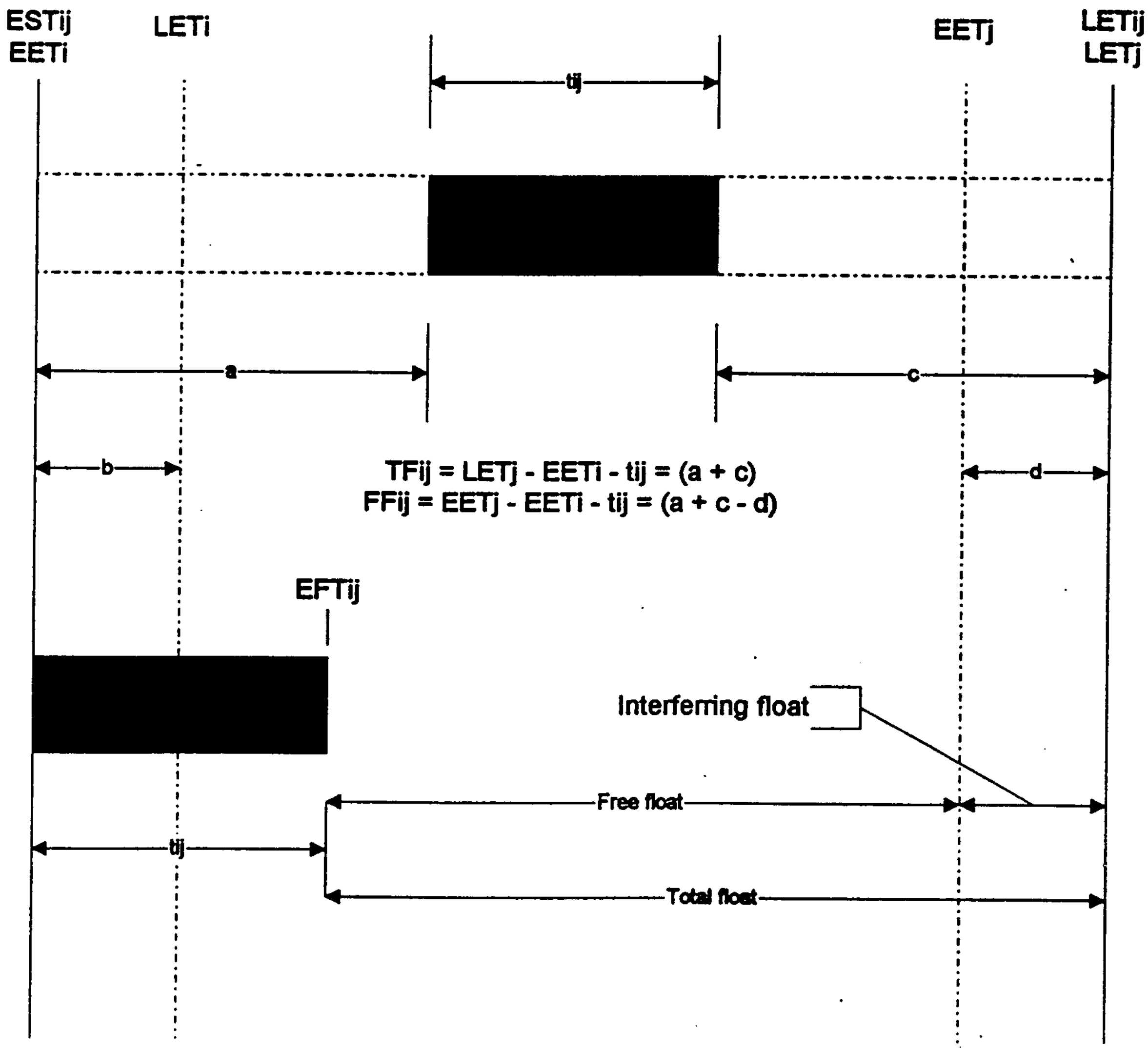
Forward Pass for "I-J" CPM



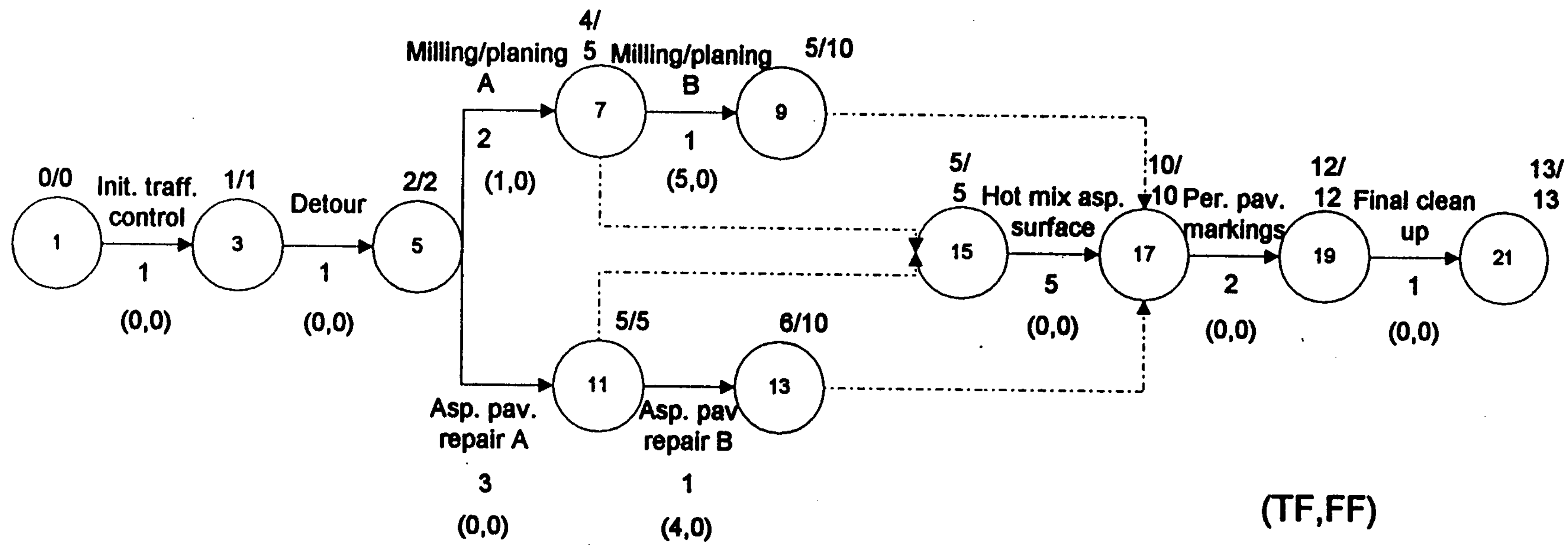
Reverse Pass for "I-J" CPM



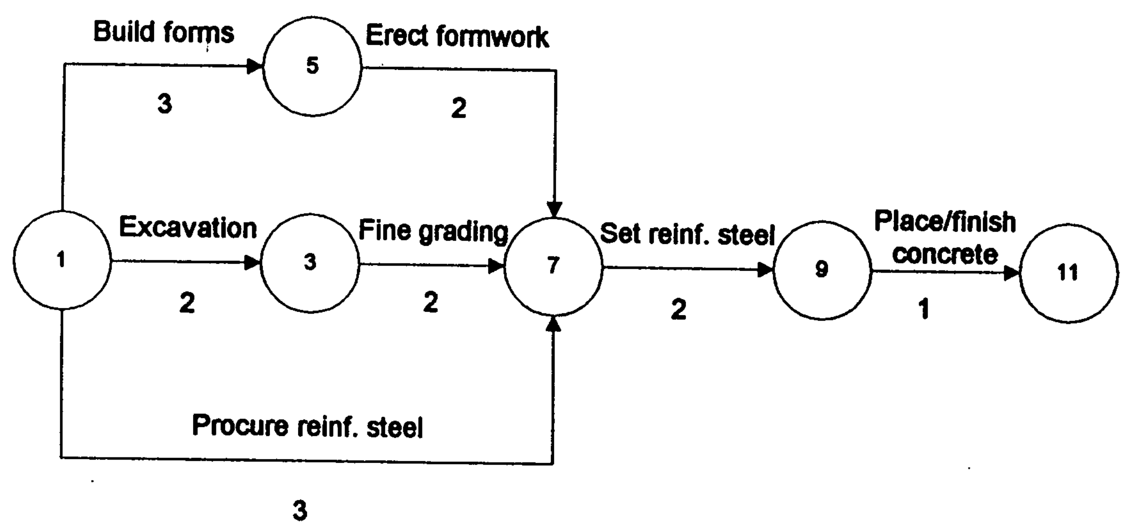
Graphic Representation of Float for CPM



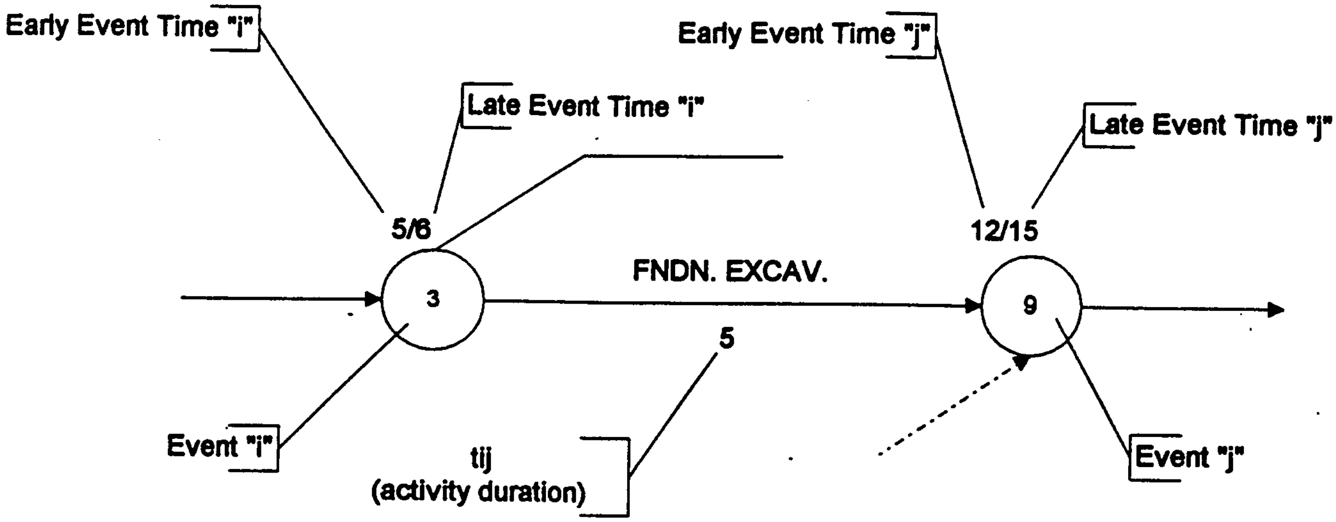
"I-J" CPM Logic Diagram with Float Times



"I-J" CPM Activities and Diagram



CPM/CAL Conversion Chart



CPM	*CAL (February '97)*	
	2	
0	3	Project start date
1	4	
2	5	
3	6	
4	7	
	8	
	9	
5	10	
6	11	
7	12	

CPM	*CAL*
8	13
9	14
	15
	16
10	17
11	18
12	19
13	20
14	21
	22
	23
15	24

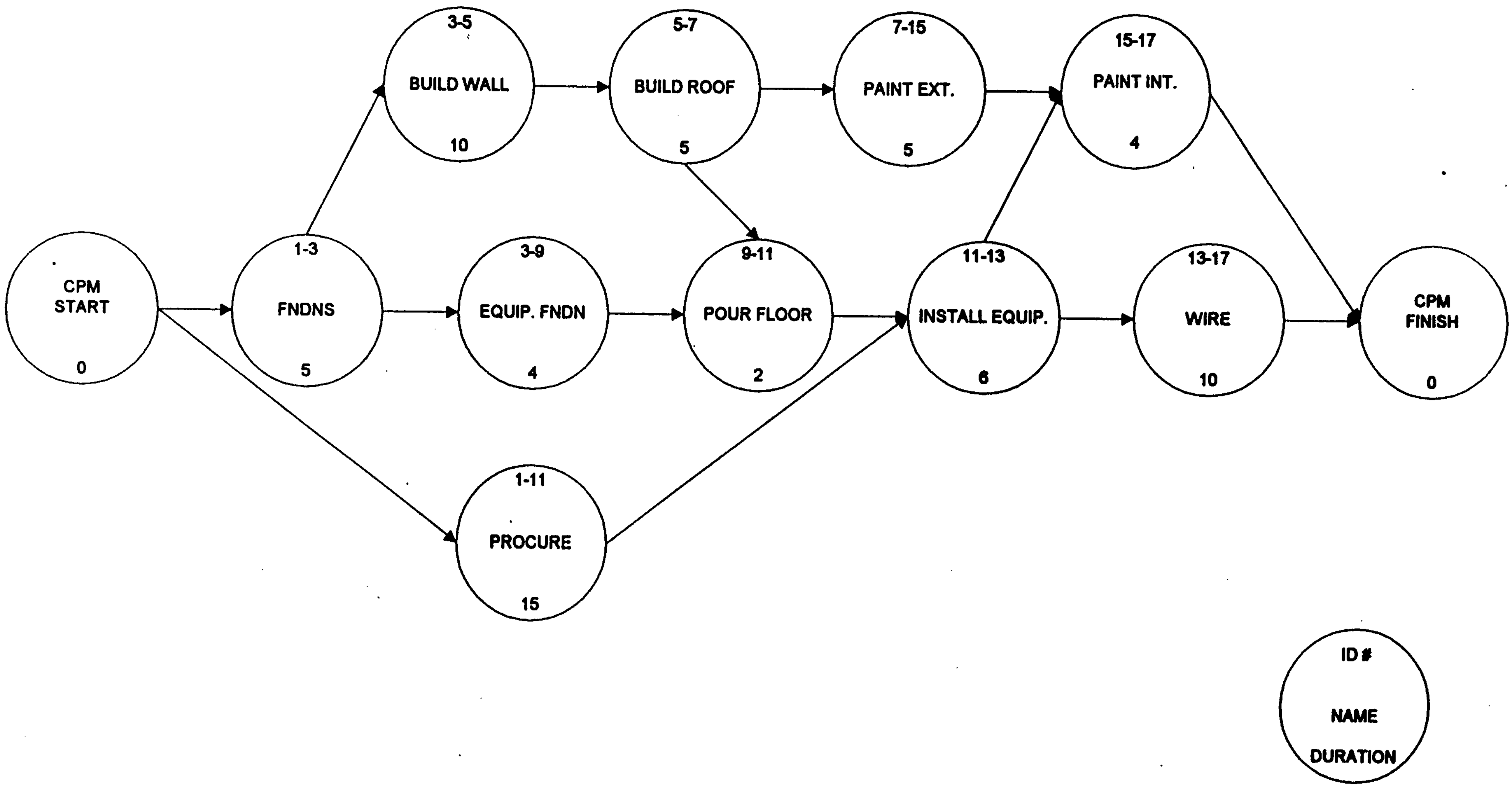
<u>NOTE:</u> CPM day (X) = work day (X + 1)
(i.e. CPM day 0 = project work day 1)

<u>CALCULATIONS</u>

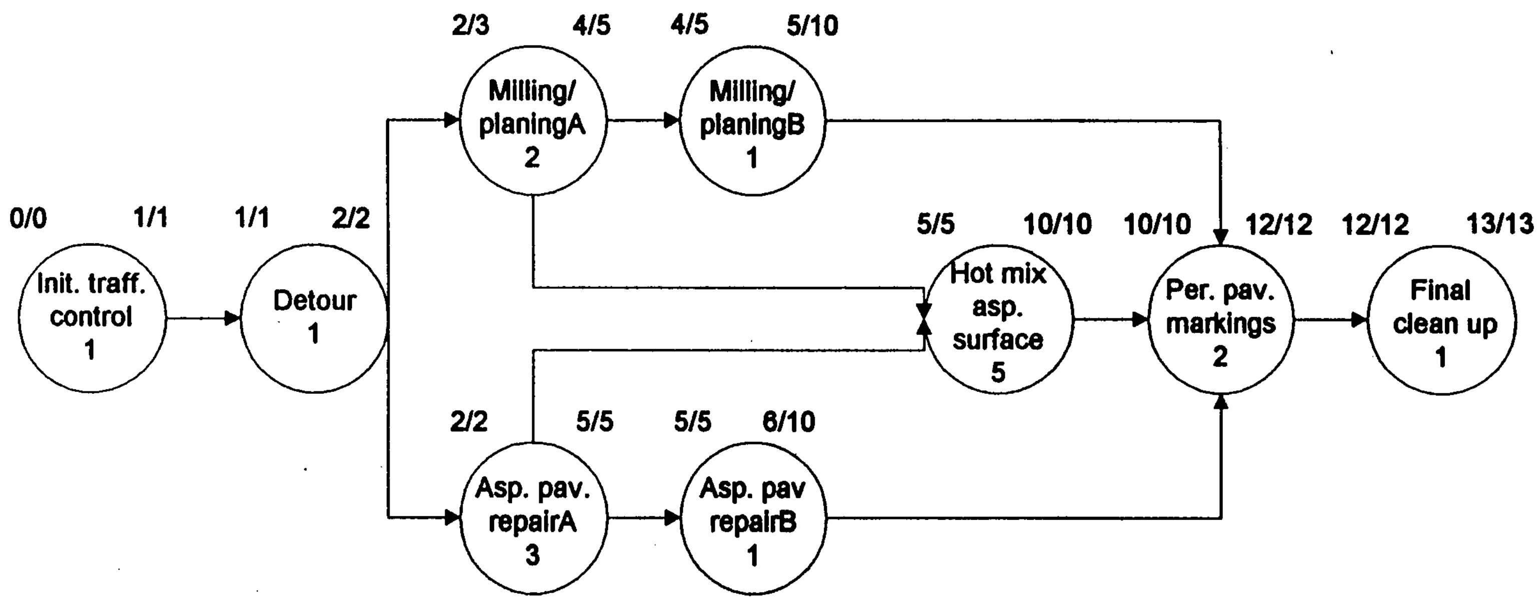
EST = 5 = Feb. 10, '97
LST = 10 = Feb. 17, '97

EFT = 10 = Feb. 14, '97
LFT = 15 = Feb. 21, '97

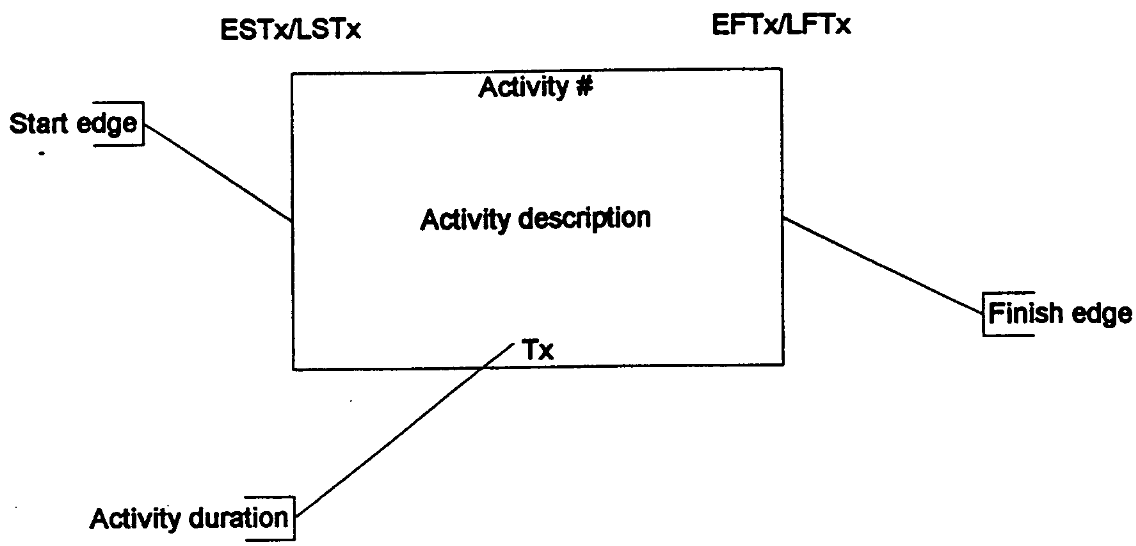
"Activity-on-Nodes" CPM Diagram

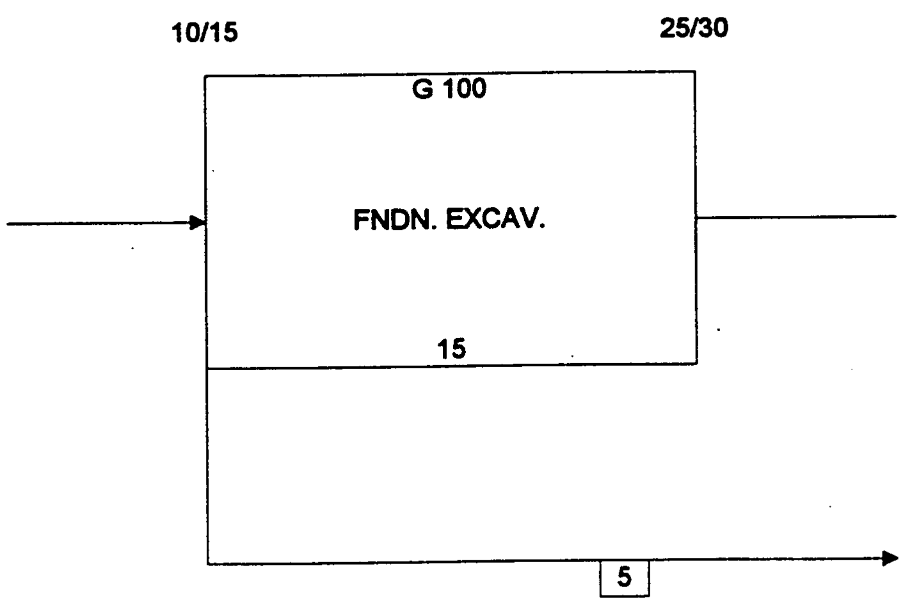


"Activity-on-Nodes" CPM diagram



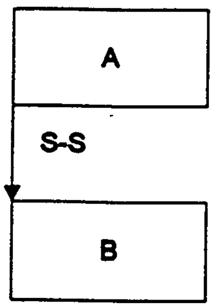
Precedence Activity Information





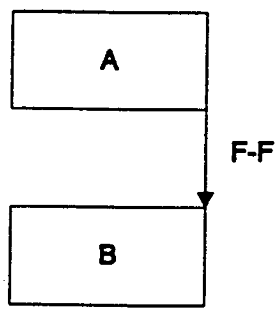
Precedence CPM Activity Relationships

Start to Start



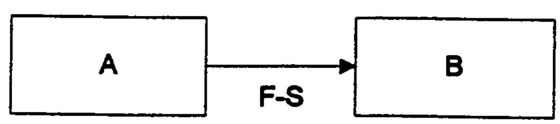
The start of B depends on the starting of A

Finish to Finish



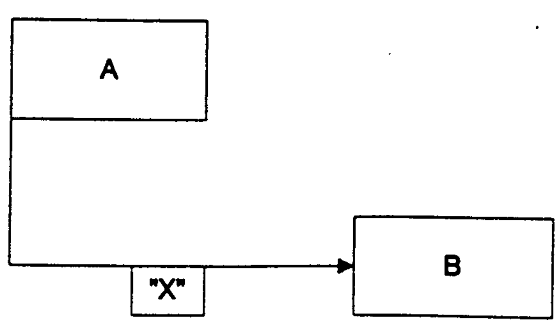
The finish of B depends on the finish of A

Finish to Start



The start of B depends on the finishing of A

Lag



B can't start until "X" days of work are done on A

Time Calculation Rules for Precedence Networks

I. Earliest Start Time

a. EST of 1st Work Item is zero (by definition).
EST of all other W.I.'s is the greater of these times:
1 EST of a preceding W.I. if start-start relation.
2 EFT of a preceding W.I. if finish-start relation.
3 EFT of a preceding W.I., less the duration of the W.I itself, if finish-finish relation.
4 EST of a preceding W.I., plus the lag, if there is a lag relation.

II. Earliest Finish Time

a. For 1st Work Item, EFT = EST + Duration
b. EFT of all other W.I.'s is the greater of these times:
1 EST of W.I. plus its duration.
2 EFT of preceding W.I. if finish-finish relation.

III. Latest Finish Time

a. LFT for last Work Item is set equal to its EFT
b. LFT for all other W.I.'s is the lesser of these times:
1 LST of following W.I. if finish-start relation.
2 LFT of following W.I. if finish-finish relation.
3 LST of following W.I., plus the duration of the W.I. itself, if there is a start-start relation.
4 LST of following W.I., less the lag, plus the duration of the W.I. itself, if there is a lag relation.

IV. Latest Start Time

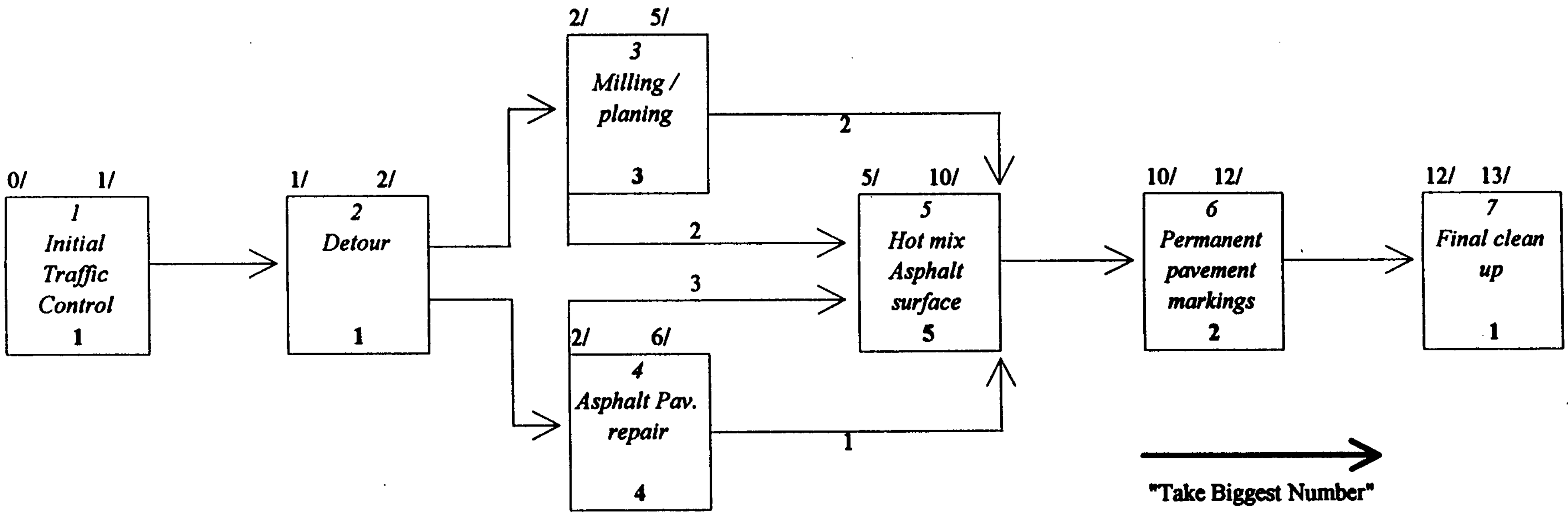
a. LST of 1st Work Item = LFT - Duration
b. LST of all other W.I.'s is the lesser of these items:
1 LFT of W.I. less its duration
2 LST of following W.I. if start-start relation
3 LST of following W.I. less the lag, if there is a lag relation.

Notes:

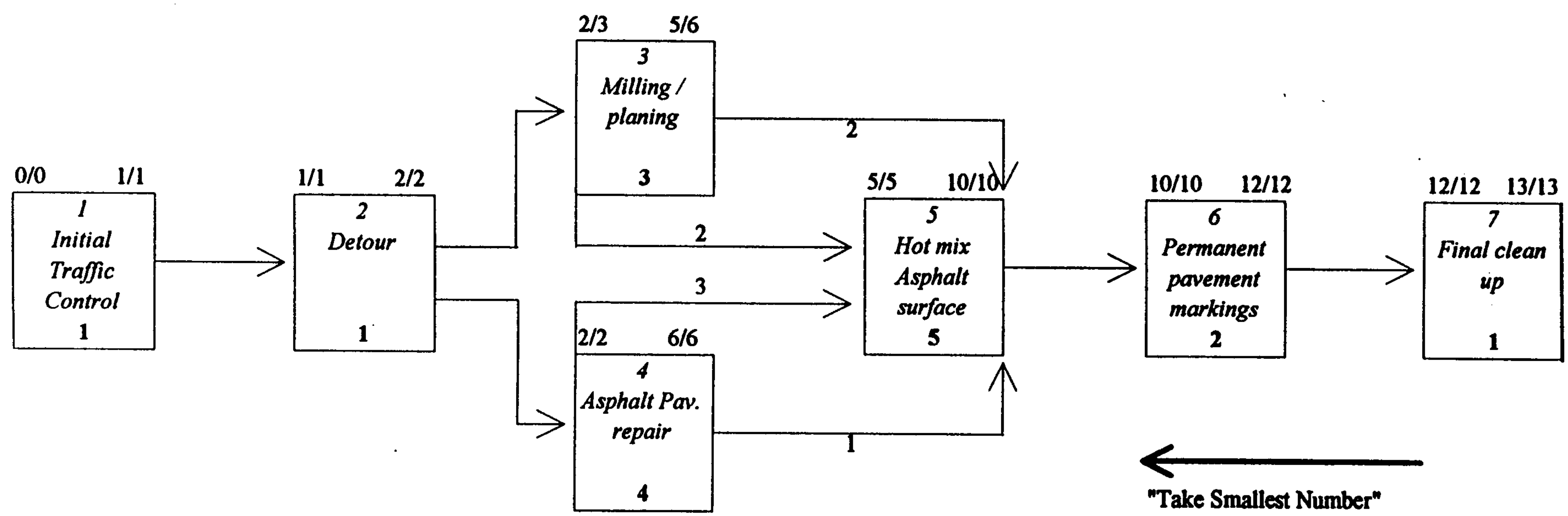
EST = Early Start Time　　LST = Late Start Time
EFT = Early Finish Time　　LFT = Late Finish Time

Lag = Number of days of lag time associated with a relationship

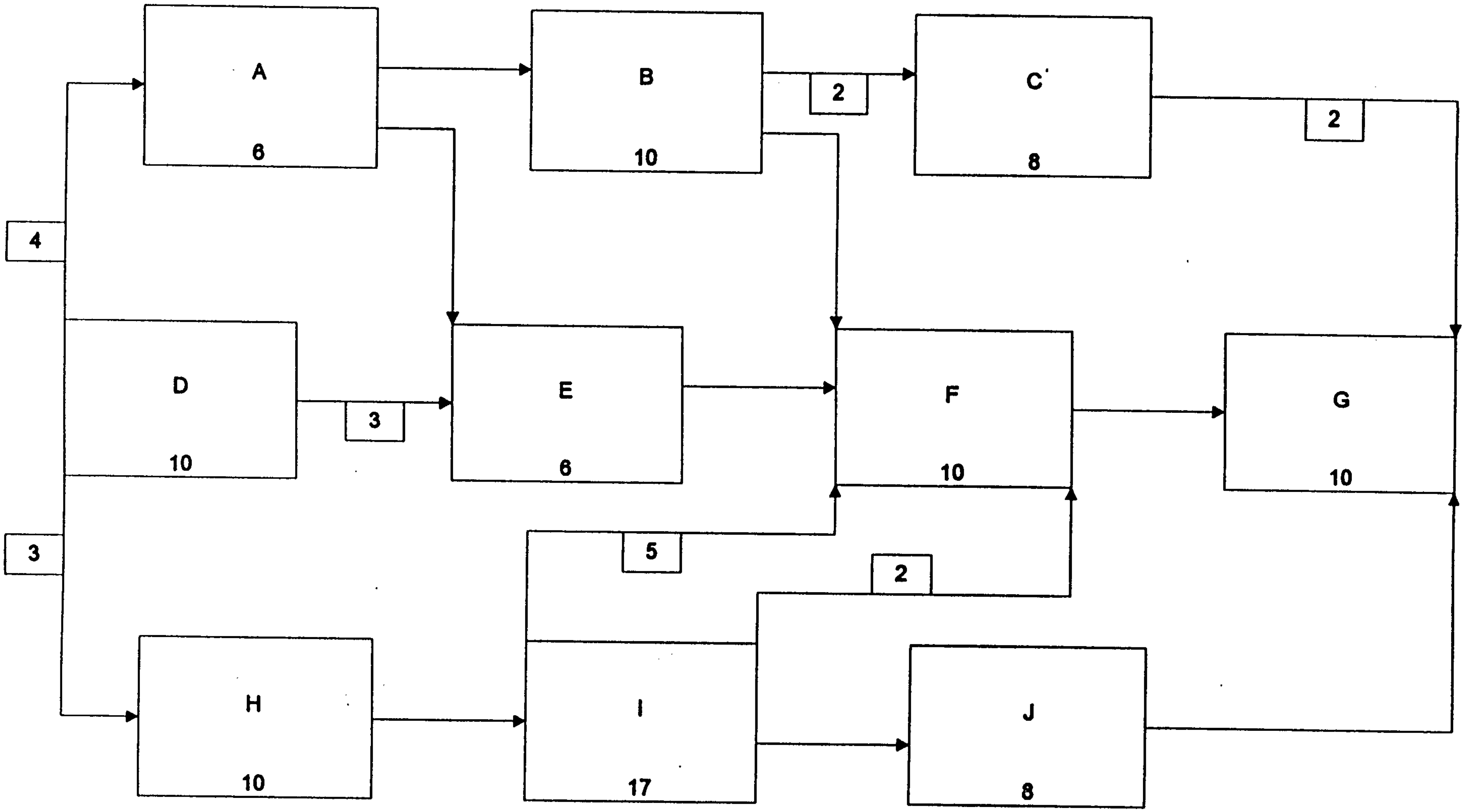
Forward Pass for "Precedence" CPM diagram



Reverse Pass for "Precedence" CPM diagram

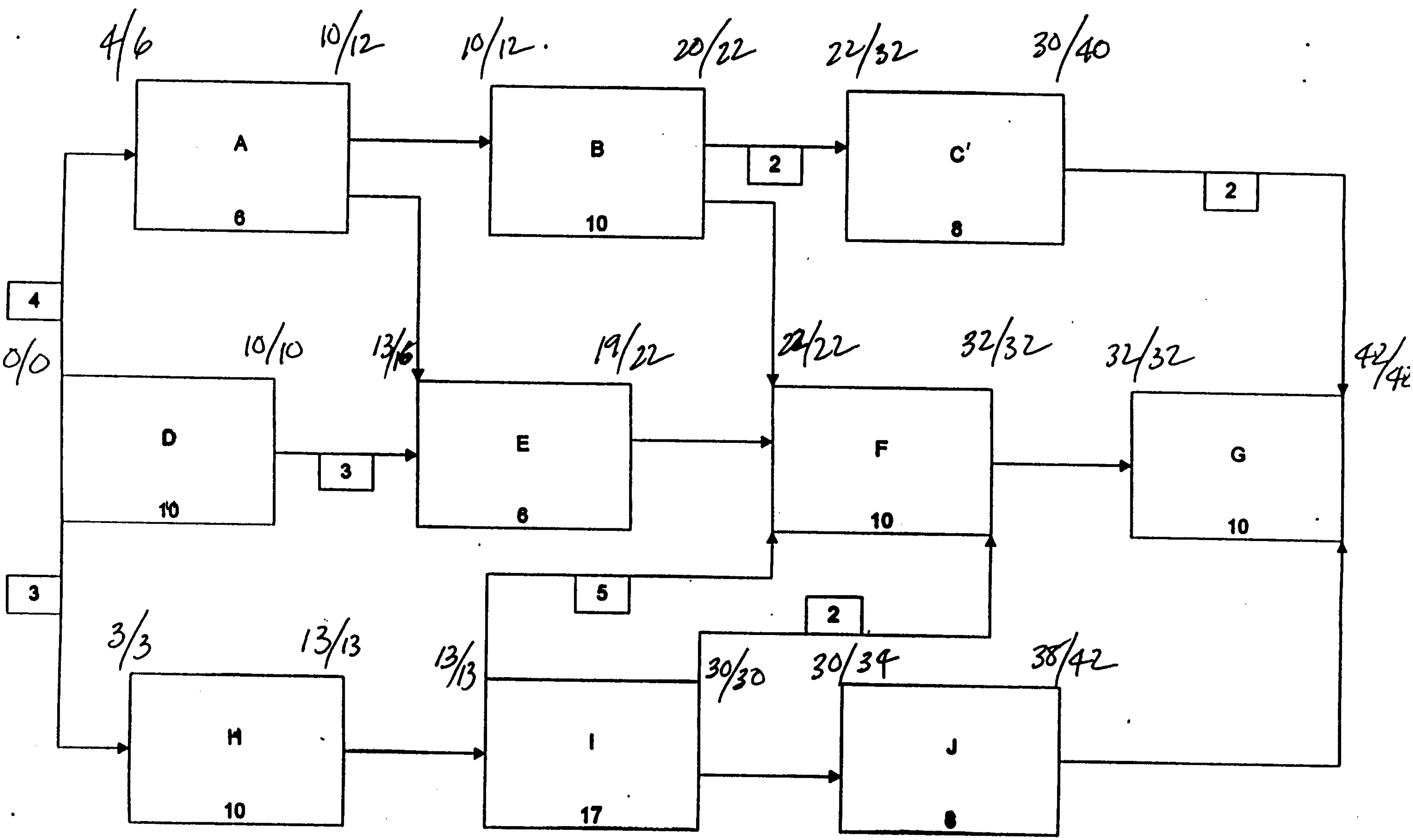


Precedence CPM Example

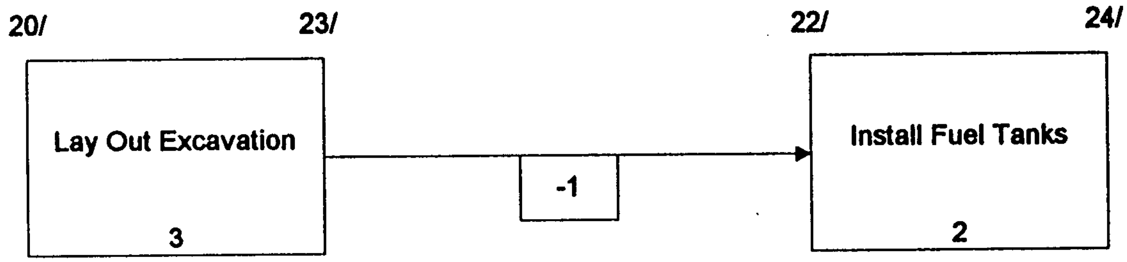


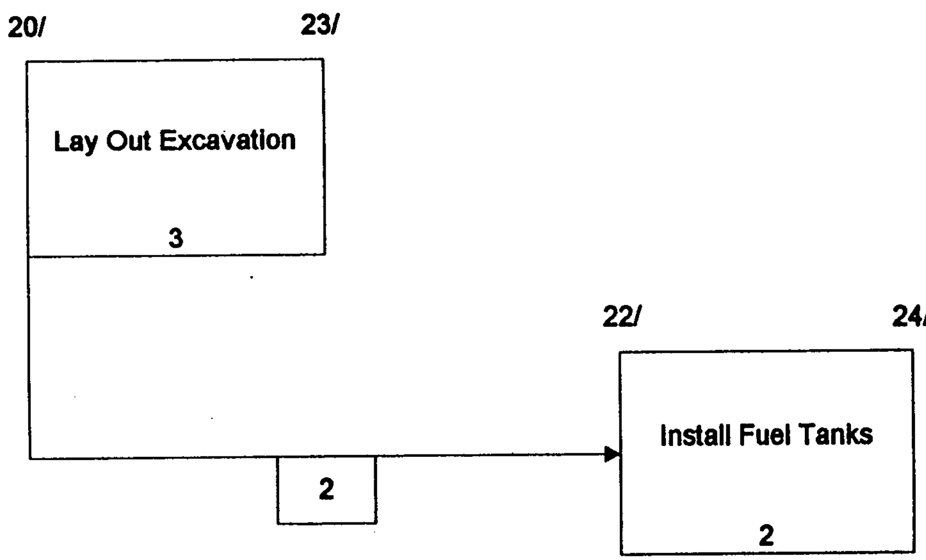
Do not include it in the manual!

Precedence CPM Example



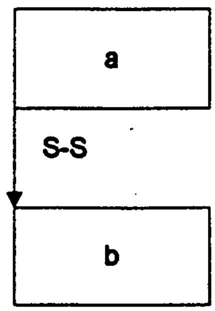
Finish to Start Relationship with Negative Lag





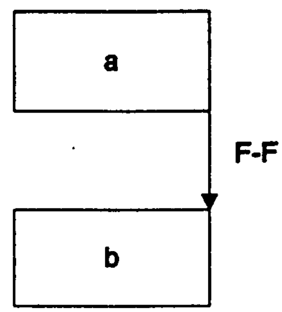
Precedence Float Calculations

Start to Start



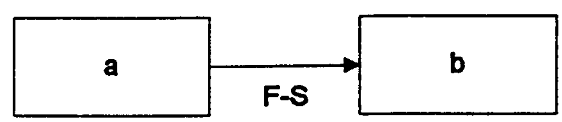
TFa = LFTa - EFTa
FFa = ESTb - ESTa

Finish to Finish



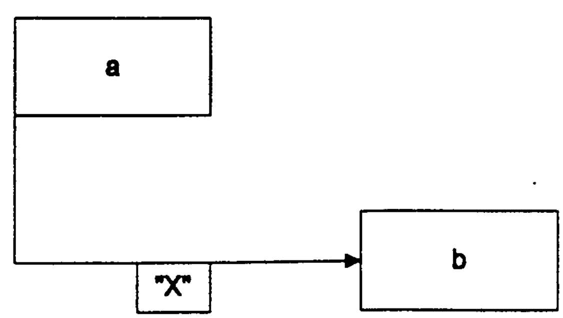
TFa = LFTa - EFTa
FFa = EFTb - EFTa

Finish to Start



TFa = LFTa - EFTa
FFa = ESTb - EFTa

Lag



TFa = LFTa - EFTa
FFa = ESTb - ESTa - "X"

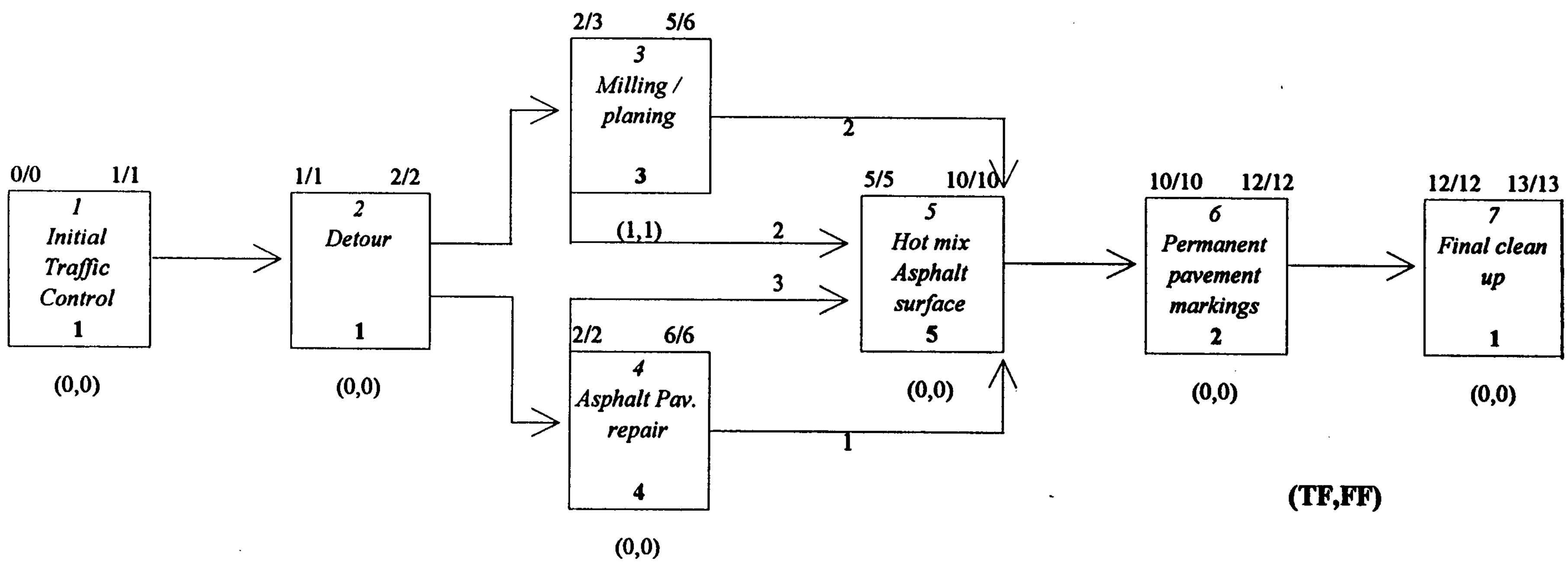
Notes:

(1) All activities assumed continuous in duration.

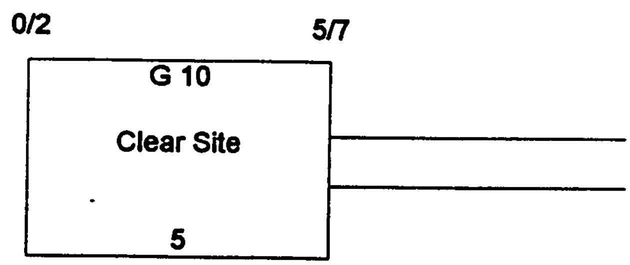
(2) The total float for all activities is always equal to their Late Finish Time minus their Early Finish Time.

(3) The Free Float calculations shown are for each type of relationship. If an activity has several following activities, then the Free Float for the activity is the SMALLEST of the Free Float calculations made for each following activity.

"Precedence" CPM Logic Diagram with Float Times



CPM Day to Calendar Day Conversion Table



CPM	CAL (February '97)	
	2	
0	3	Project start date
1	4	
2	5	
3	6	
4	7	
	8	
	9	
5	10	
6	11	
7	12	

CPM	CAL
8	13
9	14
	15
	16
10	17
11	18
12	19
13	20
14	21
	22
	23
15	24

NOTE: CPM day (X) = work day (X + 1)
(i.e. CPM day 0 = project work day 1)

CPM Days are referenced to the "morning" of project work days; therefore, for finish times, one should refer to the night of the preceding calendar date on the table.

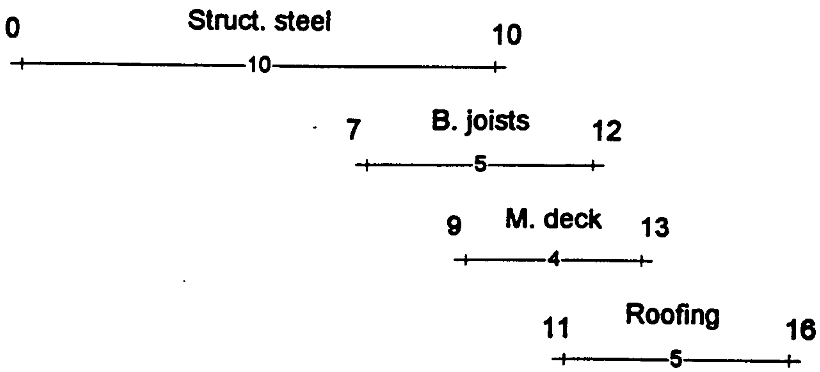
CALCULATIONS

EST = Feb. 3, '97
LST = Feb. 5, '97

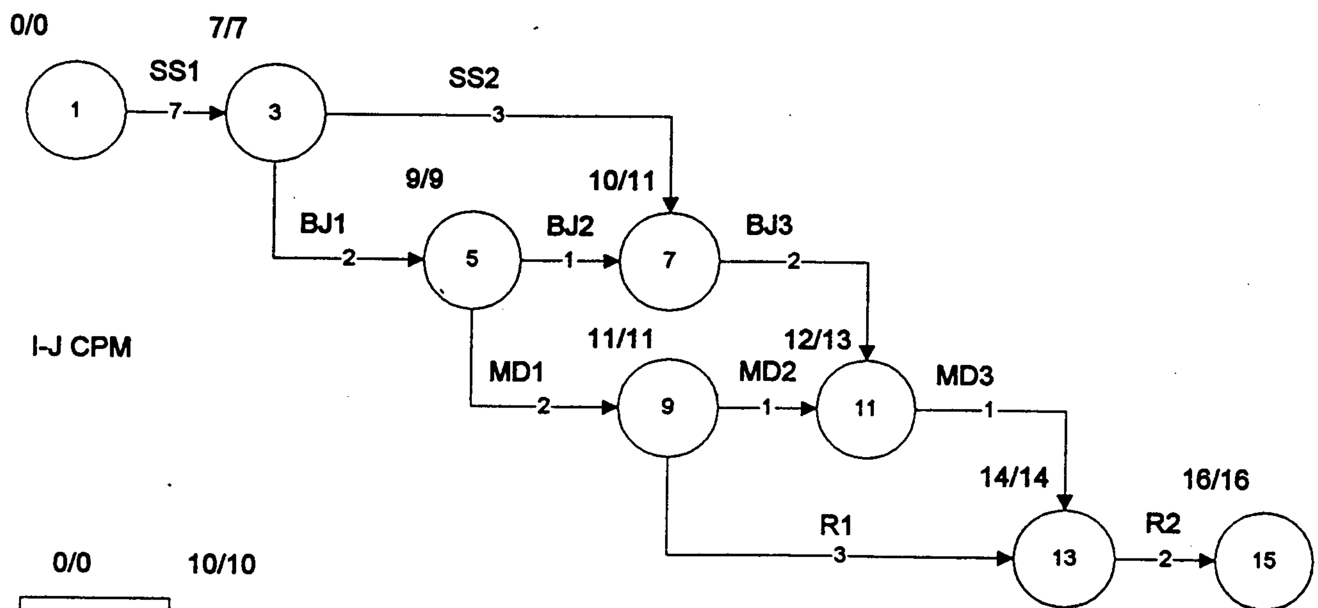
EFT = Feb. 7, '97
LFT = Feb. 11, '97

Overlapping Work Items

Bar Chart

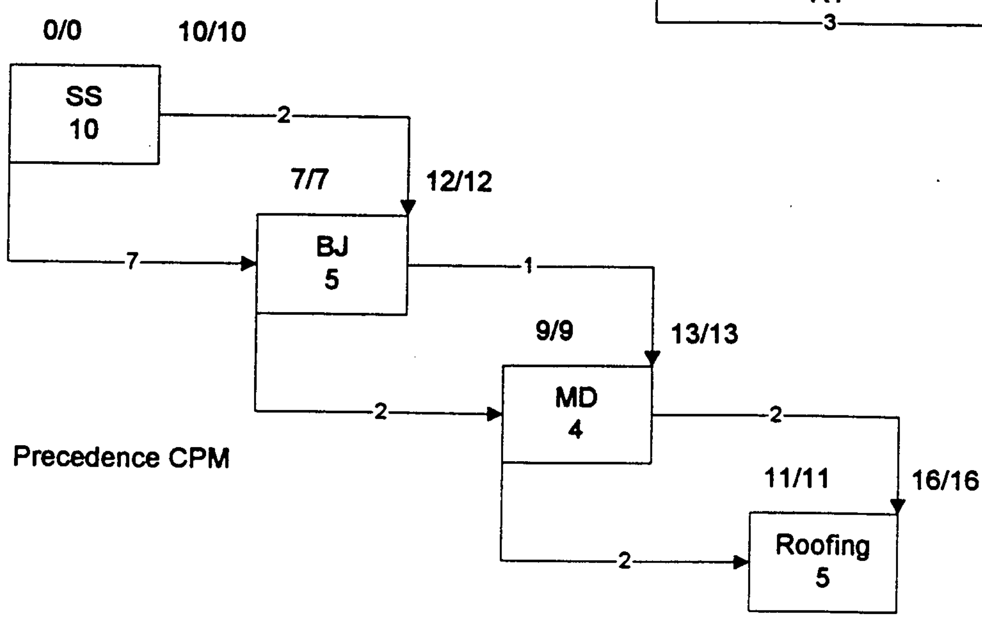


I-J CPM



(Assume continuous flow)

Precedence CPM



CONSTRUCTION PLANNING & SCHEDULING

by

The University of Kentucky
Civil Engineering Department
And
Kentucky Transportation Center

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Raymond F. Werkmeister, P.E.
Sion L. Tesone

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Introduction

One of the most important responsibilities of construction project management is the planning and scheduling of construction projects. The key to successful profit-making in any construction company is to have successful projects. Therefore, for many years, efforts have been made to plan, direct, and control the numerous project activities to obtain optimum project performance. Since every construction project is a unique undertaking, the project manager must plan and schedule his work utilizing his experience with similar projects, and applying his judgment to the particular conditions of the current project.

Until just a few years ago, there was no generally accepted formal procedure to aid in the management of construction projects. Each project manager had his own system, which usually included the use of the Gannt chart, or bar chart. The bar chart was, and still is, quite useful for illustrating the various items of work, their estimated time durations, and their position in the work schedule as of the report date represented by the bar chart. However, the relationship which exists between the identified work items is by implication only. On projects of any complexity, it is very difficult, if not virtually impossible, to identify the interrelationships between the work items, and there is no indication of the criticality of the various activities in controlling the project duration.

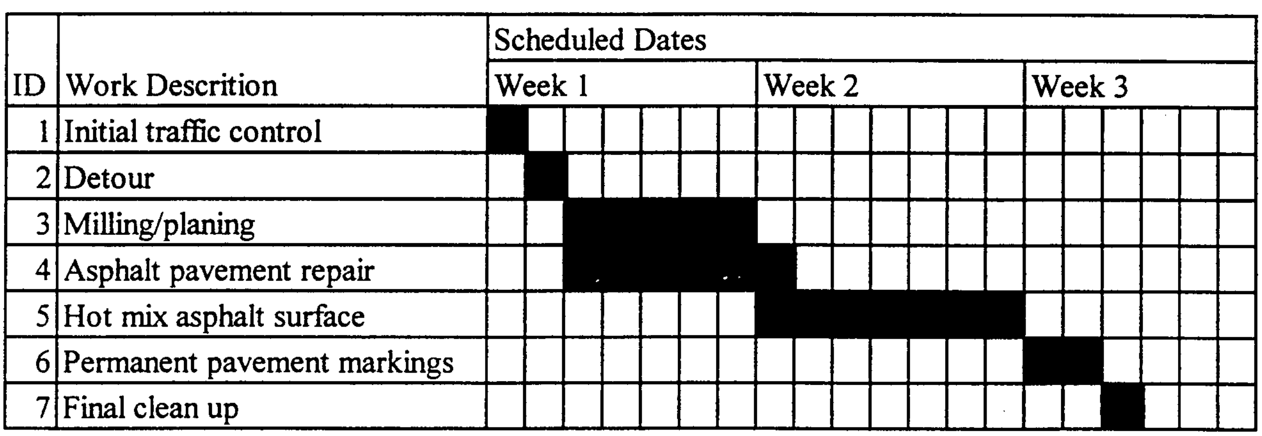


Figure 1. A sample bar chart for a construction project.

The development of the Critical Path Methods (CPM) in the late 1950's has provided the basis for a more formal and systematic approach to project management. Critical Path Methods involve a graphical display (network diagram) of the activities on a project and their interrelationships, and an arithmetic procedure which identifies the relative importance of each activity in the overall project schedule. These methods have been applied with notable success to project management in the construction industry, and several other industries, when applied earnestly as dynamic management tools. Also, they have provided a much-needed basis for performing some of the other vital tasks of the construction project manager, such as resource scheduling, financial planning, and cost control. Today's construction manager who still ignores the use of Critical Path Methods is ignoring a very useful and practical management tool.

Definitions

PLANNING -- the selection of the methods and the order of work for performing the project. (Note that there may be many feasible methods and, perhaps, more than one possible ordering for the work. Each feasible solution represents a PLAN.) The required sequence of activities (preceding, concurrent, or following) is portrayed graphically on the network diagram.

SCHEDULING -- the process of determining the timing of a work item or activity within the overall time span of the construction project. It also involves the allocation of resources (men, material, machinery, money, time) to each activity, according to its anticipated requirements.

RESOURCES -- those things which must be supplied as input to the project. They are broadly categorized as manpower, material, equipment, money, time, etc. It is frequently necessary to identify them in greater detail (i.e. draftsmen, carpenters, cranes, etc.).

CONSTRAINTS -- are limitations placed upon the allocation of one or several resources. The several types of constraints can be broadly categorized as:

> **PHYSICAL** -- constraints on the ordering of activities due to physical requirements. For instance, the foundation footings can not be completed until the footing excavation work is done.
>
> **RESOURCE** -- constraints on the ordering of activities due to an overlapping demand for resources which exceeds the available supply of the resources. For instance, if two activities can be performed concurrently, but each requires a crane and only one is available, then one will have to be done after the other.
>
> **MANAGEMENT** -- constraints on the ordering of activities due to the wishes of management. For instance, which do you install first, toilet partitions or toilet fixtures. It doesn't usually matter, but they can't be done easily at the same time. Therefore, one will be scheduled first and the other constrained to follow; this is a management constraint.

PROJECT -- any undertaking which has a definite point of beginning, and a definite point of ending, and which requires one or more resources for its execution. It must also be capable of being divided into interrelated component tasks.

ACTIVITY -- a distinct and identifiable operation within a project, whose performance will consume one or more resources. The concept of the distinct "activity" is fundamental in network analysis. The level of detail at which distinct activities are identified in planning is largely dependent upon the objectives of the analysis. An activity may also be referred to as an "operation," or "work item." A **DUMMY ACTIVITY**, which does **not** consume a resource, can be used to identify a constraint which is not otherwise apparent.

NETWORK MODEL -- the graphical display of interrelated activities on a project, showing resource requirements and constraints, is a mathematical model of the project and the proposed methods for its execution. This Network Model is actually a logic diagram which has been prepared in accordance with pre-established diagramming conventions.

FLOAT (SLACK) -- in the calculation procedures for any of the Critical Path Methods, an allowable time span is determined for each activity to be performed within. The boundaries of this time span for an activity are established by its Early Start Time and Late Finish Time. When this bounded time span exceeds the duration of the activity, the excess time is referred to as "float" time. Float can be classified according to the delayed finish time available to an activity before it affects the starting time of its following activities. It should be noted that once an activity is delayed to finish beyond its Early Finish Time, then the network calculations must be redone for all following activities before evaluating their float times.

TOTAL FLOAT -- the total time available between an activity's Early Finish Time and Late Finish Time as determined by the time calculations for the network diagram. If the activity's finish is delayed more than its number of days of Total Float, then its Late Finish Time will be exceeded and the total project duration will thus be delayed. Total Float also includes any Free Float which is available for the activity.

FREE FLOAT -- the number of days that an activity can be delayed beyond its Early Finish Time without causing any activity which follows it to be delayed beyond its Early Start Time. The Free Float for many activities will be zero since it only exists when an activity doesn't control the Early Start Time of any of the activities which follow it.

CRITICAL ACTIVITIES -- activities which have "zero" float time. This includes all activities on the Critical Path.

CRITICAL PATH -- the connected chain, or chains, of critical activities (zero float), extending from the beginning of the project to the end of the project, whose summed activity duration give the minimum project duration. Several may exist in parallel.

ACTIVITY DURATION -- the estimated time which is required to perform the activity -- the allocation of the "time resource" to each activity. It is customary to express the activity duration in work-time units, i.e.: working (8-hr.) day, shift, 40-hr. week, etc. An estimate of activity duration implies some definite allocation of other resources (labor, materials, equipment, capital), to the performance of the activity in question.

PROJECT DURATION -- the total duration of the project, based upon the network assumptions of methods and resource allocations. It is obtained as the linear sum of activity durations along the critical path.

MONITORING -- the periodic up-dating of the network schedule as the project progresses. For activities which have already been performed, their estimated durations can be replaced by their actual durations. The network can then be recalculated. It will often be necessary to re-plan and re-schedule the remaining activities as necessary to comply with the requirement that the project duration remain the same.

Planning and Scheduling

Planning for construction projects involves the logical analysis of a project, its requirements, and the plan (or plans) for its execution. This will also include consideration of the existing constraints and available resources which will affect the execution of the project. Considerable planning is required for the support functions for a project, material storage, worker facilities, office space, temporary utilities, etc. Planning, with respect to the Critical Path Methods, involves the identification of the activities for a project, the ordering of these activities with respect to each other, and the development of a network logic diagram which graphically portrays the activity planning.

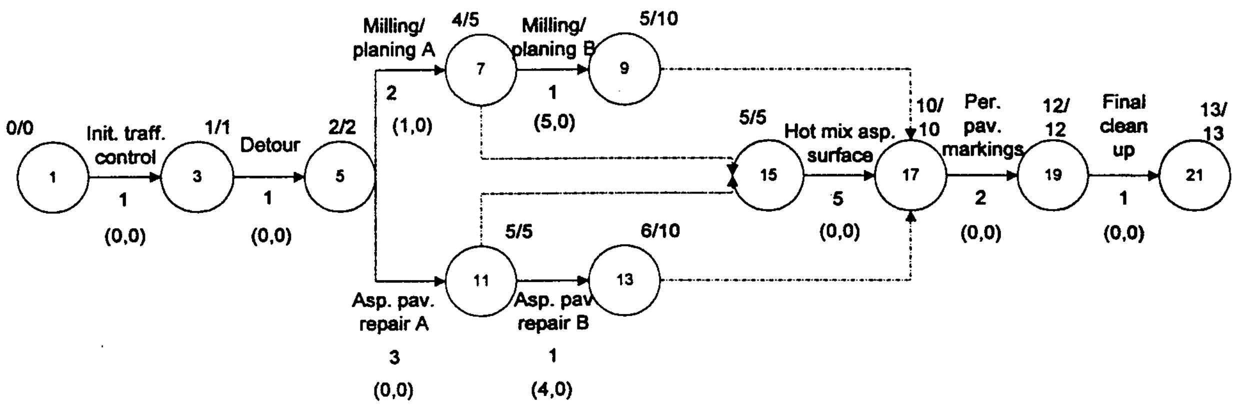


Figure 2. I-J CPM logic diagram.

The planning phase of the Critical Path Methods is by far the most difficult, but also the most important. For it is here that the construction planner must actually build the project on paper. This can only be done by becoming totally familiar with the project plans, specifications, resources, and constraints; and to then look at various plans for feasibly performing the project and selecting the one felt to be best.

The most difficult planning aspect to consider, especially for beginners, is the level of detail needed for the activities. The best answer is to "develop the minimum level of detail required to enable the user to schedule the work efficiently." For instance, a general contractor will normally consider two or three activities for mechanical work to be sufficient for his schedule. However, to the mechanical contractor, this would be totally inadequate since he will need a more detailed breakdown of his activities to schedule his work. Therefore, the level of activity detail required depends on the needs of the user of the plan, and only he can determine his needs after gaining experience in the use of Critical Path Methods.

Once the activities have been determined, then they must be arranged into a working plan in the network logic diagram. Starting with an initial activity in the project, one can apply known constraints and reason that all remaining activities must fall into one of three categories:

1) They must precede the activity in question, or
2) They must follow the activity in question, or
3) They can be performed concurrently with the activity in question.

The remaining planning function is the estimation of the time durations for each activity shown on the logic diagram. The estimated activity time should reflect the proposed method for performing the activity, plus consideration of the levels at which required resources are supplied. The estimation of activity times is always a tough task for the beginner in construction for it requires a working knowledge of the production capabilities of the various crafts in the industry, which can only be acquired through many observations of actual construction work. Therefore, the beginner will have to rely on the advice of superiors for obtaining time estimates for work schedules.

Scheduling of construction projects involves the determination of the timing of each work item, or activity, in a project within the overall time span of the project. Scheduling, with respect to the Critical Path Methods, involves the calculation of the starting and finishing times for each activity and the project duration, the evaluation of the available float for each activity, and the identification of the critical path or paths. In a broader sense it also includes the more complicated areas of construction project management such as financial funds, flow analyses, resource scheduling and leveling, and inclement weather scheduling.

The planning and scheduling of construction projects using Critical Path Methods has been discussed as two separate processes. Although the tasks performed are different, the planning and scheduling processes normally overlap. The ultimate objective of the project manager is to develop a working plan with a schedule which meets the completion date requirements for the project. This requires an interactive process of planning and replanning, and scheduling and rescheduling, until a satisfactory working plan is obtained.

Controlling

The **controlling** of construction projects involves the monitoring of the expenditure of time and money in accordance with the working plan for the project, as well as the resulting "product" quality or performance. When deviations from the project schedule occur, remedial actions must be determined which will allow the project to be finished on time and within budget if at all possible. This will often require re-planning the order of the remaining project activities.

If there is any one factor for the "unsuccessful" application of the Critical Path Methods to actual construction projects, it is the lack of project monitoring once the original schedule is developed. Construction is a dynamic process with conditions often changing during a project. The main strength of the Critical Path Methods is that they provide a basis for evaluating the effects of unexpected occurrences, such as delivery delays, on the total project schedule. The frequency for performing "updates" of the schedule depends primarily on the job conditions, but are usually needed most as the project nears completion. For most projects, monthly updates of the schedule are adequate. At the point of 50 percent completion, a major update should be made to plan and schedule the remaining work. The control function is an essential part of successful CPM scheduling.

Critical Path Methods

The Critical Path technique had its origin from 1956 to 1958 in two parallel but different problems of planning and control in projects in the United States.

In one case, the U.S. Navy was concerned with the control of contracts for its Polaris Missile program. These contracts compromised research and development work as well as the manufacture of component parts not previously made. Hence, neither cost nor time could be accurately estimated, and completion times therefore had to be based upon probability. Contractors were asked to estimate their operational time requirements on three bases: optimistic, pessimistic, and most likely dates. These estimates were then mathematically assessed to determine the probable completion date for each contract, and this procedure was referred to as the Program Evaluation and Review Technique, abbreviated to PERT. It is therefore important to understand that the PERT systems involve a "probability approach" to the problems of planning and control of projects and are best suited to reporting on works in which major uncertainties exist.

In the other case, the E.I. du Pont de Nemours Company was constructing major chemical plants in America. These projects required that both time and cost be accurately estimated. The method of planning and control that was developed was originally called Project Planning and Scheduling (PPS), and covered the design, construction, and maintenance work required for several large and complex jobs. PPS requires realistic estimates of cost and time and is thus a more definitive approach than PERT. It is this approach that has since been developed into the Critical Path Method (CPM), which is used frequently in the construction industry. Although there are some uncertainties in any construction project, the cost and time required for each operation involved can be reasonably estimated and all operations may then be reviewed by CPM in accordance with the anticipated conditions and hazards that may be encountered on the site.

There are several variations of CPM used in planning and scheduling work, but these can be divided into two major classifications: (a) Activities-on-Arrows or "I-J" CPM; or (b) Activities-on-Nodes, especially the "Precedence" version. The original CPM system was the

"I-J" system, with all others evolving from it to suit the needs and desires of the users. There is a major difference of opinions as to which of the two systems is the best to use for construction planning and scheduling. There are pros and cons for both systems, with neither system having a significant edge over the other. The only important thing to consider is that both systems be evaluated thoroughly before deciding which one to use. This way, even though both systems will do a fine job, you'll never have to wonder if your method is inadequate.

The two CPM techniques used most often for construction projects are the **"I-J"** and **"Precedence"** techniques. As was mentioned earlier, the I-J CPM technique was the first one developed. It is also, therefore, the technique used most widely in the construction industry. It is often called Activity-on-Arrows, and sometimes referred to as PERT. This last reference is a misnomer since PERT is a distinctly different technique, as noted previously; however, many people don't know the difference. An example of an "I-J" CPM diagram is shown in Figure 2, complete with calculated event times.

The other CPM technique used considerably often in construction planning and scheduling is the Precedence method. It is actually a more sophisticated version of the Activity-on-Nodes system, initiated by Professor John W. Fondahl of Stanford University.

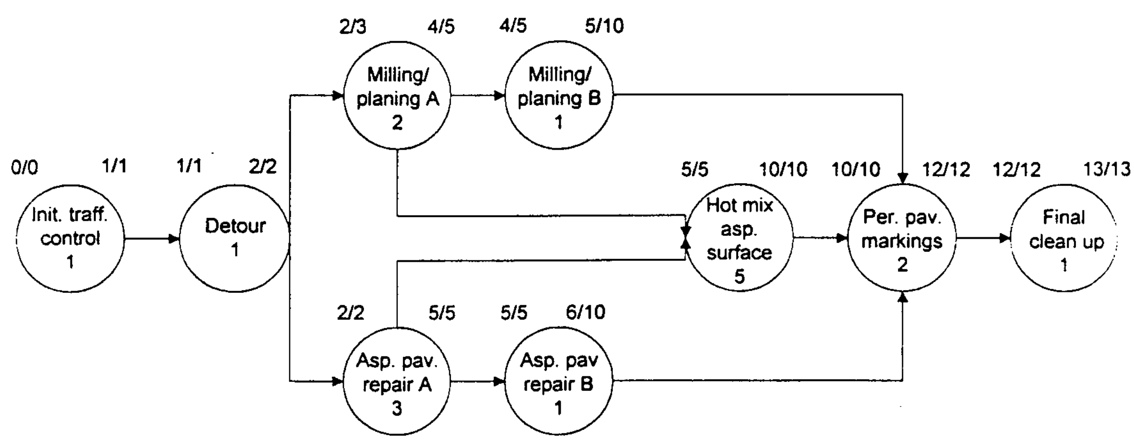


Figure 3. Diagram of an "Activity-on-Nodes"

Notice that the activities are now the nodes (or circles) on the diagram, and the arrows simply show the constraints which exist between the activities. The times calculations represent the activity's early and late start and finish times.

The Precedence technique was developed to add flexibility to the Activity-on-Nodes system. The only constraint used for Activity-on-Nodes is the Finish to Start relationship which implies that one activity must finish before its following activity can start. In the Precedence system, there are four types of relationships which can be used; also, the activities are represented by rectangles instead of circles on the logic diagram.

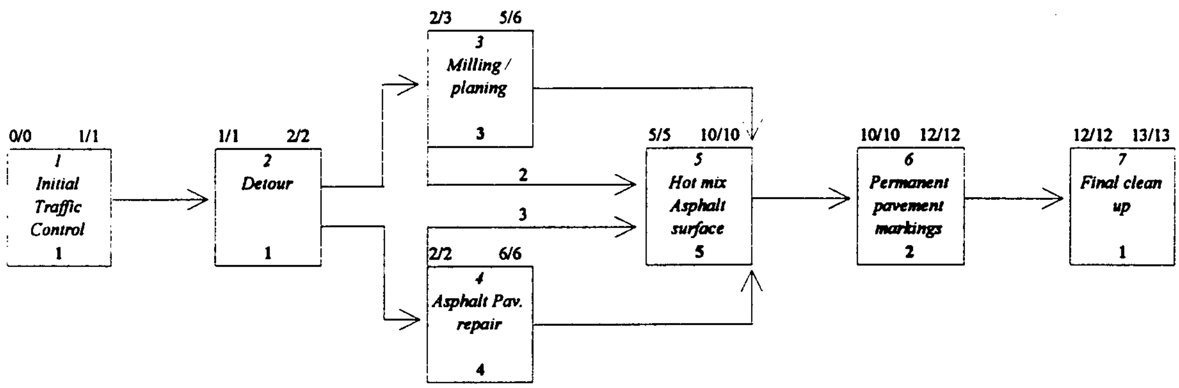


Figure 4. A "Precedence" network plus calculations.

Advantages of CPM

The Critical Path Methods have been used for planning and scheduling construction projects for over twenty years. The estimated worth of their use varies considerably from user to user, with some contractors feeling it is a waste of time and money. It is difficult to believe that anyone would feel that detailed planning and scheduling work is a waste! Most likely, the "unsuccessful" applications of CPM resulted from trying to use a level of detail far too complicated for practical use, or the schedule was developed by an outside firm with no real input by the user, or the CPM diagram was not reviewed and updated during the project.

Regardless of past "uses" or "misuses" of CPM, the basic question still prevails - "What are the advantages of using CPM for construction planning and scheduling?" Experience with the application of CPM on several projects has revealed the following observations:

1. CPM encourages a logical discipline in the planning, scheduling, and control of projects,
2. CPM encourages more long-range and detailed planning of projects,
3. All project personnel get a complete overview of the total project,
4. CPM provides a standard method of documenting and communicating project plans, schedules, and time and cost performances,
5. CPM identifies the most critical elements in the plan, focusing management's attention to the 10 to 20 percent of the project that is most constraining on the scheduling,
6. CPM provides an easy method for evaluating the effects of technical and procedural changes which occur on the overall project schedule, and
7. CPM enables the most economical planning of all operations to meet desirable project completion dates.

An important point to remember is that CPM is an open-ended process that permits different degrees of involvement by management to suit their various needs and objectives. In other words, you can use CPM at whatever level of detail you feel is necessary. However, one must always remember that "you only get out of it what you put into it." It will be the responsibility of the user to choose the technique which is the "best." They are all good and they can all be used effectively in the management of construction projects; just pick the one best liked and use it.

"I-J" Critical Path Method

The first CPM technique developed was the I-J CPM system and it is, therefore, widely used in the construction industry. It is often called Activity-on-Arrow, and sometimes referred to as PERT (which is a misnomer). The objective of this section is to instruct the reader on how to draw I-J CPM diagrams, how to calculate the event times, activity and float times, and how to handle the overlapping work schedule.

Basic Terminology for I-J CPM

There are several basic terms used in I-J CPM which need to be defined before trying to explain how the system works. A sample I-J CPM diagram is shown in Figure 5 and will be referred to while defining the basic terminology.

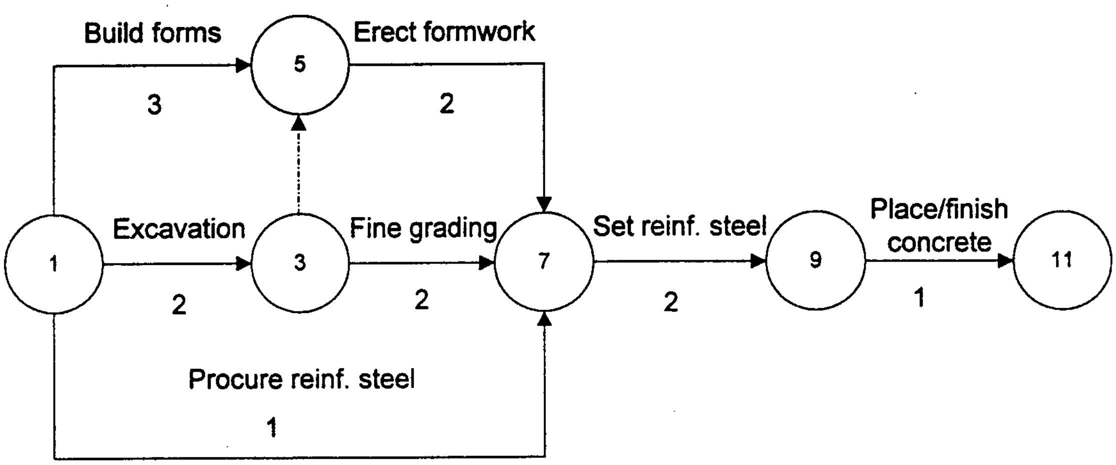


Figure 5. "I-J" CPM Activities and Diagram

EVENT (NODE) -- a point in time in a schedule, represented on the logic diagram by a circle. An event is used to signify the beginning or the end of an activity, and can be shared by several activities. An event can occur only after all the activities which terminate at the event have been completed. Each event has a unique number to identify it on the logic diagram.

ACTIVITY (Aij) -- a work item identified for the project being scheduled. The activities for I-J CPM are represented by the arrows on the logic diagram. Each activity has two events, a "preceding" event (i-node) which establishes its beginning, and a "following" event (j-node) which establishes its end. It is the use of the "i" node and "j" node references which established the term I-J CPM. In Figure 5, Excavation is referred to as Activity 1-3.

DUMMY -- a fictitious activity used in I-J CPM to show a constraint between activities on the logic diagram when needed for clarity. It is represented as a dashed arrow and has a duration of zero. In Figure 5, Activity 3-5 is a dummy activity used to show that Erect Formwork cannot start until Excavation is finished.

DURATION (Tij) -- duration of an activity, expressed in working days, usually eight-hour days based on a five-day work week.

EETi -- earliest possible occurrence time for event "i," expressed in project workdays, cumulative from the beginning of the project.

LETi -- latest permissible occurrence time for event "i," expressed in project workdays, cumulative from the end of the project.

Developing the I-J CPM Logic Diagram

The initial phase in the utilization of CPM for construction planning is the development of the CPM logic diagram, or network. This will require that the preparer first become familiar with the work to be performed on the project and constraints, such as resource limitations, which may govern the work sequence. It may be helpful to develop a list of the activities to be scheduled and their relationship to other activities. Then it is time to draw the logic diagram. This is not an exact science, but an interactive process of drawing and redrawing until a satisfactory diagram is attained.

A CPM diagram must be a closed network in order for the time and float calculations to be completed. Thus, there is a single starting node or event for each diagram and a single final node or event. In Figure 5, the starting node is Event 1 and the final node is Event 11. Also, notice in Figure 5 that Event 11 is the only event which has no activities following it. If any other event in the network is left without an activity following it, then it is referred to as a "dangling node," and will need to be closed back into the network for proper time calculations to be made.

The key to successful development of CPM diagrams is to concentrate on the individual activities to be scheduled. By placing each activity on the diagram in the sequence desired with respect to all other activities in the network, the final logic of the network will be correct. Each activity has a variety of relationships to other activities on the diagram. Some activities must precede it, some must follow it, some may be scheduled concurrently, and others will basically have no relationship to it. Obviously, the major concern is to place the activity in a proper sequence with those which must precede it and those which must follow it. In I-J CPM these relationships are established via the activity's preceding event (i-node) and following event (j-node).

The key controller of logic in I-J CPM is the event. Simply stated, all activities shown starting from an event are preceded by all activities which terminate at that event, and cannot start until all the preceding activities are completed. Therefore, one of the biggest concerns to watch for is to not carelessly construct the diagram and needlessly constrain activities when not necessary. There are several basic arrangements of activities in I-J CPM, some of the simple relationships are shown in Figure 6. Sequential relationships are the name of the game, it is just a matter of taking care to show the proper sequences.

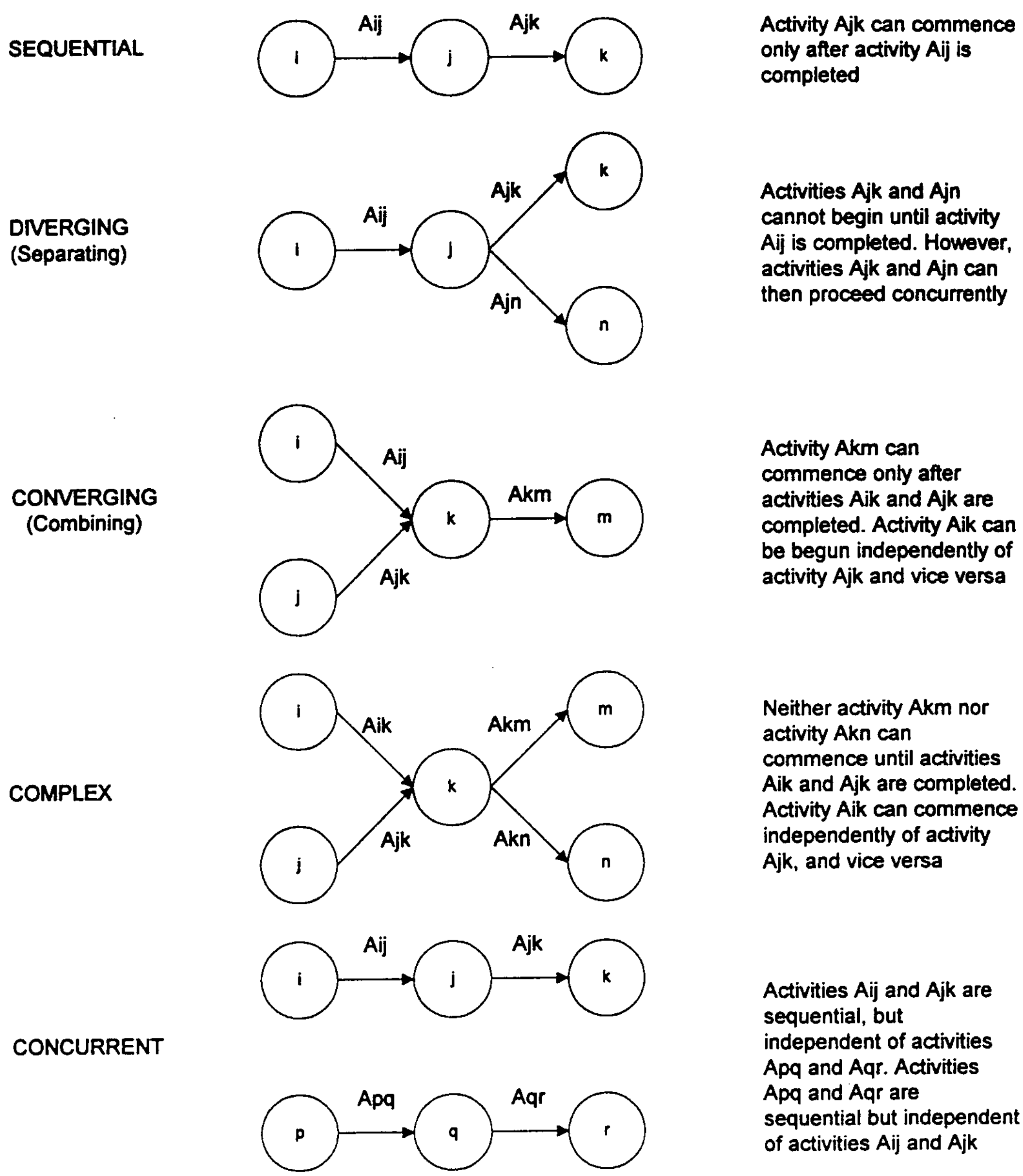


Figure 6. Typical Activity Relationships for Activities-On-Arrows CPM.

The biggest problem for most beginners in I-J CPM is the use of the "dummy" activity.

As defined earlier, the dummy activity is a special activity used to clarify logic in I-J CPM networks, is shown as a dashed line, and has a duration of zero workdays. The dummy is used primarily for two logic cases, the complex logic situation and the unique activity number problem. The complex logic situation is the most important use of the dummy activity to clarify the intended logic. The proper use of a dummy is depicted in Figure 7 where it is desired to show that activity Ars needs to be completed before both activities Ast and Ajk, and that activity Aij precedes only Ajk. The incorrect way to show this logic is depicted in Figure 8. It is true that this logic shows that Ars precedes both Ast and Ajk, but it also implies that Aij precedes both Ajk and Ast, which is not true. Essentially, the logic diagram in Figure 7 was derived from the one in Figure 8 by separating Event j into two events, j and s, and connecting the two with the dummy activity Ast.

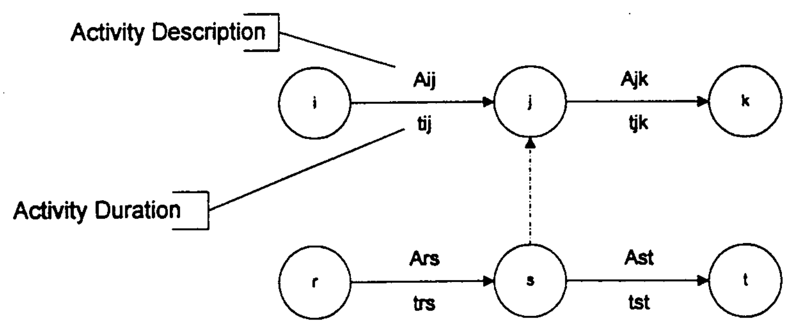


Figure 7. Correct Use of a Dummy Activity.

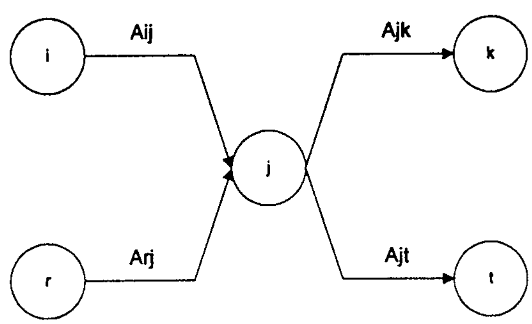


Figure 8. Incorrect Logic, Correct in Figure 7.

The other common use of the dummy activity is to insure that each activity has a unique i-node and j-node. It is desirable in I-J CPM that any two events may not be connected by more than one activity. This situation is depicted in Figure 9.

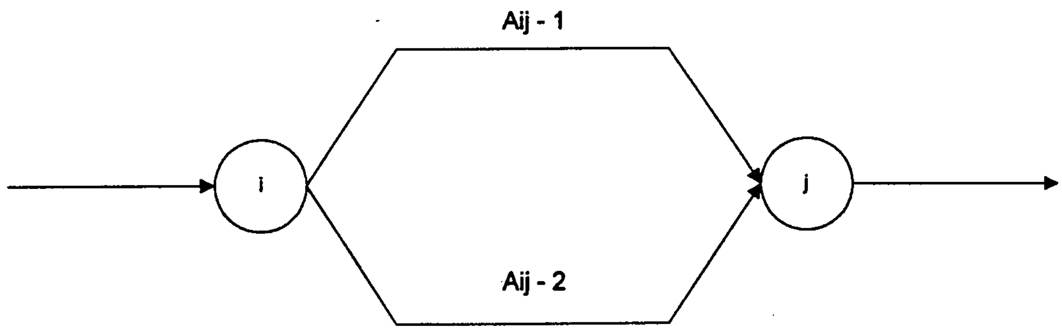


Figure 9. Incorrect Nodes for Parallel Activities.

This logic would result in two activities with the same identification number, i-j. This is not a fatal error in terms of reading the logic, but it is confusing and will cause problems if utilizing a computer to analyze the schedule. This problem can simply be solved by inserting a dummy activity at the end of one of the activities, as shown in Figure 10. It is also possible to add the dummy at the front of the activity, which is the same logic.

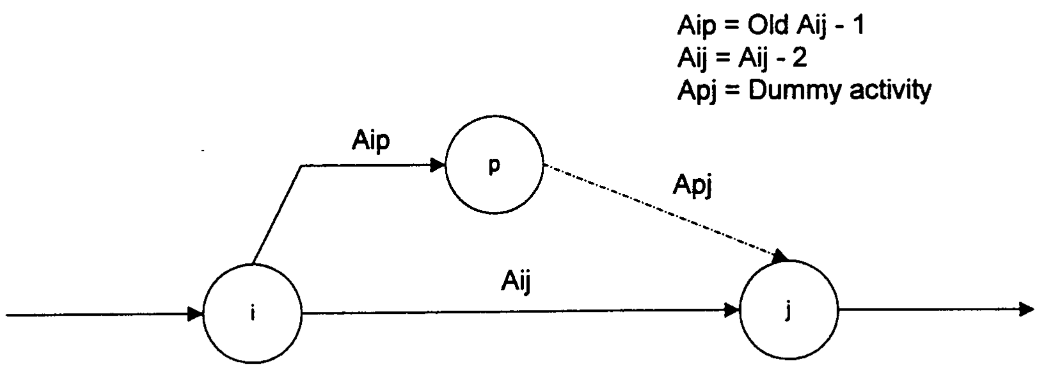


Figure 10. Correct Nodes for Parallel Activities.

Each logic diagram prepared for a project will be unique if prepared independently. Even if the same group of activities is included, the layout of the diagram, the number of dummy activities, the event numbers used, and several other elements will differ from diagram to diagram. The truth is that they are all correct if the logic is correct. When preparing a diagram for a project, the scheduler should not worry with being too neat on the first draft, but should try to include all the activities in the proper order. The diagram can be fine-tuned later after the original schedule is checked.

I-J Network Time Calculations

An important task in the development of a construction schedule is the calculation of the network times. In I-J CPM this involves the calculation of the event times, from which the activity times of interest are then determined. Each event on a diagram has two event times, the Early Event Time (EET) and the Late Event Time (LET); these are depicted in Figure 11. Each activity has two events, the preceding event or the "i-node" and the following event or the "j-node." Therefore, each activity has four associated event times, EETi, LETi, EETj, and LETj. A convenient methodology for determining these event times involves a Forward Pass to determine the early event times, and a Reverse Pass to determine the late event times.

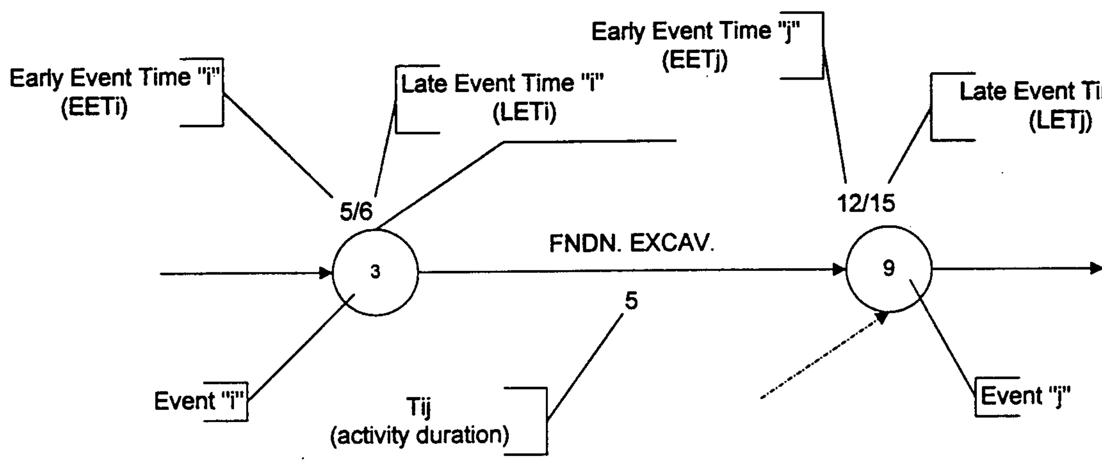


Figure 11. Terminology for "I-J" CPM Activities.

Forward Pass

The objective of the Forward Pass is to determine the early event times for each of the events on the I-J diagram. The process is started by setting the early event time of the initial event on the diagram (there is to be only one initial event) equal to zero (0). Once this is done, then all the other early event times can be calculated; this will be explained in Figure 12.

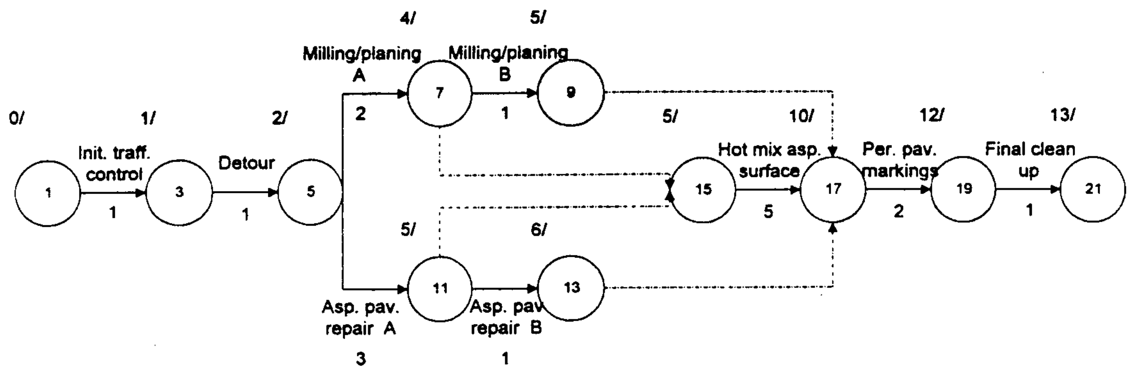


Figure 12. Forward Pass for "I-J" CPM.

The early event time of all other events is determined as the maximum of all the early finish times of all the activities which terminate at an event in question. Therefore, an event should not be considered until the early finish times of all activities which terminate at the event have first been calculated. The Forward Pass is analogous to trying all the paths on a road network, finding the maximum time that it takes to get each node. The calculations for the Forward Pass can be summarized as the following steps:

1. The earliest possible occurrence time for the initial event is taken as zero [EETi = 0 = ESTij (i = initial event)],
2. Each activity can begin as soon as its preceding event (i-node) occurs [ESTij = EETi]; [EFTij = EETi + Tij],
3. The earliest possible occurrence time for an event is the largest of

the Early Finish Times for those activities which terminate at the event [EETj = max EFTpj (p = all events that precede Event "j")],

4. The total project duration is the earliest possible occurrence time for the last event on the diagram [TPD = EETj (j = terminal event on diagram)].

The early event time of Event "1" in Figure 12 was set equal to 0, i.e. EET(1) = 0. It is then possible to calculate the early finish times for Activity 1-3. Activity early finish times are not normally shown on an I-J CPM diagram, but are shown here to help explain the process. Since both Events "Milling/Planing1" and "Asphalt Pavement Repair1" have only a single activity preceding them, their early event times can be established as 4 and 5, respectively. Event "Hot Mix Asphalt Surface" has two preceding activities, therefore the early finish times for both Activities 7-15 (= 4) and 11-15 (= 5) must be found before establishing that its early event time equals 5. Note that "dummy" activities are treated just as regular activities for calculations. The rest of the early event times on the diagram are thus wisely calculated resulting in an estimated Total Project Duration of 13 days.

Reverse Pass

The objective of the Reverse Pass is to determine the late event time for each event on the I-J diagram. This process is started by setting the late event time of the terminal, or last, event on the diagram (there is to be only one terminal event) equal to the early event time of the event, i.e. LETj = EETj. Once this is done, then all the other late event times can be calculated; this will be explained by the use of Figure 13.

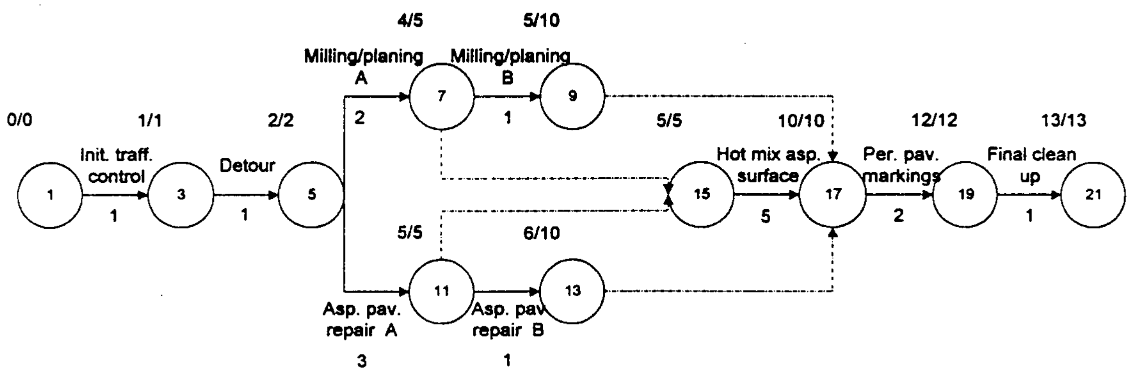


Figure 13. Reverse Pass for "I-J" CPM.

The late event time of all other events is determined as the minimum of all the late start times of all the activities which originate at an event in question. Therefore, an event should not be considered until the late event times of all activities which originate at the event have first been calculated. The calculations for the Reverse Pass can be summarized as the following steps:

1. The latest permissible occurrence time for the terminal event is set equal to early event time of the terminal event. This also equals the estimated project duration [LETj = EETj = TPD (j = terminal event on diagram)],
2. The latest permissible finish time for an activity is the latest permissible occurrence time for its following event (j-node) [LFTij = LETj]; [LSTij = LETj - Tij],

3. The latest permissible occurrence time for an event is the minimum (earliest) of the latest start times for those activities which originate at the event [LETi = min LSTip (p = all events that follow Event "i")],

4. The latest permissible occurrence time of the initial event should equal its earliest permissible occurrence time (zero). This provides a numerical check [LETi = EETi = 0 (i = initial event on diagram)].

The late event time of Event "Final Clean Up" in Figure 13 was set equal to 13. It is then possible to calculate the late start times for Activity 21-19. Activity late start times are not normally shown on an I-J CPM diagram, but are shown here to help explain the Reverse Pass process. Since both Events "Final Clean Up", "Permanent Pavement Markings" and "Hot Mix Asphalt Surface" have only a single activity which originates from them, their late event times can be established as 12, 10 and 5 respectively. Event "Asphalt Pavement Repair1" has two originating activities, therefore, the late start times for both Activities 15-11 (=5) and 13-11 (=9) must be found before establishing that its late event time equals 5. Note that "dummy" activities are treated just as regular activities for calculations. Likewise, the late event time for Event "Detour" cannot be determined until the late start times for Activities 7-5 (=3) and 11-5 (=2) have been calculated. LET(Detour) is then set as 2. The rest of the late event times on the diagram are thus wisely calculated resulting in the late event time of Event "Initial Traffic Control" checking in as zero.

Activity Float Times

One of the primary benefits of the Critical Path Methods is the ability to evaluate the relative importance of each activity in the network by its calculated float, or slack, time. In the calculation procedures for CPM, an allowable time span is determined for each activity; the boundaries of this time span is established by the activity's Early Start Time and Late Finish Time. When this bounded time span exceeds the activity's duration, the excess time is referred to as "float" time. Float time can only exist for non-critical activities; activities with zero float are "critical" activities and make up the Critical Path(s) on the network. There are three basic float times for each activity, Total Float, Free Float, and Interfering Float. It should be noted that once an activity is delayed to finish beyond its Early Finish Time, then the network event times must be recalculated for all following activities before evaluating their float times.

Total Float

The Total Float for an activity is the total amount of time that the activity can be delayed beyond its Early Finish Time before it delays the overall project completion time. This delay will occur if the activity is not completed by its Late Finish Time. Therefore, the Total Float is equal to the time difference between the activity's Late Finish Time and its Early Finish Time. The Total Float for an activity can be calculated by the following expression:

$$TFij = LETj - EETI - Tij.$$

Since the LETj for any activity is its Late Finish Time, and the EETi plus the duration, Tij, equals the Early Finish Time, then the above expression for the Total Float of an activity reduces to:

$$TFij = LFTij - EFTij.$$

The calculation of the Total Float can be illustrated by referring to Figure 14 where the Total Float and Free Float for each activity is shown below the activity.

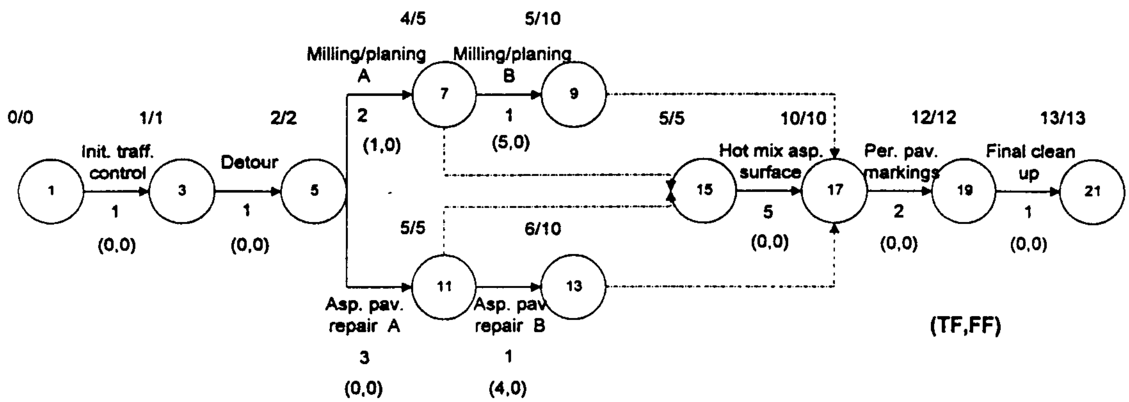


Figure 14. "I-J" CPM Diagram with Float Times.

For Activity "Milling/Planing1" the Total Float = 5 - 2 - 2 = 1, while for Activity "Milling/Planing2" the Total Float = 10 - 1 - 4 = 5. The Total Float for most of the other activities is zero, thus these activities make up the Critical Path for this diagram. Float Times are not usually noted on dummy activities, however, dummies do have float since they are activities. Activity 11 - 15 connects two critical activities and has zero Total Float, thus it is on the Critical Path and should be marked as such.

One of the biggest problems in the use of CPM for scheduling is the misunderstanding of float. Although the Total Float for each activity is determined independently, it is not an independent property, but is shared with other activities which precede or follow it. The float value calculated is only good for the event times on the diagram. If any of the event times for a diagram change, then the float times must be recalculated for all the activities affected. A chain of activities is a series of activities linked sequentially in a CPM network. Obviously, there are many different possible chains of activities for a given network. Often, a short chain will have the same Total Float. Note that if the Total Float is used up by an earlier activity in a chain, then it will not be available for following activities. Thus, one should be very careful when discussing the float time available for an activity with persons not familiar with CPM. This problem can be avoided if it is always a goal to start all activities by their Early Start Time, if feasible, and save the float for activities which may need it when problems arise.

Free Float

Free Float is the total amount of time that an activity can be delayed beyond its Early Finish Time before it delays the Early Start Time of a following activity. This means that the activity must be finished by the Early Event Time of its "j-node," thus the Free Float is equal to the time difference between the EETj and its Early Finish Time. The Free Float can be calculated by the following expressions:

$$FFij = EETj - EETi - Tij \quad \text{(or)} \quad FFij = EETj - EFTij.$$

The calculation of Free Float can be illustrated by referring to Figure 14 where the Total Float and Free Float for each activity is shown below the activity. For Activity "Milling/Planing2" the Free Float = 5 - 4 - 1 = 0.

The Free Float for most activities on a CPM diagram will be zero, as can be seen in Figure 14. This is because Free Float only occurs when two or more activities merge into an event, such as Event 5. The activity(s) which controls the Early Event Time of the event will, by definition, have a Free Float of zero while the other activity(s) will have Free Float values greater than zero. Of course, if two activities tie in the determination of the Early Event Time, then both will have zero Free Float. This characteristic can be illustrated by noting that Activities 7-15 and 11-15 merge at Event 15, with Activity 11-5 controlling the EET = 5. Thus the Free Float for Activity 11-15 will be zero, while the Free Float for Activity 7-15 is equal to one. Any time you have a single activity preceding another activity, then the Free Float for the preceding activity is immediately known to be zero, since it must control the Early Start Time of the following activity. Free Float can be used up without hurting the scheduling of a following activity, while this cannot be said for Total Float.

Interfering Float

Interfering Float for a CPM activity is the difference between the Total Float and the Free Float for the activity. The expression for Interfering Float is:

$$IFij = LETj - EETj \quad \text{(or)} \quad IFij = TFij - FFij.$$

The concept of Interfering Float comes from the fact that if one uses the Free Float for an activity, then the following activity can still start on its Early Start Time, thus no real interference. However, if any additional float is used, then the following activity's Early Start Time will be delayed. In practice, the value of Interfering Float is seldom used; it is presented here since it helps one to better comprehend the overall system or float, for CPM activities. The reader is encouraged to carefully review the sections on activity float, and refer to Figures 14 and 15 for graphic illustrations.

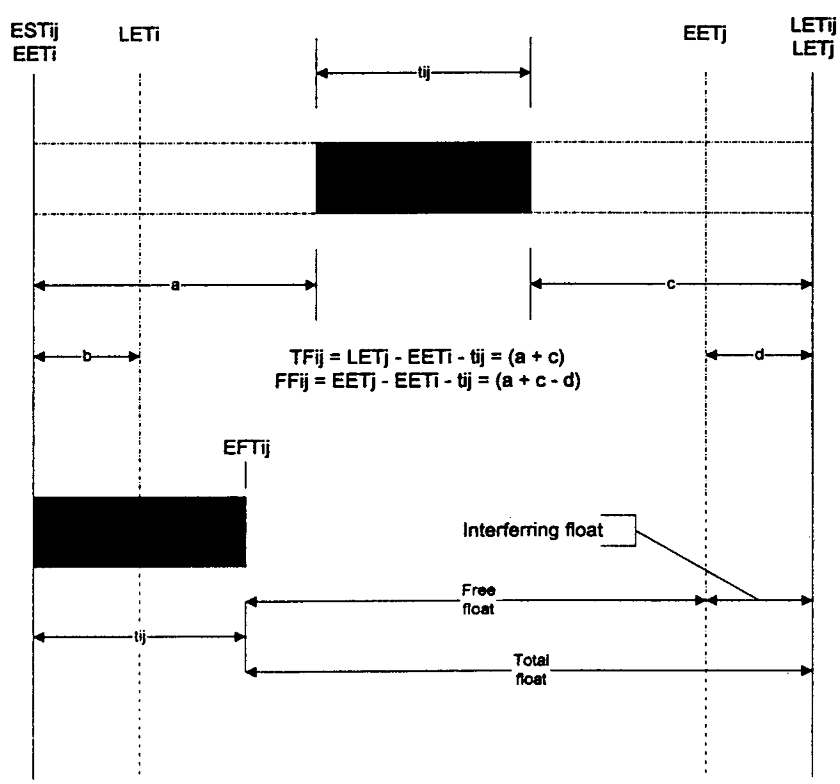


Figure 15. Graphic Representation of Float for CPM.

Activity Start and Finish Times

One of the major reasons for the utilization of CPM in the planning of construction projects is to estimate the schedule for conducting various phases, activities, of the project. Thus, it is essential that one know how to determine the starting and finishing times for each activity on a CPM diagram. Before explaining how to do this, it is important to note that any starting or finish time determined is only as good as the CPM diagram and will not be realistic if the diagram is not kept up to date as the project progresses. If one is only interested in general milestone planning, this is not as critical. However, if one is using the diagram to determine detailed work schedules and delivery dates, then updating is essential. This topic will be discussed later.

The determination of the early and late starting and finish times for I-J CPM activities will be illustrated by reference to Figure 14. There are four basic times to determine for each activity: Early Start Time, Late Start Time, Early Finish Time, and Late Finish Time. Activity "Detour" on Figure 14, as for all other activities on an I-J CPM diagram, has four event times:

$$EETi = 1, LETi = 1, EETj = 2, LETj = 2.$$

A common mistake is to refer to these four times as the Early Start Time, Late Start Time, Early Finish Time, and Late Finish Time for Activity "Detour", or Activity 3-5. Although this is true for all critical activities and may be true of some other activities, this is not true of many of the activities on an I-J diagram and this procedure should not be used. The basic activity times can simply be determined by the four relationships below:

Early Start Time, ESTij = EETi	(= 1 for Activity "Detour"),
Late Start Time, LSTij = LETj - Tij	(= 2 - 1 = 1 for Activity "Detour"),
Early Finish Time, EFTij = ESTij + Tij	(= 1 + 1 = 2 for Activity "Detour"),
Late Finish Time, LFTij = LETj	(= 2 for Activity "Detour").

As can be seen, the Early Finish Time for Activity "Detour" is 2, and the Late Start Time is 1.

The four basic activity times can be found quickly and easily, but cannot be read directly off the diagram. For many construction projects today the starting and finishing times for all activities are shown on a computer printout, not only in CPM days, but in calendar days also.

Overlapping Work Items in I-J CPM

One of the most difficult scheduling problems encountered is the "overlapping work items" problem. This occurs often in construction and requires careful thought by the scheduler whether using I-J CPM or Precedence CPM technique (Precedence will be discussed later). The overlapping work situation occurs when two or more work items which must be sequenced will take too long to perform end to end, thus following items started before their preceding work items are completed. Obviously, the preceding work items must be started and worked on sufficiently in order for the following work items to begin. This situation occurs often with construction work such as concrete wall (Form, Pour, Cure, Strip, Finish) and underground utilities (Excavate, Lay Pipe, Test Pipe, Backfill). Special care must be taken to show the correct logic to follow on the I-J diagram, while not restricting the flow of the work as the field forces use the CPM schedule.

The overlapping work item problem is also encountered for several other reasons in construction scheduling. A major reason is the scheduling required to optimize scarce or expensive resources, such as concrete forms. It is usually too expensive or impractical to purchase enough forms to form an entire concrete structure at one time; therefore, the work must be broken down into segments and scheduled with the resource constraints identified. Another reason for overlapping work items could be for safety or for practicality. For instance, in utilities work, the entire pipeline could be excavated well ahead of the pipe-laying operation. However, this would expose the pipe trench to weather or construction traffic which could result in the collapse of the trench, thus requiring expensive rework. Therefore, the excavation work is closely coordinated with the pipe-laying in selected segments to develop a more logical schedule.

The scheduling of overlapping work items will be further explained by the use of an example. Assume that a schedule is to be developed for a small building foundation. The work has been broken down into four separate phases: Excavation, Formwork, Concrete Placement, and Stripping and Backfilling. A preliminary analysis of the work has determined the following work day durations of the four work activities: 4, 8, 2, and 4, respectively. If the work items are scheduled sequentially, end to start, the I-J CPM diagram for this work would appear as depicted in Figure 16. Notice that the duration for the completion of all the work items is 18 work days.

A more efficient schedule can be developed for the work depicted in Figure 16. Assume that the work is to be divided into two halves, with the work to be overlapped instead of done sequentially. A bar chart schedule for this work is shown in Figure 17. The work items have been abbreviated as E1 (Start Excavation), E2 (Complete Excavation), etc. to simplify the diagrams. Since there is some float available for some of the work items, there are actually several alternatives possible. Notice that the work scheduled on the bar chart will result in a total project duration of 13 work days, which is five days shorter than the CPM schedule of Figure 16.

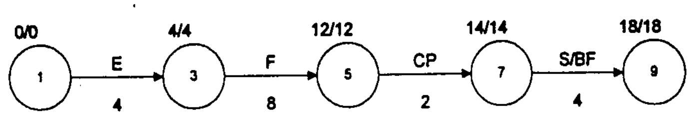


Figure 16. Sequential "I-J" CPM Activities.

An I-J CPM schedule has been developed for the work shown on the bar chart of Figure 17 and is depicted in Figure 18.

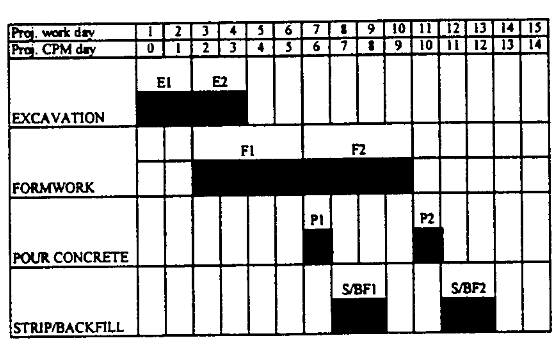


Figure 17. Bar Chart for Overlapping Work Items.

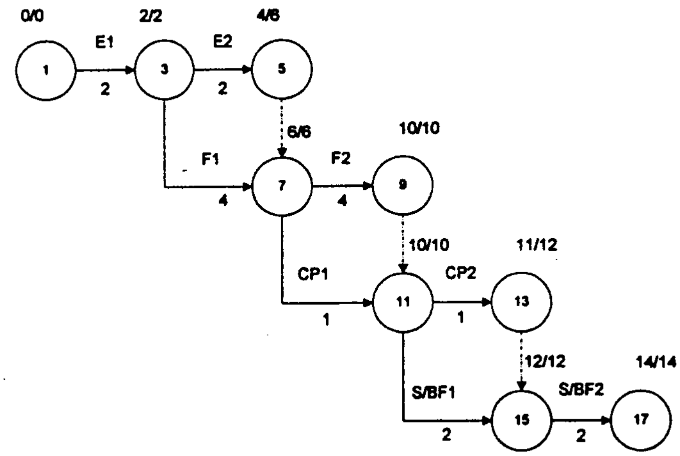


Figure 18. "I-J" CPM #1 for Overlapping Work Items.

At first glance the diagram looks fine except for one obvious difference, the project duration is 14 days instead of 13 days for the bar chart schedule. Closer review reveals that there are serious logic errors in the CPM diagram at both Events 7 and 11. As drawn, the second half of the excavation (E2) must be completed before the first concrete placement (CP1) can start. Likewise, the first wall pour cannot be stripped and backfilled (S/BF1) until the second half of the formwork is completed (F2). These are common logic errors caused by the poor development of I-J activities interrelationships. The diagram shown in Figure 19 is a revised version of the I-J CPM diagram of Figure 18 with the logic errors at Events 7 and 11 corrected. Notice that the project duration is now 13 days as for the bar chart.

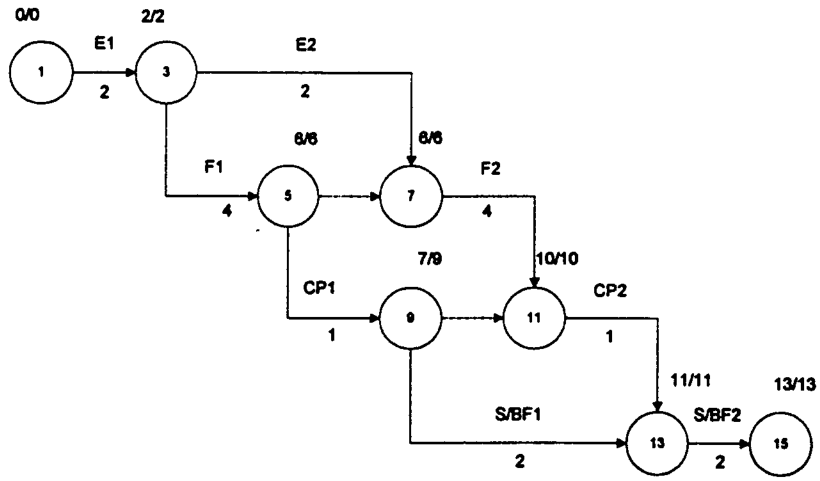


Figure 19. "I-J" CPM #2 for Overlapping Work Items.

Great care must be taken to show the correct logic for a project when developing any CPM diagram. One should always review a diagram when it is completed to see if any unnecessary or incorrect constraints have been developed by improper drawing of the activities and their relationships to each other. This is especially true for I-J CPM diagrams where great care must be taken to develop a sufficient number of events and dummy activities to show the desired construction work item sequences. The scheduling of overlapping work items often involves more complicated logic and should be done with care. Although beginning users of I-J CPM tend to have such difficulties, they can learn to handle such scheduling problems in a short time period.

"Precedence" Critical Path Method

The other Critical Path Method used widely in the construction industry is the "Precedence" method. This planning and scheduling system was developed by modifying the Activity on Node method discussed earlier and was depicted in Figure 3. In Activity on Node networks each node or circle represents a work activity. The arrows between the activities are all "finish to start" relationships, i.e. the preceding activity must finish before the following activity can start. The four times shown on each node represent the Early Start Time/Late Start Time and Early Finish Time/Late Finish Time for the activity. In the Precedence system, see Figure 20, there are several types of relationships which can exist between activities allowing for greater flexibility in developing the CPM network.

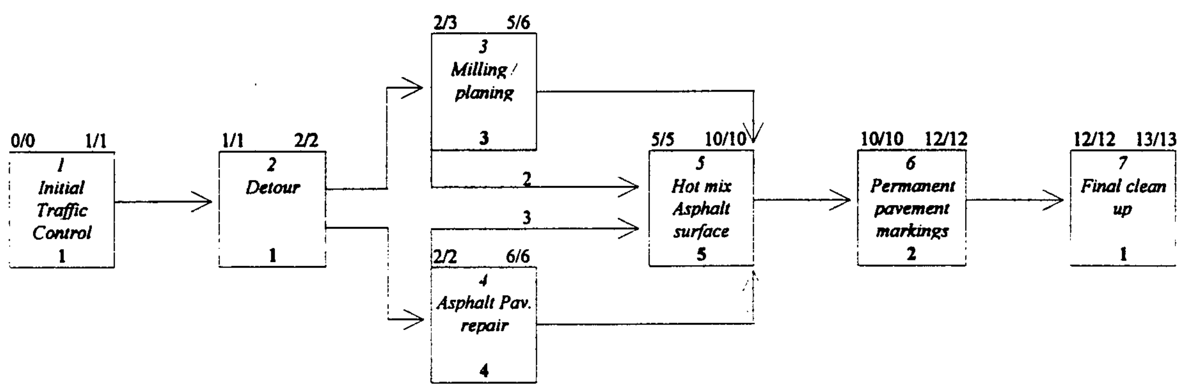


Figure 20. Precedence CPM Diagram.

The construction activity on a Precedence diagram is typically represented as a rectangle, see Figure 21. There are usually three items of information placed within the activity's box, the "Activity Number," the "Activity Description," and the "Activity Time" (or duration). The activity number is usually an integer number, although alphabetical characters are often added to denote the group responsible for management of the activity's work scope. The activity time represents the number of workdays required to perform the activity's work scope, unless otherwise noted.

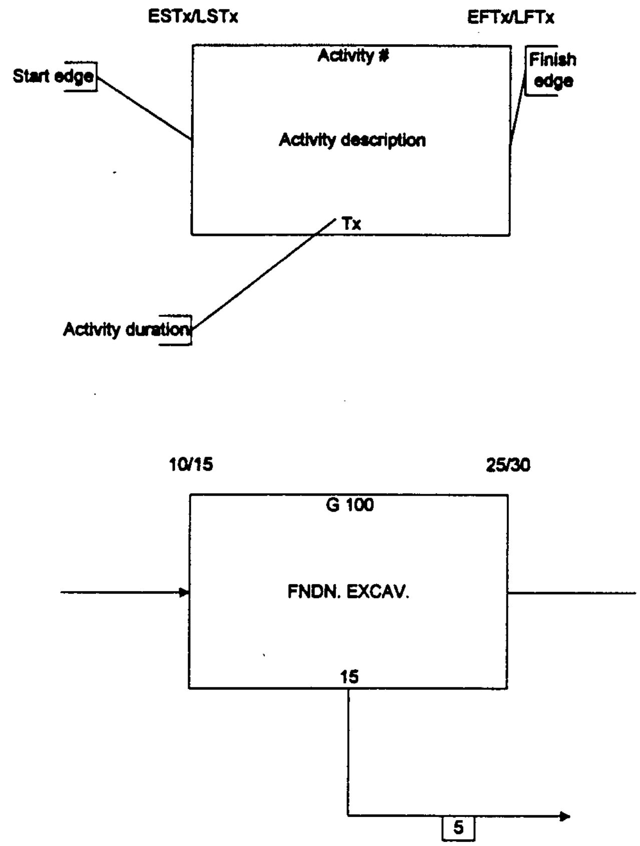


Figure 21. Precedence Activity Information.

There are two other important items of information concerning the activity shown on a Precedence diagram. First, the point at which the relationship arrows touch the activity's box is important. The left edge of the box is called the "start edge;" therefore, any arrow contacting this edge is associated with the activity's start time. The right edge of the box is called the "finish edge;" therefore, any arrow contacting this edge is associated with the activity's finish time. Secondly, the calculated numbers shown above the box on the left represent the Early Start Time and the Late Start Time of the activity, while the numbers above on the right represent the Early Finish Time and the Late Finish Time of the activity. This is different from I-J CPM where the calculated times represent the event times and not activity times.

Precedence Relationships

The arrows on a Precedence diagram represent the relationships that exist between different activities. There are four basic relationships which are used, as depicted in Figure 22. The Start-to-Start relationship states that Activity B can not start before Activity A starts, i.e. EST(B) greater than or equal to EST(A). The greater-than situation will occur when another activity which precedes Activity B has a greater time constraint than the EST(A).

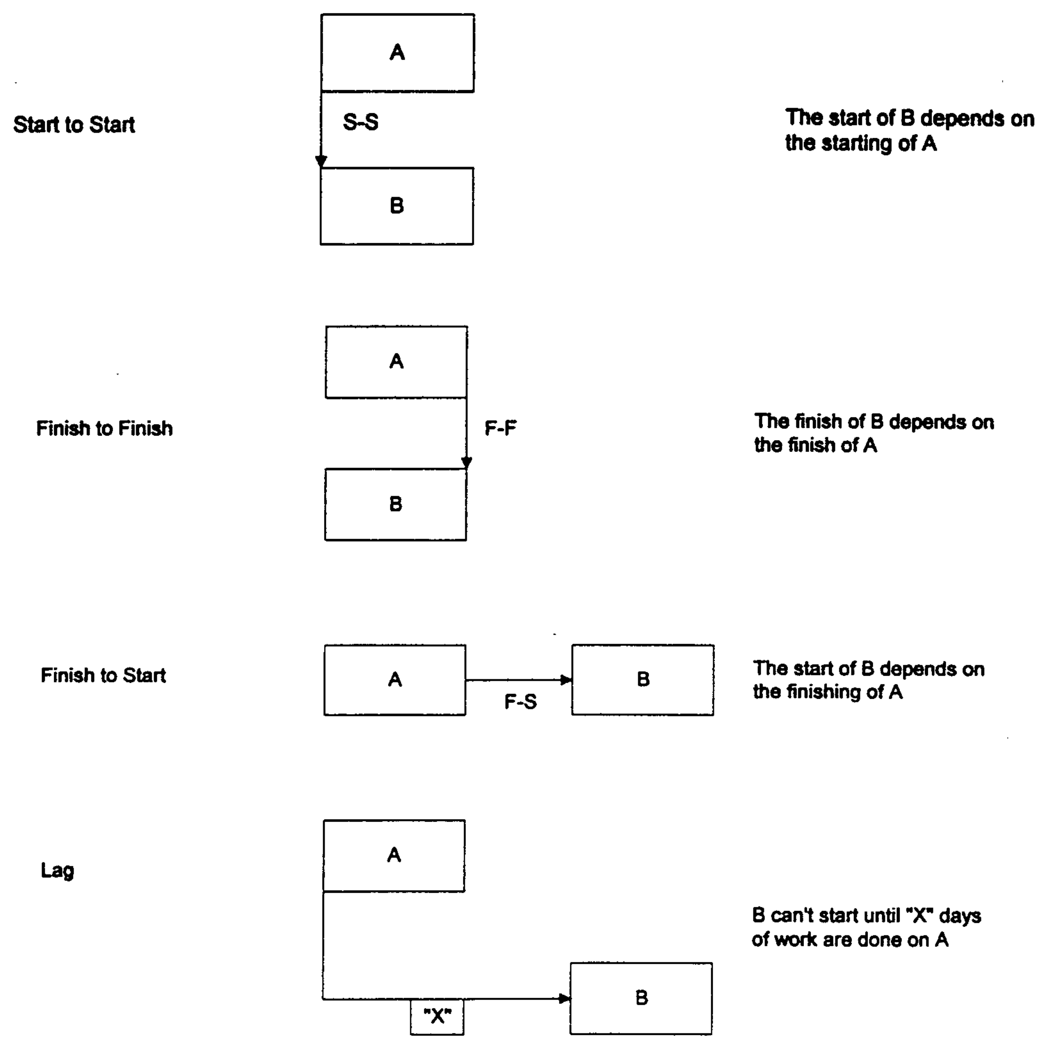


Figure 22. Precedence CPM Activity Relationships.

The Finish-to-Start relationship states that Activity B can not start before Activity A is finished, i.e. EST(B) is greater than or equal to EFT(A). This relationship is the one most commonly used on a Precedence diagram. The Finish-to-Finish relationship states that Activity B can not finish before Activity A finishes, i.e. EFT(B) is greater than or equal to the EFT(A). This relationship is used mostly in Precedence networks to show the finish to finish relationships between overlapping work activities.

The fourth basic relationship is the Lag relationship. Lag can be shown for any of the three normal Precedence relationships and represents a time lag between the two activities. The Lag relationship shown in Figure 22 is a start to start (S-S) Lag. It means that Activity B can not start until "X" days of work are done on Activity A. Often when there is a S-S Lag between two activities, there is a corresponding F-F Lag noting that the following activity will require "X" days of work to complete after the preceding activity is completed. The use of Lag time on the relationships allows much greater flexibility in scheduling delays between activities (such as curing time) and for scheduling overlapping work items (such as excavation, laying pipe and backfilling). A Precedence with all three basic relationships and two lags is shown in Figure 23.

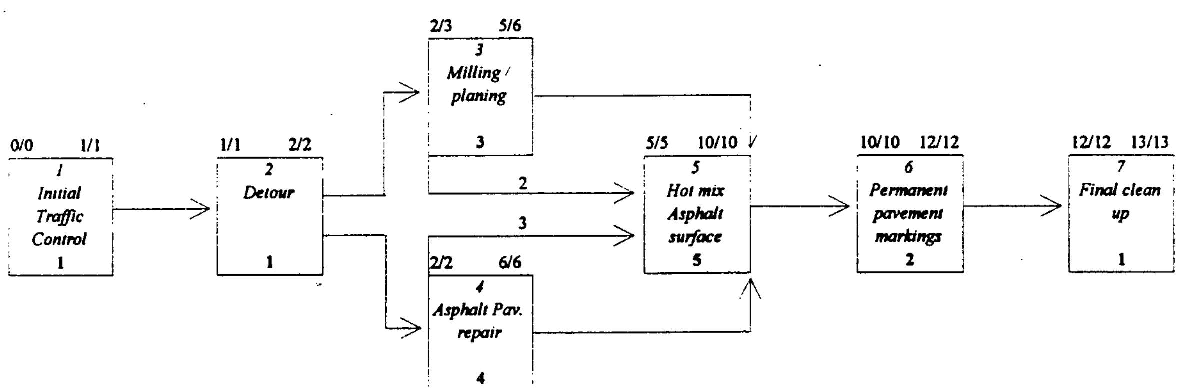


Figure 23. Precedence Diagram with Activity Times.

Precedence Time Calculations

The time calculations for Precedence are somewhat more complex than for I-J CPM. The time calculation rules for Precedence networks are shown in Figure 24.

I. Earliest Start Time

a. EST of 1st Work Item is zero (by definition).
EST of all other W.I.'s is the greater of these times:
1 EST of a preceding W.I. if start-start relation.
2 EFT of a preceding W.I. if finish-start relation.
3 EFT of a preceding W.I., less the duration of the W.I itself, if finish-finish relation.
4 EST of a preceding W.I., plus the lag, if there is a lag relation.

II. Earliest Finish Time

a. For 1st Work Item, EFT = EST + Duration
b. EFT of all other W.I.'s is the greater of these times:
1 EST of W.I. plus its duration.
2 EFT of preceding W.I. if finish-finish relation.

III. Latest Finish Time

a. LFT for last Work Item is set equal to its EFT
b. LFT for all other W.I.'s is the lesser of these times:
1 LST of following W.I. if finish-start relation.
2 LFT of following W.I. if finish-finish relation.
3 LST of following W.I., plus the duration of the W.I. itself, if there is a start-start relation.
4 LST of following W.I., less the lag, plus the duration of the W.I. itself, if there is a lag relation.

IV. Latest Start Time

a. LST of 1st Work Item = LFT - Duration
b. LST of all other W.I.'s is the lesser of these items:
1 LFT of W.I. less its duration
2 LST of following W.I. if start-start relation
3 LST of following W.I. less the lag, if there is a lag relation.

Notes:

EST = Early Start Time — LST = Late Start Time
EFT = Early Finish Time — LFT = Late Finish Time

Lag = Number of days of lag time associated with a relationship

Figure 24. Time Calculations Rules for Precedence Networks.

These rules are based on the assumption that all activities are "continuous" in time, i.e. once started, they are worked through to completion. In reality this assumption simplifies interpretation of the network and the activity float times. It assures that the EFT = (EST + Duration) for a given activity.

The time calculations involve both a forward pass and a reverse pass, as in I-J CPM. However, for Precedence, one is calculating activity start and finish times directly and not event times as in I-J. In the forward pass one evaluates all activities preceding a given activity to determine its EST. For Activity 5 in Figure 23 there are four choices:

4 to 5 (Start to Start), EST(5) = 2 + 3 = 5;

4 to 5 (Finish to Finish), EST(5) = 6 - 5 = 1;

3 to 5 (Start to Start), EST(5) = 2 + 2 = 4;

3 to 5 (Finish to Finish), EST(5) = 5 - 5 = 0;

since 5 is the largest EST, the 4 to 5 (S-S) relationship controls. The EFT is then determined as the (EST + Duration); for Activity 5, the EFT = 10.

For the reverse pass in Precedence one evaluates all activities following a given activity to determine its LFT. For Activity 5 the only following activity is Activity 6, therefore the LFT(F) = 10 - 0 = 10. For Activity 4 there are two choices for LFT:

5 to 4 (Start to Start, with Lag) LFT(4) = 5 - 3 + 4 = 6;

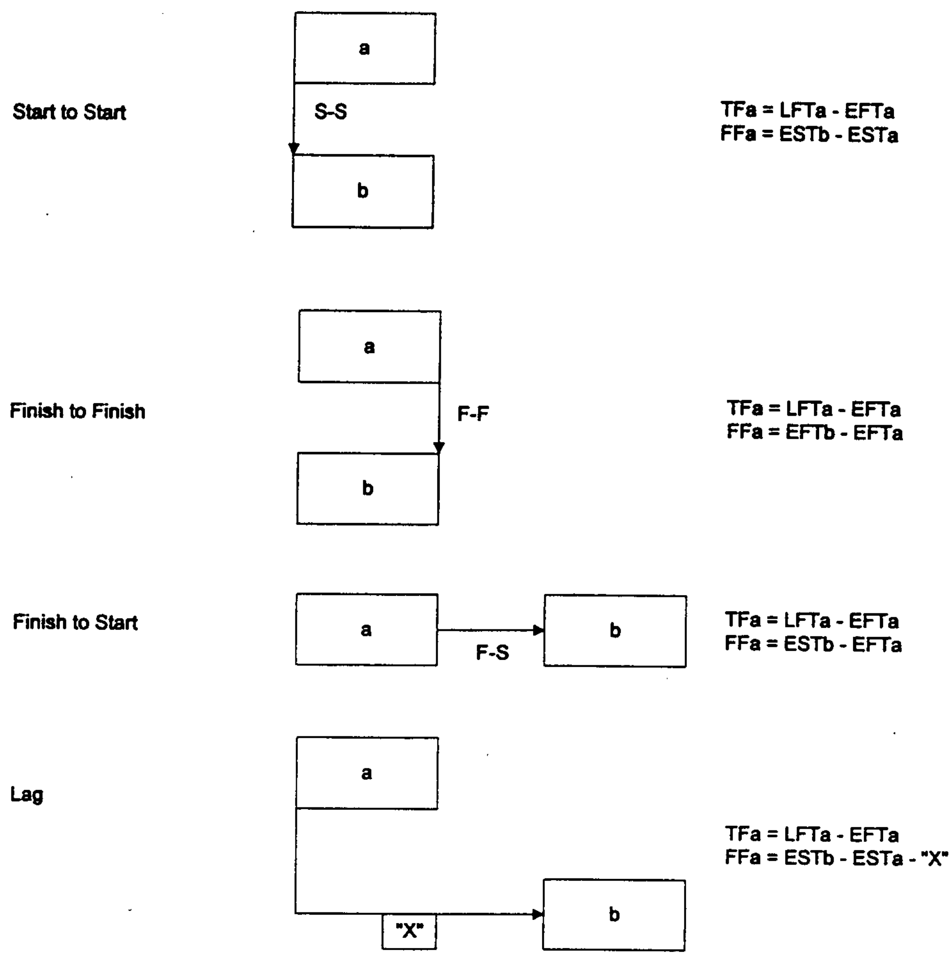
5 to 4 (Finish to Finish), LFT(4) = 10 - 0 = 10;

since 6 is the smallest LFT, the 5 to 4 (S-S) relationship controls. The LST is then determined as the (LFT - Duration); for Activity 4, the LST is 2.

A major advantage of the Precedence system is that the times shown on a Precedence activity truly represent actual start and finish times for the activity. Thus, lesser trained personnel can more quickly read these times from the Precedence network than from an I-J network. As for I-J CPM the activity times represent CPM days which relate to work days on the project. The conversion from CPM days to Calendar dates will be covered later.

Precedence Float Calculations

The float times for Precedence activities have the same meaning as for I-J activities; however, the calculations are different. Before float calculations can be made, all activity start and finish times must be calculated as just described. Remember again that all activities are assumed to be "continuous" in duration. The float calculations for Precedence networks are depicted in Figure 25.



Notes:

(1) All activities assumed continuous in duration.
(2) The total float for all activities is always equal to their Late Finish Time minus their Early Finish Time.
(3) The Free Float calculations shown are for each type of relationship. If an activity has several following activities, then the Free Float for the activity is the SMALLEST of the Free Float calculations made for each following activity.

Figure 25. Precedence Float Calculations

The Total Float of an activity is defined as the "total amount of time that an activity can be delayed before it affects the total project duration." This means that the activity must be completed by its late finish time; therefore, the total float for any Precedence activity is equal to its LFT minus its EFT. For Activity 4 in Figure 23 its Total Float = 6 - 6 = 0.

The Free Float of an activity is defined as the "total amount of time that an activity can be delayed beyond its EFT before it delays the EST of a following activity." In I-J CPM this is a simple calculation equal to the EET of its "j-node" minus the EET of its "i-node" minus its duration. However, for a Precedence activity it is necessary to check the free float existing between it and each of the activities which follows it, as depicted in Figure 25. The actual free float for the activity is then determined as the "minimum" of all the free float options calculated for the following activities. For most Precedence activities, as for I-J, the free float time is normally equal to zero. For Activity 2 in Figure 23 there are two choices:

3 to 2 (Finish to Start), FF = 2 - 0 - 2 = 0;

4 to 2 (Finish to Start), FF = 2 -0 - 2 = 0;

since the smallest is 0, then both relationships control and the FF = 0.

Overlapping Work Items

A major reason that many persons like to use the Precedence CPM system for construction scheduling is its flexibility for overlapping work items.

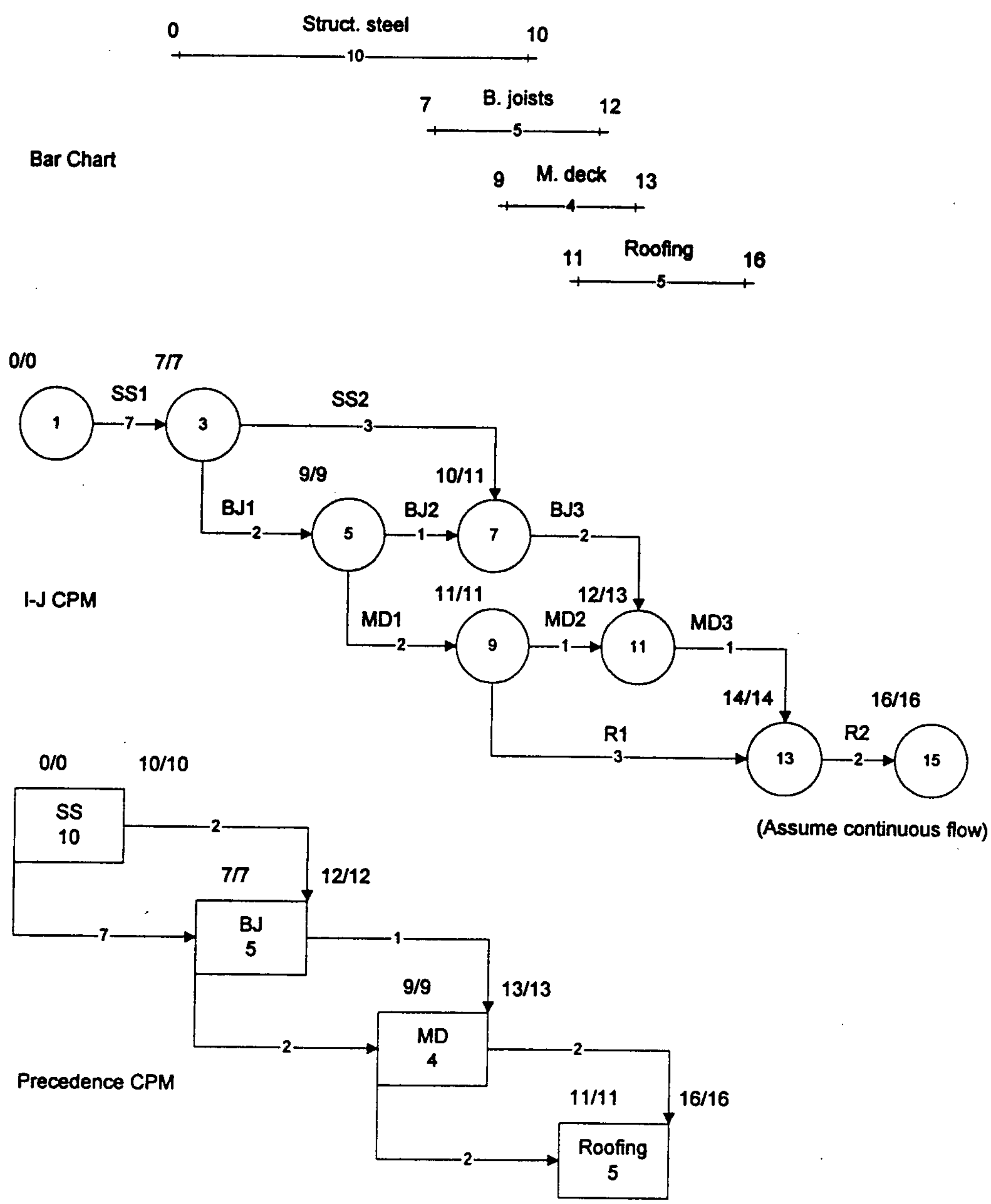
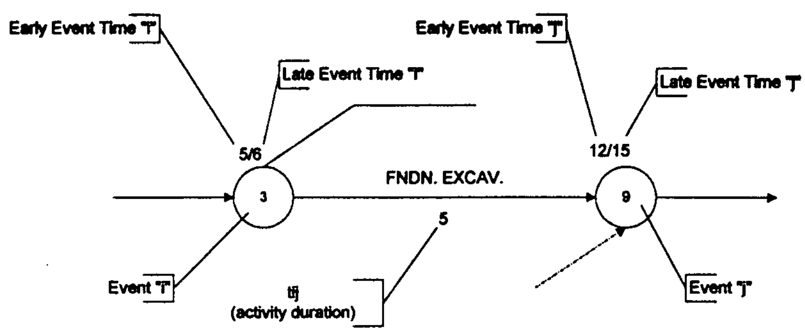


Figure 26. Overlapping Work Items.

Figure 26 depicts the comparable I-J and Precedence diagrams necessary to show the logic and time constraints shown in the bar chart at the top of the figure. Although the Precedence version is somewhat easier to draw, one does have to be careful in calculating the activity times. There is also a tendency for all of the Precedence activities to be critical due to the continuous time constraint for the activities. If one understands how to use either CPM system, the network development will not be difficult; therefore, it is mostly a matter of preference.

CPM Day to Calendar Day Conversion

All CPM times on the logic diagrams are noted in CPM days which are somewhat different from Project Workdays and decidedly different from Calendar days or dates. Since most persons utilizing the activity times from a CPM diagram need to know the starting and finishing time requirements in calendar dates, one needs to know how to convert from CPM days to calendar dates. To illustrate this relationship please refer to Figure 27 which depicts a typical activity from an I-J CPM activity, plus a CPM day to CAL day conversion chart.



CPM	CAL (February)	
	2	
0	3	Project start date
1	4	
2	5	
3	6	
4	7	
	8	
	9	
5	10	
6	11	
7	12	

CPM	CAL
8	13
9	14
	15
	16
10	17
11	18
12	19
13	20
14	21
	22
	23

NOTE: CPM day (X) = work day (X + 1)
(i.e. CPM day 0 = project work day 1)

EST=5=February 5, 1997
LST=10=February 17, 1997

EFT=10=February 14, 1977
LFT=15=February 21,1997

Figure 27. CPM/CAL Conversion Chart.

The CPM/CAL conversion table represents CPM days on the left and regular calendar days on the right. For the sample project shown the project start date is February 3, 1997. Accordingly, the first CPM day is "0" and is shown on the left side. CPM days are then noted consecutively only skipping weekends, holidays or other non-workdays for the project. CPM days are referenced to the "morning" of a workday; therefore, CPM Day "0" is equal to the morning of project Workday "1" and also equal to the morning of February 3, 1997.

Activity start dates are read directly from the conversion table since they start on the morning. For instance, if an activity has an early start on CPM Day 5, then it would start on February 10, 1997. This is also the morning of Workday 6. Finish times can also be read directly from the table, but one must remember that the date is referenced to the morning of the day. For instance, if an activity has an early finish of CPM Day 8, then it must finish on the morning of February 13. However, most persons are familiar with finish times referenced to the end of the day; therefore, unless working 24 hour days, one must back off by one CPM day to give the finish date of the evening of the workday before. This means the finish time for the activity finishing by the morning of February 12 would be given as February 12, 1997. This process is followed for both the Early Finish Time and the Late Finish Time for an activity.

The activity shown in Figure 27 has the following activity times:

Early Start Time = CPM Day 5

Late Start Time = 15 - 5 = CPM Day 10

Early Finish Time = 5 + 5 = CPM Day 10 (Morning) or CPM Day 9 (Evening)

Late Finish Time = 15 = CPM Day 15 (Morning) or CPM Day 14 (Evening)

The activity times in calendar dates can be obtained for the activity depicted in Figure 27 using the CPM/CAL conversion table:

Early Start Time = February 10, 1997

Late Start Time = February 17, 1997

Early Finish Time = February 17 (Morning) or February 14 (Evening)

(February 14 would be the date typically given)

Late Finish Time = February 24 (Morning) or February 21 (evening)

(February 21 would be the date typically given)

The conversion of CPM activity start and finish times to calendar dates is the same process for either I-J CPM or Precedence CPM. The CPM/CAL conversion table should be made when developing the original CPM schedule since it is necessary to convert all project constraint dates, such as delivery times, to CPM days for inclusion into the CPM logic diagram. The charts can be made up for several years and only the project start date is needed to show the CPM days.

Updating the CPM Network

Updating the network is the process of revising the logic diagram to reflect project changes and actual progress on the work activities. A CPM diagram is a dynamic model which can be used to monitor the project schedule if the diagram is kept current, or up to date. One of the major reasons for dissatisfaction with the use of CPM for project planning is that once the original schedule was developed, it was never revised to reflect actual progress. Thus, after some time the schedule was no longer valid and was discarded. If it is kept up to date as it should be, it will be a dynamic and very useful management tool.

There are several causes for changes in a project CPM diagram, such as:

1. Revised project completion date.
2. Changes in project plans, specifications or site conditions.
3. Activity durations do not equal the estimated durations.
4. Construction delays (i.e. weather, delivery problems, subcontractor delays, labor problems, natural disasters, owner indecision, etc.)

In order to track such occurences the project schedule should be monitored and the following information collected for all activities underway and those just completed or soon to start. The following information should be collected:

1. Actual start and/or finish dates, including actual workdays completed.
2. If not finished, workdays left to complete and estimated finish date.
3. Reasons for any delays or quick completion times.
4. Lost project workdays and the reasons for the work loss.

Frequency of Updating

A major concern is the frequency of updates required for a project schedule. The obvious answer is, "frequent enough to control the project." The major factor is probably cost, since monitoring and updating are expensive and do cause disturbances, no matter how slight for the project staff. Other factors are the management level of concern, the average duration of most activities, total project duration and the amount of critical activities. Some general practices followed for updating frequencies are:

1. Uniform intervals (daily, weekly, monthly).
2. Only when significant changes occur on the project schedule.
3. Less in the beginning, more as the project completion draws near.
4. At well-defined milestones in the project schedule.
5. In addition to keeping up with the actual project progress, there are other reasons that make it beneficial to revise the original project network:
    a. To provide a record for legal action or for future schedule estimates.
    b. To illustrate the impact of changes in project scope or design on the schedule.
    c. To determine the impact of delays on the project schedule.
    d. To correct errors or make changes as the work becomes better defined.

Methods for Revising the Project Network

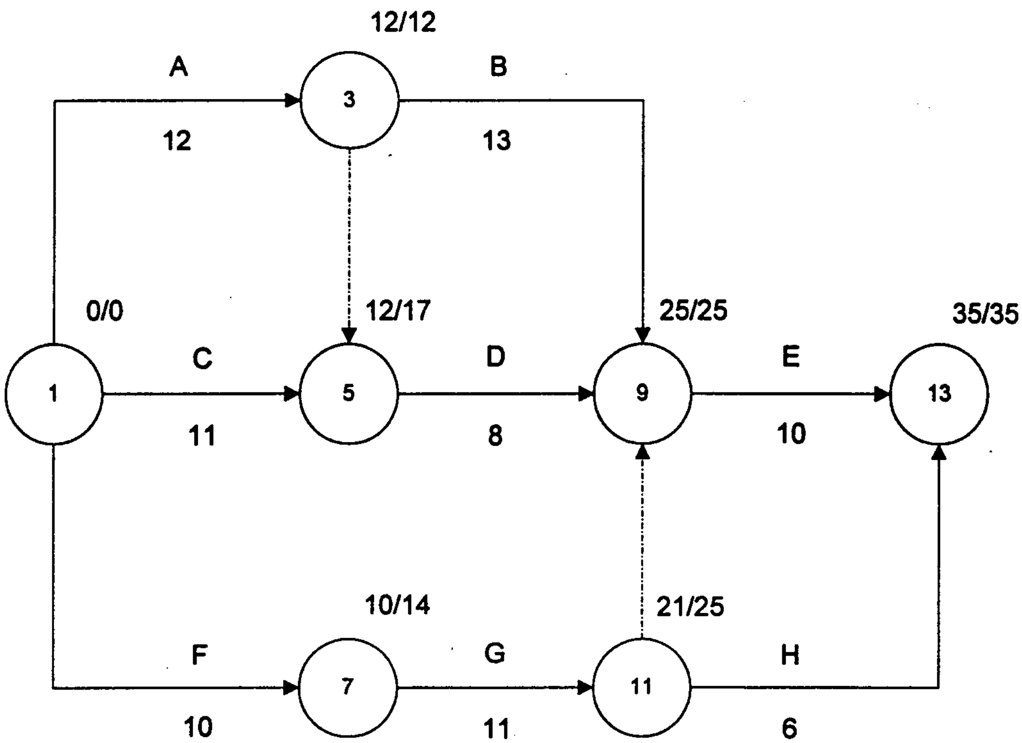


Figure 28. "I-J" CPM for Updating Example.

If it is determined that the current project network is to far off of the actual progress on a project, then there are three basic methods to modify the network. These methods will be illustrated for a small network where the original schedule is shown in Figure 28 and the project's progress was evaluated at the end of CPM Day 10.

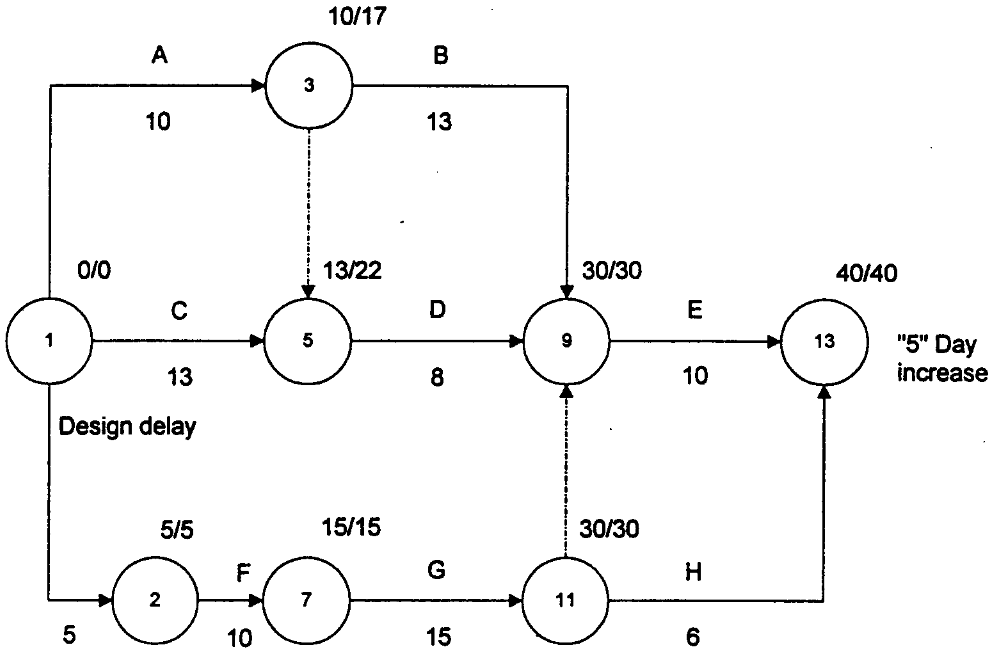


Figure 29. Update "I-J" CPM (Version I)

I. Revise Existing Network (see Figure 29)

a. Correct diagram to reflect actual durations and logic changes for the work completed on the project schedule.

b. Revise logic and duration estimates on current and future activities as needed to reflect known project conditions.

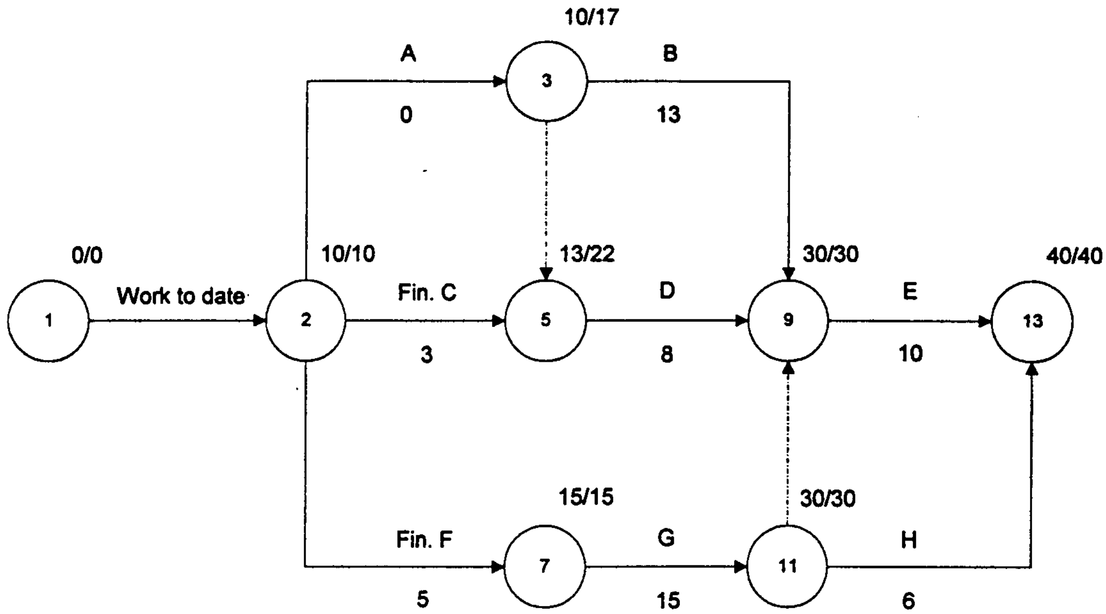


Figure 30. Update "I-J" CPM (Version II)

II. Revise Existing Network (see Figure 30)

a. Set durations equal to zero for all work completed and set the EET (first event) equal to the CPM day of the schedule update.

b. Revise logic and duration estimates on current and future activities as needed to reflect known project conditions.

III. Develop a Totally New Network for Remainder of Project Work if Extensive Revisions are Required of the Current CPM Schedule.

SURETRAK PROJECT PLANNER

FOR

CRITICAL PATH METHODS SCHEDULING SEMINAR

for
The Kentucky Transportation Cabinet

by
The University of Kentucky
Civil Engineering Department
And
Kentucky Transportation Center

Donn E. Hancher, Ph.D., P.E.
Raymond F. Werkmeister, P.E.
Sion L. Tesone

SURETRACK PROJECT PLANNER

This handout was prepared by the Civil Engineering Department of the University of Kentucky for the Kentucky Transportation Cabinet (KyTC). Its purpose is to help give you a good introduction to Primavera Suretrak CPM scheduling. The software is powerful and can easily be used for managing the KyTC construction project.

Suretrack is a more compact, and a much smaller size than the larger popular scheduling software "Primavera Project Planner", P3. Suretrak is produced by the same people, and has many of the same features as "Primavera Project Planner", P3. It provides for integrated merging and data exchange between the two packages.

In this handout, you are going to learn how to:

- Create a new project
- Add activities
- Link these activities together to build a network
- Schedule these activities to calculate the start and finish dates for each activity, as well as for the whole project
- Produce printed reports in both tabular report form and graphical bar-charts format.

Advanced project management techniques such as resource leveling and cost management are not addressed here. The important functions of the KyTC construction engineers are: 1.) To know how to review the contractor's construction schedule, 2.) To know how to check for validity and correctness, 3.) To know to suggest corrective measures when needed, and 4.) To know how to make sure the contractor's schedule can be accomplished with the resources available to him.

1 - Creating a new project:

After installing Suretrack, the first step would be to select it from the main menu in windows by clicking on its icon. The following steps guide the user to creating a new project:

1. From the file menu, select New
2. In the New Project window, there are some main fields to be filled, and there are some other secondary fields that can be left blank. Among the main fields are:
   - Project name: This is the only project identifier that is recognized by Suretrack. In this field you can enter any name of up to four alphanumeric characters to identify your project.
   - Directories: Stating where you want the newly created project to be stored.
   - Planning unit: which is the minimum planning unit for your project, usually selected as Day.
   - Project Start: Denoting the expected start date for the project. All dates are going to be calculated starting from this baseline date.

   Other secondary fields include:

   - Project Number/Version: which is not a substitute for the Project name, but an additional identifier.
   - Must Finish By: Also called imposed finish date, which acts as a constraint for the latest date for completing this project.
   - Project Title: for your own usage to differentiate between several projects.
   - Company Name: another additional piece for information related to your project.

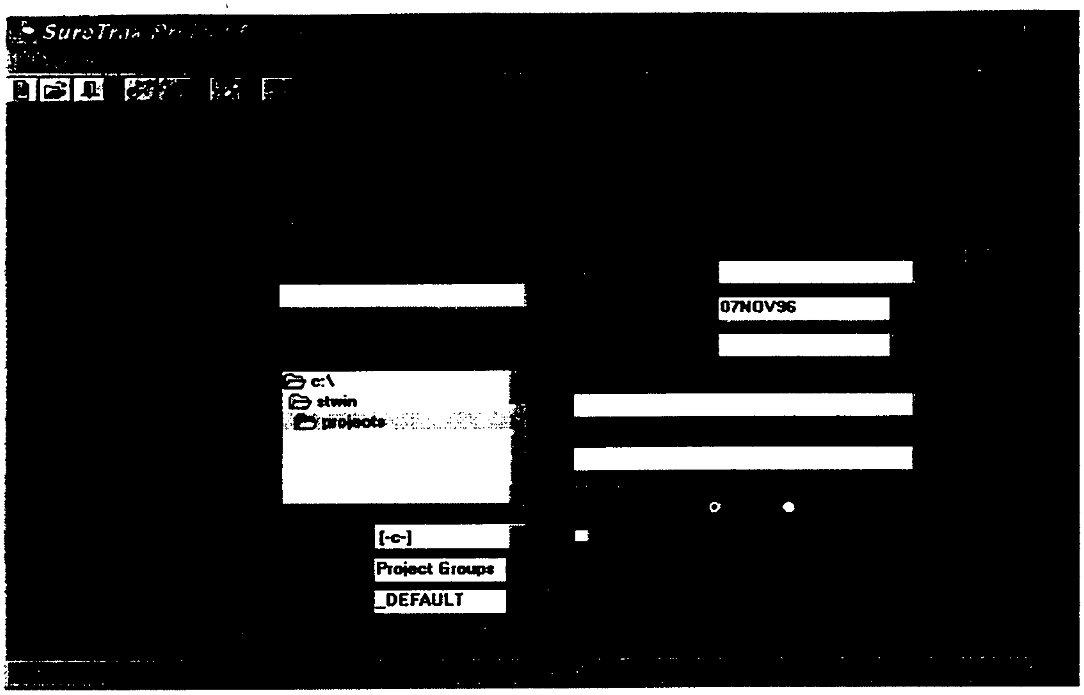


Figure 1 - New Project Screen

Again, this is only for your own usage. However, this line is going to appear on any printed report (tabular of graphic).

Once this information has been entered, click on the OK button to add this project to your directory. Figure 1 shows the New Project screen and its different components.

2 - Adding activities:

After clicking the OK button in the New Project screen, a new screen appears showing a tabular part on left side and a graphical part on the right side, as shown in Figure 2.

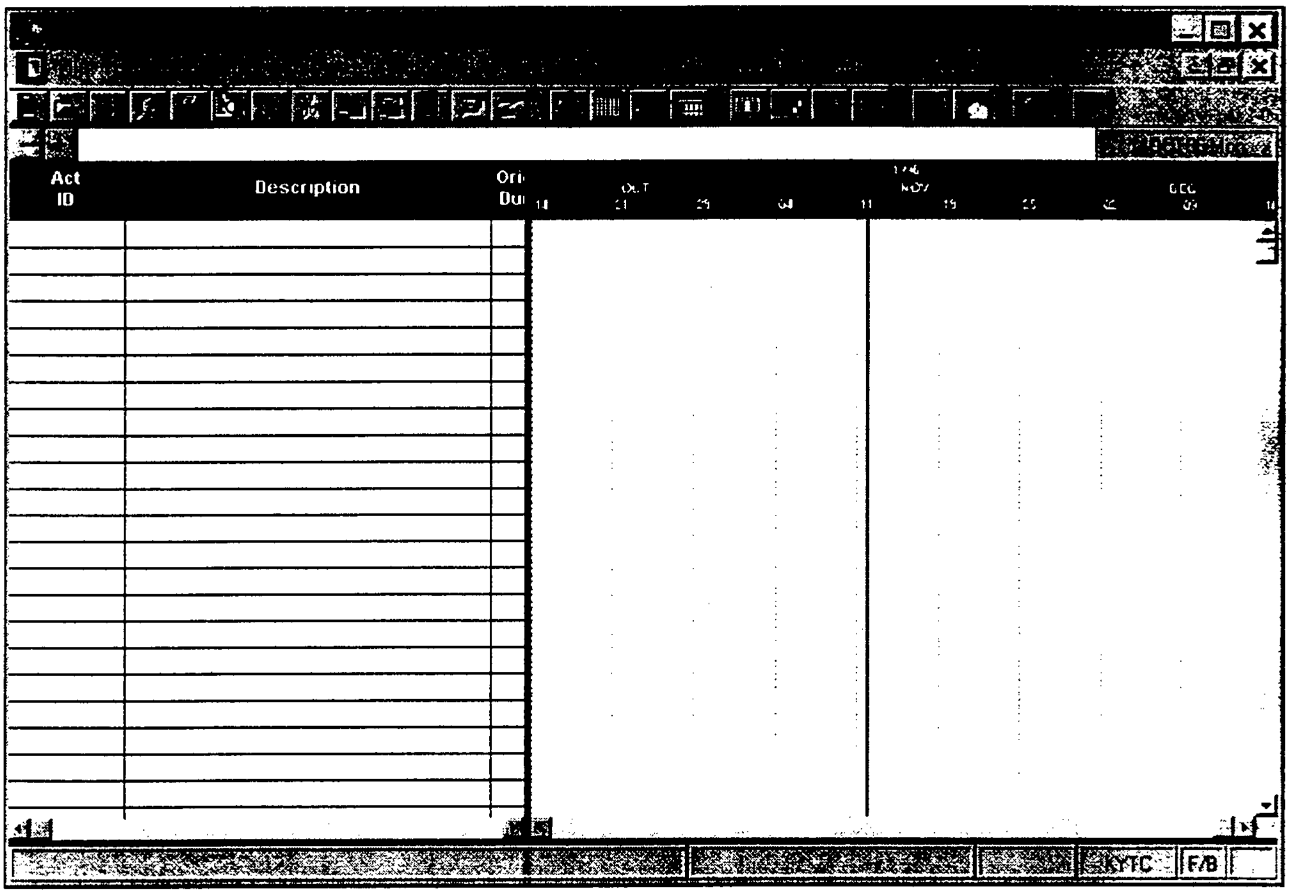


Figure 2 - Project layout window

To add a new activity, simply click on the first line in the left part of the screen, an activity ID or identifier is going to appear automatically, starting with 1000. This activity identifier can be any alpha-numeric value, including special characters and spaces of up to ten characters. This ID is unique for each activity, and cannot be duplicated. In the column next to the ID, type an activity title to describe the type of work to be achieved through this activity. This activity title or description is optional, and can be any string including letters, digits, special characters, and spaces of up to 48 characters. Activity titles can be duplicated and edited any time during project progress.

Double clicking on any activity will open the activity data form, which appears at the bottom of the screen in Figure 3. This form can also be opened by clicking on the activity form icon in the toolbar.

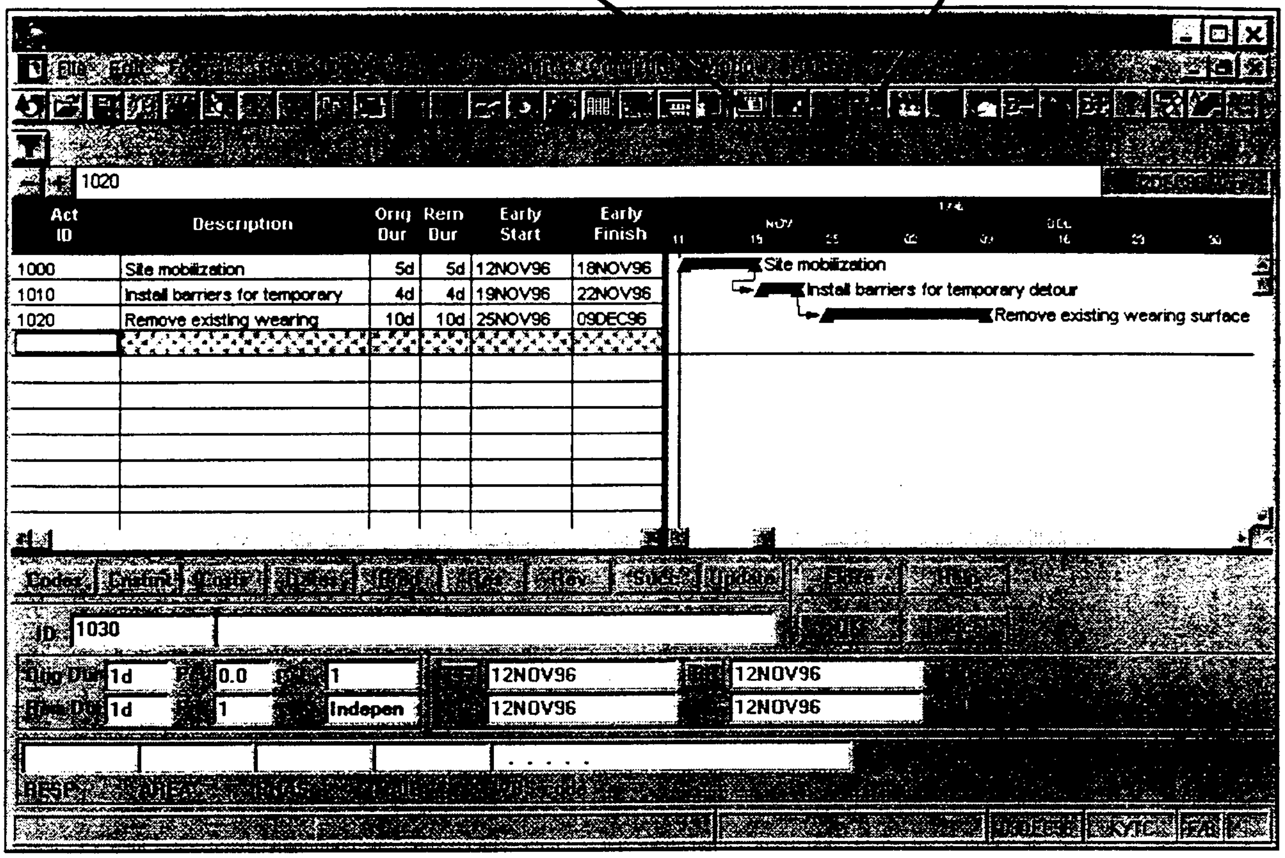


Figure 3 - Project layout and activity data form.

Within the activity data form, some of the fields must be filled, while others are optional. The essential fields are:

1. Activity ID: where the users may select their own identification numbering plans (e.g. 1000..1100..1200, or A11..A12..B11.., etc.).
2. Original Duration (OD): which establishes the original duration of the activity, based on which the schedule is going to be calculated. This original duration may be entered in hours, days, or weeks. The default value is 1d which is equal to one working day. Notice that the number of planning units (Hours, days or weeks) is entered as working units not calendar units.

3. PCT: or percentage of completion, which is only entered when statusing or updating the project. When a new plan is established, this percentage is left as zero, as long as work on this activity has not started yet.
4. Actual Dates: in case of recording project progress, or updating the project, the actual start ands finish dates have to be entered for each activity under progress in-lieu of the calculated early and late dates.
5. Activity Type: an activity can be designated as a tack, start milestone (SM), finish milestone (FM), hammock, or independent activity. Our main concern will be with the task, SM, and FM.
6. The fields reserved for early start (ES), early finish (EF), late start (LS), late finish (LF), total float (TF) and free float (FF) are automatically generated by the software, and the user should not input anything therein, except if it is an actual start or finish date as mentioned above.

All other fields in the activity data form are optional, and can be left blank. These fields include: activity description, activity codes, calendar number (is set to default calendar 1 if no other calendars exist), and type of project (Primavera, Suretrack, or Concentric).

Upon completing the activity data, the user should click on an empty line in the activity data screen, to start entering data for a new activity. The same steps are going to be repeated for each activity until all activities are entered.

3 - Linking activities using relationships

After entering all the project activities, the next step is to link them together according to the appropriate logic. Suretrack can accept any of four types of relationships:

1. Start to Start (SS): where the start of the second activity (Successor) is dependent on the start of the first activity (Predecessor).

2. Finish to Start (FS): Which is the default unless otherwise specified, and where the start of the second activity (Successor)depends on the finish of the first activity (Predecessor).
3. Finish to Finish (FF): Where the finish of the successor depends on the finish, not the start, of the predecessor.
4. Start to Finish (SF): Which is very rarely used, and where the finish of the successor depends on the start of the predecessor.

Any of these relationships can accept positive or negative lag time. In case positive lag time is introduced, this means that the predecessor lags by that number of planning units specified behind the successor. This lag can be applied to any of the four types of relationships. Similarly, in case negative lag time is introduced, which is called overlap, this shows the amount the successor overlaps or has a common duration with the predecessor.

Entering a relationship between to activities can be done in one of two ways:

- Tabular: From the activity data form, click on the button [Succ] which stands for successor. A pop-up window will open showing the required data to be entered, basically: the successor, the type of relationship, and the lag or overlap if any. There is no restriction on the number of successors an activity might have. Figure 4 shows the successor pop-up window. If the user selects, activities can be also linked in a reverse way, i.e. entering predecessors instead of successors. To achieve this, the user should press the button [Pred] which stands for predecessor, and follow the same steps as adding a successor.

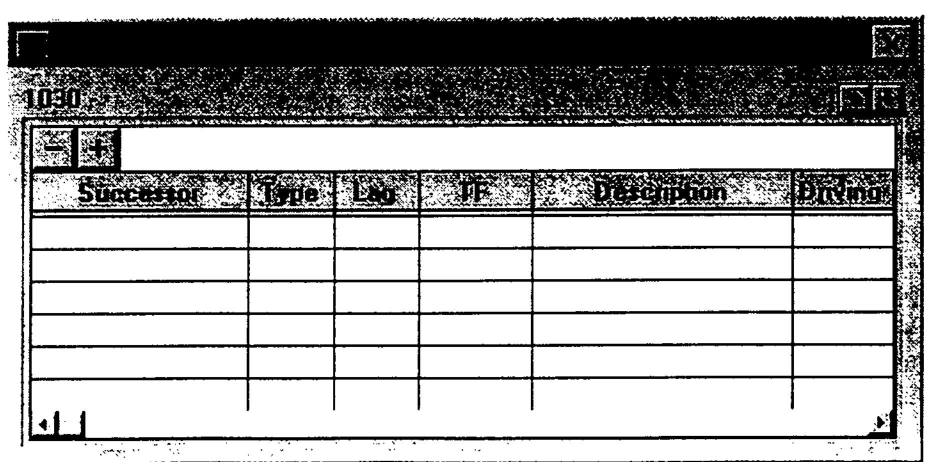


Figure 4 - successor pop-up window

- Graphical: From the main toolbar, click on the "Pitchfork" icon, and notice that the cursor changes into a pitchfork. Move to the predecessor activity and click on where you want to link it from (Start or finish), and drag your mouse to the successor activity's start or finish. Repeat the same procedure in case you want to link one single predecessor to multiple successors. This method can also be used backwards, i.e. the user can start with the successor and link it backwards to a predecessor. In case a lag or overlap needs to be added, double clicking on the line linking the two activities will activate a dialog box where the user can add lags, overlaps, or change the type of relationship, as shown in Figure 5 .

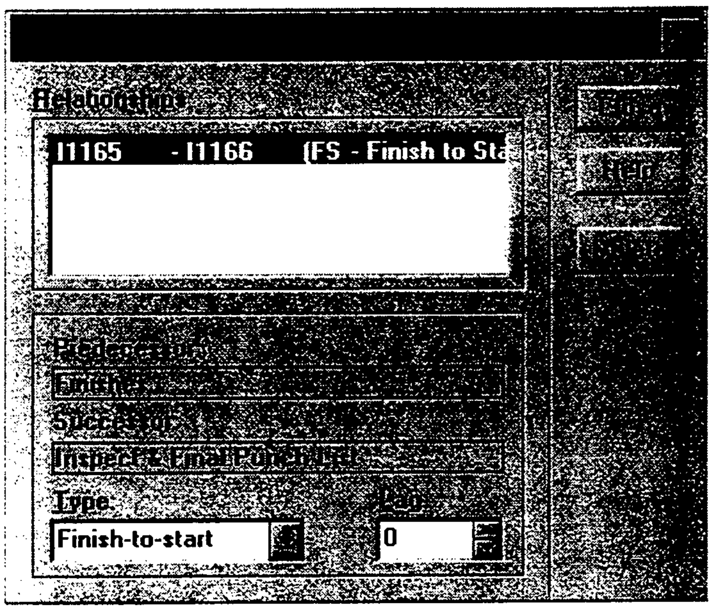


Figure 5 - relationships dialog box

4 - Scheduling the project

After entering all the project activities, determining the logic and establishing the relationships linking the activities, together with the lag/overlap times, the following step is to schedule the project to determine the critical activities, the early and late dates for each activity, as well as the total and free float.

This process can simply be performed by clicking on the clock icon in the toolbar .

This will activate a dialog box asking the user to determine the project data date, i.e. the date on which this computation is going to take place. The default is the calendar date of the computer itself (i.e. today's date). Another way of calculating the schedule would be by clicking on the configure tab in the main toolbar, and entering the selections for calculating the schedule.

Suretrack can calculate the schedule in one of two modes:

- Retained logic: Which respects the logic the user has entered, which means that unless a predecessor in a finish to start relationship has been completed, none of its successors can start.
- Progress over-ride: Which means that the actual progress can over-ride the logic in which activities were initially entered. An activity can start even if its predecessor has not been completed.

Figure 6 shows the project scheduling dialog box. A schedule run should be performed each time activity data have been changed either by adding activities, deleting activities, changing relationships, or changing activity durations.

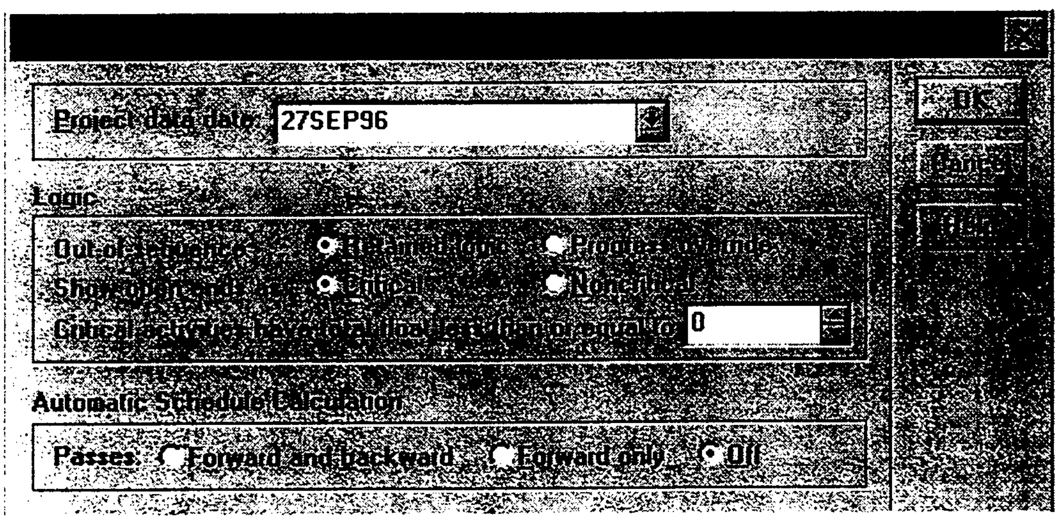


Figure 6 - Scheduling dialog box

If you have left automatic schedule calculation on, Suretrack calculates it each time you add or delete an activity or relationship, or change an activity duration or relationship type. If you have turned off automatic schedule calculation, you can choose the Schedule Now tool or press F9 to immediately schedule the project based on current Schedule dialog box settings, without opening the Schedule dialog box.

5 - Updating the Schedule

After entering all the schedule data and running its computations, the user needs first to establish a baseline against which the actual progress is going to be compared. This is done through setting target dates, e.g. early dates, for the activities to be performed. Clicking on the Target icon in the toolbar, or selecting the "Set Target Dates" command from the file menu will help the user set these dates. These target dates can also be entered from the activity data form, under the tab "Dates". Figure 7 shows an example of the dates dialog box.

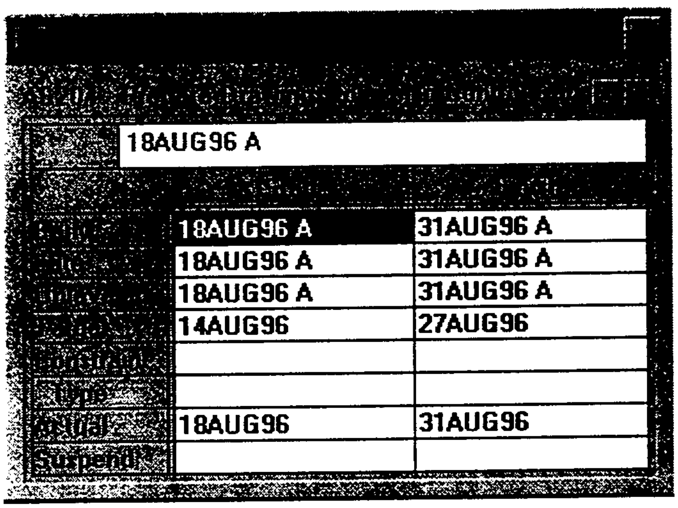


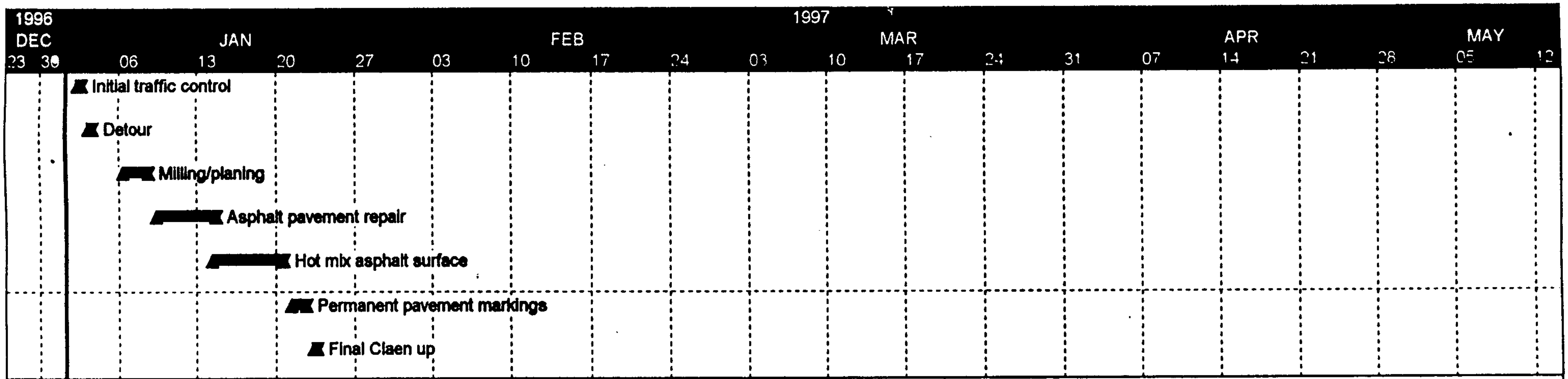
Figure 7 - Dates dialog box

Computer Example:

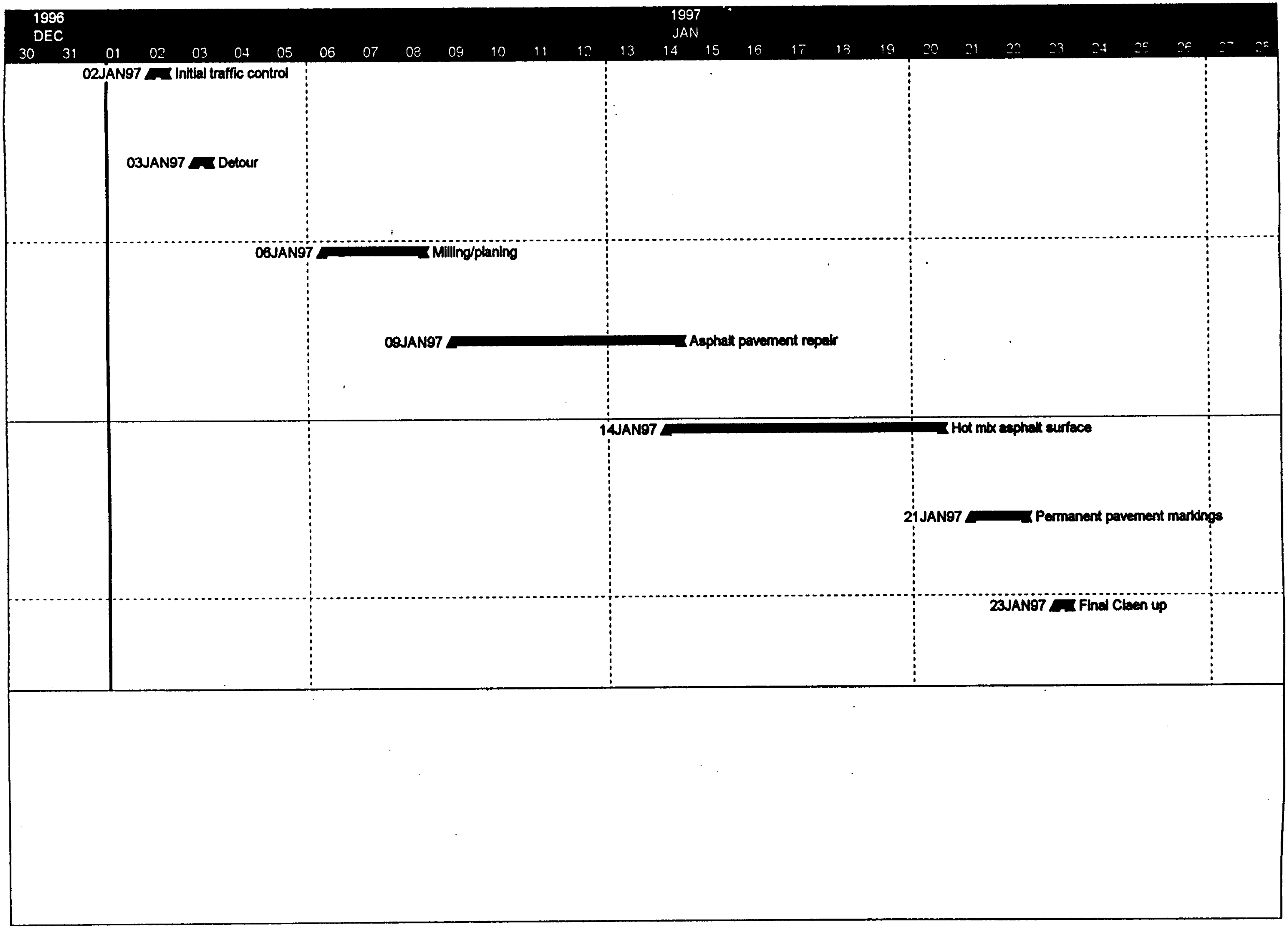
PAVEMENT OVERLAY - 2 MILE (URBAN)

Activity ID	Activity name	Duration (days)	Type of relationship	Preceding activity
1	Initial traffic control	1		
2	Detour	1	F-S	1
3	Milling/planing	3	F-S	2
4	Asphalt pavement repair	4	F-S	2
5	Hot mix asphalt surface	5	S-S (Lag 2)	3
			F-F (Lag 2)	3
			S-S (Lag 3)	4
			F-F (Lag 1)	4
6	Permanent pavement markings	2	F-S	5
7	Final clean up	1	F-S	6

PAVEMENT OVERLAY - 2 MILE (URBAN)



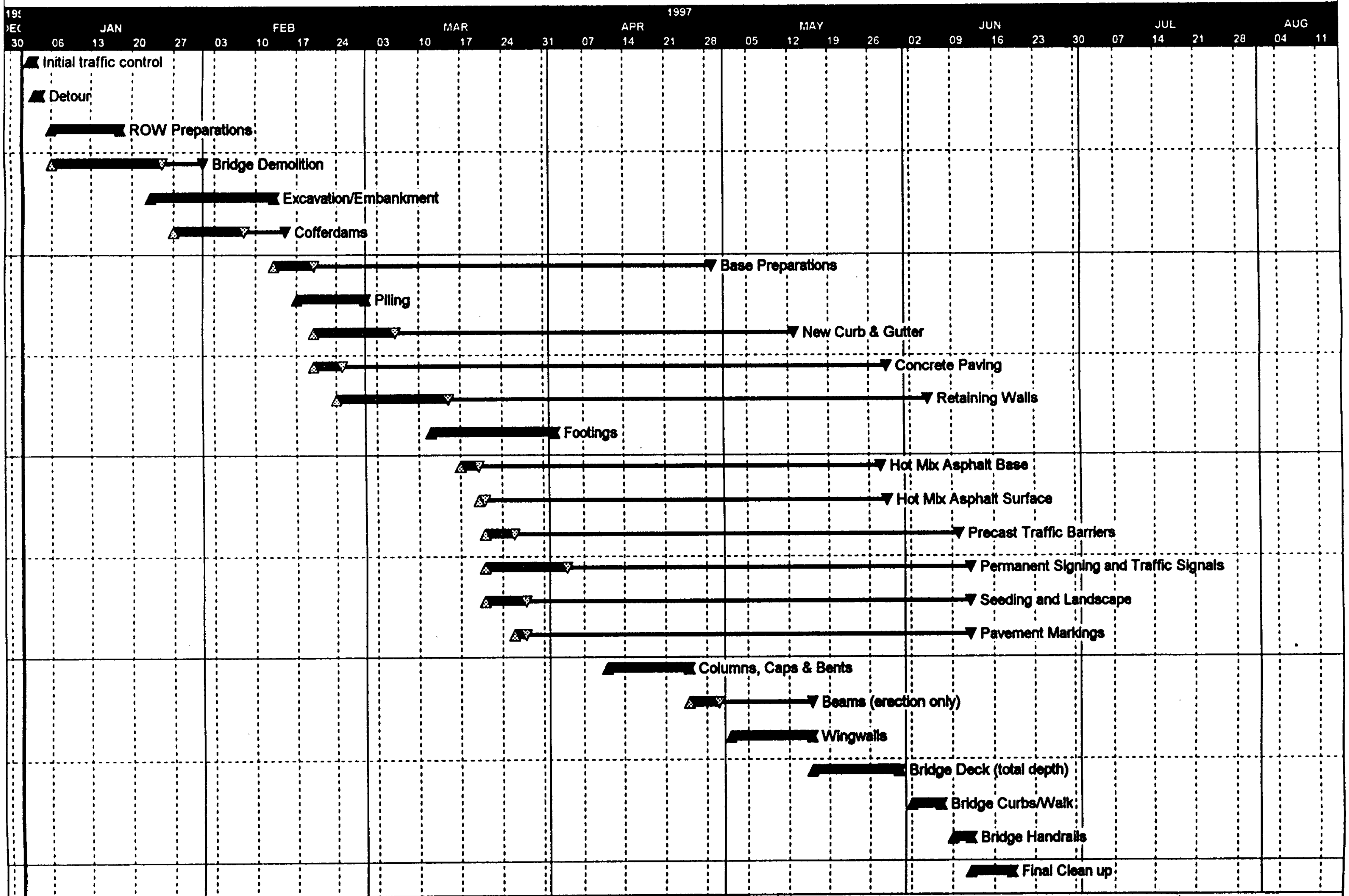
PAVEMENT OVERLAY - 2 MILE (URBAN)



PAVEMENT OVERLAY - 2 MILE (URBAN)

Activity ID	Description	Original Duration	Predecessors	Early Start	Early Finish
1	Initial traffic control	1d		02JAN97	02JAN97
2	Detour	1d	1	03JAN97	03JAN97
3	Milling/planing	3d	2	06JAN97	08JAN97
4	Asphalt pavement repair	4d	3	09JAN97	14JAN97
5	Hot mix asphalt surface	5d	3, 4	14JAN97	20JAN97
6	Permanent pavement markings	2d	5	21JAN97	22JAN97
7	Final Claen up	1d	6	23JAN97	23JAN97

BRIDGE WIDENING/REHABILITATION



BRIDGE WIDENING/REHABILITATION

Act ID	Description	Orig Dur	Rem Dur	Early Start	Early Finish	Total Float
1	Initial traffic control	1	1	02JAN97	02JAN97	0
2	Detour	1	1	03JAN97	03JAN97	0
3	ROW Preparations	10	10	06JAN97	17JAN97	0
5B	Bridge Demolition	15	15	06JAN97	24JAN97	5d
4	Excavation/Embankment	15	15	23JAN97	12FEB97	0
5C	Cofferdams	10	10	27JAN97	07FEB97	5d
7	Base Preparations	5	5	13FEB97	19FEB97	48d
5D	Piling	10	10	17FEB97	28FEB97	0
8	New Curb & Gutter	10	10	20FEB97	05MAR97	48d
10	Concrete Paving	3	3	20FEB97	24FEB97	66d
6	Retaining Walls	15	15	24FEB97	14MAR97	57d
5E	Footings	15	15	12MAR97	01APR97	0
9	Hot Mix Asphalt Base	3	3	17MAR97	19MAR97	48d
11	Hot Mix Asphalt Surface	1	1	20MAR97	20MAR97	48d
12	Precast Traffic Barriers	3	3	21MAR97	25MAR97	53d
13	Permanent Signing and Traffic Signals	10	10	21MAR97	03APR97	48d
14	Seeding and Landscape	5	5	21MAR97	27MAR97	53d
15	Pavement Markings	2	2	26MAR97	27MAR97	53d
5F	Columns, Caps & Bents	10	10	11APR97	24APR97	0
5H	Beams (erection only)	3	3	25APR97	29APR97	12d
5G	Wingwalls	10	10	02MAY97	15MAY97	0
5I	Bridge Deck (total depth)	10	10	16MAY97	30MAY97	0
5J	Bridge Curbs/Walk	5	5	02JUN97	06JUN97	0
5K	Bridge Handrails	3	3	09JUN97	11JUN97	0
16	Final Clean up	5	5	12JUN97	18JUN97	0