Research report
KTC 96-15

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

By

James D. Stevens
Associate Professor of Civil Engineering
and

Donn E. Hancher
Chairman and Professor of Civil Engineering
and

Ihab M. Hamdi
CE Graduate Research Assistant

Kentucky Transportation Center
College of Engineering
University of Kentucky

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16. Abstract

The Critical Path Method is a proven management technique used for determining the critical activities that would need additional care in any type of construction projects. The KTC requires that CPM schedules be used on selected highway projects. This research project offers a detailed idea on CPM scheduling application in highway construction projects, as well as current practices in other departments of transportation nationwide, together with specifications for proper application of CPM scheduling.

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- Appendix B: Sample of a bar chart schedule for simple projects
- Appendix C: Sample of a network schedule for complex projects

INTRODUCTION:

The Critical Path Method (CPM) is a proven management technique that can be used for various types of construction projects to determine the critical activities, i.e. the ones that need special care not to delay the anticipated completion of the project, and the path that links them over the project phase under investigation. This technique can be applied successfully to the pre-construction as well as the construction phases.

The KyTC requires that CPM schedules be used on selected highway projects. CPM has proven to be beneficial for planning and monitoring on many highway projects, in Kentucky and in other states. However, contracts requiring the use of CPM often result in confusion and claims, indicating the need for better specifications and a better understanding of the requirements of both contractors and KyTC personnel.

PROBLEM STATEMENT :

Problems with the use of the Critical Path Method (CPM) for scheduling construction projects can be caused by an inadequate specification and/or lack of training on the part of KyTC and contractor personnel. A process is needed whereby all parties involved understand exactly what is expected when CPM scheduling is specified, in order to facilitate communication and reduce the incidence of claims. Another problem of equal importance is the need for a

systematic method for estimating project contract duration, which plays an important role in determining the financing and staffing plans for the project. These two problems, CPM specification and usage, and project time determination, are directly interrelated, as the former requires the latter as a basis for planning, and the latter requires the former for monitoring and control.

RESEARCH OBJECTIVES:

The objectives of this research were:

A - To understand the needs of the KyTC for scheduling highway construction work and to learn as much as possible about current practices in Kentucky and elsewhere.

B - To develop a specification for the use of the Critical Path Method (CPM) schedules for highway construction in Kentucky that will clarify requirements for contractors and reduce the number of schedule-related claims.

C - 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.

RESEARCH METHODOLOGY:

The methodology followed to achieve the research objectives consisted of several steps, including:

A - **Literature review**:

A review was made of similar research projects, published articles in specialized journals and magazines, and a computer search on related topics with such key-words as : Highway construction, highway scheduling, and CPM for highway scheduling. This literature review yielded several articles related to other DOT efforts in scheduling, as well as different scheduling techniques used in highway construction scheduling, including bar charts, networks, and linear scheduling methods (LSM).

B - **Nationwide questionnaire**:

This questionnaire was prepared with the goal of assessing current practices as well as the projected future trends of applying scheduling techniques, particularly CPM, by the DOTs in different states, and making use of the best of these practices. A blank copy of the questionnaire is enclosed in appendix A of this report, along with the statistical analysis of the questionnaire results.

C - **Site visits and telephone conversations:**

Site visits were made to different highway districts statewide, to get information about scheduling efforts in the Commonwealth of Kentucky, about the

current problems faced due to the lack of scheduling on some projects, and to assess the training needs for construction personnel, which will assist in properly designing a tailor-made training course on scheduling. These site visits were followed by telephone conversations to confirm the findings reported from the visits, and to update the districts on the anticipated plan. The results of the site visits and the telephone conversations are listed under "Current practices" in this report.

QUESTIONNAIRE RESULTS:

Fifty questionnaires were sent to different departments of transportation nationwide, and thirty-six responses were returned. The questionnaire included a set of questions about the current use of any scheduling techniques, specific utilization of CPM and its frequency, providing contractors with milestone schedules, requiring the contractors to submit schedules with their bids, the inclusion of CPM specifications in their contracts, problems faced while using CPM, and the availability of trained personnel to review the schedules. Following is an analysis of the responses to the questionnaire:

1 - What planning techniques were used to schedule the project during the pre-construction phases?

Most of the respondents (58.33 percent) stated that they were using bar charts, for their simplicity and ease of preparation and follow-up, whereas other

techniques were used by a smaller percentage of the DOTs. However, almost 39 percent of the respondents were using CPM in both its forms (14 percent arrow diagramming, and 25 percent precedence diagramming), while no DOT used Linear Scheduling Methods (Line of Balance, ..etc.)

2 - How often was CPM used in scheduling the project during the pre-construction phases?

Among the departments responding to the questionnaire, 22 percent stated they were always using it, whereas almost 39 percent stated they never used it, other departments used it on an irregular basis.

3 - Does the DOT provide the contractor with a milestone schedule in the bid documents?

Sixty-five percent of the respondents stated that they did include a milestone schedule with the bid documents, and that the successful bidder had to abide by the general requirements of that schedule. Thirty-five percent stated that they did not include any milestone schedules.

While having a milestone schedule in the bid documents has its advantages, as it guarantees beforehand that all bidders will follow the same guidelines and a common general logic, it should not be construed as an imposed schedule obliging the contractor to follow a certain method of construction or a detailed sequence of

work. Imposing a detailed schedule on the contractor might have negative legal implications, and lead to claims or disputes.

4 - Is the contractor required to submit a CPM schedule with his bid?

Twenty-six percent of the respondents stated that they required the contractor to submit a CPM schedule, either with his bid, or within a very short period from the notice to proceed. Eighty-four percent of the respondents did not require any CPM schedules with the bid or shortly after the award of contract.

However, it is a good practice to require the contractor to submit a schedule either with his bid , or very shortly after the award of contract, to guarantee a reasonable and steady rate of performance.

5 - How often did the contracts include special provisions for CPM preparation and updating?

Only 20 percent of the respondents stated that they always included provisions for using CPM in their contracts, while the majority (36 percent) stated they seldom had such provisions. The remaining percentage of respondents was distributed as 17 percent for never having such provisions, and 27 percent often having them.

6 - What criteria control the use of CPM on a project?

The respondents could mark more than one of the available criteria, or even add their own criteria. The distribution of criteria showed:

- Degree of complexity: 50 percent
- Time constraints: 55 percent
- Dollar amount: 31 percent
- Always used: 8 percent
- Other: 8 percent

7 - What were the problems faced while monitoring and/or controlling the CPM construction schedule?

Multiple answers to this question were allowed. Responses were distributed as follows:

- We don't know how to follow-up the CPM schedule: 25 percent
- The contractor does not know how to prepare/update the schedule: 50 percent
- The schedule is not regularly/timely updated: 56 percent
- No problems: 3 percent
- Not applicable: 17 percent

From the above answer distribution, it appears clear that the major problems concerning the preparation and updating of the schedule are related to the fact that often neither party, the DOT or the contractor, knows how to prepare the schedule, and whenever a schedule is presented, it is seldom looked at or updated. A proposed remedy for these problems is selecting an easily understandable software package that will enable both the DOT and/or the

contractor to develop a schedule, and regularly update it to reflect the actual progress and its comparison to the initial plans. Training personnel from both parties to have a common language is a major issue.

8 - How frequently is the contractor required to update the schedule?

Fifty-six percent of the respondents require regular updates, which ranged from weekly to bimonthly. Other answers included: Occasionally (11 percent), upon problem occurrence (33 percent) and never (3 percent).

Again, it appears that the best way of making use of the CPM schedule is to regularly update it. In case of major deviation from the initial plan, an overhaul of the schedule might be needed.

9 - What are other uses of the CPM schedule than just scheduling?

Answers given to this question included:

- Claims resolution: 61 percent
- Cash flow preparation: 6 percent
- Other: 17 percent

Under other, responses included such uses as:

- Evaluating change in construction sequence requests
- Communicating and coordinating between the DOT and the contractor
- Informing the public
- Documenting work progress and productivity rates

- Identifying the reasons of delay
- Identifying the amount and impact of delay
- Evaluating time extension and time suspension requests
- Evaluating the effects of weather
- Identifying ways to mitigate delays
- Contract time determination
- and finally: Design project management.

10 - Do you have trained staff to check and review the contractor-submitted CPM schedule?

Sixty percent of the respondents did not have any trained staff to perform the task of reviewing, evaluating and commenting on the contractor's CPM schedule, whereas the remaining 40 percent had such staff with variable levels of experience.

It is a necessity to have available trained staff to perform this task, otherwise, the main advantage of using a CPM schedule will be wasted.

11 - Do you offer such training for your staff?

Responses were distributed exactly on the same lines as the previous question. Sixty percent did not offer any training, whereas the remaining 40 percent offered training with different levels of detail and thoroughness.

CURRENT SCHEDULING PRACTICES:

Through the conducted site visits and phone calls with construction personnel in different state highway districts, as well as contractors, it was concluded that CPM had been used on very few projects in Kentucky, usually the ones including major intersections and structures, with some problems resulting from lack of training and lack of understanding the network scheduling rules.

When asked about the method used to determine project contract duration, the districts' construction staff said it was decided centrally in Frankfort, without any involvement on their part. The contractors' comment on the allowable project duration was that it is usually (in 90 percent of the cases) on the flexible side, whereas about 10 percent of the projects have a tight given duration. Some of the contractors complained that this inconsistency makes it harder for them to determine the project indirect costs, including overhead.

On the other hand, most of the construction staff interviewed showed great enthusiasm toward learning and applying the principles of network scheduling in order to be able to monitor and control the project progress. Another point worth noting is that the state has an excellent post-construction evaluation document to evaluate the performance of the contractors. Although this document is filled by the construction staff at the end of the project, and sent to Frankfort for future

reference and action, there is no feedback concerning the results of such evaluations returned to the districts.

Additional points discussed included the need for improved public relations efforts to inform the public about future closures and detours, especially for major construction. The discussions also included the need for scheduling the design work for these major projects in order to avoid any misunderstandings resulting from unequal allocation of time for different design activities which might result in late completion of design. The questionnaire analysis revealed that more than 50 percent of the interviewed state DOTs schedule their own pre-construction activities, including design, either always or often.

Concerning the current method used in measuring progress, discussions showed that it was done through expenditure comparison, where the expenditure to date is compared to the total project budget, and the resulting percentage is used to represent the percentage of work progress to date. However, this method might not yield very accurate results, as materials stored on site do not represent actual work progress, whereas the contractor is paid partially for it.

One of the unique features to some of the remote districts was the limited number of available contractors (3 or 4), which almost guarantees each of these contractors a certain amount of work. This necessitates more stringent control on schedule performance, as any time slippage in one project might be repeated in other projects.

As for current practices in other states, both the questionnaire and telephone conversations showed some positive trends including:

- Public relations for highway projects including notification of public, advertising of scheduled closures and detours on billboards as well as in different media.
- Cost + Time bidding, which requires the contractors to submit a schedule with their bids. These bids are not going to be evaluated based only on the cost, but on the schedule as well. A point system is set to evaluate different features in the schedule, and convert the number of working days to equivalent monetary value. This would enhance the use of innovative methods of construction, and most likely result in a better overall project performance.
- Flexible scheduling: which including letting a group of projects in the same bid, and giving the contractor the flexibility to start with any of these projects, provided that the completion date for all projects does not exceed the specified time frame. These are usually small projects that are done on a regular basis like resurfacing and painting.
- Scheduling pre-construction activities, including design, utility relocation and right-of-way acquisition. This practice will fairly distribute the project's overall duration between these activities.

PRELIMINARY FINDINGS:

Based on the literature review, the questionnaire analyses, the site visits and the telephone conversations, the following findings were reached:

- Network scheduling should be introduced to all projects containing multiple structures, tight time constraints or complicated phasing
- Multiple levels of scheduling should exist:

    1. One for small, linear projects
    2. Another for mid-size projects
    3. And a third for large sized projects with multiple structures.

The level of detail as well as the scheduling tool would differ between these three types of projects, ranging from check lists, to bar charts, linear scheduling diagrams, and ending with detailed CPM networks.

- Detailed clauses should be added to the specifications specifying the method of preparation of the schedule, level of detail, frequency of updating, as well as consequences of non-compliance.
- Training, including state-of-the-art scheduling software, should be offered for construction staff in all districts, as well as for willing contractors, and methods for building, updating, and reporting schedules. This training is to be divided between theory and hands-on training including computer software utilization.

1996-97 WORK PLAN:

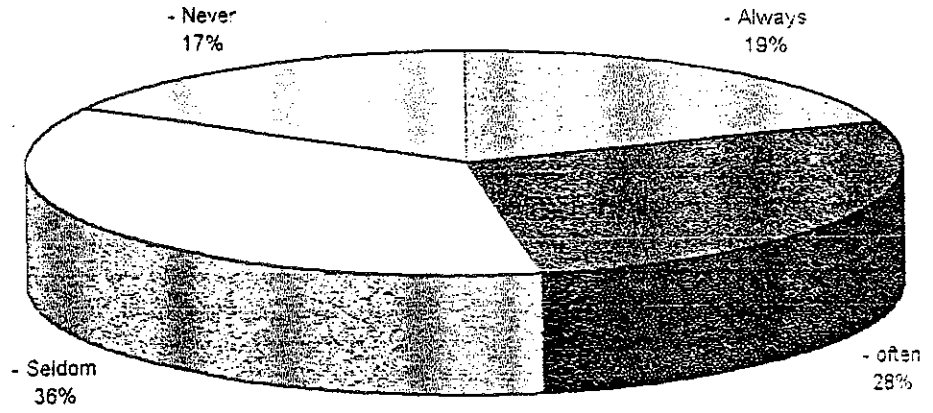
A meeting with the project advisory committee will be held to review project progress to date, and to finalize the project work plan for next year. Items proposed are an improved specification for KyTC construction project schedules, a scheduling training program for both KyTC and its contractor personnel, and possibly, a revised contract time determination method.

APPENDICES

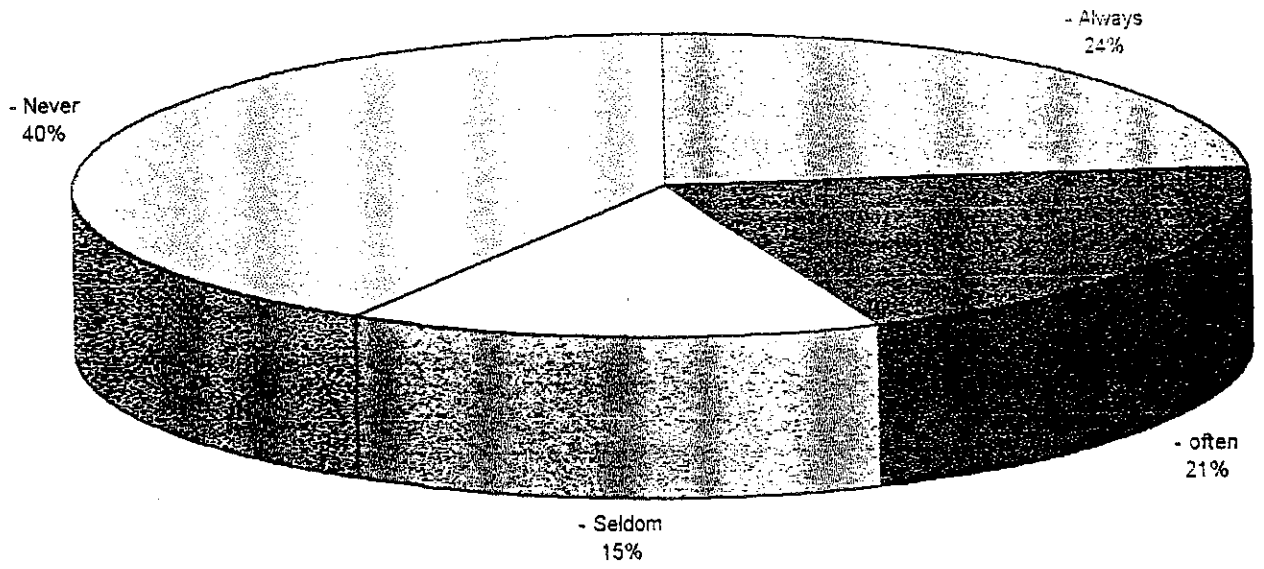
- APPENDIX A: QUESTIONNAIRE ANALYSIS
- APPENDIX B: SAMPLE OF BAR CHART SCHEDULE
- APPENDIX C: SAMPLE OF NETWORK SCHEDULE

PLANNING TOOLS	NO.OF STATES	%	STATES RESPONDING
- Bar charts	21	58.33	ALASKA
- PJ networks (Arrow diagrams)	5	13.89	ARIZONA
- Precedence diagrams	9	25.00	ARKANSAS
- Line of balance	0	0.00	COLORADO
- Other (please state)	7	19.44	DELAWARE
- None of the above	5	13.89	FLORIDA
			GEORGIA
			IDAHO
FREQUENCY OF CPM USAGE IN PRE-CONSTRUCTION			ILLINOIS
- Always	8	22.22	INDIANA
- often	7	19.44	IOWA
- Seldom	5	13.89	KENTUCKY
- Never	14	38.89	LOUISIANA
			MARYLAND
PROVIDING MILESTONE SCHEDULES WITH BID DOCUMENTS			MASSACHUSETTS
NO/YES	13 / 23		MINNESOTA
CONTRACTOR REQUIRED TO SUBMIT CPM SCHEDULE WITH BID			MISSISSIPPI
NO/YES	26 / 10		MONTANA
			N.CAROLINA
FREQUENCY OF USING CPM CONTRACT CLAUSES			N.DAKOTA
- Always	7	19.44	N.HAMPSHIRE
- often	10	27.78	NEBRASKA
- Seldom	13	36.11	NEVADA
- Never	6	16.67	NEW JERSEY
			NEW YORK
CRITERIA FOR USING CPM			OHIO
- Always used	3	8.33	RHODE ISLAND
- Degree of complexity	18	50.00	S.CAROLINA
- Dollar amount	11	30.56	S.DAKOTA
- Time constraints	20	55.56	TEXAS
- Other (please state)	3	8.33	VERMONT
			VIRGINIA
			WASHINGTON
PROBLEMS WITH CPM USAGE			WISCONSIN
- We don't know how to follow-up the CPM schedule	9	25.00	WYOMING
- the contractor does not know How to prepare/update the schedule	18	50.00	
- the schedule is not regularly and/or timely updated	20	55.56	
- Other (please state)	5	13.89	
- No problems	1	2.78	
- not applicable	6	16.67	
FREQUENCY OF SCHEDULE UPDATING			
- regularly	20	55.56	
- Occasionally	4	11.11	
- Upon problem occurrence	12	33.33	
- Never	1	2.78	
OTHER USES FOR CPM SCHEDULES			
- Claims resolution	22	61.11	
- Cash flow preparation	2	5.56	
- Other (please state)	6	16.67	
DO YOU HAVE TRAINED STAFF			
NO / YES	20 / 14		
DO YOU OFFER TRAINING FOR YOUR STAFF			
NO / YES	19 / 14		
WOULD YOU LIKE TO BE UPDATED ON THIS PROJECT			
NO / YES	1 / 35		

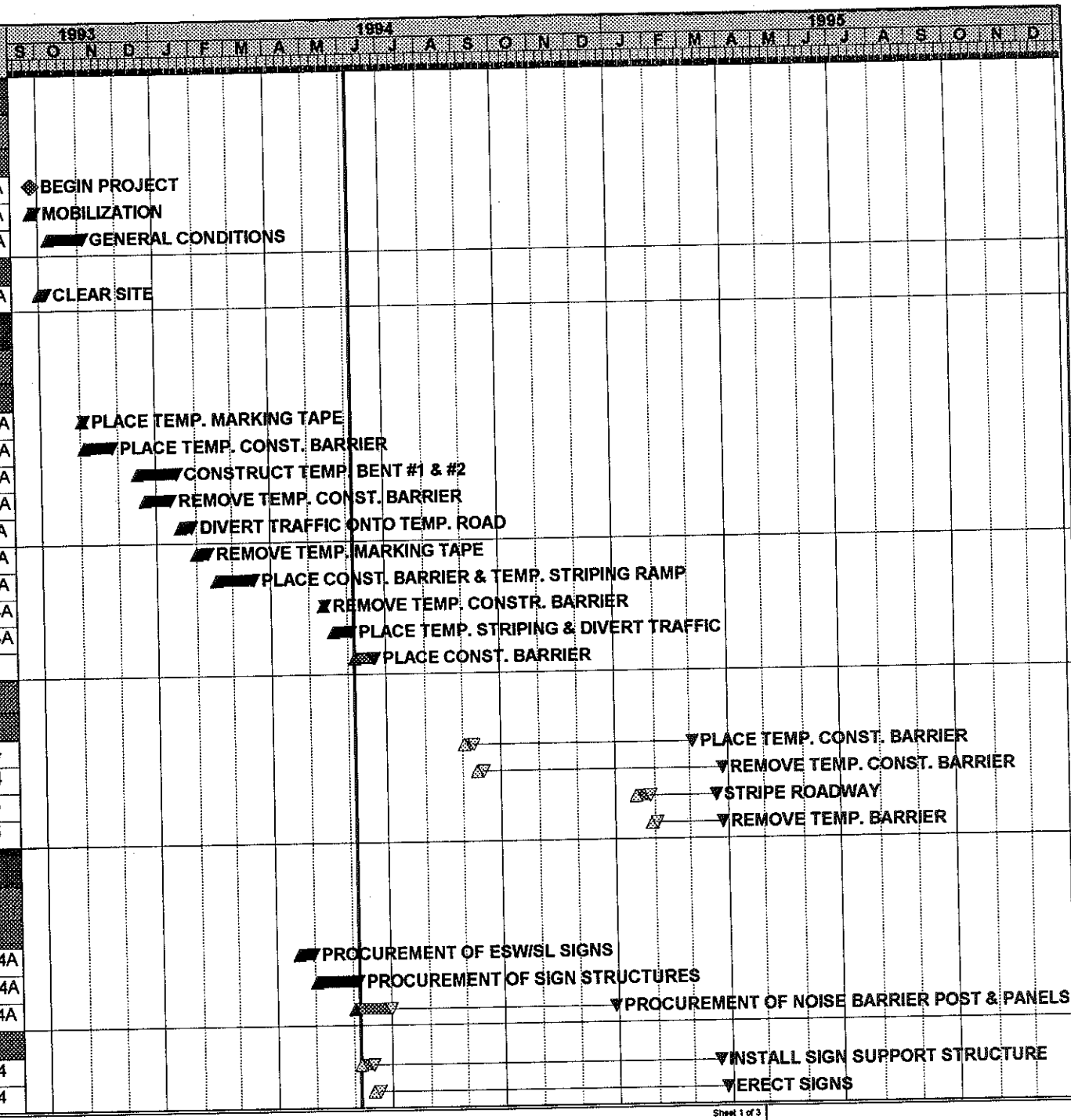
CONTRACT CLAUSES FOR CPM



USAGE OF CPM BY OTHER DOTs



Activity ID	Closed Lane	%	Original Duration	Remaining Duration	Early Start
Start-up					
General Construction					
P1G098		100	0	0	24SEP93A
P1G100		100	4	0	24SEP93A
P1G110		100	13	0	08OCT93A
P1G105		100	4	0	01OCT93A
Traffic Control					
Southbound Outer Lane					
P1N1140	NO7	100	1	0	03NOV93A
P1N1145	NO7	100	1	0	04NOV93A
P1N1202	NO8	100	20	0	17DEC93A
P1N1180	NO7	100	1	0	23DEC93A
P1N1190	NO7	100	1	0	20JAN94A
P1N1195	NO7	100	1	0	01FEB94A
P1N1200	NO7	100	4	0	17FEB94A
P1N1235	NO7	100	1	0	13MAY94A
P1N1240	NO7	100	1	0	20MAY94A
P1N2100	NO7	0	12	12	06JUN94
Northbound Outer Lane					
P2N3100	SO3	0	6	6	02SEP94
P2N3225A	SO3	0	5	5	12SEP94
P2N2196	SO4	0	9	9	17JAN95
P2N2198	SO4	0	4	4	30JAN95
Signals					
General Construction					
P1G200B		100	10	0	19APR94A
P1NP200		100	10	0	02MAY94A
P1NP100		0	10	19	02JUN94A
P1N2190	NO5	0	8	8	06JUN94
P1N2195	NO5	0	3	3	16JUN94



Sheet 1 of 3

Project Start	24SEP93
Project Finish	28MAR95
Data Date	06JUN94
Plot Date	19JUL96

Early Bar
Float Bar
Progress Bar
Critical Activity

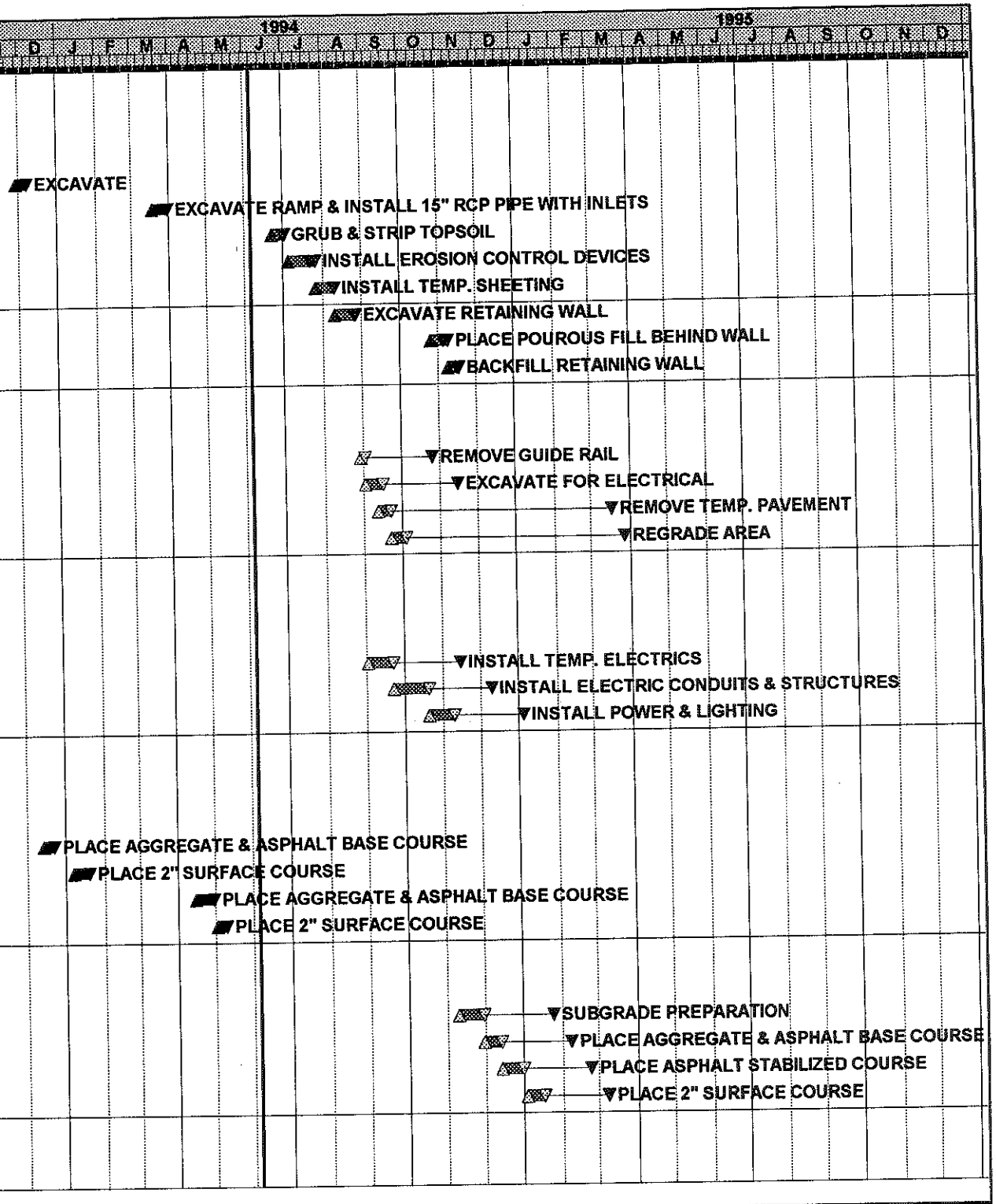
HWY1

C.M. Construction, Inc.

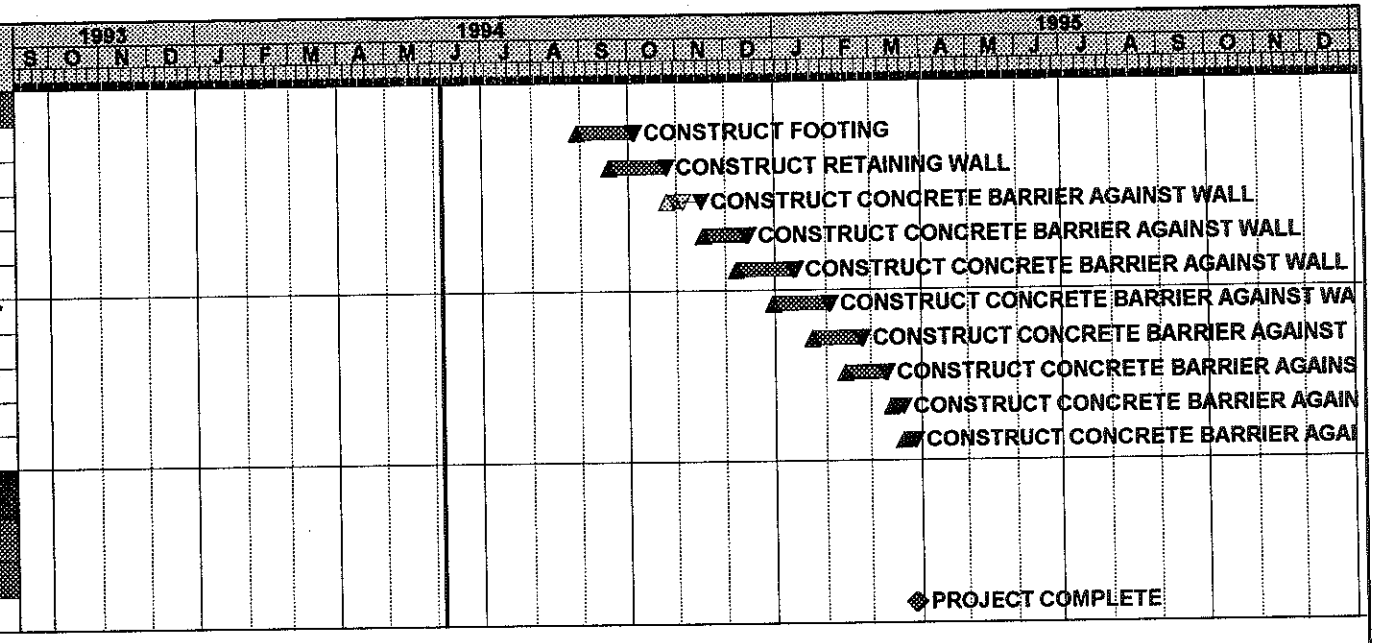
Highway Widening

By Work Type/Area Of Roadway/Resp.

Activity ID	Closed Lane	%	Original Duration	Remaining Duration	Early Start
Southbound Outer Lane					
P1N1150	NO7	100	5	0	29NOV93A
P1N1210	NO7	100	10	0	18MAR94A
P1N2115A	NO7	0	8	8	22JUN94
P1N2105B	NO7	0	15	15	05JUL94
P1N2200	NO7	0	12	12	26JUL94
P1N2210	NO8	0	12	12	11AUG94
P1N2240	NO8	0	9	9	26OCT94
P1N2250	NO8	0	7	7	08NOV94
Northbound Outer Lane					
P2N2115B	SO4	0	4	4	29AUG94
P2N2125A	SO4	0	10	10	02SEP94
P2N3110	SO3	0	9	9	12SEP94
P2N3120	SO3	0	7	7	23SEP94
Northbound Outer Lane					
P2N2125B	SO4	0	15	15	02SEP94
P2N2130	SO4	0	19	19	23SEP94
P2N2140	SO4	0	15	15	20OCT94
Southbound Outer Lane					
P1N1170	NO7	100	6	0	14DEC93A
P1N1185	NO7	100	3	0	07JAN94A
P1N1220	NO7	100	4	0	15APR94A
P1N1230	NO7	100	3	0	02MAY94A
Northbound Outer Lane					
P2N2150	SO4	0	14	14	10NOV94
P2N2170	SO4	0	10	10	30NOV94
P2N2180	SO4	0	12	12	14DEC94
P2N2185	SO4	0	10	10	03JAN95

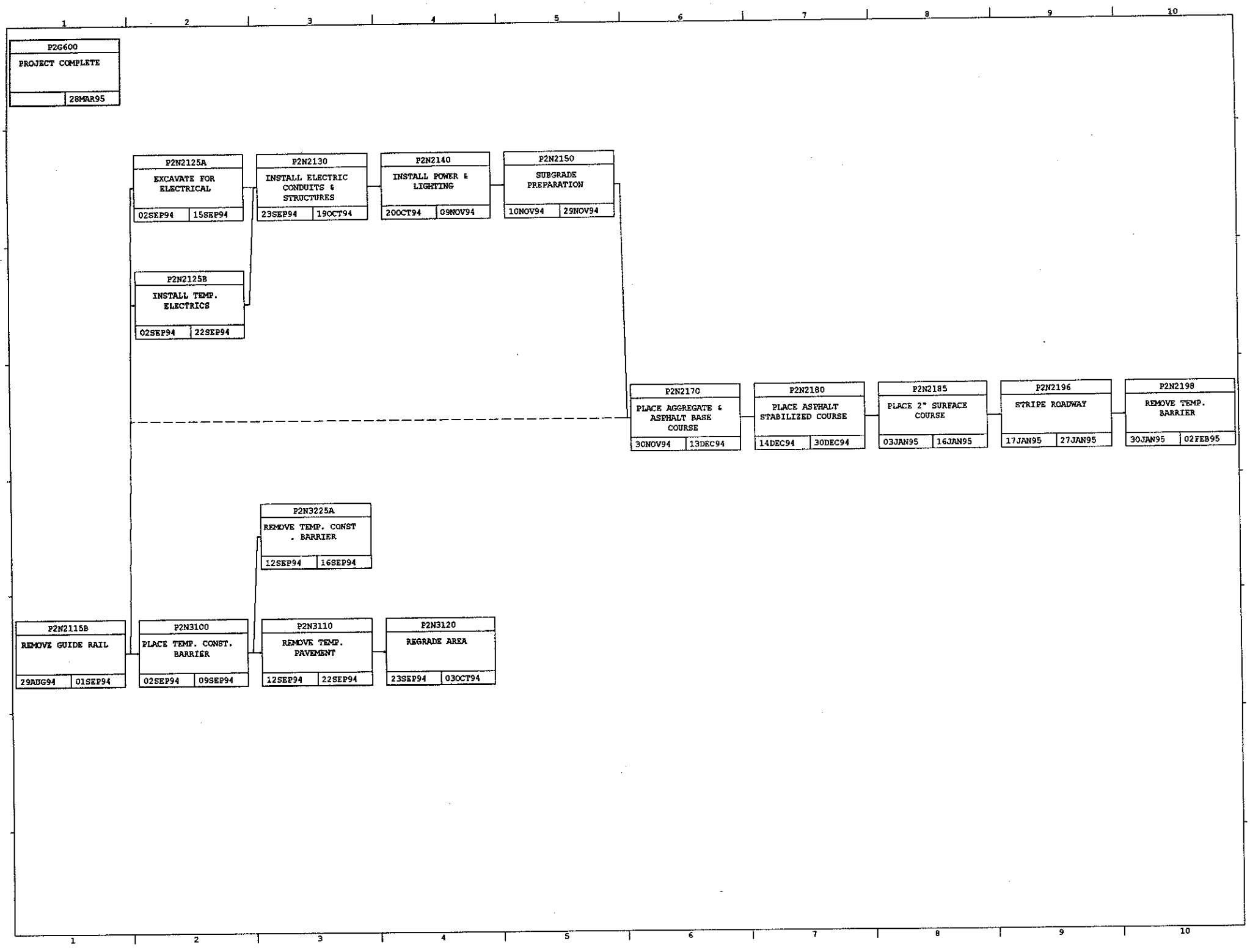


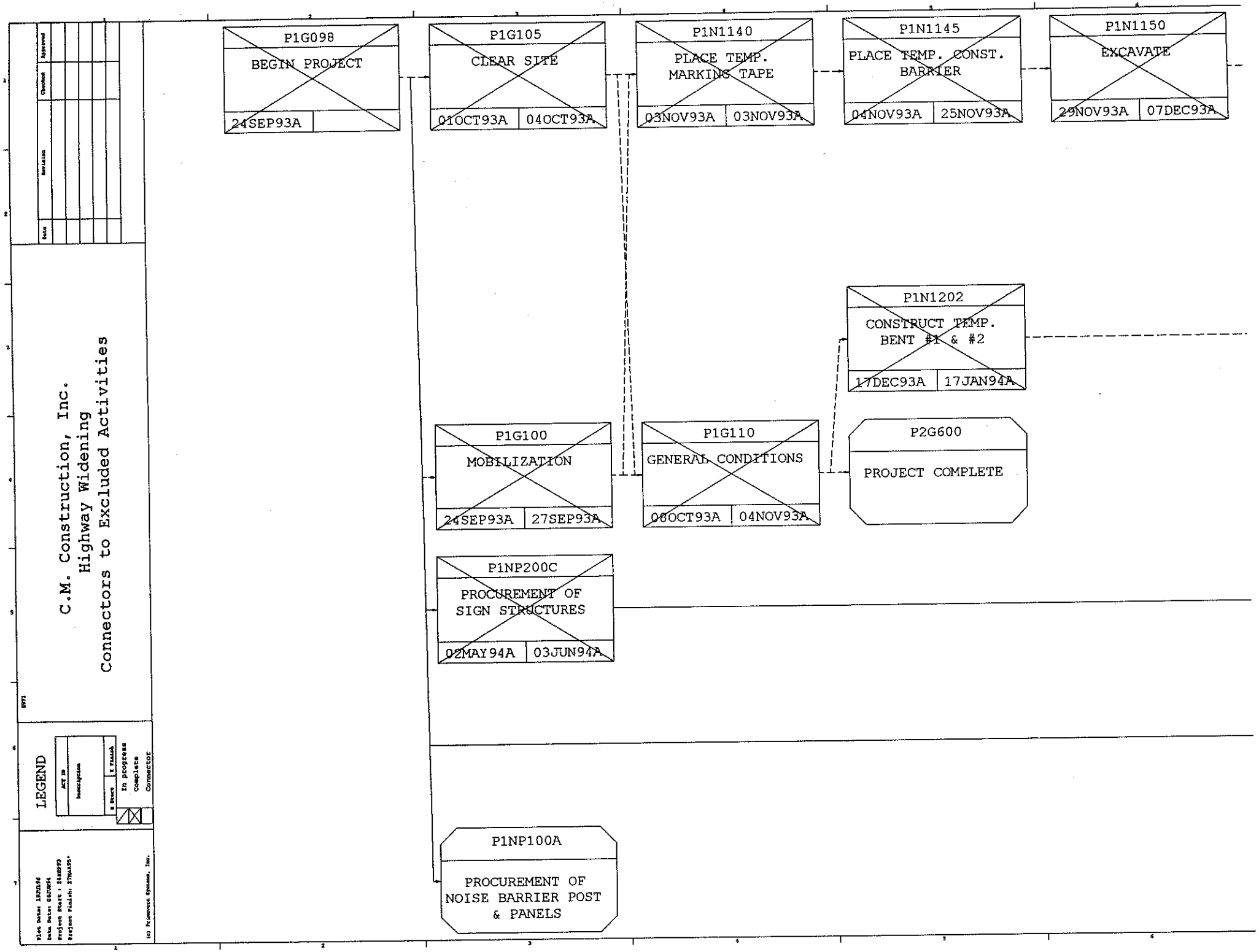
Activity ID	Closed Lane	%	Original Duration	Remaining Duration	Early Start
P1N2220	NO8	0	27	27	29AUG94
P1N2230	NO8	0	27	27	19SEP94
P1G5200	NO8	0	8	8	26OCT94
P1N2260	NO8	0	20	20	17NOV94
P1N2270	NO8	0	24	24	08DEC94
P1N2300	NO8	0	25	25	30DEC94*
P1N2320	NO8	0	24	24	23JAN95
P1N3200	NO8	0	20	20	13FEB95*
P1N3220	NO8	0	6	6	13MAR95
P1N3225B	NO8	0	6	6	21MAR95
General Construction					
P2G600		0	0	0	

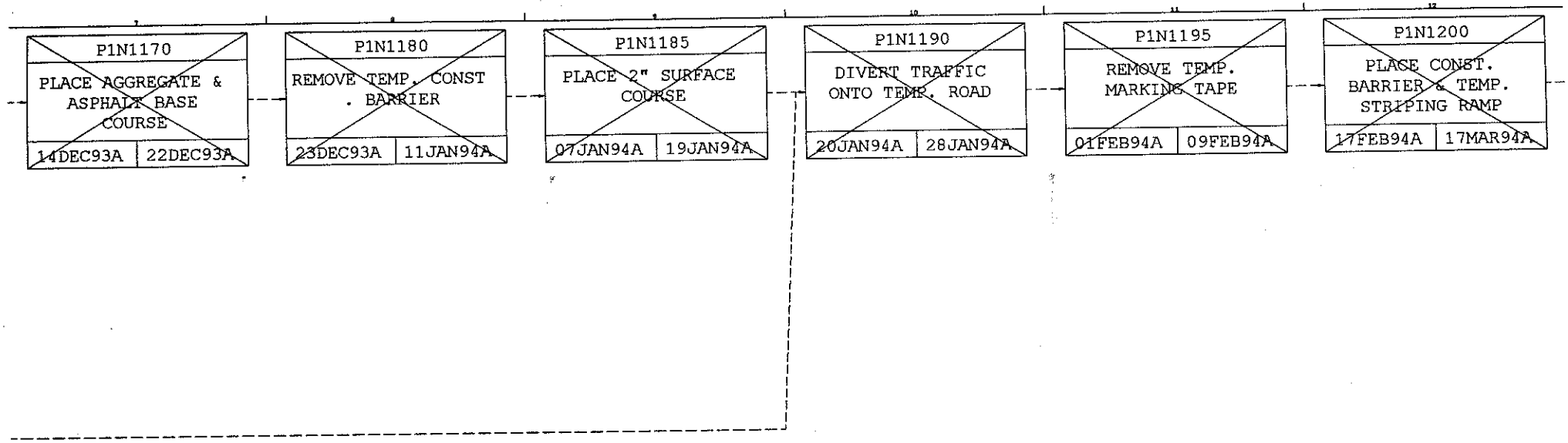


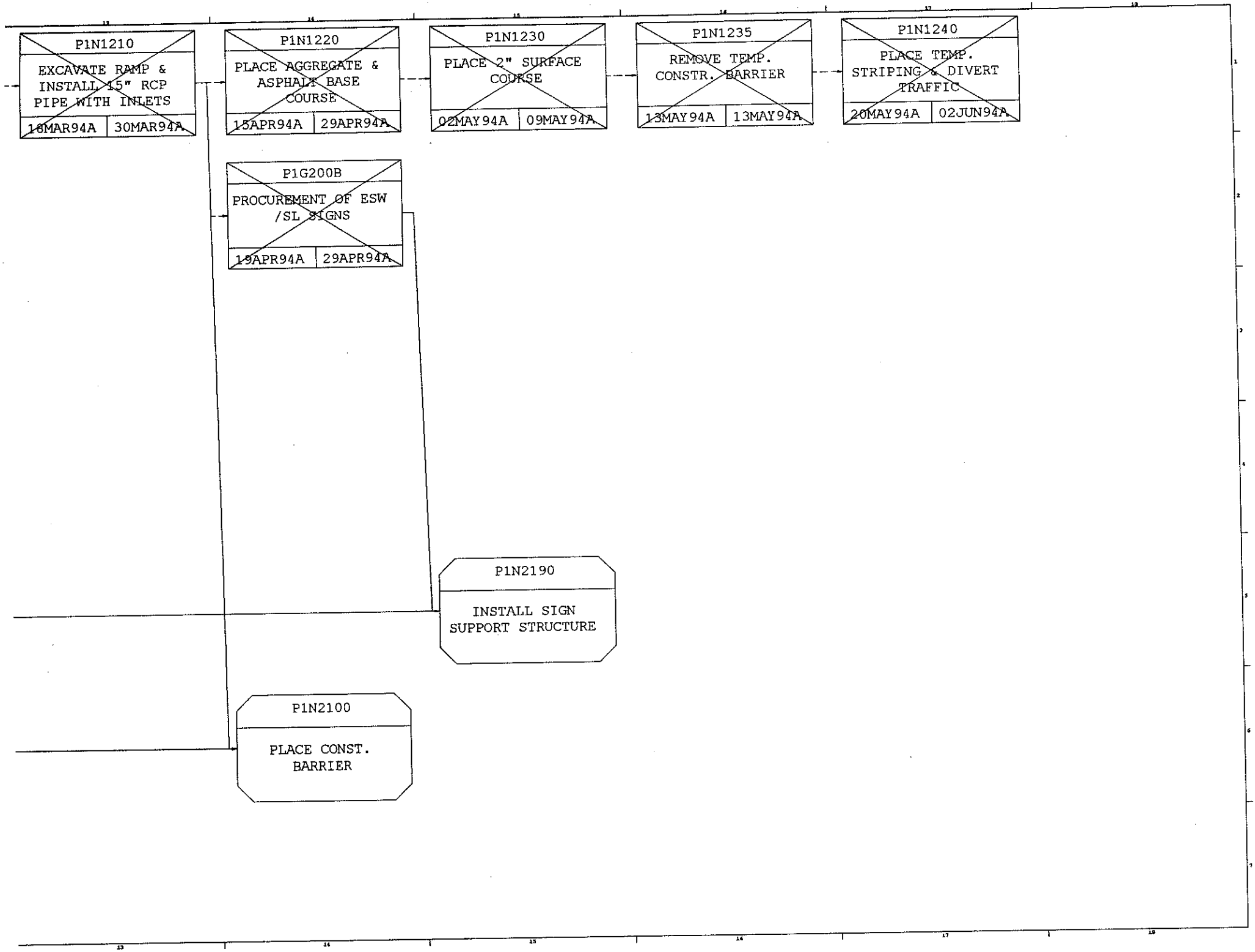
APPENDIX C

Sample of a Network Schedule for Complex Projects


P2G600
PROJECT COMPLETE
28MAR95
P2N2125A
EXCAVATE FOR ELECTRICAL
02SEP94
15SEP94
P2N2130
INSTALL ELECTRIC CONDUITS & STRUCTURES
23SEP94
19OCT94
P2N2140
INSTALL POWER & LIGHTING
20OCT94
09NOV94
P2N2150
SUBGRADE PREPARATION
10NOV94
29NOV94
P2N2125B
INSTALL TEMP. ELECTRICS
02SEP94
22SEP94
P2N2170
PLACE AGGREGATE & ASPHALT BASE COURSE
30NOV94
13DEC94
P2N2180
PLACE ASPHALT STABILIZED COURSE
14DEC94
30DEC94
P2N2185
PLACE 2" SURFACE COURSE
03JAN95
16JAN95
P2N2196
STRIPE ROADWAY
17JAN95
27JAN95
P2N2198
REMOVE TEMP. BARRIER
30JAN95
02FEB95
P2N3225A
REMOVE TEMP. CONST . BARRIER
12SEP94
16SEP94
P2N2115B
REMOVE GUIDE RAIL
29AUG94
01SEP94
P2N3100
PLACE TEMP. CONST. BARRIER
02SEP94
09SEP94
P2N3110
REMOVE TEMP. PAVEMENT
12SEP94
22SEP94
P2N3120
REGRADE AREA
23SEP94
03OCT94


C.M. Construction, Inc.
Highway Widening
Connectors to Excluded Activities
LEGEND
In progress
Complete
Connector
P1G098
BEGIN PROJECT
24SEP93A
P1G105
CLEAR SITE
01OCT93A
04OCT93A
P1N1140
PLACE TEMP. MARKING TAPE
03NOV93A
03NOV93A
P1N1145
PLACE TEMP. CONST. BARRIER
04NOV93A
25NOV93A
P1N1150
EXCAVATE
29NOV93A
07DEC93A
P1N1202
CONSTRUCT TEMP. BENT #1 & #2
17DEC93A
17JAN94A
P1G100
MOBILIZATION
24SEP93A
27SEP93A
P1G110
GENERAL CONDITIONS
08OCT93A
04NOV93A
P2G600
PROJECT COMPLETE
P1NP200C
PROCUREMENT OF SIGN STRUCTURES
02MAY94A
03JUN94A
P1NP100A
PROCUREMENT OF NOISE BARRIER POST & PANELS


P1N1170
PLACE AGGREGATE & ASPHALT BASE COURSE
14DEC93A
22DEC93A
P1N1180
REMOVE TEMP. CONST. BARRIER
23DEC93A
11JAN94A
P1N1185
PLACE 2" SURFACE COURSE
07JAN94A
19JAN94A
P1N1190
DIVERT TRAFFIC ONTO TEMP. ROAD
20JAN94A
28JAN94A
P1N1195
REMOVE TEMP. MARKING TAPE
01FEB94A
09FEB94A
P1N1200
PLACE CONST. BARRIER & TEMP. STRIPING RAMP
17FEB94A
17MAR94A


P1N1210
EXCAVATE RAMP & INSTALL 15" RCP PIPE WITH INLETS
16MAR94A
30MAR94A
P1N1220
PLACE AGGREGATE & ASPHALT BASE COURSE
15APR94A
29APR94A
P1N1230
PLACE 2" SURFACE COURSE
02MAY94A
09MAY94A
P1N1235
REMOVE TEMP. CONSTR. BARRIER
13MAY94A
13MAY94A
P1N1240
PLACE TEMP. STRIPING & DIVERT TRAFFIC
20MAY94A
02JUN94A
P1G200B
PROCUREMENT OF ESW /SL SIGNS
19APR94A
29APR94A
P1N2190
INSTALL SIGN SUPPORT STRUCTURE
P1N2100
PLACE CONST. BARRIER