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CPM
A PROGRAM FOR CRITICAL PATH MANAGEMENT

John R. McCall

April 9, 1973

Prepared for U.S. Atomic Energy Commission under contract No. W-7405-Eng-48

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Foreword

The effort reported herein is an expansion, augmentation, and combination of two programs developed by Virginia Hansen of the LLL Computation Department. Major portions of program NETWRK (reported in CIC Report H8-002) and program ASR have been retained essentially in the state of the earlier work. Her work is gratefully acknowledged.

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CPM

A PROGRAM FOR CRITICAL PATH MANAGEMENT

Abstract

A computer program to assist in the application of the Critical Path technique of project management (CPM) is presented. The purpose and philosophy of the technique are described. Preparation of the input deck is detailed. The available output options are described. A simple example is followed from project conception to examination of the computer generated output. The Appendix details the algorithm used for generation of the CPM project chart.

Introduction

In a complex endeavor it is often difficult to comprehend the structure of the effort, evaluate the sufficiency of available resources, and determine the project cost and duration. In particular, it may be impossible to determine critical portions of a project; i.e., those activities which if delayed will delay the entire project. It may also be difficult to assess the effects of reordering of project activities or of diversion of resources.

The critical path technique has been developed to help a manager deal with these problems. Three variations of the technique, CPM, PERT, and precedence networks, have become popular and each have their adherents. This paper describes a program to implement the simplest of these techniques, CPM.

The Philosophy of CPM

As with so many other applications of computers, CPM, both the technique and the program, is no more than a tool. This tool, while an aid to management in understanding and planning a project, cannot substitute for management effort. The technique cannot:

- Schedule the order of activities within the project more intelligently,
- Ensure technical success,
- Compensate for poor estimates of activity duration or required resources,
- Guarantee timely delivery from suppliers,
- Avoid budget cuts, staff illness, etc., or
- Ensure that anyone will do anything when he promises to.

As obvious as the above caveats may seem, lack of realization of these factors can easily render the use of CPM utterly worthless.

The program can:

- Graphically illustrate the relationship of activities within the project,
- Demonstrate critical paths in order of criticality,
- Generate sorted listings by time, resource required, or criticality,
- Generate bar charts of activities,
- Apply scheduling algorithms to avoid peaking of manpower resource requirements, and
- Tabulate capital funding requirements.

The value of the above functions will depend strongly on several factors. Principal among these are accuracy, timeliness, and complexity. The accuracy of estimates used in preparing the input is directly reflected in the value of the output. As with other uses of computers, "garbage in—garbage out." The presentation must reflect the current state of affairs. This implies a frequent updating of the input, especially when significant changes or reestimates occur. A few minutes per week in updating the CPM is time well spent. Finally, a careful balance between too little detail to describe the project and too much for the manager to comprehend must be established. This balance is more difficult to realize than might be assumed.

The Anatomy of CPM

Any project may be thought of as consisting of a number of activities. These activities are related through a logical network. The connections of a network are termed nodes. A node indicates a logical point in the schedule of a system. All activities which terminate at a given node must be completed before any activity beginning from that node may be started.

Associated with each activity are several parameters:

1. The node numbers from which the activity begins and on which the activity ends
2. The duration of the activity in weeks
3. The manpower required for the activity
4. The type of manpower
5. An account number or person responsible
6. Capital funds to be committed as a result of this activity
7. A description of the activity

One of the major problems in preparation of a CPM chart is a determination of what is to be an activity. For a very large, expensive, program, a single activity may commit several heads of effort for months and spend a million dollars. For a more modest program, for instance an electronic design, an activity might be a single technician

spending a day on printed circuit board layout. Proper selection of the activities to track will have major impact on the goals of accuracy, timeliness and complexity.

The following steps are recommended in the preparation of a CPM chart.

1. A rough hand drawing should be prepared by the project manager with worker assistance as required. This should emphasize the logical relationship of all activities which are to be followed.
2. The workers who will actually have to accomplish the activities should be called upon to assist in preparation of duration and manpower estimates for each activity.
3. An input deck for the activities should then be prepared. It is usually desirable to include the type of personnel (craft code), person responsible or account number, and rough capital commitment at this time.

From this rough preparation a first run may be made. If there are no errors detected, a copy of the plan will then exist to be refined.

Input

The input deck for CPM consists of three control cards followed by one card for each activity in the project. This may optionally be followed by a set of constraint cards.

LABEL AND OPTION CONTROL

The first control card gives the title to be incorporated in all requested output, and controls both output and scheduling options. For all options a nonzero entry in the appropriate column invokes the option, a zero entry requests that the option not be used.

Column	Format	Name	Description
1-60	6A10	TITLE	Title of project
61	I1	LIST(1)	Write a "CALCOMP" tape for off-line plotting of CPM chart
62	I1	LIST(2)	Produce a set of printouts separated by Craft Code
63	I1	LIST(3)	Produce a printout sorted by activity completion time Col. 63 = 1, sort by late completion time = 2, sort by early completion time
64	I1	LIST(4)	Produce a printout sorted by activity start time Col. 64 = 1, sort by late start time = 2, sort by early start time
65	I1	LIST(5)	Produce a "DD80" plot showing the project bar chart. If LIST(5) = 2, also produce a bar chart for each person responsible.
66	I1	LIST(6)	Produce a set of printouts separated by person responsible.

The remaining options govern a scheduling algorithm to be applied to the project. The code will schedule activities to use resources to the limits defined on the second control card. At each interval of time in the project, one or more activities may be candidates for scheduling. The relative priority for use of available resources is controlled by the priority option:

Column	Format	Name	Description
67	I1	LIST(7)	Assign scheduling priority to the activity having the least float
68	I1	LIST(8)	Assign scheduling priority to the activity requiring the greatest number of man-days to complete

If either of these is "1," the scheduling will be done. If "2," a list of scheduled resource usage will also be printed.

In the scheduling process, conflicts for resources may delay an activity to a point where further delay would delay the entire project. This is detected by the float of that activity being zero. When this occurs, one of two loading options is applied.

69	I1	LIST(9)	Increase the critical path length (i.e., delay project completion) to remain within the limit of available manpower
70	I1	LIST(10)	Exceed manpower limit temporarily to keep the project on schedule

MANPOWER LEVELING CONTROL

CPM allows the specification of type of manpower to be assigned to each activity. This is given by the "craft code" entry on each activity card. Any code between 1 and 39 may be used and there are no inherent definitions between an entry and the type of employee represented. To improve computational efficiency, it is suggested that only the codes from one through the maximum required be used.

If the craft code for a project is entered as zero, it will be set to 1. However, sorts on craft code will ignore such an activity. Sorts on Person Responsible (NACT) will ignore such activities if the NACT field is blank.

The use of the scheduling options requires that the program be told the maximum personnel available in each craft code. This may be done either by explicitly specifying the limit or by allowing calculation of the limit. If calculated, the limit will be the total man-days required for that craft divided by the project duration in days. If the first loading option is used (increase critical path to stay within manpower limit), each manpower limit will be adjusted upwards as necessary to provide at least the largest force required for a single activity.

Column	Format	Name	Description
1-4	I4	NICC	The maximum craft code actually to be used. Less than or equal to 39. Any craft code used larger than NICC will be set to NICC
5-6	I2	LISTCC(1)	The number of the first craft to be explicitly limited
7-9	F3.0	LIMITCC(1)	The manpower limit for this craft
10-11	I2	LISTCC(2)	The second craft to be limited
12-14	F3.0	LIMITCC(2)	The limit for the second craft
Etc. up to 13 crafts			

As an example, a card containing (b is blank)

bbb8b1bb3b4b,5b6bb2

would allow eight crafts to be defined and would limit craft 1 to three people, 4 to 0.5 people, and 6 to two people. The limits for crafts 2,3,5,7, and 8 would be calculated.

DATE, DEADLINE, AND TAPE CARD

Time results produced by CPM are in terms of calendar date, taking into account weekends, holidays, etc. It is also possible to specify a deadline date. The code will attempt to adjust float to meet the deadline. For activities where the float from a calculation which does not use the deadline is less than the time between the deadline and the normal completion date, the float will be negative.

Column	Format	Name	Description
1-8	A8	TZERO	Start date of project; i.e., of activities leaving the first node—right justified. Dates are specified as, e.g., 24AUG72, where the month abbreviations are JAN, FEB, MAR, APR, MAY, JUN, JLY (not JUL), AUG, SEP, OCT, NOV, and DEC.
9-10	2X		
11-18	A8	DDLINE	Deadline date—right justified
19-20	I2	IDSIG	Option control for deadline calculation—nonzero invokes the calculation
21-25	R5	CCT	Tape vault number of tape to be used for offline Calcomp plotting

ACTIVITY CARDS

One card is required for each activity in the project. Each activity must be part of a continuous path through the network. The numbering of nodes is completely arbitrary between "2" and "3999" with the exception of the start and termination nodes. The start node must be numbered "1" and the terminal node "4000."

Column	Format	Name	Description
1-4	I4	I	Start node for activity
5-8	I4	J	End node for activity
9-10	2X		
11-14	F4.0	D	Duration of activity in <u>weeks</u>
15-16	2X		
17-20	F4.0	MNPOWR	Number of employees assigned to activity
21-22	2X		
23-24	I2	CC	Craft code
25-26	2X		
27-32	A6	NACT	Identifier for person responsible for activity—typically his initials
33-62	3A10	JOB	Description of the activity
63-66	4X		
67-72	F6.0	DOLR	Resource to be committed as a result of this activity. Typically used for capital equipment in thousands of dollars. If DOLR is positive, the resource is committed at the beginning of the activity. If DOLR is negative, the resource (absolute value) is committed at the completion of the activity.

There may be up to 1500 activities in the project. The actual number is kept in the internal variable "K."

FORCED SCHEDULE OPTION

If no forcing of the schedule (other than a possible deadline calculation as described above) is desired, the activity cards are followed by a blank card and the input is complete.

An option may be invoked to place limits on the scheduled dates of nodes. The time of late arrival at a node may be limited, preventing the use of float on a specified activity if contrary to project planning. In addition, an earliest time to leave a node may be specified. This may be used, for instance, to avoid beginning an activity before start of a fiscal year or before completion of some activity not shown on this CPM chart.

To use this option the blank card after the activity card is replaced by a card which specifies the number of nodes to be forced.

Column	Format	Name	Description
1-4	I4	NIN	Number of nodes to be forced (i.e., number of cards following)

Each node is distinguished by two dates. These are TE, the earliest date at which all activities entering the node can be completed, and TL, the latest date by which the

most critical activity leaving the node must be begun. Specified dates will be used to replace these if possible.

Column	Format	Name	Description
1-5	I5	IND	The node number to be forced
8-15	A8	ATL	The date desired as a replacement for TL
18-25	A8	TEF	The date desired to replace TE

For the network presented to the code it may not be possible to schedule the date ATL in place of TL. This will occur if ATL is earlier than TE. In this case, TE will be used rather than ATL.

In the printout, a listing will be made of nodes forced, the requested date and the actual date used. If these last two are different, an error flag of "****" will be printed.

One additional item of input is required, namely the calendar file "CALFIL." This is a list of actual working days. Currently the file extends to 5JAN77.

Output

Figure 1 shows the gross flow of the CPM code. In particular, the regular and optional outputs are shown.

After the input is read it is listed back for reference and update purposes. A listing is made of all of the nodes used, the number of activities entering and leaving each, and the earliest and latest times to reach that node. The critical path length and completion date are listed. The basic CPM calculations are performed and the results printed with time in weeks. The results listed on this and successive outputs are:

- I—The node on which the activity begins
- J—The node on which the activity ends
- Early and Late Begin time are the earliest date at which the activity may be started; i.e., all preceding activities might be completed, and the time when the activity must be begun to avoid delaying the project.
- Early and Late Complete are the earliest date by which the activity might be completed and the date by which it must be completed to avoid delaying the project.
- Total Float measures the criticality of a path. Along a given simple path, i.e., a string of nodes with one entering activity and one activity out, the total float will be a constant. It represents the time which may be "wasted" along that path.
- Free Float will be nonzero where one simple path joins a more critical path. It represents the waiting time for this path before others entering the same node can be completed.

Fig. 1a. CPM flow chart.

Fig. 1b. CPM flow chart. (Continued)

Fig. 1c. CPM flow chart. (Continued)

Fig. 1d. CPM flow chart. (Continued)

A plot is made of the use of each craft code and of all manpower versus time. The cumulative number of manweeks is also plotted.

If scheduling is requested, it is now done. Certain subsequent listings will then have only the scheduled begin and complete dates, not early and late dates.

The time in weeks is then converted to calendar dates and the list is sorted. This sorting arranges the most critical activities at the head of the list. For activities of equal criticality, i.e., float, the list is sorted by increasing late start time.

Optional printouts and plots are then generated.

The last output to be generated, if requested, is the CALCOMP plot of the activity network. A sample is shown later in Fig. 19. Several points should be noted on this example. First, there is no implicit correlation between distance to the right on the plot and time, other than time monotonically increasing to the right along a given path. Each activity is plotted with the associated activity description above the line. Below the line, values of activity duration (D), manpower (M), person responsible and craft code (CC) are plotted if they were input. Values left blank on input are not plotted. If manpower and duration are both zero, the activity is plotted as a dotted line.

Each node is labeled with the node number and the early and late times at that node. If these are the same, i.e., the node is critical, only the single date is plotted. Any node which connects to the terminal node (1050 to 4000 in this example) and has no manpower or activity is not plotted.

The plot is labeled with the project title and with the time, date, and machine where it was run.

A "roadmap" is listed which tells the location of the nodes. This can be useful in analyzing complicated networks.

If an activity cannot be plotted on the available width of paper, it and any activities which succeed it are not plotted. A listing is made of all such activities.

Following the CALCOMP plot, a tabulation of the program running times is made and the program exits.

Running Instructions

The files required to run CPM are stored on tape FE423. The files are:

CALFIL	Calendar file. Always required
CPM76 CPM66	7600 and 6600 versions for interactive execution from TTY
CPM76P CPM66P	7600 and 6600 versions for running as production jobs under the ORDER operating system

INTERACTIVE USE

To run CPM on the 7600 from teletype,

You: CPM76 / t v

TTY: TYPE NAME (8 CHAR) AND BOX NO (3 CHAR) where NAME is any identifier of eight or less characters with no embedded blanks, e.g.

You: MCCALL H31

TTY: INPUT FILE

You: filename OPT
where filename is the file containing the control cards and activity cards. The second symbol "OPT" is optional. If entered, the program will ask for the option controls normally specified on the Title card and override those.

TTY: HSP OR PRINT

You: answer PRINT to save HSP output file(s) HSPØ. Any other answer, e.g., HSP will send files out to the high-speed printer.

If OPT was entered with the input file name, the program will ask:

TTY: OPTIONS

You: 012211101 e.g., specifying the options desired in the same format as on the Title card

The program should now run to completion without further intervention.

PRODUCTION USE

The deck for ORDER should be set up as follows:

*ID nnnaaa your name Box ann

*V FE423 *(calcomp tape number if needed)

*RDFILES FE423 CPM76P CALFIL

*XEQ CPM76P .

*DATA

 deck of data cards

Running instructions for the 6600 are the same, using the "66" files instead of the "76" files.

Example

As an example of the use of CPM consider a project to build a system to acquire data, input it to a minicomputer and process it. The system development will require purchasing the minicomputer and analog-to-digital converter (A/D), interfacing them, and developing software. Four craft codes are involved:

- 1 Management
- 2 Engineer
- 3 Technician
- 4 Programmer

Figure 2 is the original hand chart showing project logic. Figure 3 is the input. Figures 4 through 18 are the results of the computer run with no scheduling. Figure 19 is the Calcomp plot.

An examination of the manpower plot, Fig. 16b, for craft code 2 (Engineer) shows a peak demand of two engineers. Assuming only one engineer is available, a second run is made limiting craft code 2. Selected output from the result is shown in Figs. 20 through 24. Note particularly Fig. 23 showing the leveling of the engineer demand with no project delay.

Several points may be noted in this example.

- a) The activity of "Project Scope" requires three disciplines. To properly represent this, it is necessary to define three concurrent activities.
- b) A "constraint" or dummy activity is used from node 800 to nodes 700 and 900 indicating a relationship not defined by a specific activity.
- c) A dummy activity is used from the end of the project to node 4000. This dummy is not plotted. While this is not particularly useful on this simple example, a project which has many parallel terminal activities will produce a cleaner Calcomp plot if terminals are tied to 4000 with a dummy.
- d) No technician was available until July 23, thus a constraint was placed on node 1010. This delayed the activity "Build Interface" but not the project.
- e) In the scheduled run, Figs. 21, 22, and 24 present only the scheduled dates, not the early and late dates.

Maximum Parameters

Certain values on a **PARAMETER** statement control the size, and thus capacity, of the CPM program:

Name	Description	Value	# Variables	# Arrays ^a	Core
IBSZ	Buffer for Calcomp output	2000	1	1	2000
INODE	Maximum number of nodes	4000	11	4	16000
IACT	Maximum number of activities	1500	MAXOUT+24=39	20	30000
NSEG	Maximum number of X segments on plot	100	6	6	600
MAXDAY	Maximum number of days which can be scheduled	1340	MXCRFT-3=42	10	13400
MXCRFT	Maximum number of craft codes allowed	39	4	4	156
MAXOUT	Maximum number of activities which may leave a node (when scheduling done)	15	0	0	0
LENCAL	Length of calendar table	1340	2	2	2680 64836

^a Full-word arrays—variables packed into bytes.

With the addition of the program itself, some minor arrays, and operating system resident support, CPM nearly fills available core on the 6600's. It would easily be possible to reduce, at least somewhat, the size of CPM. For example, for INODE = 500, IACT = 200, MXCRFT = 4, and MAXOUT = 7, the above array total would be reduced by nearly 50,000 words. The decision to use nearly all of available core was dictated by idiosyncrasies of the scheduling algorithm in use at the time the program was developed.

Typical Timing Information

The following are sample timing of five 6600 CPM runs. An X indicates the option was not requested (time in seconds):

No. of activities	27	37	149	137	220
No. of nodes	17	20	107	77	141
Input	3.7	4.0	5.8	4.8	2.7
Calculation	0.6	0.7	2.8	1.7	3.2
Scheduling	4.7 ^a	6.3 ^a	3.9 ^{a,b}	7.1 ^a	16.6
Calendar	0.5	0.4	3.5	10.8	2.6
Bar chart	0.6	2.3	3.3	8.2	35.6 ^a
List by craft code	0.3	X	X	1.4	1.9
List by start	0.2	0.4	1.4	1.2	2.3
List by completion	0.3	0.5	1.5	1.2	2.3
Deadline	X	X	X	X	X
Calcomp	13.4	26.6	146.7	87.1	120.8

^a No scheduling done—time reflects plot of manpower loading (unscheduled).

^b No division of project into craft codes.

^c Long project duration.

As is obvious, there is not always a direct correlation between the number of activities and nodes and the required running times. The complexity and amount of interconnection in the project logic is very significant for calculation and scheduling, and the project duration affects the bar chart, etc. It can be seen that the program consumes little time unless the dominating factor, the Calcomp plot, is requested. These numbers should be used only as rough guidelines for expected cost.

Fig. 2. CPM hand chart.

Fig. 3b. CPM input. (Continued)

ACTIVITY	FROM	TO	ESTIMATED DURATION	ACTIVITY	FROM	TO	ESTIMATED DURATION
1	1	2	1	10	10	11	1
2	2	3	1	11	11	12	1
3	3	4	1	12	12	13	1
4	4	5	1	13	13	14	1
5	5	6	1	14	14	15	1
6	6	7	1	15	15	16	1
7	7	8	1	16	16	17	1
8	8	9	1	17	17	18	1
9	9	10	1	18	18	19	1
10	10	11	1	19	19	20	1
11	11	12	1	20	20	21	1
12	12	13	1	21	21	22	1
13	13	14	1	22	22	23	1
14	14	15	1	23	23	24	1
15	15	16	1	24	24	25	1
16	16	17	1	25	25	26	1
17	17	18	1	26	26	27	1
18	18	19	1	27	27	28	1
19	19	20	1	28	28	29	1
20	20	21	1	29	29	30	1
21	21	22	1	30	30	31	1
22	22	23	1	31	31	32	1
23	23	24	1	32	32	33	1
24	24	25	1	33	33	34	1
25	25	26	1	34	34	35	1
26	26	27	1	35	35	36	1
27	27	28	1	36	36	37	1
28	28	29	1	37	37	38	1
29	29	30	1	38	38	39	1
30	30	31	1	39	39	40	1
31	31	32	1	40	40	41	1
32	32	33	1	41	41	42	1
33	33	34	1	42	42	43	1
34	34	35	1	43	43	44	1
35	35	36	1	44	44	45	1
36	36	37	1	45	45	46	1
37	37	38	1	46	46	47	1
38	38	39	1	47	47	48	1
39	39	40	1	48	48	49	1
40	40	41	1	49	49	50	1
41	41	42	1	50	50	51	1
42	42	43	1	51	51	52	1
43	43	44	1	52	52	53	1
44	44	45	1	53	53	54	1
45	45	46	1	54	54	55	1
46	46	47	1	55	55	56	1
47	47	48	1	56	56	57	1
48	48	49	1	57	57	58	1
49	49	50	1	58	58	59	1
50	50	51	1	59	59	60	1
51	51	52	1	60	60	61	1
52	52	53	1	61	61	62	1
53	53	54	1	62	62	63	1
54	54	55	1	63	63	64	1
55	55	56	1	64	64	65	1
56	56	57	1	65	65	66	1
57	57	58	1	66	66	67	1
58	58	59	1	67	67	68	1
59	59	60	1	68	68	69	1
60	60	61	1	69	69	70	1
61	61	62	1	70	70	71	1
62	62	63	1	71	71	72	1
63	63	64	1	72	72	73	1
64	64	65	1	73	73	74	1
65	65	66	1	74	74	75	1
66	66	67	1	75	75	76	1
67	67	68	1	76	76	77	1
68	68	69	1	77	77	78	1
69	69	70	1	78	78	79	1
70	70	71	1	79	79	80	1
71	71	72	1	80	80	81	1
72	72	73	1	81	81	82	1
73	73	74	1	82	82	83	1
74	74	75	1	83	83	84	1
75	75	76	1	84	84	85	1
76	76	77	1	85	85	86	1
77	77	78	1	86	86	87	1
78	78	79	1	87	87	88	1
79	79	80	1	88	88	89	1
80	80	81	1	89	89	90	1
81	81	82	1	90	90	91	1
82	82	83	1	91	91	92	1
83	83	84	1	92	92	93	1
84	84	85	1	93	93	94	1
85	85	86	1	94	94	95	1
86	86	87	1	95	95	96	1
87	87	88	1	96	96	97	1
88	88	89	1	97	97	98	1
89	89	90	1	98	98	99	1
90	90	91	1	99	99	100	1
91	91	92	1	100	100	101	1
92	92	93	1	101	101	102	1
93	93	94	1	102	102	103	1
94	94	95	1	103	103	104	1
95	95	96	1	104	104	105	1
96	96	97	1	105	105	106	1
97	97	98	1	106	106	107	1
98	98	99	1	107	107	108	1
99	99	100	1	108	108	109	1
100	100	101	1	109	109	110	1
101	101	102	1	110	110	111	1
102	102	103	1	111	111	112	1
103	103	104	1	112	112	113	1
104	104	105	1	113	113	114	1
105	105	106	1	114	114	115	1
106	106	107	1	115	115	116	1
107	107	108	1	116	116	117	1
108	108	109	1	117	117	118	1
109	109	110	1	118	118	119	1
110	110	111	1	119	119	120	1
111	111	112	1	120	120	121	1
112	112	113	1	121	121	122	1
113	113	114	1	122	122	123	1
114	114	115	1	123	123	124	1
115	115	116	1	124	124	125	1
116	116	117	1	125	125	126	1
117	117	118	1	126	126	127	1
118	118	119	1	127	127	128	1
119	119	120	1	128	128	129	1
120	120	121	1	129	129	130	1
121	121	122	1	130	130	131	1
122	122	123	1	131	131	132	1
123	123	124	1	132	132	133	1
124	124	125	1	133	133	134	1
125	125	126	1	134	134	135	1
126	126	127	1	135	135	136	1
127	127	128	1	136	136	137	1
128	128	129	1	137	137	138	1
129	129	130	1	138	138	139	1
130	130	131	1	139	139	140	1
131	131	132	1	140	140	141	1
132	132	133	1	141	141	142	1
133	133	134	1	142	142	143	1
134	134	135	1	143	143	144	1
135	135	136	1	144	144	145	1
136	136	137	1	145	145	146	1
137	137	138	1	146	146	147	1
138	138	139	1	147	147	148	1
139	139	140	1	148	148	149	1
140	140	141	1	149	149	150	1
141	141	142	1	150	150	151	1
142	142	143	1	151	151	152	1
143	143	144	1	152	152	153	1
144	144	145	1	153	153	154	1
145	145	146	1	154	154	155	1
146	146	147	1	155	155	156	1
147	147	148	1	156	156	157	1
148	148	149	1	157	157	158	1
149	149	150	1	158	158	159	1
150	150	151	1	159	159	160	1
151	151	152	1	160	160	161	1
152	152	153	1	161	161	162	1
153	153	154	1	162	162	163	1
154	154	155	1	163	163	164	1
155	155	156	1	164	164	165	1
156	156	157	1	165	165	166	1
157	157	158	1	166	166	167	1
158	158	159	1	167	167	168	1
159	159	160	1	168	168	169	1
160	160	161	1	169	169	170	1
161	161	162	1	170	170	171	1
162	162	163	1	171	171	172	1
163	163	164	1	172	172	173	1
164	164	165	1	173	173	174	1
165	165	166	1	174	174	175	1
166	166	167	1	175	175	176	1
167	167	168	1	176	176	177	1
168	168	169	1	177	177	178	1
169	169	170	1	178	178	179	1
170	170	171	1	179	179	180	1
171	171	172	1	180	180	181	1
172	172	173	1	181	181	182	1
173	173	174	1	182	182	183	1
174	174	175	1	183	183	184	1
175	175	176	1	184	184	185	1
176	176	177	1	185	185	186	1
177	177	178	1	186	186	187	1
178	178	179	1	187	187	188	1
179	179	180	1	188	188	189	1
180	180	181	1	189	189	190	1
181	181	182	1	190	190	191	1
182	182	183	1	191	191	192	1
183	183	184	1	192	192	193	1
184	184	185	1	193	193	194	1
185	185	186	1	194	194	195	1
186	186	187	1	195	195	196	1
187	187	188	1	196	196	197	1
188	188	189	1	197	197	198	1
189	189	190	1	198	198	199	1
190	190	191	1	199	199	200	1
191	191	192	1	200	200	201	1
192	192	193	1	201	201	202	1
193	193	194	1	202	202	203	1
194	194	195	1	203	203	204	1
195	195	196	1	204	204	205	1
196	196	197	1	205	205	206	1
197	197	198	1				

EXAMPLE CPM FOR DATA SYSTEM

112111000000

1 0. 2 1.0 3 0. 4 0.

22JAN73-0

-OFE424

1	100	3.00	0.50	1	JOHN	PROJECT SCOPE	-0.
1	100	4.00	1.00	2	JOHN	PROJECT SCOPE	-0.
1	100	4.00	1.00	4	JOHN	PROJECT SCOPE	-0.
100	200	5.00	0.10	1	JOHN	OBTAIN PROJECT APPROVAL	-0.
100	200	4.00	1.00	2	JOE	DETAIL PROJECT AND FUNDING	-0.
200	300	2.00	0.80	2	JOE	SPECIFY A/D	-0.
300	400	3.00	0.10	2	JOE	BIDS FOR A/D	-0.
200	800	8.00	0.50	1	JOHN	OBTAIN FUNDING	-0.
200	500	2.00	1.00	2	JOE	SPECIFY COMPUTER	-0.
500	600	6.00	0.10	2	JOE	BIDS FOR COMPUTER	-0.
500	900	4.00	1.00	4	SAM	SPECIFY SOFTWARE FUNCTIONS	-0.
400	700	1.00	0.50	2	JOE	SELECT A/D VENDOR	-0.
800	700	-0.	-0.	-0			-0.
800	900	-0.	-0.	-0			-0.
600	900	2.00	0.50	2	JOE	SELECT COMPUTER VENDOR	-0.
700	1030	6.00	0.10	2	JOE	PURCHASE A/C	3.50
900	1000	4.00	0.20	1	JOHN	OBTAIN AEC CK	-0.
1000	1030	12.00	0.10	2	JOE	PURCHASE COMPUTER	23.00
900	1010	4.00	0.80	2	JOE	DESIGN INTERFACE	-4.20
1010	1030	4.00	0.80	3	JOE	BUILD INTERFACE	-0.
900	1020	4.00	1.00	4	SAM	DETAIL SOFTWARE SPECS	-0.
1020	1040	6.00	0.90	4	SAM	WRITE SOFTWARE	-0.
1030	1040	4.00	1.00	2	JOE	ASSEMBLE AND CHECKOUT	-0.
1040	1050	4.00	1.00	2	JOE	SYSTEM CHECKOUT	-0.
1040	1050	4.00	1.00	4	JOE	SYSTEM CHECKOUT	-0.
1030	1040	4.00	1.00	3	JOE	ASSEMBLE AND CHECKOUT	-0.
1050	4000	-0.	-0.	-0			-0.
1	-0	-0.	-0.	-0			-0.

27 ACTIVITIES

Fig. 4. Listing of Input.

1 CONSTRAINTS

NOCE
1010

LATE

EARLY
23JLY73

Fig. 5. Constraints.

LISTING OF NODES USED

NODE	ENTER	LEAVE	TE	TLJ
1	0	3	0.	0.
100	3	2	4.0	4.0
200	2	3	9.0	9.0
300	1	1	11.0	25.0
400	1	1	14.0	28.0
500	1	2	11.0	11.0
600	1	1	17.0	17.0
700	2	1	17.0	29.0
800	1	2	17.0	19.0
900	3	3	19.0	19.0
1000	1	1	23.0	23.0
1010	1	1	25.4	31.0
1020	1	1	23.0	33.0
1030	3	2	35.0	35.0
1040	3	2	39.0	39.0
1050	2	1	43.0	43.0
4000	1	0	43.0	43.0

CRITICAL PATH LENGTH = 43.0
COMPLETION DATE IS 27NOV73

Fig. 6. Listing of nodes used.

EXAMPLE CPM FOR DATA SYSTEM

LISTING IN ORDER OF INPUT DATA

I	J	JOB DESCRIPTION	CRAFT CODE	PERSON RESP.	BEGIN		NO. WEEKS	NO. MEN	COMPLETE		FLOAT	
					EARLY	LATE			EARLY	LATE	FREE	TOTAL
1	100	PROJECT SCOPE	1	JOHN	0.	1.0	3.0	0.5	3.0	4.0	1.0	1.0
1	100	PROJECT SCOPE	2	JOHN	0.	0.	4.0	1.0	4.0	4.0	0.	0.
1	100	PROJECT SCOPE	4	JOHN	0.	0.	4.0	1.0	4.0	4.0	0.	0.
100	200	OBTAIN PROJECT APPROVAL	1	JOHN	4.0	4.0	5.0	0.1	9.0	9.0	0.	0.
100	200	DETAIL PROJECT AND FUNDING	2	JOE	4.0	5.0	4.0	1.0	8.0	9.0	1.0	1.0
200	300	SPECIFY A/D	2	JOE	9.0	23.0	2.0	0.8	11.0	25.0	0.	14.0
300	400	BIDS FOR A/D	2	JOE	11.0	25.0	3.0	0.1	14.0	28.0	0.	14.0
200	800	OBTAIN FUNDING	1	JOHN	9.0	11.0	8.0	0.5	17.0	19.0	0.	2.0
200	500	SPECIFY COMPUTER	2	JOE	9.0	9.0	2.0	1.0	11.0	11.0	0.	0.
500	600	BIDS FOR COMPUTER	2	JOE	11.0	11.0	6.0	0.1	17.0	17.0	0.	0.
500	900	SPECIFY SOFTWARE FUNCTIONS	4	SAM	11.0	15.0	4.0	1.0	15.0	19.0	4.0	4.0
400	700	SELECT A/D VENDOR	2	JOE	14.0	28.0	1.0	0.5	15.0	29.0	2.0	14.0
800	700		1		17.0	29.0	-0.	-0.	17.0	29.0	0.	12.0
800	900		1		17.0	19.0	-0.	-0.	17.0	19.0	2.0	2.0
600	900	SELECT COMPUTER VENDOR	2	JOE	17.0	17.0	2.0	0.5	19.0	19.0	0.	0.
700	1030	PURCHASE A/D	2	JOE	17.0	29.0	6.0	0.1	23.0	35.0	12.0	12.0
900	1000	OBTAIN AEC OK	1	JOHN	19.0	19.0	4.0	0.2	23.0	23.0	0.	0.
1000	1030	PURCHASE COMPUTER	2	JOE	23.0	23.0	12.0	0.1	35.0	35.0	0.	0.
900	1010	DESIGN INTERFACE	2	JOE	19.0	27.0	4.0	0.8	23.0	31.0	2.4	8.0
1010	1030	BUILD INTERFACE	3	JOE	25.4	31.0	4.0	0.8	29.4	35.0	5.6	5.6
900	1020	DETAIL SOFTWARE SPECS	4	SAM	19.0	29.0	4.0	1.0	23.0	33.0	0.	10.0
1020	1040	WRITE SOFTWARE	4	SAM	23.0	33.0	6.0	0.9	29.0	39.0	10.0	10.0
1030	1040	ASSEMBLE AND CHECKOUT	2	JOE	35.0	35.0	4.0	1.0	39.0	39.0	0.	0.
1040	1050	SYSTEM CHECKOUT	2	JOE	39.0	39.0	4.0	1.0	43.0	43.0	0.	0.
1040	1050	SYSTEM CHECKOUT	4	JOE	39.0	39.0	4.0	1.0	43.0	43.0	0.	0.
1030	1040	ASSEMBLE AND CHECKOUT	3	JOE	35.0	35.0	4.0	1.0	39.0	39.0	0.	0.
1050	4000		1		43.0	43.0	-0.	-0.	43.0	43.0	0.	0.

Fig. 7. Listing in order of data input.

EXAMPLE CPM FOR DATA SYSTEM

LISTING IN SORTED ORDER - ACTUAL DATES

I	J	JOB DESCRIPTION	CRAFT CODE	PERSON RESP.	BEGIN		NO. WEEKS	NO. MEN	COMPLETE		FLOAT	
					EARLY	LATE			EARLY	LATE	FREE	TOTAL
1	100	PROJECT SCOPE	2	JOHN	22JAN73	22JAN73	4.0	1.0	19FEB73	19FEB73	0.	0.
1	100	PROJECT SCOPE	4	JOHN	22JAN73	22JAN73	4.0	1.0	19FEB73	19FEB73	0.	0.
100	200	OBTAIN PROJECT APPROVAL	1	JOHN	19FEB73	19FEB73	5.0	0.1	27MAR73	27MAR73	0.	0.
200	500	SPECIFY COMPUTER	2	JOE	27MAR73	27MAR73	2.0	1.0	10APR73	10APR73	0.	0.
500	600	BIDS FOR COMPUTER	2	JOE	10APR73	10APR73	6.0	0.1	22MAY73	22MAY73	0.	0.
600	900	SELECT COMPUTER VENDOR	2	JOE	22MAY73	22MAY73	2.0	0.5	6JUN73	6JUN73	0.	0.
900	1000	OBTAIN AEC OK	1	JOHN	6JUN73	6JUN73	4.0	0.2	5JLY73	5JLY73	0.	0.
1000	1030	PURCHASE COMPUTER	2	JOE	5JLY73	5JLY73	12.0	0.1	28SEP73	28SEP73	0.	0.
1030	1040	ASSEMBLE AND CHECKOUT	2	JOE	28SEP73	28SEP73	4.0	1.0	26OCT73	26OCT73	0.	0.
1030	1040	ASSEMBLE AND CHECKOUT	3	JOE	28SEP73	28SEP73	4.0	1.0	26OCT73	26OCT73	0.	0.
1040	1050	SYSTEM CHECKOUT	2	JOE	26OCT73	26OCT73	4.0	1.0	27NOV73	27NOV73	0.	0.
1040	1050	SYSTEM CHECKOUT	4	JOE	26OCT73	26OCT73	4.0	1.0	27NOV73	27NOV73	0.	0.
1050	4000		1		27NOV73	27NOV73	-0.	-0.	27NOV73	27NOV73	0.	0.
1	100	PROJECT SCOPE	1	JOHN	22JAN73	29JAN73	3.0	0.5	12FEB73	19FEB73	1.0	1.0
100	200	DETAIL PROJECT AND FUNDING	2	JOE	19FEB73	27FEB73	4.0	1.0	20MAR73	27MAR73	1.0	1.0
200	800	OBTAIN FUNDING	1	JOHN	27MAR73	10APR73	8.0	0.5	22MAY73	6JUN73	0.	2.0
800	900		1		22MAY73	6JUN73	-0.	-0.	22MAY73	6JUN73	2.0	2.0
500	900	SPECIFY SOFTWARE FUNCTIONS	4	SAV	10APR73	8MAY73	4.0	1.0	8MAY73	6JUN73	4.0	4.0
1010	1030	BUILD INTERFACE	3	JOE	23JLY73	30AUG73	4.0	0.8	20AUG73	28SEP73	5.6	5.6
900	1020	DESIGN INTERFACE	2	JOE	6JUN73	2AUG73	4.0	0.8	5JLY73	30AUG73	2.4	8.0
900	1020	DETAIL SOFTWARE SPECS	4	SAV	6JUN73	16AUG73	4.0	1.0	5JLY73	14SEP73	0.	10.0
1020	1040	WRITE SOFTWARE	4	SAV	5JLY73	14SEP73	6.0	0.9	16AUG73	26OCT73	10.0	10.0
800	700		1		22MAY73	16AUG73	-0.	-0.	22MAY73	16AUG73	0.	12.0
700	1030	PURCHASE A/D	2	JOE	22MAY73	16AUG73	6.0	0.1	5JLY73	28SEP73	12.0	12.0
200	300	SPECIFY A/D	2	JOE	27MAR73	5JLY73	2.0	0.8	10APR73	19JLY73	0.	14.0
300	400	BIDS FOR A/D	2	JOE	10APR73	19JLY73	3.0	0.1	1MAY73	9AUG73	0.	14.0
400	700	SELECT A/D VENDOR	2	JOE	1MAY73	9AUG73	1.0	0.5	8MAY73	16AUG73	2.0	14.0

Fig. 8. Listing in sorted order, actual dates.

EXAMPLE CPM FOR DATA SYSTEM

LIST OF JOBS FOR WHICH JOHN IS RESPONSIBLE

LISTING IN SORTED ORDER - ACTUAL DATES

I	J	JOB DESCRIPTION	CRAFT CODE	PERSON RESP.	BEGIN		NO. WEEKS	NO. MEN	COMPLETE		FLOAT	
					EARLY	LATE			EARLY	LATE	FREE	TOTAL
1	100	PROJECT SCOPE	2	JOHN	22JAN73	22JAN73	4.0	1.0	19FEB73	19FEB73	0.	0.
1	100	PROJECT SCOPE	4	JOHN	22JAN73	22JAN73	4.0	1.0	19FEB73	19FEB73	0.	0.
1	100	PROJECT SCOPE	1	JOHN	22JAN73	29JAN73	3.0	0.5	12FEB73	19FEB73	1.0	1.0
100	200	OBTAIN PROJECT APPROVAL	1	JOHN	19FEB73	19FEB73	5.0	0.1	27MAR73	27MAR73	0.	0.
200	800	OBTAIN FUNDING	1	JOHN	27MAR73	10APR73	8.0	0.5	22MAY73	6JUN73	0.	2.0
900	1000	OBTAIN AEC UK	1	JOHN	6JUN73	6JUN73	4.0	0.2	5JLY73	5JLY73	0.	0.

Fig. 8a. Listing of jobs for which John is responsible.

EXAMPLE CPM FOR DATA SYSTEM

LIST OF JOBS FOR WHICH JOE IS RESPONSIBLE

LISTING IN SORTED ORDER - ACTUAL DATES

I	J	JOB DESCRIPTION	CRAFT CODE	PERSON RESP.	BEGIN		NO. WEEKS	NC. MEN	COMPLETE		FLOAT	
					EARLY	LATE			EARLY	LATE	FREE	TOTAL
100	200	DETAIL PROJECT AND FUNDING	2	JOE	19FEB73	27FEB73	4.0	1.0	20MAR73	27MAR73	1.0	1.0
200	500	SPECIFY COMPUTER	2	JOE	27MAR73	27MAR73	2.0	1.0	10APR73	10APR73	0.	0.
200	300	SPECIFY A/D	2	JOE	27MAR73	5JLY73	2.0	0.8	10APR73	19JLY73	0.	14.0
500	600	BIDS FOR COMPUTER	2	JOE	10APR73	10APR73	6.0	0.1	22MAY73	22MAY73	0.	0.
300	400	BIDS FOR A/D	2	JOE	10APR73	19JLY73	3.0	0.1	1MAY73	9AUG73	0.	14.0
400	700	SELECT A/D VENDOR	2	JOE	1MAY73	9AUG73	1.0	0.5	8MAY73	16AUG73	2.0	14.0
600	900	SELECT COMPUTER VENDOR	2	JOE	22MAY73	22MAY73	2.0	0.5	6JUN73	6JUN73	0.	0.
700	1030	PURCHASE A/D	2	JOE	22MAY73	16AUG73	6.0	0.1	5JLY73	28SEP73	12.0	12.0
900	1010	DESIGN INTERFACE	2	JOE	6JUN73	2AUG73	4.0	0.8	5JLY73	30AUG73	2.4	8.0
1000	1030	PURCHASE COMPUTER	2	JOE	5JLY73	5JLY73	12.0	0.1	28SEP73	28SEP73	0.	0.
1010	1030	BUILD INTERFACE	3	JOE	23JLY73	30AUG73	4.0	0.8	20AUG73	28SEP73	5.6	5.6
1030	1040	ASSEMBLE AND CHECKOUT	2	JOE	28SEP73	28SEP73	4.0	1.0	26OCT73	26OCT73	0.	0.
1030	1040	ASSEMBLE AND CHECKOUT	3	JOE	28SEP73	28SEP73	4.0	1.0	26OCT73	26OCT73	0.	0.
1040	1050	SYSTEM CHECKOUT	2	JOE	26OCT73	26OCT73	4.0	1.0	27NOV73	27NOV73	0.	0.
1040	1050	SYSTEM CHECKOUT	4	JOE	26OCT73	26OCT73	4.0	1.0	27NOV73	27NOV73	0.	0.

Fig. 9b. List of jobs for which Joe is responsible.

EXAMPLE CPM FOR DATA SYSTEM

LIST OF JOBS FOR WHICH SAM IS RESPONSIBLE

LISTING IN SORTED ORDER - ACTUAL DATES

I	J	JOB DESCRIPTION	CRAFT CODE	PERSON RESP.	BEGIN		NO. WEEKS	NO. MEN	COMPLETE		FLOAT	
					EARLY	LATE			EARLY	LATE	FREE	TOTAL
500	900	SPECIFY SOFTWARE FUNCTIONS	4	SAM	10APR73	8MAY73	4.0	1.0	8MAY73	6JUN73	4.0	4.0
900	1020	DETAIL SOFTWARE SPECS	4	SAM	6JUN73	16AUG73	4.0	1.0	5JLY73	14SEP73	0.	10.0
1020	1040	WRITE SOFTWARE	4	SAM	5JLY73	14SEP73	6.0	0.9	16AUG73	26OCT73	10.0	10.0

Fig. 9c. List of jobs for which Sam is responsible.

EXAMPLE CPM FOR DATA SYSTEM

LISTING FOR CRAFT CODE 1

I	J	JOB DESCRIPTION	CRAFT PERSON CODE RESP.	BEGIN		NO. WEEKS	NO. MEN	COMPLETE		FLOAT	
				EARLY	LATE			EARLY	LATE	FREF	TOTAL
1	100	PROJECT SCOPE	1 JOHN	22JAN73	29JAN73	3.0	0.5	12FEB73	19FEB73	1.0	1.0
100	200	OBTAIN PROJECT APPROVAL	1 JOHN	19FEB73	19FEB73	5.0	0.1	27MAR73	27MAR73	0.	0.
200	800	OBTAIN FUNDING	1 JOHN	27MAR73	10APR73	8.0	0.5	22MAY73	6JUN73	0.	2.0
900	1000	OBTAIN AEC OK	1 JOHN	6JUN73	6JUN73	4.0	0.2	5JLY73	5JLY73	0.	0.

Fig. 10a. Listing for craft code 1.

LISTING FOR CRAFT CODE 2

I	J	JOB DESCRIPTION	CRAFT CODE	PERSON RESP.	BEGIN		NO. WEEKS	NC. MEN	COMPLETE		FLOAt	
					EARLY	LATE			EARLY	LATE	FREE	TOTAL
1	100	PROJECT SCOPE	2	JOHN	22JAN73	22JAN73	4.0	1.0	19FEB73	19FEB73	0.	0.
100	200	DETAIL PROJECT AND FUNDING	2	JOE	19FEB73	27FEB73	4.0	1.0	20MAR73	27MAR73	1.0	1.0
200	500	SPECIFY COMPUTER	2	JOE	27MAR73	27MAR73	2.0	1.0	10APR73	10APR73	0.	0.
200	300	SPECIFY A/D	2	JOE	27MAR73	5JLY73	2.0	0.8	10APR73	19JLY73	0.	14.0
500	600	BIDS FOR COMPUTER	2	JOE	10APR73	10APR73	6.0	0.1	22MAY73	22MAY73	0.	0.
300	400	BIDS FOR A/D	2	JOE	10APR73	19JLY73	3.0	0.1	1MAY73	9AUG73	0.	14.0
400	700	SELECT A/D VENDOR	2	JOE	1MAY73	9AUG73	1.0	0.5	8MAY73	16AUG73	2.0	14.0
600	900	SELECT COMPUTER VENDOR	2	JOE	22MAY73	22MAY73	2.0	0.5	6JUN73	6JUN73	0.	0.
700	1030	PURCHASE A/D	2	JOE	22MAY73	16AUG73	6.0	0.1	5JLY73	28SEP73	12.0	12.0
900	1010	DESIGN INTERFACE	2	JOE	6JUN73	2AUG73	4.0	0.8	5JLY73	30AUG73	2.4	8.0
1000	1030	PURCHASE COMPUTER	2	JOE	5JLY73	5JLY73	12.0	0.1	28SEP73	28SEP73	0.	0.
1030	1040	ASSEMBLE AND CHECKOUT	2	JOE	28SEP73	28SEP73	4.0	1.0	26OCT73	26OCT73	0.	0.
1040	1050	SYSTEM CHECKOUT	2	JOE	26OCT73	26OCT73	4.0	1.0	27NOV73	27NOV73	0.	0.

Fig. 10b. Listing for craft code 2.

EXAMPLE CPM FOR DATA SYSTEM

LISTING FOR CRAFT CODE 3

I	J	JOB DESCRIPTION	CRAFT CODE	PERSON RESP.	BEGIN		NO. WEEKS	NO. PEN	COMPLETE		FLOAT	
					EARLY	LATE			EARLY	LATE	FREE	TOTAL
1010	1030	BUILD INTERFACE	3	JOE	23JLY73	30AUG73	4.0	0.8	20AUG73	28SEP73	5.6	5.6
1030	1040	ASSEMBLE AND CHECKOUT	3	JOE	28SEP73	28SEP73	4.0	1.0	26OCT73	26OCT73	0.	0.

Fig. 10c. Listing for craft code 3.

EXAMPLE CPM FOR DATA SYSTEM

LISTING FOR CRAFT CODE 4

I	J	JOB DESCRIPTION	CRAFT CODE	PERSON RESP.	BEGIN		NO. WEEKS	NO. MEN	COMPLETE		FLAT	
					EARLY	LATE			EARLY	LATE	FREE	TOTAL
1	100	PROJECT SCOPE	4	JOHN	22JAN73	22JAN73	4.0	1.0	19FEB73	19FEB73	0.	0.
500	900	SPECIFY SOFTWARE FUNCTIONS	4	SAM	10APR73	8MAY73	4.0	1.0	8MAY73	6JUN73	4.0	4.0
900	1020	DETAIL SOFTWARE SPECS	4	SAM	6JUN73	16AUG73	4.0	1.0	5JLY73	14SEP73	0.	10.0
1020	1040	WRITE SOFTWARE	4	SAM	5JLY73	14SEP73	6.0	0.9	16AUG73	26OCT73	10.0	10.0
1040	1050	SYSTEM CHECKOUT	4	JOE	26OCT73	26OCT73	4.0	1.0	27NOV73	27NOV73	0.	0.

Fig. 10d. Listing for craft code 4.

EXAMPLE CPM FOR DATA SYSTEM

LISTING IN ORDER OF INCREASING EARLY COMPLETION TIME

I	J	JOB DESCRIPTION	CRAFT CODE	PERSON RESP.	BEGIN		NO. WEEKS	NC. MEN	COMPLETE		FL7AI	
					EARLY	LATE			EARLY	LATE	FREE	TOTAL
1	100	PROJECT SCOPE	1	JOHN	22JAN73	29JAN73	3.0	0.5	12FEB73	19FEB73	1.0	1.0
1	100	PROJECT SCOPE	2	JOHN	22JAN73	22JAN73	4.0	1.0	19FEB73	19FEB73	0.	0.
1	100	PROJECT SCOPE	4	JOPN	22JAN73	22JAN73	4.0	1.0	19FEB73	19FEB73	0.	0.
100	200	DETAIL PROJECT AND FUNDING	2	JOE	19FEB73	27FEB73	4.0	1.0	20MAR73	27MAR73	1.0	1.0
100	200	OBTAIN PROJECT APPROVAL	1	JOHN	19FEB73	19FEB73	5.0	0.1	27MAR73	27MAR73	0.	0.
200	500	SPECIFY COMPUTER	2	JOE	27MAR73	27MAR73	2.0	1.0	10APR73	10APR73	0.	0.
200	300	SPECIFY A/D	2	JOE	27MAR73	5JLY73	2.0	0.8	10APR73	19JLY73	0.	14.0
300	400	RIDS FOR A/D	2	JOE	10APR73	19JLY73	3.0	0.1	1MAY73	9AUG73	0.	14.0
500	900	SPECIFY SOFTWARE FUNCTIONS	4	SAM	10APR73	8MAY73	4.0	1.0	8MAY73	6JUN73	4.0	4.0
400	700	SELECT A/D VENDOR	2	JOE	1MAY73	9AUG73	1.0	0.5	8MAY73	16AUG73	2.0	14.0
500	600	RIDS FOR COMPUTER	2	JOE	10APR73	10APR73	6.0	0.1	22MAY73	22MAY73	0.	0.
200	800	OBTAIN FUNDING	1	JOHN	27MAR73	10APR73	8.0	0.5	22MAY73	6JUN73	0.	2.0
800	900		1		22MAY73	6JUN73	-0.	-0.	22MAY73	6JUN73	2.0	2.0
800	700		1		22MAY73	16AUG73	-0.	-0.	22MAY73	16AUG73	0.	12.0
600	900	SELECT COMPUTER VENDOR	2	JOE	22MAY73	22MAY73	2.0	0.5	6JUN73	6JUN73	0.	0.
900	1000	OBTAIN AEC OK	1	JOHN	6JUN73	6JUN73	4.0	0.2	5JLY73	5JLY73	0.	0.
900	1010	DESIGN INTERFACE	2	JOE	6JUN73	2AUG73	4.0	0.8	5JLY73	30AUG73	2.4	8.0
900	1020	DETAIL SOFTWARE SPECS	4	SAM	6JUN73	16AUG73	4.0	1.0	5JLY73	14SEP73	0.	10.0
700	1030	PURCHASE A/D	2	JOE	22MAY73	16AUG73	6.0	0.1	5JLY73	28SEP73	12.0	12.0
1020	1040	WRITE SOFTWARE	4	SAM	5JLY73	14SEP73	6.0	0.9	16AUG73	26OCT73	10.0	10.0
1010	1030	BUILD INTERFACE	3	JOE	23JLY73	30AUG73	4.0	0.8	20AUG73	28SEP73	5.6	5.6
1000	1030	PURCHASE COMPUTER	2	JOE	5JLY73	5JLY73	12.0	0.1	28SEP73	28SEP73	0.	0.
1030	1040	ASSEMBLE AND CHECKOUT	2	JOE	28SEP73	28SEP73	4.0	1.0	26OCT73	26OCT73	0.	0.
1030	1040	ASSEMBLE AND CHECKOUT	3	JOE	28SEP73	28SEP73	4.0	1.0	26OCT73	26OCT73	0.	0.
1040	1050	SYSTEM CHECKOUT	2	JOE	26OCT73	26OCT73	4.0	1.0	27NOV73	27NOV73	0.	0.
1040	1050	SYSTEM CHECKOUT	4	JOE	26OCT73	26OCT73	4.0	1.0	27NOV73	27NOV73	0.	0.
1050	4000		1		27NOV73	27NOV73	-0.	-0.	27NOV73	27NOV73	0.	0.

Fig. 11. Listing in order of increasing early completion time.

EXAMPLE CPM FOR DATA SYSTEM

LISTING IN ORDER OF INCREASING LATE START TIME

I	J	JOB DESCRIPTION	CRAFT CODE	PERSON RESP.	BEGIN		NO. WEEKS	NC. MEN	COMPLETE		FL001 FREE	TOTAL
					EARLY	LATE			EARLY	LATE		
1	100	PROJECT SCOPE	2	JOHN	22JAN73	22JAN73	4.0	1.0	19FEB73	19FEB73	0.	0.
1	100	PROJECT SCOPE	4	JOHN	22JAN73	22JAN73	4.0	1.0	19FEB73	19FEB73	0.	0.
1	100	PROJECT SCOPE	1	JOHN	22JAN73	29JAN73	3.0	0.5	12FEB73	19FEB73	1.0	1.0
100	200	OBTAIN PROJECT APPROVAL	1	JOHN	19FEB73	19FEB73	5.0	0.1	27MAR73	27MAR73	0.	0.
100	200	DETAIL PROJECT AND FUNDING	2	JOE	19FEB73	27FEB73	4.0	1.0	20MAR73	27MAR73	1.0	1.0
200	500	SPECIFY COMPUTER	2	JOE	27MAR73	27MAR73	2.0	1.0	10APR73	10APR73	0.	0.
500	600	BIDS FOR COMPUTER	2	JOE	10APR73	10APR73	6.0	0.1	22MAY73	22MAY73	0.	0.
200	800	OBTAIN FUNDING	1	JOHN	27MAR73	10APR73	8.0	0.5	22MAY73	6JUN73	0.	2.0
500	900	SPECIFY SOFTWARE FUNCTIONS	4	SAM	10APR73	8MAY73	4.0	1.0	8MAY73	6JUN73	4.0	4.0
600	900	SELECT COMPUTER VENDOR	2	JOE	22MAY73	22MAY73	2.0	0.5	6JUN73	6JUN73	0.	0.
900	1000	OBTAIN AEC OK	1	JOHN	6JUN73	6JUN73	4.0	0.2	5JLY73	5JLY73	0.	0.
800	900		1		22MAY73	6JUN73	-0.	-0.	22MAY73	6JUN73	2.0	2.0
1000	1030	PURCHASE COMPUTER	2	JOE	5JLY73	5JLY73	12.0	0.1	28SEP73	28SEP73	0.	0.
200	300	SPECIFY A/D	2	JOE	27MAR73	5JLY73	2.0	0.8	10APR73	19JLY73	0.	14.0
300	400	BIDS FOR A/D	2	JOE	10APR73	19JLY73	3.0	0.1	1MAY73	9AUG73	0.	14.0
900	1010	DESIGN INTERFACE	2	JOE	6JUN73	2AUG73	4.0	0.8	5JLY73	30AUG73	2.4	8.0
400	700	SELECT A/D VENDOR	2	JOE	1MAY73	9AUG73	1.0	0.5	8MAY73	16AUG73	2.0	14.0
900	1020	DETAIL SOFTWARE SPECS	4	SAM	6JUN73	16AUG73	4.0	1.0	5JLY73	14SEP73	0.	10.0
800	700		1		22MAY73	16AUG73	-0.	-0.	22MAY73	16AUG73	0.	12.0
700	1030	PURCHASE A/D	2	JOE	22MAY73	16AUG73	6.0	0.1	5JLY73	28SEP73	12.0	12.0
1010	1030	BUILD INTERFACE	3	JOE	23JLY73	30AUG73	4.0	0.8	20AUG73	28SEP73	5.6	5.6
1020	1040	WRITE SOFTWARE	4	SAM	5JLY73	14SEP73	6.0	0.9	16AUG73	26OCT73	10.0	10.0
1030	1040	ASSEMBLE AND CHECKOUT	2	JOE	28SEP73	28SEP73	4.0	1.0	26OCT73	26OCT73	0.	0.
1030	1040	ASSEMBLE AND CHECKOUT	3	JOE	28SEP73	28SEP73	4.0	1.0	26OCT73	26OCT73	0.	0.
1040	1050	SYSTEM CHECKOUT	2	JOE	26OCT73	26OCT73	4.0	1.0	27NOV73	27NOV73	0.	0.
1040	1050	SYSTEM CHECKOUT	4	JOE	26OCT73	26OCT73	4.0	1.0	27NOV73	27NOV73	0.	0.
1050	4000		1		27NOV73	27NOV73	-0.	-0.	27NOV73	27NOV73	0.	0.

Fig. 12. Listing in order of increasing late start time.

1CAPITAL EQUIPMENT COMMITMENTS

DATE	ACTIVITY	COST \$K	TOTAL \$K
22MAY73	PURCHASE A/D	3.50	3.50
5JLY73	PURCHASE COMPUTER	23.00	26.50
5JLY73	DESIGN INTERFACE	4.20	30.70

Fig. 13. Capital equipment commitments.

I ROADMAP TO FIND NODES ON CPM CHART

NODE NO.	X INDEX	X INCHES	Y LEVEL
1	1	1.0	1
100	2	5.0	1
200	3	8.0	1
300	4	11.5	5
400	5	14.5	5
500	4	11.5	1
600	5	14.5	1
700	6	18.0	4
800	4	11.5	3
900	6	18.0	1
1000	7	21.5	1
1010	7	21.5	2
1020	7	21.5	3
1030	8	25.0	1
1040	9	28.5	1
1050	10	31.5	1
4000	11	34.5	1

Fig. 14. Road map to find nodes on CPM chart.

1 TIMING INFORMATION

INPUT	1.472
CALCULATE	0.079
SCHEDULE	1.590
CALENDAR	0.062
BAR GRAPH	0.580
LIST BY CC	0.033
LIST LATE COMP.	0.080
LIST LATE START	0.104
DEADLINE	0.000
CALCOMP	12.200

Fig. 15. Timing information.

Fig. 16b. Manpower plot, unscheduled, craft code 2.

EXAMPLE CPM FOR DATA SYSTEM
MANHOURS - CUM.

Fig. 16c. Manpower plot, unscheduled, craft code 3.

Fig. 16d. Manpower plot, unscheduled, craft code 4.

Fig. 16e. Manpower plot, unscheduled, total effort.

EXAMPLE CPM FOR DATA SYSTEM

JAN TO JUN, 1973

ALL JOBS

Fig. 17a. Project bar chart, January to June.

EXAMPLE CPM FOR DATA SYSTEM
JULY TO DEC, 1973

ALL JOBS

Fig. 17b. Project bar chart, July to December

EXAMPLE FOR DATA SYSTEM

Fig. 18. Capital equipment plot.

0.1-M JOE 2 00

SOFTWARE SPEEDS 5 JUL 73 1020 WRITE SOFTWARE 14 SEP 73 6.0-D 0.9-M SAM 4 00

INTERFACE 23 JUL 73 1010 BUILD INTERFACE 30 AUG 73 4.0-D 0.8-M JOE 3 00

RED OK 5 JUL 73 1000 PURCHASE COMPUTER 28 SEP 73 1030

0.2-M JOHN 1 00 12.0-D 0.1-M JOE 2 00

ABSEP 4.0- 4.0- ABSEP 4.0-

2

¹

CRAFT CODE	TOTAL MANWEEKS	MANPOWER LIMIT
1	6.8	1.0
2	27.0	1.0
3	7.2	1.0
4	21.4	1.0

PRIORITY OPTION = BY LEAST FLOAT

LOADING OPTION = INCREASE CRITICAL PATH LENGTH IF NECESSARY TO STAY WITHIN RESOURCE LIMIT

Fig. 20. Scheduling constraints.

EXAMPLE CPM FOR DATA SYSTEM

ALLOCATION AND SCHEDULING OF RESOURCES

I	J	JOB DESCRIPTION	PERSON RESP.	CRAFT CODE	NUMBER OF MEN	DURATION (WEEKS)	START	FINISH	FLOAT
1	100	PROJECT SCOPE	JOHN	1	0.5	3.0	0.	3.0	1.0
1	100	PROJECT SCOPE	JOHN	2	1.0	4.0	0.	4.0	0.
1	100	PROJECT SCOPE	JOHN	4	1.0	4.0	0.	4.0	0.
100	200	OBTAIN PROJECT APPROVAL	JOHN	1	0.1	5.0	4.0	9.0	0.
100	200	DETAIL PROJECT AND FUNDING	JOE	2	1.0	4.0	4.0	8.0	1.0
200	300	SPECIFY A/D	JOE	2	0.8	2.0	11.0	13.0	12.0
300	400	BIDS FOR A/D	JOE	2	0.1	3.0	13.0	16.0	12.0
200	800	OBTAIN FUNDING	JOHN	1	0.5	8.0	9.0	17.0	2.0
200	500	SPECIFY COMPUTER	JOE	2	1.0	2.0	9.0	11.0	0.
500	600	BIDS FOR COMPUTER	JOE	2	0.1	6.0	11.0	17.0	0.
500	900	SPECIFY SOFTWARE FUNCTIONS	SAM	4	1.0	4.0	11.0	15.0	4.0
400	700	SELECT A/D VENDOR	JOE	2	0.5	1.0	16.0	17.0	12.0
800	700			1	-0.	-0.	17.0	17.0	12.0
800	900			1	-0.	-0.	17.0	17.0	2.0
600	900	SELECT COMPUTER VENDOR	JOE	2	0.5	2.0	17.0	19.0	0.
700	1030	PURCHASE A/D	JOE	2	0.1	6.0	17.0	23.0	12.0
900	1000	OBTAIN AEC OK	JOHN	1	0.2	4.0	19.0	23.0	0.
1000	1030	PURCHASE COMPUTER	JOE	2	0.1	12.0	23.0	35.0	0.
900	1010	DESIGN INTERFACE	JOE	2	0.8	4.0	19.0	23.0	8.0
1010	1030	BUILD INTERFACE	JOE	3	0.8	4.0	25.4	29.4	5.6
900	1020	DETAIL SOFTWARE SPECS	SAM	4	1.0	4.0	19.0	23.0	10.0
1020	1040	WRITE SOFTWARE	SAM	4	0.9	6.0	23.0	29.0	10.0
1030	1040	ASSEMBLE AND CHECKOUT	JOE	2	1.0	4.0	35.0	39.0	0.
1040	1050	SYSTEM CHECKOUT	JOE	2	1.0	4.0	39.0	43.0	0.
1040	1050	SYSTEM CHECKOUT	JOE	4	1.0	4.0	39.0	43.0	0.
1030	1040	ASSEMBLE AND CHECKOUT	JOE	3	1.0	4.0	35.0	39.0	0.
1050	4000			1	-0.	-0.	43.0	43.0	0.

Fig. 21. Listing in order of inputs, scheduled.

EXAMPLE CPM FOR DATA SYSTEM

SCHEDULED DATES

I	J	JOB DESCRIPTION	PERSON RESP.	CRAFT CODE	NUMBER CF MEN	DURATION (WEEKS)	START	FINISH	FLOAT
1	100	PROJECT SCOPE	JOHN	2	1.0	4.0	22JAN73	19FEB73	0.
1	100	PROJECT SCOPE	JOHN	4	1.0	4.0	22JAN73	19FEB73	0.
100	200	OBTAIN PROJECT APPROVAL	JOHN	1	0.1	5.0	19FEB73	27MAR73	0.
200	500	SPECIFY COMPUTER	JOE	2	1.0	2.0	27MAR73	10APR73	0.
500	600	RIDS FOR COMPUTER	JOE	2	0.1	6.0	10APR73	22MAY73	0.
600	900	SELECT COMPUTER VENDOR	JOE	2	0.5	2.0	22MAY73	6JUN73	0.
900	1000	OBTAIN AEC OK	JOHN	1	0.2	4.0	6JUN73	5JLY73	0.
1000	1030	PURCHASE COMPUTER	JOE	2	0.1	12.0	5JLY73	28SEP73	0.
1030	1040	ASSEMBLE AND CHECKOUT	JOE	2	1.0	4.0	28SEP73	26OCT73	0.
1030	1040	ASSEMBLE AND CHECKOUT	JOE	3	1.0	4.0	28SEP73	26OCT73	0.
1040	1050	SYSTEM CHECKOUT	JOE	2	1.0	4.0	26OCT73	27NOV73	0.
1040	1050	SYSTEM CHECKOUT	JOE	4	1.0	4.0	26OCT73	27NOV73	0.
1050	4000			1	-0.	-0.	27NOV73	27NOV73	0.
1	100	PROJECT SCOPE	JOHN	1	0.5	3.0	22JAN73	12FEB73	1.0
100	200	DETAIL PROJECT AND FUNDING	JOE	2	1.0	4.0	19FEB73	20MAR73	1.0
200	800	OBTAIN FUNDING	JOHN	1	0.5	8.0	27MAR73	22MAY73	2.0
800	900			1	-0.	-0.	22MAY73	22MAY73	2.0
500	900	SPECIFY SOFTWARE FUNCTIONS	SAM	4	1.0	4.0	10APR73	8MAY73	4.0
1010	1030	BUILD INTERFACE	JOE	3	0.8	4.0	23JLY73	20AUG73	5.6
900	1010	DESIGN INTERFACE	JOE	2	0.8	4.0	6JUN73	5JLY73	8.0
900	1020	DETAIL SOFTWARE SPECS	SAM	4	1.0	4.0	6JUN73	5JLY73	10.0
1020	1040	WRITE SOFTWARE	SAM	4	0.9	6.0	5JLY73	16AUG73	10.0
200	300	SPECIFY A/D	JOE	2	0.8	2.0	10APR73	24APR73	12.0
300	400	BIDS FOR A/D	JOE	2	0.1	3.0	24APR73	15MAY73	12.0
400	700	SELECT A/D VENDOR	JOE	2	0.5	1.0	15MAY73	22MAY73	12.0
800	700			1	-0.	-0.	22MAY73	22MAY73	12.0
700	1030	PURCHASE A/D	JOE	2	0.1	6.0	22MAY73	5JLY73	12.0

Fig. 22. Sorted listing with calendar dates, scheduled.

EXAMPLE CPM FOR DATA SYSTEM

JAN TO JUN, 1973

ALL JOBS

Fig. 24a. Project bar chart, scheduled, January to June.

EXAMPLE CPM FOR DATA SYSTEM

JULY TO DEC, 1973

ALL JOBS

Fig. 24b. Project bar chart, scheduled, July to December.

Appendix

Computer Generation of CPM Plots

The most tedious effort in generation and maintenance of CPM is the generation of the chart of activities. Typically, the efforts of a draftsman who can ill be spared from other work are required. Timely updating and investigation of alternative organization of effort may be discouraged by the lack of someone free to draw the chart.

To solve this problem, a package of subroutines are incorporated in the CPM program. This appendix will describe the technique used in the principal routine, CPMPLOT, to generate a tape for offline plotting.

Figure A-1 shows a simple chart consisting of six nodes and eight activities. This chart will be used to illustrate the algorithm.

The principal problem to be solved is the placing of nodes and activities in a fashion which is both informative and aesthetic. The information content is given by the labeling of activities and nodes, by the logical relationship between activities, and by position on the chart in the vertical direction. In the vertical, or "y" direction, the most critical activities are at the bottom of the chart. More specifically, of activities leaving a given node, the most critical will be drawn at the lowest possible level. In the given example, activity C is more critical than activity D which is in turn more critical than activity E. However, both D and E may be less critical than activity B.

The plotting by criticality also contributes to the aesthetics of the chart. There is a tendency to group activities in a logical fashion which helps avoid the problem of crossing activities (illustrated by B crossing E). Another aesthetic consideration is to avoid "stairstepping" of an activity. A possible technique, and one which was used in an earlier version of CPMPLOT, would save space in the vertical direction at the cost of aesthetic considerations. Such an approach is illustrated by the dotted activity labeled B'. This generated unappealing plots.

The task of the algorithm is to determine the x and y coordinates for each node in the chart. The y coordinate is identified by an index value or level number with subsequent levels being 0.75 inches apart. The x coordinate is also identified by an index

Fig. A-1. Sample CPM chart.

number and physical values in inches are calculated on the basis of number from and to a given node. Several arrays are used in the algorithm:

1. Arrays indexed by node number

- IXC(N) The x index at which node N is to be drawn
- IYC(N) The y index at which node N is to be drawn
- IFLX(N) A flag used in x index determination. If nonzero of node N has been determined.
- IFLA(N) A variable used in tracing of the chart. Values
 - Positive integer—chart tracing of a path to node in progress. The integer is the number preceding this node on the path being traced
 - Zero—no processing of this node has begun.
 - Minus one—all activities leaving this node completed.
- NX(N) If nonzero, node N is used in the chart

2. Arrays indexed by activity number

- I(M) Start node for activity M
- J(M) End node for activity M
- IDRAW(M) A flag which is set to one when an activity has been and drawn

3. Arrays indexed by x index

- NEX(N) The maximum number of activities entering and drawn at this x index location
- NLX(N) The maximum number activities leaving any node at this x index location
- XC(N) The location in inches of x index N
- XS(N) The location in inches of the start of the horizontal activities between x indices N and N+1
- XE(N) The location in inches of the end of the horizontal
- IOK(N) The value of the lowest y level available in the x indices of N and N+1. Initially 1.

The operation of the algorithm depends to a great extent on the order activities are sorted. Sorting is such that the activities are in order of criticality; i.e., increasing float, and activities of equal float are sorted by late start time. For the example in Fig. A-1, assuming B is more critical, the order of activities is A, C, G, H, B, D, F, E. With this ordering, path chart will occur in the order in which they are to be plotted, with the one occurring first. Paths A-C-G-H and D-F can be seen in the example.

To begin, the x index of each node is determined. The first pass through nodes 1, 2, 3, and 4, the index values of 1, 2, 3, and 4 respectively. A second pass determine that node 6 must be at x index 3 which will relocate nodes 3 and 4 respectively. The physical locations XC, XS, and XE are then calculated.

The plot generation begins with node 1. The most critical activity is identified as A and is drawn. IFLA(2) is set to 1 to indicate the path

x index = N

x index = N + 1

NLX(N) is the maximum number of activities leaving any node with x index = N
 NEX(N) is the maximum number of activities entering any node with x index = N

$$XS(N) = XC(N) + (NLX(N) - 1) * .5$$

$$XE(N) = XS(N) + 2.$$

$$XC(N+1) = XE(N) + (NEX(N) - 1) * .5$$

} Coordinates in inches

Fig. A-2. Illustration of position terminology.

node 2. Activity C is now drawn and IFLA(3) set to 2. This process continues until activities G and H are drawn. Since the end node of H is 4000, we have reached the end of the plot and no nodes out of 4000 are found. We backstep to node 4, retrieving that node number from IFLA(4000). IFLA(4000) is set to -1 to indicate we are finished with the node. Likewise, since there are no more activities to process out of nodes 4 and 3, IFLA(4) and IFLA(3) are set to -1 and we backstep to node 2.

During the above process, IOK(1) through IOK(5) have been set to 2 to indicate that level 1 has been used across the paper. This will force the next activity drawn at any of these x values to go higher on the paper. D is now identified as the next most critical activity leaving node 2. Since IFLA(6) is zero, the node has not been referenced and a y value must be assigned. IYC(6) is thus set to 2. Activity D is drawn at level 2 and IOK(2) is set to 3 to indicate that the level has been used. IFLA(5) is set to 2 to remember the predecessor node. Activity F terminates on node 3, for which IFLA is -1. Since this indicates that the subpath is done, we draw F and again retrace to node 2, setting IOK(3) to 3. Activity E is drawn at level 3, completing all activities leaving node 2. IFLA(2) is set to -1 and we retrace to node 1.

To determine the level at which to draw activity B, a search is made for the highest level required between node 1 and 3. This is 4 and determines the level for drawing B. Since IFLA(3) is -1, and there are no further activities out of the current node, and the current node is node 1, we are finished. The circles indicating the nodes are now drawn and the subroutine terminates.