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AEC RESEARCH AND DEVELOPMENT REPORT

CRITICAL PATH SCHEDULING IN MAINTENANCE

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UNION CARBIDE NUCLEAR COMPANY
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A B S T R A C T

Adaptation of the "Critical Path" Scheduling (CPS) technique and use of our Computer Facility have led to development of a more rapid and accurate method of evaluating and leveling ORGDP Maintenance manpower requirements. CPS is applied to multi-craft performance of short duration jobs after preselection of calendar time duration and specific limitations on the number of personnel and crafts involved.

Developed schedules and supplementary data forms such as that described in this report provide: 1) an efficient foreman's guide and check of work performance, 2) a versatile and rapid means of evaluating and improving present scheduling practices, and 3) a basis for job study, simplification, and subsequent maintenance job cost reduction.

Trial application of CPS for special Maintenance work described in this report resulted in a 19.5% reduction of job labor costs. It is anticipated that further CPS application will reduce job labor costs as much as 30%.

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INTRODUCTION

The "Critical Path" Scheduling (CPS) technique was first introduced at the ORGDP Central Data Processing Facility in a seminar conducted by Mr. M. Frischberg of IBM. He described the development and use of this technique in conjunction with minimum job cost data for scheduling projects of relatively long duration. Also stressed was the use of computer programming technology as a rapid and accurate means of developing criteria for scheduling on a "normal" or "crash" basis.

Although the technique is relatively new, approximately 35 large companies and corporations have instituted CPS on either a trial or full-scale basis. This report is written to describe adaptation at ORGDP of this technique for scheduling special Maintenance multi-craft shutdown jobs of relatively short duration.

SUMMARY

The "Critical Path" Scheduling technique was not introduced until 75% of the series of shutdown jobs, such as that described in this report, were completed and man-hour expenditure had been reasonably leveled. Significantly, scheduled in-cell work and total field man-hour expenditure for the remaining shutdowns were reduced 26.8% and 19.5%, respectively. Further analysis indicates that "Critical Path" Scheduling of all field work would have reduced the total man-hour expenditure approximately 30%.

The Maintenance Scheduling Department and field supervision cooperated in instituting this revised scheduling system on a satisfactory trial basis. A much improved system is presently in use for other special Maintenance work which will eventually include all Maintenance jobs requiring significant use of man-power and material resources.

The following narrative interspersed with figures and attached reference exhibits is designed to acquaint the reader with the scheduling procedure developed at ORGDP, trial results and evaluation, subsequent improvement, further application, and use in conjunction with our IBM 7090 Computer. For the convenience of readers not acquainted with the CPS technique and computer terminology, a glossary of terms used in this report is presented as Exhibit 1.

SCHEDULING PROCEDURE

Limitations

General scheduling procedure is presented graphically on the CPS Flow Chart (Exhibit 2). Scheduling of the K-25 B.C. Modification described in the following narrative was completed in three work days subject to the following limitations:

1. Scope of work (general layout, Exhibit 3) included removal and replacement of large heavy piping, centrifugal

pumps, auxiliary lines, instrument alignment, and subsequent oil and gas system test.

2. Calendar time duration: 3 days or six 8-hour shifts.

3. Tasks scheduled included only in-cell activity for welders and mechanics (approximately 75% of craft man-hours).

4. Maximum available craftsmen: 30 mechanics (MM) and 12 welders (W) on 8 - 4 shift and 7 mechanics and 6 welders on the 4 - 12 shift.

5. Schedule for minimum manning on 8 - 4 shift and maximum manpower use on 4 - 12 shift.

6. Task durations and manning established from previous study.

Procedure

Note: The mechanics of preparing and using computer input and output data in connection with the arrow diagram referred to here are detailed in the section entitled "Computer Analysis".

In conjunction with field supervision, task time durations and manning were previously collected on pre-prepared data collection and summary forms (Exhibit 4). An Arrow Diagram (Exhibit 5) was prepared showing required job performance in the preferred task sequence with identifying numbered nodes, task description and durations. The diagram was reviewed with field supervision for accuracy.

A task listing was prepared for 7090 computer input (Figure 3) to obtain a computer output listing (Figure 4) designating initial "Critical Path" tasks from which the shortest over-all job calendar time duration is established.

Using the Arrow Diagram (Exhibit 5) as a guide, a Manning Chart (Exhibit 6) was prepared for leveling manpower within the limitations previously described and using the following criteria:

1. Welders were established as "critical" craft.

2. Tasks involving welders were charted in sequence minimizing Maintenance Mechanic assignment on related tasks, and effecting maximum use of calendar time for welders.

3. To minimize scheduled delays and optimize manpower use, it was necessary to delay and/or change the sequence of some tasks which in turn created a new and longer "Critical Path" (Exhibit 7). Extension of this critical path was accomplished satisfactorily within the job calendar time duration established by initial schedule limitations.

   Significantly, a procedure was established for altering the "base case" whereby altered task data is listed on the computer input data sheet (Figure 5) to obtain a new output list (Figure 6) for optional Arrow Diagram and Manning Chart preparation (job lead time permitting).

From the approved Manning Chart a schedule (Exhibit 8) and/or worker task assignment cards (Exhibit 9) are prepared for the foreman's use to effect the completed job schedule.

EVALUATION AND CRITIQUE

Advantages

Use of the published schedule and worker assignment cards provide the foreman with an efficient guide for measuring daily worker performance, effecting optimum task scheduling, and a rapid means of resolving schedule delays when unforeseen troubles arise. Issuance of individual worker assignment cards establishing firm task durations provide benchmark standards which are subjected to further applied time and resource use analysis and subsequent cost reduction.

Previous scheduling methods for this type of work did not provide adequate source data (i.e., task description, durations, resources used) for proper job evaluation and study to reduce costs. This type of scheduling requires that all tasks and resources be listed and evaluated in advance of work performance making subsequent improvement possible on similar jobs or tasks.

Management, and specifically the Scheduling Department, is provided with a more complete picture of work and worker performance. At the same time, the CPS technique provides: 1) a more versatile and rapid means of scheduling, 2) a basis for job study simplification, and subsequent cost reduction, and 3) a tool for better job planning and predicted manpower needs.

Criticism

Development and initiation of any new scheduling system must be wholeheartedly supported by management; specifically, front-line foremen and their supervision. Without their cooperation the ultimate goal of maintenance cost reduction

cannot be reached. Therefore, it becomes imperative that Scheduling Department personnel present their scheduling system to field supervision for review and possible compromise until mutual agreement on its use and inception is reached. Once initiated, follow up changes can be made which are beneficial to both groups.

Our present scheduling method has evolved primarily through use of the CPS Arrow Diagram. Use of the computer saves considerable time in developing a matrix establishing task starting and finishing times and float durations. For jobs with a small number of tasks, such a matrix can be developed by following procedure as described in innumerable articles published on "Critical Path Scheduling".

RESULTS AND CONCLUSION

CPS effectiveness is illustrated in Figure 1-a (below) through comparison of man-hour expenditures experienced for the last two cell modifications with six cell modifications previously completed by our former scheduling method. Because our cost collect system did not show "in-cell" costs, a job study was made indicating average man-hour expenditure per cell for "other field work" remained constant. Total "in-cell field work" man-hour expenditures for the two periods were then extracted for comparison. A 26.8% man-hour reduction was reflected for scheduled "in-cell" work which decreased total "field work" labor requirements 19.5%.

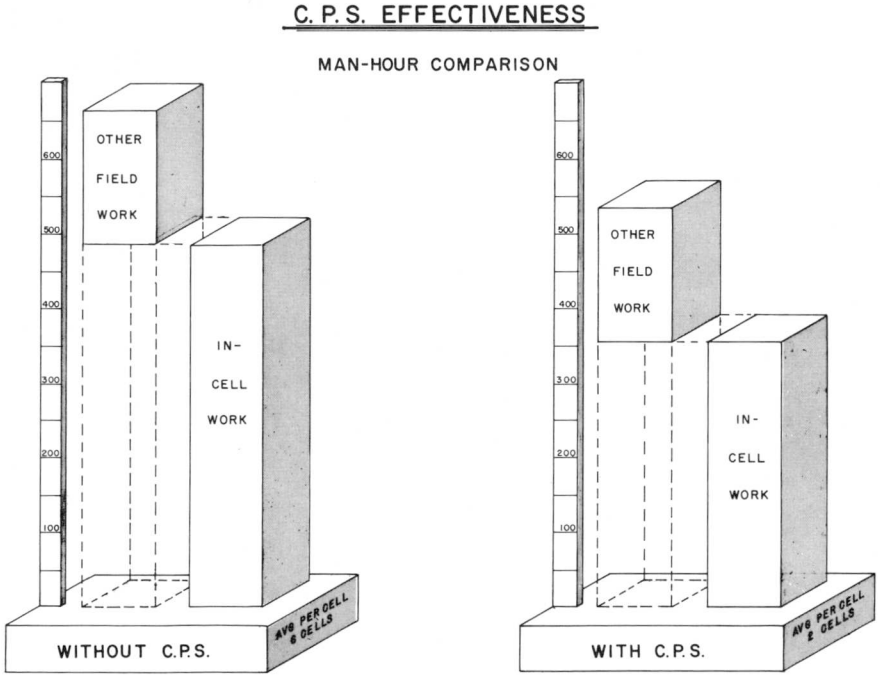


FIGURE 1-a

Optimum application of CPS to all field work would have reduced total man-hour expenditure an additional 10%. At the same time it provides a sound basis for further methods improvement and subsequent cost reduction.

Use of the CPS technique is a great improvement over our previous scheduling system in terms of scheduling costs and schedule use. The method has been successfully adapted and used as a primary aid to the Maintenance job planning, scheduling, and work performance functions.

Present plans are to reduce our present scheduling costs through improved computer programming and extend CPS coverage to all fields of significant maintenance resource use. It is anticipated that further application of CPS in Maintenance will reduce initially incurred labor costs as much as 30%.

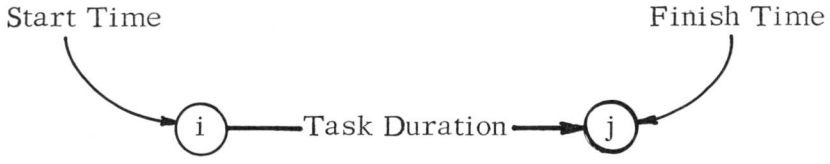
COMPUTER ANALYSIS

A medium-sized computer, such as that used at ORGDP, is not necessary but does offer the advantages of accuracy and high-speed results.

Computer analysis is presented in two stages of development experienced during adaptation of the CPS Method at ORGDP for Maintenance work: Original and Present Input-Output.

Arrow Diagram Description

Each arrow-diagrammed task consists of three parts:



The task start and finish times are points in time, labelled i (start time) and j (finish time). The i-j times as represented on the diagram are called "nodes" as used in general vector diagramming. The arrow diagram is not a vector diagram and is not dimensional with respect to direction or length.

Arrow Diagram Requirements

Computer input data is taken from the arrow diagram. The following conditions must be satisfied by the diagram before the computer will accept the input list (Refer to Figures 1 and 2).

ARROW DIAGRAM EXTRACT

OPTION 0

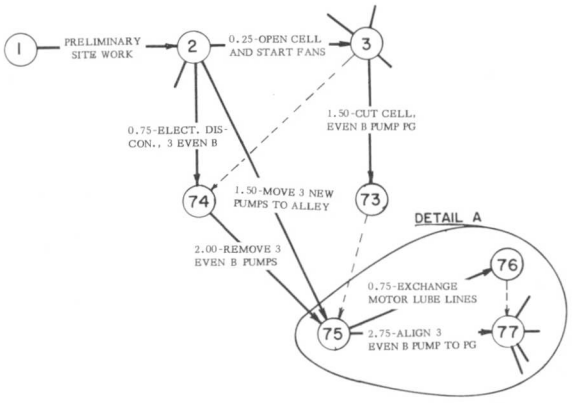


FIGURE 1

OPTION 0: MODIFIED

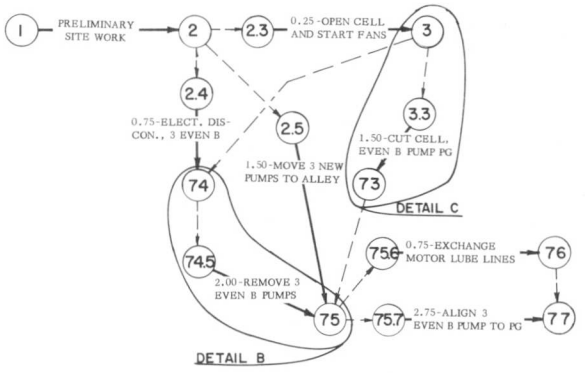


FIGURE 2

1. With the exception of the last task, each task j is the i for one or more succeeding tasks.

2. Each task must have one i-j pair with a j numerical value higher than its preceding i.

3. Each task must have a positive duration of zero or greater.

4. Each task must have a discrete i-j pair (Figure 1, Detail A). Tasks 75-76 and 75-77 depend on the same system of tasks and must be performed before any of the four tasks whose i is 77. To prevent both tasks from being numbered 75-77, node 76 was "invented". One task remains 75-77, one is identified as 75-76, and both j's are connected by a "dummy" task, 76-77, with a task duration time of 0.

Original Input List

Input data must be prepared in standard form (Figure 3). For each diagram, there are two types of input--title and data--which are listed on the C.P.S. Data Sheet. Each line entry will be punched on a card exactly as listed. Therefore, the list must be made with care and thoroughly checked.

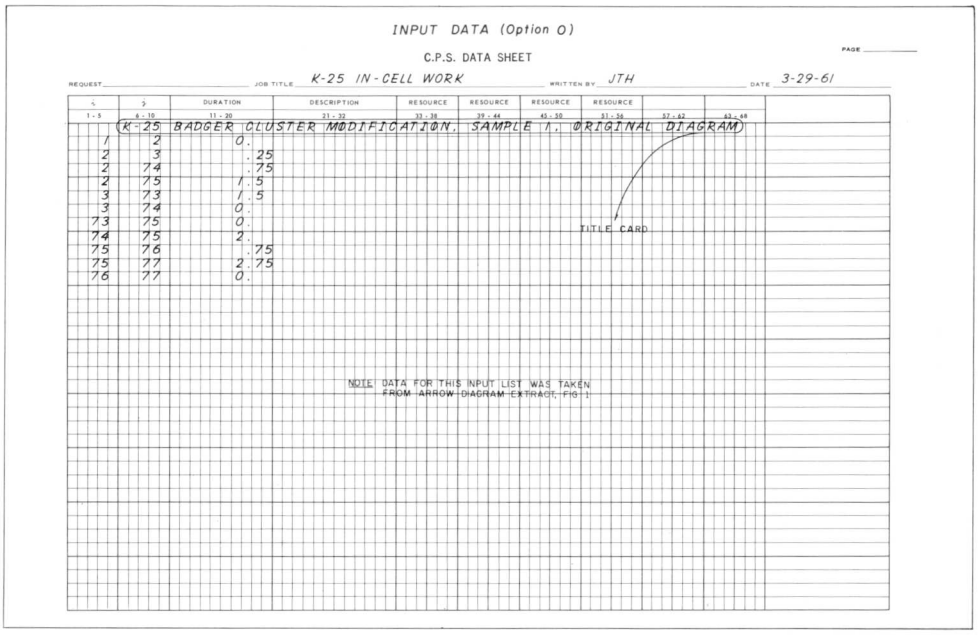


FIGURE 3

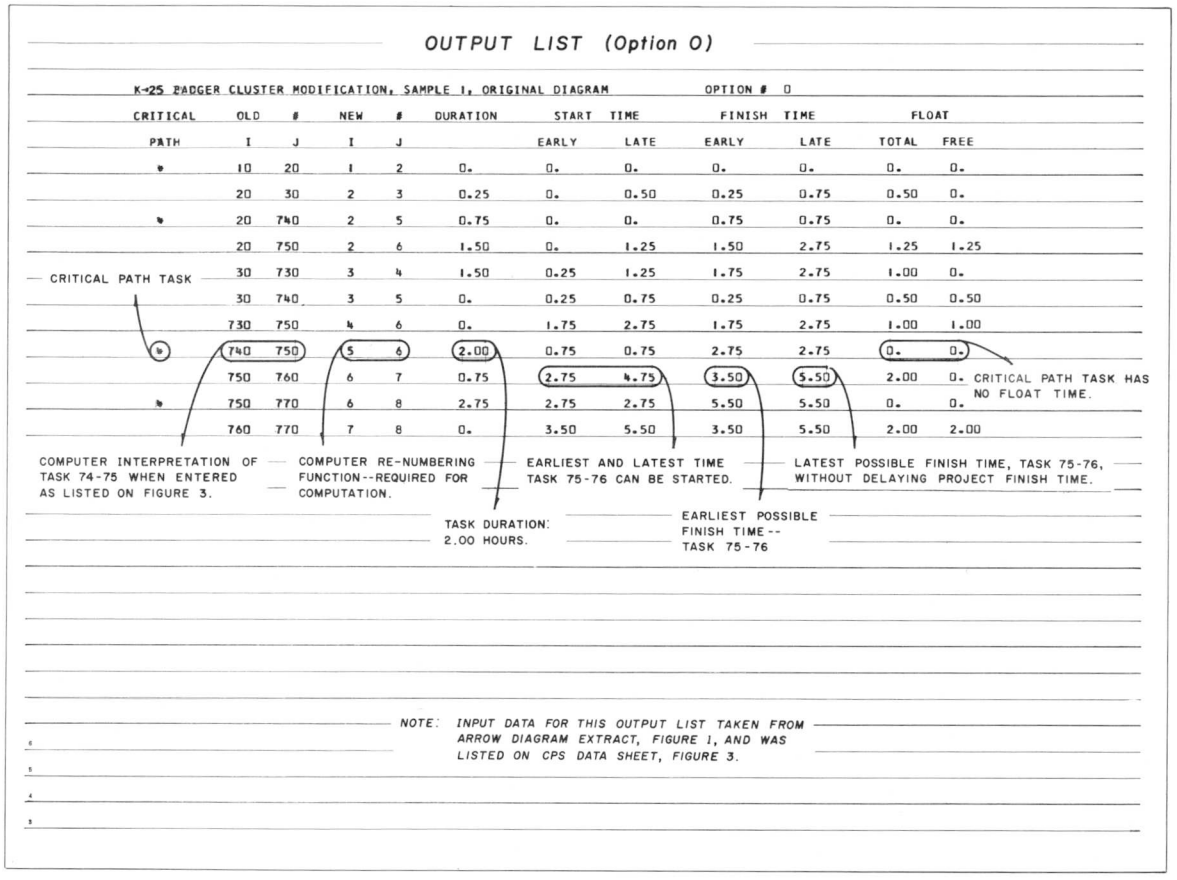
Title card information appears on the first line. Any title is permissible if entered between Columns 6 and 72.

Data card information requires one line entry per task. Each arrow-diagrammed task must be entered as follows:

> Any i-j may be entered (i in Col. 1-5, j in Col. 6-10), but care must be taken to insure continuity. If the entry is made as in Line 2, with i in Col. 4 and j in Col. 9, the computer will read i = 10 and j = 20. This illustrates that continuity of numbering is not necessary, providing that each j is the i for at least one succeeding task (excepting the last task). The entry of i and j is in the form of whole numbers only. If a decimal point is used, the computer will not accept the data.
>
> Any positive number may be entered for durations (Col. 11-20). Decimal point is permissible and entry is permissible anywhere in the field (group of columns), but zeros will be entered to the right of the last number to Column 20.

Original Output List

The input previously discussed will yield basic critical path information as illustrated in Figure 4, below.



OUTPUT LIST (Option 0)

K-25 BADGER CLUSTER MODIFICATION, SAMPLE 1, ORIGINAL DIAGRAM — OPTION # 0

CRITICAL PATH	OLD I	OLD J	NEW I	NEW J	DURATION	START TIME EARLY	START TIME LATE	FINISH TIME EARLY	FINISH TIME LATE	FLOAT TOTAL	FLOAT FREE
*	10	20	1	2	0.	0.	0.	0.	0.	0.	0.
	20	30	2	3	0.25	0.	0.50	0.25	0.75	0.50	0.
*	20	740	2	5	0.75	0.	0.	0.75	0.75	0.	0.
	20	750	2	6	1.50	0.	1.25	1.50	2.75	1.25	1.25
	30	730	3	4	1.50	0.25	1.25	1.75	2.75	1.00	0.
	30	740	3	5	0.	0.25	0.75	0.25	0.75	0.50	0.50
	730	750	4	6	0.	1.75	2.75	1.75	2.75	1.00	1.00
*	740	750	5	6	2.00	0.75	0.75	2.75	2.75	0.	0.
	750	760	6	7	0.75	2.75	4.75	3.50	5.50	2.00	0.
*	750	770	6	8	2.75	2.75	2.75	5.50	5.50	0.	0.
	760	770	7	8	0.	3.50	5.50	3.50	5.50	2.00	2.00

CRITICAL PATH TASK

COMPUTER INTERPRETATION OF TASK 74-75 WHEN ENTERED AS LISTED ON FIGURE 3.

COMPUTER RE-NUMBERING FUNCTION--REQUIRED FOR COMPUTATION.

TASK DURATION: 2.00 HOURS.

EARLIEST AND LATEST TIME TASK 75-76 CAN BE STARTED.

EARLIEST POSSIBLE FINISH TIME -- TASK 75-76

LATEST POSSIBLE FINISH TIME, TASK 75-76, WITHOUT DELAYING PROJECT FINISH TIME.

0. CRITICAL PATH TASK HAS NO FLOAT TIME.

NOTE: INPUT DATA FOR THIS OUTPUT LIST TAKEN FROM ARROW DIAGRAM EXTRACT, FIGURE 1, AND WAS LISTED ON CPS DATA SHEET, FIGURE 3.

FIGURE 4

Modified Arrow Diagram

It is often desirable to perform project work in a stated time interval with minimum use of manpower. It then becomes necessary to delay some tasks to "level" the manpower. To accomplish this in the computer, a "dummy" task must be introduced before the beginning of the task to be delayed. (See Figure 2, Details B and C.)

To delay any task, our present practice is to insert a "dummy" task before each "real" task. If task 74-74.5 (Detail B) is given a duration, task 74.5-75 will be delayed. Although the "dummy" insert is necessary only before the task to be delayed, our present practice is to precede all tasks with a "dummy" so any delay or combination of delays may be made. This provides additional flexibility and contingency in scheduling.

Input List

To facilitate resource leveling, the CPS Computer Program was altered to accept a 12-column job description and four 6-column fields for resource listing. The term "resource" instead of "manpower" or "craft" is preferred because equipment and/or materials may also be noted in the resource fields. This makes arrow diagram listing lengthier, but more flexible. (See Figure 5 below.)

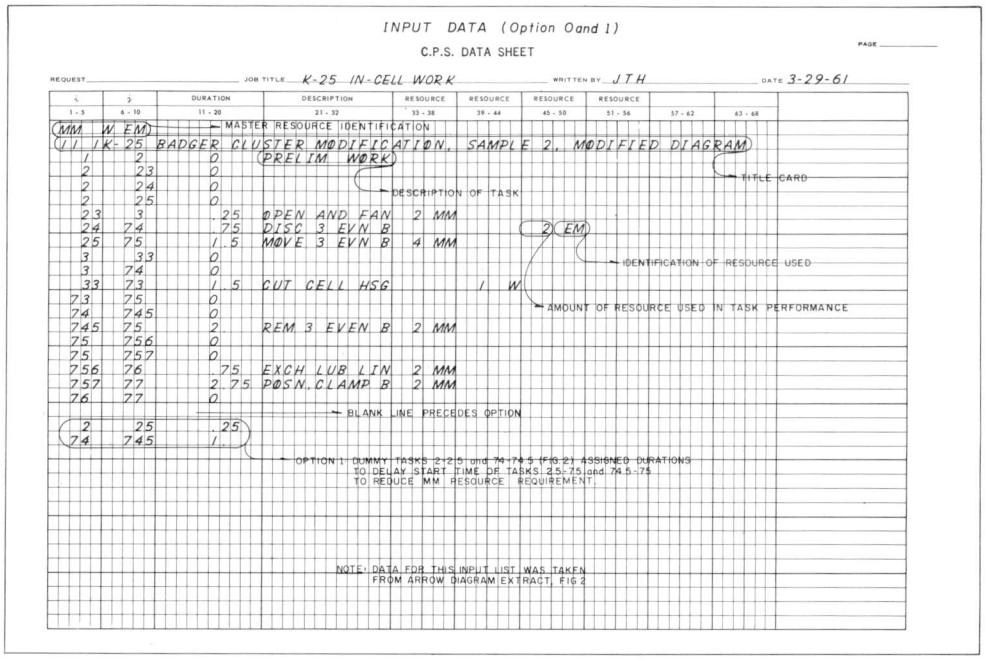


FIGURE 5

To obtain computer resource use summary in any time period, a resource identification card is prepared. (See Figure 5, "Master Resource Identification".) Fifteen resource classes may be used for each project and are noted in consecutive 3-column fields from Columns 1 to 45. Each resource identification is entered in the extreme right-hand portion of each 3-column field.

Title card information is basically the same as the original input listing (Figure 3), but "controls" are added in Columns 2 through 5. Columns 2 and 3 control output of resource summary and task identification. Any single digit entry is permissible, but the digit "1" is normally used for convenience. A "1" in Column 3 causes a task identification to precede the i-j columns on the output list. Columns 4 and 5 designate the number of options listed in the input. In Figure 5, one option is listed, and "1" appears in Column 5.

Columns 1-20 in the data portion of the list are identical as described previously for Input List (Figure 3).

"Description" is a 12-column field, entered as illustrated in Figure 5. Note that "ϕ" designates the letter and "O" the number zero; "I" is the letter, "1" is the number; in addition, "Z" is written "Ƶ" to differentiate from the number "2".

"Resource" is entered in a 6-column field. The first three columns are used for the amount of resource, the second three for resource identification. Both amount and identification are entered at the extreme right of the 3-column field.

An option is separated from the basic data list (termed "option O" or "base case") by a blank line. (A blank card will be inserted here when the list is punched on cards.)

The option consists of the i-j and new duration of each task to be altered.

Output List

OUTPUT LIST (Option O, Modified)

K-25 BADGER CLUSTER MODIFICATION. SAMPLE 2. MODIFIED DIAGRAM — OPTION = 0

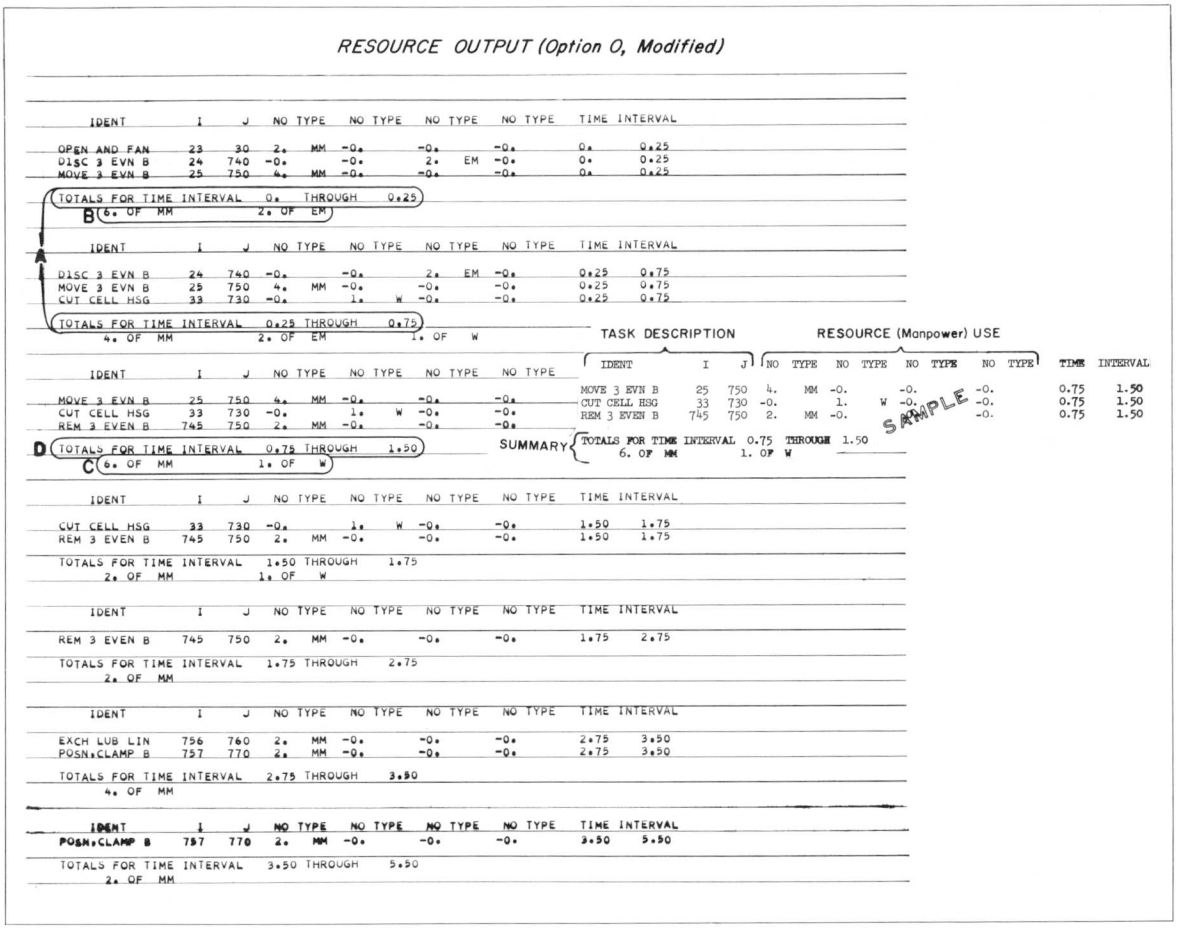
IDENT	CRITICAL PATH	OLD I	OLD J	NEW I	NEW J	DURATION	START TIME EARLY	START TIME LATE	FINISH TIME EARLY	FINISH TIME LATE	FLOAT TOTAL	FLOAT FREE
PRELIM WORK	*	10	20	1	2	0.	0.	0.	0.	0.	0.	0.
		20	23	2	3	0.	0.	0.50	0.	0.50	0.50	0.
	*	20	24	2	4	0.	0.	0.	0.	0.	0.	0.
		20	25	2	5	(0.) A	0.	1.25	0.	1.25	1.25	0.
OPEN AND FAN		23	30	3	6	0.25	0.	0.50	0.25	0.75	0.50	0.
DISC 3 EVN B	*	24	740	4	9	0.75	0.	0.	0.75	0.75	0.	0.
MOVE 3 EVN B		25	750	5	11	1.50	(0.)	1.25	1.50	2.75	(1.25)	(1.25) B
TASK DESCRIPTION		30	33	6	7	0.	0.25	1.25	0.25	1.25	1.00	0.
		30	740	6	9	0.	0.25	0.75	0.25	0.75	0.50	0.50
CUT CELL HSG		33	730	7	8	1.50	0.25	1.25	1.75	2.75	1.00	0.
		730	750	8	11	0.	1.75	2.75	1.75	2.75	1.00	1.00
	(*) C	740	745	9	10	(0.) C	0.75	0.75	0.75	0.75	0.	0.
REM 3 EVEN B	*	745	750	10	11	2.00	(0.75) C	0.75	2.75	2.75	0.	0.
		750	756	11	12	0.	2.75	4.75	2.75	4.75	2.00	0.
	*	750	757	11	13	0.	2.75	2.75	2.75	3.75	0.	0.
EXCH LUB LIN		756	760	12	14	0.75	2.75	4.75	3.50	5.50	2.00	0.
POSN. CLAMP B	*	757	770	13	15	2.75	2.75	2.75	(5.50)	(5.50)	0.	0.
		760	770	14	15	0.	3.50	5.50	3.50	5.50	2.00	2.00

PROJECT FINISH TIME

NOTE: INPUT DATA FOR THIS OUTPUT LIST TAKEN FROM ARROW DIAGRAM EXTRACT, FIG. 2, AND WAS LISTED ON C.P.S. DATA SHEET, FIG. 5. IT DOES NOT INCLUDE THE TASKS LISTED ON OPTION 1.

FIGURE 6

The Critical Path List (Figure 6) is identical to that described for Original Output (Figure 4), with the addition of the "IDENT" column which corresponds to the information entered in Columns 21-32, Figure 5.



RESOURCE OUTPUT (Option 0, Modified)

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME	INTERVAL
OPEN AND FAN	23	30	2.	MM	-0.		-0.		-0.		0.	0.25
DISC 3 EVN B	24	740	-0.		-0.		2.	EM	-0.		0.	0.25
MOVE 3 EVN B	25	750	4.	MM	-0.		-0.		-0.		0.	0.25

TOTALS FOR TIME INTERVAL 0. THROUGH 0.25
6. OF MM 2. OF EM

B

A

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME	INTERVAL
DISC 3 EVN B	24	740	-0.		-0.		2.	EM	-0.		0.25	0.75
MOVE 3 EVN B	25	750	4.	MM	-0.		-0.		-0.		0.25	0.75
CUT CELL HSG	33	730	-0.		1.	W	-0.		-0.		0.25	0.75

TOTALS FOR TIME INTERVAL 0.25 THROUGH 0.75
4. OF MM 2. OF EM 1. OF W

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE
MOVE 3 EVN B	25	750	4.	MM	-0.		-0.		-0.	
CUT CELL HSG	33	730	-0.		1.	W	-0.		-0.	
REM 3 EVEN B	745	750	2.	MM	-0.		-0.		-0.	

D TOTALS FOR TIME INTERVAL 0.75 THROUGH 1.50
C 6. OF MM 1. OF W

TASK DESCRIPTION / RESOURCE (Manpower) USE

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME	INTERVAL
MOVE 3 EVN B	25	750	4.	MM	-0.		-0.		-0.		0.75	1.50
CUT CELL HSG	33	730	-0.		1.	W	-0.		-0.		0.75	1.50
REM 3 EVEN B	745	750	2.	MM	-0.		-0.		-0.		0.75	1.50

SAMPLE

SUMMARY: TOTALS FOR TIME INTERVAL 0.75 THROUGH 1.50
6. OF MM 1. OF W

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME	INTERVAL
CUT CELL HSG	33	730	-0.		1.	W	-0.		-0.		1.50	1.75
REM 3 EVEN B	745	750	2.	MM	-0.		-0.		-0.		1.50	1.75

TOTALS FOR TIME INTERVAL 1.50 THROUGH 1.75
2. OF MM 1. OF W

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME	INTERVAL
REM 3 EVEN B	745	750	2.	MM	-0.		-0.		-0.		1.75	2.75

TOTALS FOR TIME INTERVAL 1.75 THROUGH 2.75
2. OF MM

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME	INTERVAL
EXCH LUB LIN	756	760	2.	MM	-0.		-0.		-0.		2.75	3.50
POSN.CLAMP B	757	770	2.	MM	-0.		-0.		-0.		2.75	3.50

TOTALS FOR TIME INTERVAL 2.75 THROUGH 3.50
4. OF MM

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME	INTERVAL
POSN.CLAMP B	757	770	2.	MM	-0.		-0.		-0.		3.50	5.50

TOTALS FOR TIME INTERVAL 3.50 THROUGH 5.50
2. OF MM

FIGURE 7

The Resource Use Summary (Figure 7) requested by a "1" entered in Column 2 (Figure 5, Title Card) gives the output illustrated in Figure 7. The time intervals are variable and chosen by the computer. A time interval is started a) when resource use is changed, or b) when a task is started or finished.

A Critical Path and Resource Use Summary will be printed for each base case and option as designated by the number of options on the input list (Columns 4 and 5, Title Card, Figure 5).

The effects of the option on the Critical Path are shown by comparing the lists as shown in Figures 6 and 8.

OUTPUT LIST (Option 1, Modified)

K-25 BADGER CLUSTER MODIFICATION. SAMPLE 2. MODIFIED DIAGRAM OPTION = 1

IDENT	CRITICAL PATH	OLD I	OLD J	NEW I	NEW J	DURATION	START TIME EARLY	START TIME LATE	FINISH TIME EARLY	FINISH TIME LATE	FLOAT TOTAL	FLOAT FREE
PRELIM WORK	*	10	20	1	2	0.	0.	0.	0.	0.	0.	0.
		20	23	2	3	0.	0.	0.50	0.	0.50	0.50	0.
	*	20	24	2	4	0.	0.	0.	0.	0.	0.	0.
		20	25	2	5	(0.25)	0.	2.00	0.25	2.25	2.00	0.
OPEN AND FAN		23	30	3	6	0.25 A	0.	0.50	0.25	0.75	0.50	0.
DISC 3 EVN B	*	24	740	4	9	0.75	0.	0.	0.75	0.75	0.	0.
MOVE 3 EVN B		25	750	5	11	1.50	(0.25)	2.25	1.75	3.75	(2.00)	(2.00) B
		30	33	6	7	0.	0.25	2.25	0.25	2.25	2.00	0.
		30	740	6	9	0.	0.25	0.75	0.25	0.75	0.50	0.50
CUT CELL HSG		33	730	7	8	1.50	0.25	2.25	1.75	3.75	2.00	0.
		730	750	8	11	0.	1.75	3.75	1.75	3.75	2.00	2.00
	(*) C	740	745	9	10	(1.00) C	0.75	0.75	1.75	1.75	0.	0.
REM 3 EVEN B	*	745	750	10	11	2.00	(1.75) C	1.75	3.75	3.75	0.	0.
		750	756	11	12	0.	3.75	5.75	3.75	5.75	2.00	0.
	*	750	757	11	13	0.	3.75	3.75	3.75	3.75	0.	0.
EXCH LUB LIN		756	760	12	14	0.75	3.75	5.75	4.50	6.50	2.00	0.
POSN.CLAMP B	*	757	770	13	15	2.75	3.75	3.75	6.50	6.50	0.	0.
		760	770	14	15	0.	4.50	6.50	4.50	6.50	2.00	2.00

NOTE: INPUT DATA FOR THIS OUTPUT LIST TAKEN FROM ARROW DIAGRAM EXTRACT, FIG. 2, LISTED ON C.P.S. DATA SHEET, FIG. 5, AND INCLUDES THE TASKS LISTED ON OPTION 1.

FIGURE 8

A delay along the Critical Path (C) will delay the project and affect float times (B). A delay <u>not</u> on the Critical Path will not affect the project duration, but will affect the float times (A and B).

The effects of delay on resource use are more apparent on the Resource Use Summary (Figure 9, below).

RESOURCE OUTPUT (Option 1, Modified)

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME INTERVAL
	20	25	-0.		-0.		-0.		-0.		0. 0.25
OPEN AND FAN	23	30	2.	MM	-0.		-0.		-0.		0. 0.25
DISC 3 EVN B	24	740	-0.		-0.		2.	EM	-0.		0. 0.25
TOTALS FOR TIME INTERVAL 0. THROUGH 0.25											
B (2. OF MM					2. OF EM)						

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME INTERVAL
A											
DISC 3 EVN B	24	740	-0.		-0.		2.	EM	-0.		0.25 0.75
MOVE 3 EVN B	25	750	4.	MM	-0.		-0.		-0.		0.25 0.75
CUT CELL HSG	33	730	-0.		1.	W	-0.		-0.		0.25 0.75
TOTALS FOR TIME INTERVAL 0.25 THROUGH 0.75											
4. OF MM					2. OF EM				1. OF W		

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME INTERVAL
MOVE 3 EVN B	25	750	4.	MM	-0.		-0.		-0.		0.75 1.75
CUT CELL HSG	33	730	-0.		1.	W	-0.		-0.		0.75 1.75
	740	745	-0.		-0.		-0.		-0.		0.75 1.75
D TOTALS FOR TIME INTERVAL 0.75 THROUGH 1.75											
C (4. OF MM					1. OF W)						

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME INTERVAL
REM 3 EVEN B	745	750	2.	MM	-0.		-0.		-0.		1.75 3.75
TOTALS FOR TIME INTERVAL 1.75 THROUGH 3.75											
2. OF MM											

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME INTERVAL
EXCH LUB LIN	756	760	2.	MM	-0.		-0.		-0.		3.75 4.50
POSN.CLAMP B	757	770	2.	MM	-0.		-0.		-0.		3.75 4.50
TOTALS FOR TIME INTERVAL 3.75 THROUGH 4.50											
4. OF MM											

IDENT	I	J	NO	TYPE	NO	TYPE	NO	TYPE	NO	TYPE	TIME INTERVAL
POSN.CLAMP B	757	770	2.	MM	-0.		-0.		-0.		4.50 6.50
TOTALS FOR TIME INTERVAL 4.50 THROUGH 6.50											
2. OF MM											

FIGURE 9

Resource use of MM (Maintenance Mechanics) for time interval 0. through 0.25 is reduced from 6 to 2 (B, Figures 7 and 9). It is also reduced during time interval 0.75 through 1.50 (C, Figures 7 and 9) from 6 to 4.

Time intervals listed are not necessarily equal in duration (see A, Figures 7 and 9) nor are they constant between the base case and option (see D, Figures 7 and 9). Differences between base case and option are due to manipulation of dummy task durations for manpower leveling purposes. Refer to Manning Chart.

Proposed Programming

Our present aim in programming CPS for Maintenance work at ORGDP is computer resource leveling. It is anticipated that the machine will adjust dummy task durations to perform leveling. Anticipated machine output is: a) Critical Path list as derived from the basic arrow diagram; b) Critical Path list after leveling, and c) Resource Use Summary after leveling. An output similar to the present "Schedule" (Exhibit 8) may also be printed. This computer program modification will further reduce present scheduling costs.

EXHIBIT 1

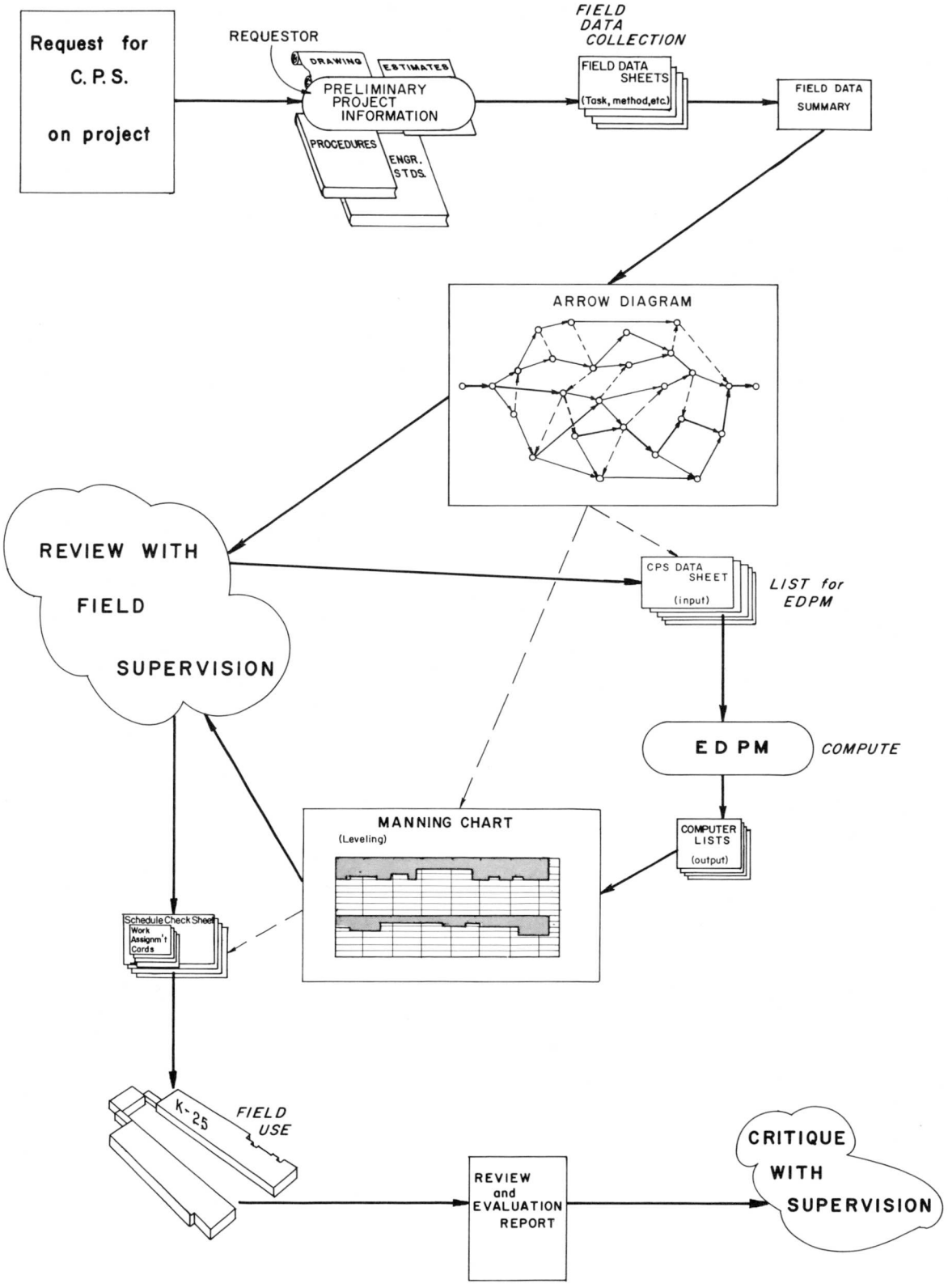
TERM DEFINITIONS

Arrow Diagram	Graphic presentation of work flow and task inter-dependencies. (Exhibits 5 and 7)
Base Case	Original schedule prepared from the initial choice of task time durations on the arrow diagram; in computer terms, output derived from raw data input without alternate considerations.
Critical Path	Longest time path from project start time to project finish time without delays. (Exhibits 5 and 7)
C.P.S. Data Sheet	Input format from arrow diagram to computer from which cards are punched. (Figures 3 and 5)
Data Card	Card punched from the C.P.S. Data Sheet.
Dummy Task	A task not described and requiring no resource use for accomplishment.
Duration	Calendar time required to perform a task.
Field	A field is a group of columns (C.P.S. Data Sheet) used to record information for card punching.
Float Time	Time a task may be extended or delayed.
Float, Free	Time a task may be extended or delayed without affecting the start time of another real task.
Float, Total	Time a task may be extended or delayed without extending the project duration.
i (start time)	Identification of a point on the arrow diagram designating when a task starts.
j (finish time)	Identification of a point on the arrow diagram designating task completion.
Leveling	Changing start time and/or duration of real tasks to bring resources required for task performance within the limits of available resources.
Manning Chart	Graphic aid indicating resource use on which manpower leveling is performed. (Exhibit 6)

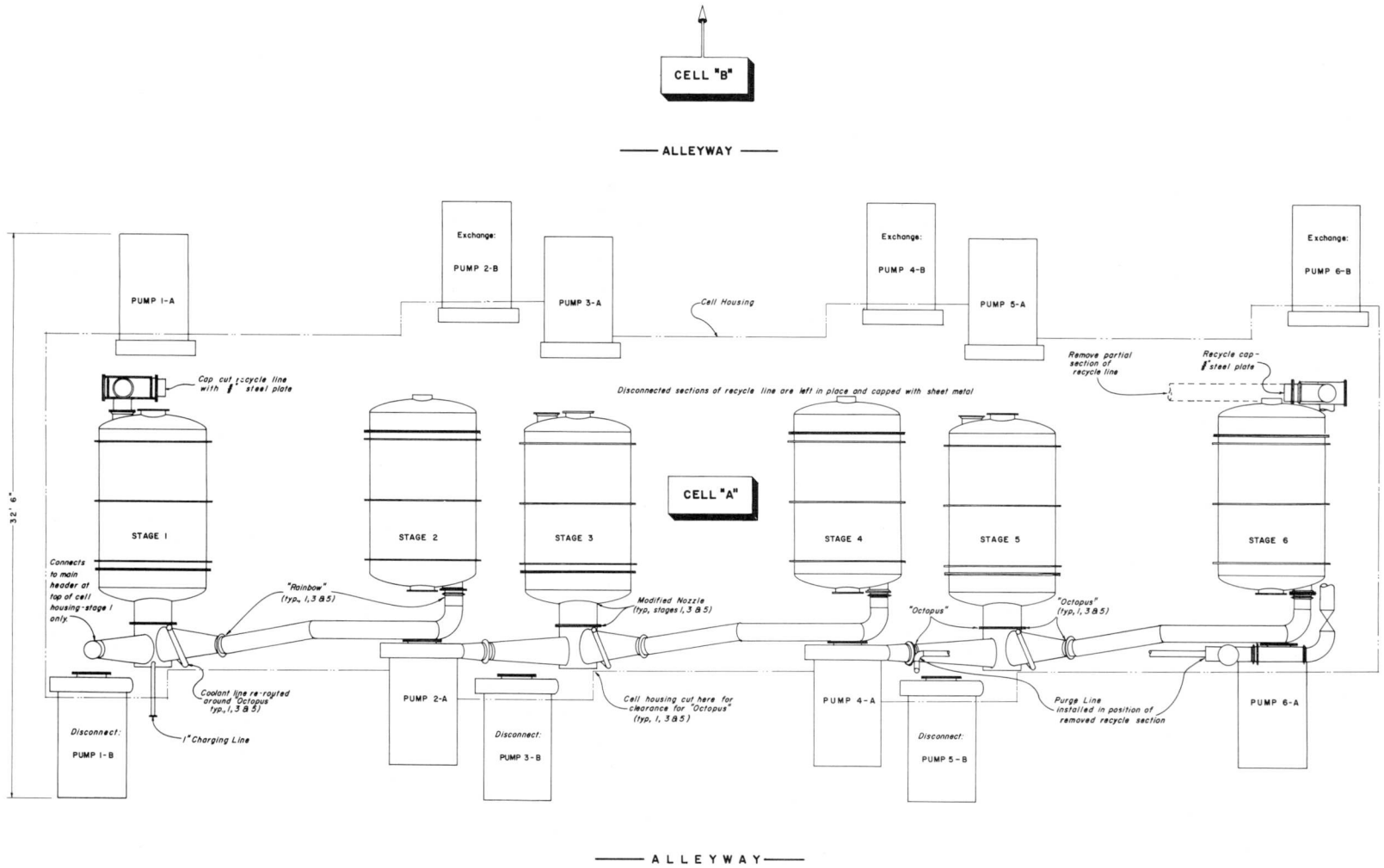
Node	Point on the arrow diagram where one or more tasks are started or finished.
Option	A series of tasks (one or more) substituted by the computer into proper positions in the base case for re-computation. Each task in each option must have an identical i-j in the base case.
Real Task	Work described with calendar time and resources for accomplishment.
Resource	Manpower, equipment or materials required for task performance.
Resource Identification Card	Card prepared before the title card, when a Resource Summary List is requested, noting each resource used in the project.
Resource Summary	Printed computer list indicating the tasks, task resource requirements, and total resources required at any time during the project. (Figures 7 and 9)
Schedule	Format given to supervision showing task sequence, performance times, and manning scheduled for work performance. (Exhibit 8)

EXHIBIT 2

C. P. S. FLOW



K-25 B.C. CELL LAYOUT



FIELD DATA SHEET

DATE: 2-8-61 (8-4 Shift)

JOB TITLE: K-25 B.C. Modification

LOCATION: K-25

OBSERVER: T. L. Miller

CRAFT MM	CRAFT W	CRAFT E	JOB DESCRIPTION	JOB NO.	START	COMPL.	(N) DELAYS		(U) DELAYS	
3			Rig Rainbow and other piping							
			P2A and 3B; P4A and 5B		8:30	8:45				
3			Rig P6A piping		8:45	9:10				
3			Rig P1B piping		9:00	9:30				
	1		Cut hole in housing at P1B Recycle		9:20	9:25	9:22	9:24		
	1		Cut inlet flange P5B		9:30	9:40			9:40	9:43
	1		Cut pipe at pump 5B exhaust (8")		9:43	9:53	9:44	9:46	9:46	9:49
	1		Cut inlet spool at converter (12")		9:55	10:00			10:00	10:25
2	1		Position octopus, Stage 1		8:25	9:45				
	1		Weld spool at converter, Stage 1		10:00	1:25	*9:10	10:00		
							*Wait for Riggers			
	1		Weld rainbow to Stage 5 octopus		9:30	11:00	9:45	9:47		
							10:00	10:10		

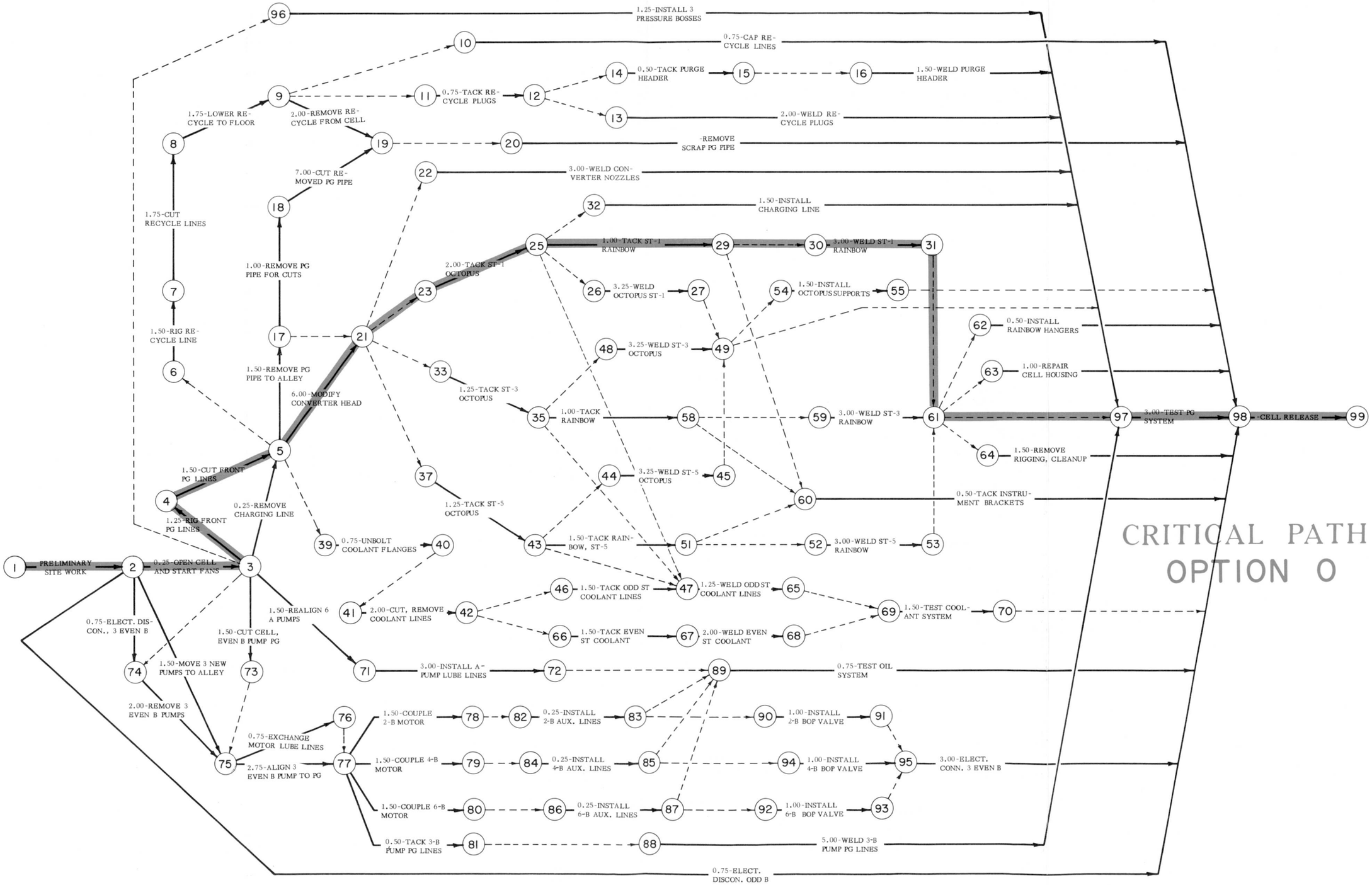
SAMPLE
(Data Collection & Summary)

EXHIBIT 4

EXHIBIT 5

ARROW DIAGRAM

K-25 B. C. CELL MODIFICATION



MANNING CHART

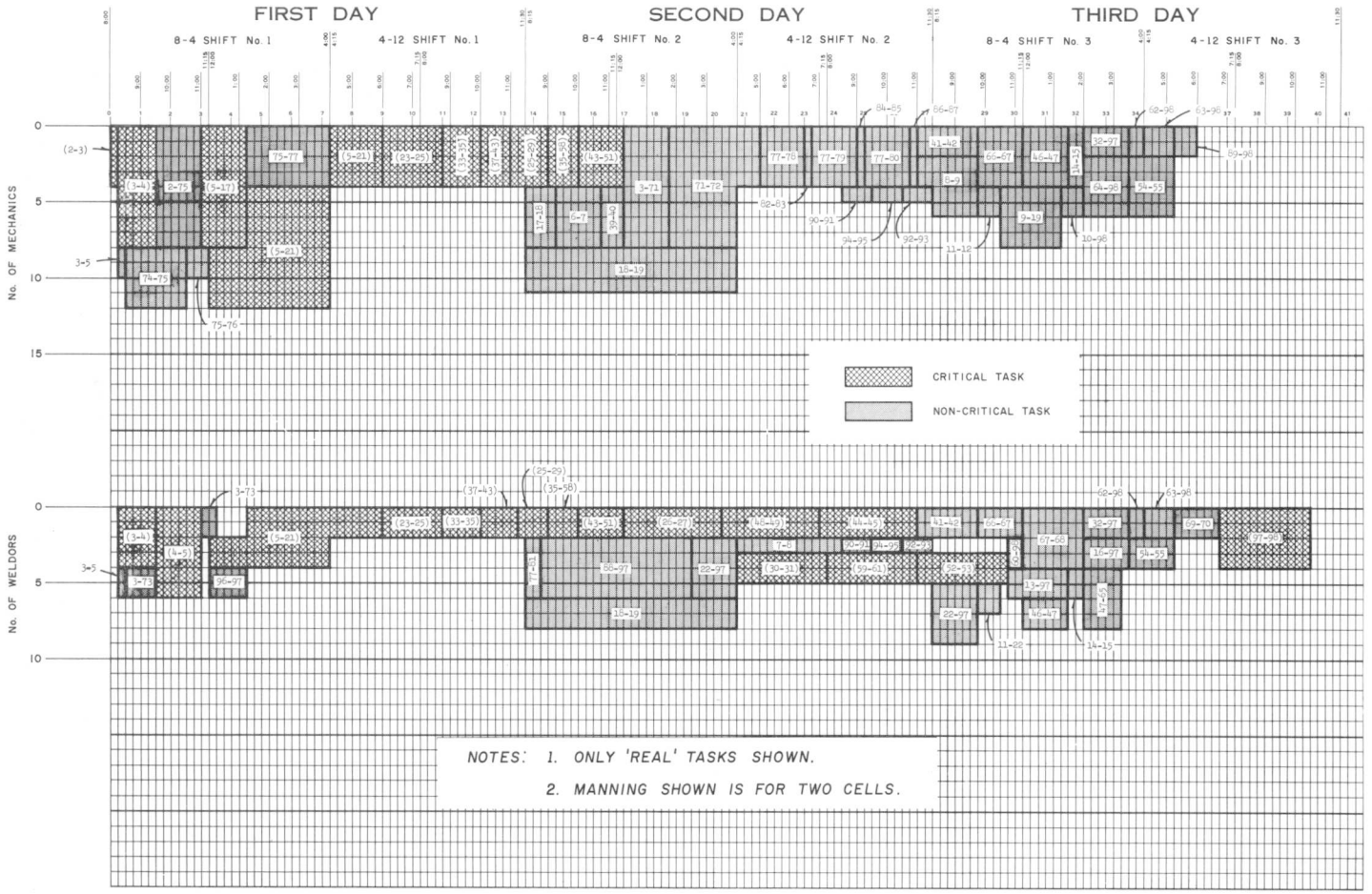
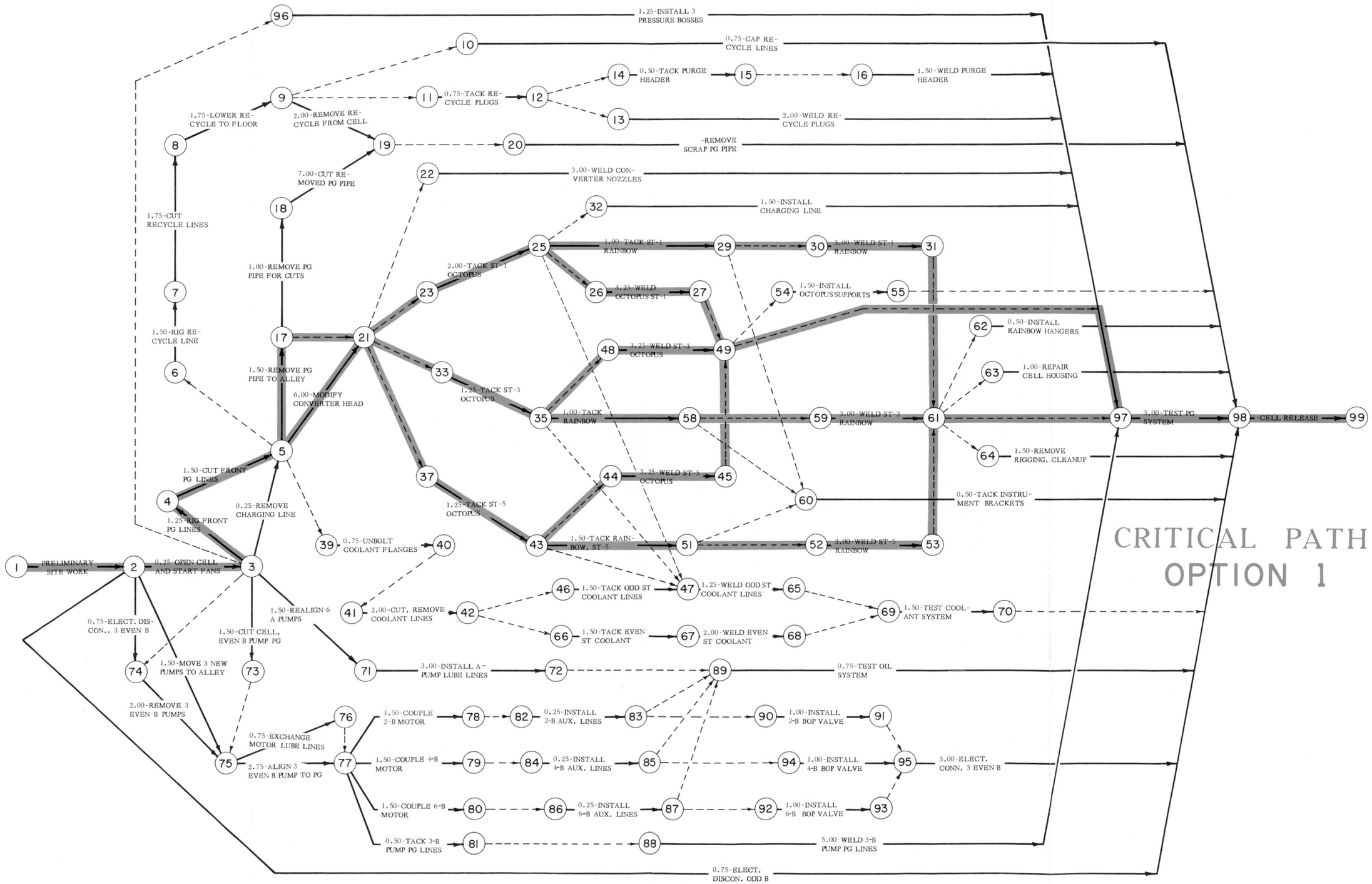


EXHIBIT 6

EXHIBIT 7

ARROW DIAGRAM

K-25 B. C. CELL MODIFICATION



CRITICAL PATH
OPTION 1

SCHEDULE

JOB K-25 B. C. MODIFICATION DATE ---------- SHIFT ---------- SUPR. ----------

TASK	DURATION	DESCRIPTION	SCHEDULE				PERFORMED			
			Manning		Time		Manning		Time	
			M	W	Start	Finish	M	W	Start	Finish
1-2 *	----	Preliminary Site Work	-	-						
2-3 *	0.25	Open Cell Start Fans	2	-	8:00 A-1	8:15 A-1				
3-4 *	1.25	Rig Front PG Lines	4	2	8:15 A-1	9:30 A-1				
3-5	0.25	Remove Charging Line	1	1	8:15 A-1	8:30 A-1				
3-73	1.50	Cut Cell, Even B-Pump PG	-	1	8:30 A-1	12:15 A-1				
2-74	0.75	Elect. Discon., 3 Even B	(2	E)						
74-75	2.00	Remove 3 Even B-Pumps	2	-	8:30 A-1	10:30 A-1				
2-75	1.50	Move 3 New Pumps to Alley	4	-	9:30 A-1	11:00 A-1				
4-5 *	1.50	Cut Front PG Lines	-	3	9:30 A-1	11:00 A-1				
75-76	0.75	Exchange Motor Lube Lines	1	-	10:30 A-1	11:15 A-1				
5-17 *	1.50	Remove PG Pipe to Alley	4	-	11:00 A-1	1:15 A-1				
96-97	1.25	Install 3 Pressure Bosses	-	1	11:15 A-1	1:15 A-1				
5-21 *	6.00	Modify Converter Head	2	1	12:00 A-1	6:00 B-1				
75-77	2.75	Align 3 Even B-Pumps to PG	2	-	1:15 A-1	4:00 A-1				
23-25 *	2.00	Tack St-1 Octopus	2	1	6:00 B-1	8:45 B-1				
33-35 *	1.25	Tack St-3 Octopus	2	1	8:45 B-1	10:00 B-1				
37-43 *	1.25	Tack St-5 Octopus	2	1	10:00 B-1	11:15 B-1				
25-29 *	1.00	Tack St-1 Rainbow	2	1	11:15 B-1	9:00 A-2				
17-18	1.00	Remove PG Pipe for Cuts	2	-	8:15 A-2	9:15 A-2				
77-81	0.50	Tack 3 B-Pump PG Lines	-	2	8:15 A-2	8:45 A-2				
18-19	7.00	Cut Removed PG Pipe	3	2	8:15 A-2	4:00 A-2				
88-97	5.00	Weld 3 B-Pump PG Lines	-	2	8:45 A-2	2:30 A-2				
35-58 *	1.00	Tack St-3 Rainbow	2	1	9:00 A-2	10:00 A-2				
6-7	1.50	Rig Recycle Line	2	-	9:15 A-2	10:45 A-2				
43-51 *	1.50	Tack Rainbow, St-5	2	1	10:00 A-2	12:15 A-2				
39-40	0.75	Unbolt Coolant Flanges	2	-	10:45 A-2	12:15 A-2				
3-71	1.50	Realign 6 A-Pumps	4	-	12:15 A-2	1:45 A-2				
26-27 *	3.25	Weld Octopus, St-1	-	1	12:15 A-2	3:30 A-2				
71-72	3.00	Install A-Pump Lube Lines	4	-	1:45 A-2	5:00 B-2				
22-97	3.00	Weld Converter Nozzle	-	2	2:30 A-2	9:45 A-3				
48-49 *	3.25	Weld St-3 Octopus	-	1	3:30 A-2	7:00 B-2				
7-8	1.75	Cut Recycle Lines	-	1	4:15 B-2	8:30 B-2				
30-31	3.00	Weld St-1 Rainbow	-	1	4:15 B-2	7:15 B-2				
77-78	1.50	Couple 2-B Motor	2	-	5:00 B-2	6:30 B-2				
82-83	0.25	Install 2-B Aux. Lines	2	-	6:30 B-2	6:45 B-2				
77-79	1.50	Couple 4-B Motor	2	-	6:45 B-2	9:00 B-2				
44-45 *	3.25	Weld St-5 Octopus	-	1	7:00 B-2	11:00 B-2				
59-61 *	3.00	Weld St-3 Rainbow	-	1	8:00 B-2	11:00 B-2				
90-91	1.00	Install 2-B BOP Valve	1	1	8:30 B-2	9:30 B-2				
84-85	0.25	Install 4-B Aux. Lines	2	-	9:00 B-2	9:15 B-2				
77-80	1.50	Couple 6-B Motor	2	-	9:15 B-2	10:45 B-2				
94-95	1.00	Install 4-B BOP Valve	1	1	9:30 B-2	10:30 B-2				
92-93	1.00	Install 6-B BOP Valve	1	1	10:30 B-2	11:30 B-2				
86-87	0.25	Install 6-B Aux. Lines	2	-	10:45 B-2	11:00 B-2				
41-42	2.00	Cut, Remove Coolant Pipe	1	1	11:00 B-2	9:45 A-3				
8-9	1.75	Lower Recycle to Floor	2	-	11:00 B-2	9:45 A-3				
52-53 *	3.00	Weld St-5 Rainbow	-	1	11:00 B-2	10:45 A-3				
66-67	1.50	Tack Even St. Coolant	2	1	9:45 A-3	11:15 A-3				
11-12	0.75	Tack Recycle Plugs	1	1	9:45 A-3	10:30 A-3				
9-19	2.00	Remove Recycle from Cell	2	-	10:30 A-3	1:15 A-3				
13-97	2.00	Weld Recycle Plugs	-	1	10:45 A-3	1:30 A-3				
60-98	0.50	Tack Instrument Brackets	-	1	10:45 A-3	11:15 A-3				
46-47	1.50	Tack Odd St. Coolant Lines	2	1	12:00 A-3	1:30 A-3				
67-68	2.00	Weld Even St. Coolant	-	2	12:00 A-3	2:00 A-3				
10-98	0.75	Cap Recycle Line	1	-	1:15 A-3	2:00 A-3				
14-15	0.50	Tack Purge Header	2	1	1:30 A-3	2:00 A-3				
32-97	1.50	Install Charging Line	1	1	2:00 A-3	3:30 A-3				
64-98	1.50	Remove Rigging, Cleanup	2	-	2:00 A-3	3:30 A-3				
16-97	1.50	Weld Purge Header	-	1	2:00 A-3	3:30 A-3				
47-65	1.25	Weld Odd St. Coolant Lines	-	2	2:00 A-3	3:15 A-3				
62-98	0.50	Install Rainbow Hangers	1	1	3:30 A-3	4:00 A-3				
54-55	1.50	Install Octopus Supports	2	1	3:30 A-3	5:15 B-3				
63-98	1.00	Repair Cell Housing	1	1	4:15 B-3	5:15 B-3				
69-70	1.50	Test Coolant System	-	1	5:15 B-3	6:45 B-3				
89-98	0.75	Test Oil System	1	-	5:15 B-3	6:00 B-3				
97-98 *	3.00	Test PG System	-	2	6:45 B-3	10:30 B-3				
2-98	0.75	Elect. Discon., Odd-B	(4	E)	----	----				
20-98	----	Remove Scrap Pipe	-	-	----	----				
95-98	3.00	Elect. Conn., 3 Even-B	(4	E)	----	----				
98-99 *	----	Cell Release	-	-	----	----				

* CRITICAL JOB
(E) OTHER CRAFT NOT SCHEDULED

A: 8 - 4 SHIFT
B: 4 - 12 SHIFT
} DAYS 1-2-3

NOTE: SCHEDULED ACTIVITY FOR ONE CELL ONLY.

EXHIBIT 9

WORK ASSIGNMENT CARD

WORK ASSIGNMENT

Name JOHN DOE Craft MM

Job K-25 B.C. Modification Location

Date Day 1 Shift 8 - 4

SCHEDULE

TASK DESCRIPTION	JOB NO.	START	FINISH
Open Cell and Start Fans	2-3	8:00	8:15
Rig Front PG Lines	3-4	8:15	9:30
Move New Pumps to Alley	2-75	9:30	11:00
Remove Cut PG Pipe to Alley	5-17	11:00	1:15
Align 3 Even "B" Pumps to PG	75-77	1:15	4:00