CPM-BASED SYSTEM FOR SCHEDULING AND ALLOCATING RESOURCES TO PROJECT DESIGN

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As part of the system for managing the design of engineering projects, the Seattle Engineering Department uses a computer program based on the critical path method. This system, when used with the other parts of the larger project management system, provides a means of controlling a $250 million, 10-year capital improvement program that results in at least $20 million of construction each year. The input to the computer includes the estimate of time and manpower requirements for each project, the logical sequence of work activities for each project, the relative importance or priority of each project, and the total manpower available to accomplish the design of projects. The computer is programmed to calculate a critical path for all projects and to schedule and allocate resources for each project activity, based on priorities and available manpower. The output from the computer includes a critical path for all the projects, a master schedule for all the projects, an individual schedule for each project, reports showing the utilization of each type of manpower, graphs of the manpower utilization, and a time-scaled arrow diagram for each project.

•AN ENGINEERING MANAGER must meet his organization's goals and objectives through the most efficient use of available resources. Allocating resources efficiently with respect for priorities is difficult. Historically, managers have used a combination of experience, charts, and "calculated guesswork" to plan and schedule their work. The critical path method (CPM) offers the manager an additional tool to accomplish his job. A CPM system uses a manager's experience and provides a multiproject schedule that efficiently guides allocation of resources.

In 1963, the Seattle Engineering Department began using a computer to assist CPM scheduling of projects and allocation of resources to preconstruction activities. Since that time the program has been modified and improved. Today it is an important, dynamic management tool. The objectives of the Seattle Engineering Department in using the CPM process are to

1. Obtain maximum utility from available manpower resources,
2. Provide line managers with a tool for planning day-to-day activities,
3. Provide a rational basis for making decisions on projects in progress, and
4. Facilitate long-range planning for the use of resources.

The computer is programmed to calculate a critical path for a whole network containing all projects and to schedule and allocate resources for each project activity considering priority and available manpower.

When scheduling is complete, the computer prints several reports: a critical path report for the entire network of projects; a manpower scheduling report that shows the start or finish of every activity on any work day; a complete schedule on a project-by-project basis; a schedule by craft rather than by project that shows the start of each activity for each craft by workday; and the craft usage graph, which shows the manpower utilization day-by-day for the first 240 working days in the schedule. The computer also generates a time-scaled arrow diagram for each project. All these reports can be used by several levels of management for both long- and short-range decision-making.

Seattle's experience shows that successful application of this system requires that key people in the organization be prepared to accept and use it. In 1963 the program was used on selected individual projects. It required that a CPM specialist work closely with the project manager in each case. Successful multiproject scheduling and resource allocating occurred after management, line supervisors, and project engineers were trained in the process and accepted the objectives of preplanned work flow and openly adopted project milestones. Teaching the technical process has been relatively easy. Gaining acceptance of a change from a process in which project accomplishment was haphazard and unplanned to a carefully planned, performance-oriented approach has been more difficult.

As with any significant management change, support by top-level management has proved essential. Top management need not know all the step-by-step mechanical details but must understand and agree with the concept and objectives of the system and demonstrate management support of the system by using the reports to assist decision-making. Line supervisors have had to realize that a computer program can and does allocate resources and schedule projects by using the same logic they use. It took some experience with the system for many supervisors to realize that the computer was not making design or management decisions for them and that it was in fact a valuable aid in giving them management information and lead time for making decisions. Some sections of the department are more successful in using the system than others. In general, success can be traced to the level of commitment of the supervisor to work planning and results.

The third critical group is project engineers, the managers of individual projects. They must be able to plan their projects in a CPM format. They must be able to identify the activities to be done, to estimate the time and manpower required for each activity, and to arrange the activities in a logical sequence such as an arrow diagram. In Seattle, a 4-hour in-house course in CPM basics was developed and presented to project engineers and their supervisors. Interested top management persons also attended the class.

With these three groups prepared, there is still a need for someone to have an intimate knowledge of the entire scheduling and resource allocating system. In the Seattle Engineering Department, that person is assisted by three others and performs the following duties: (a) advises project engineers and supervisors on system or CPM questions, (b) provides analysis of the output reports, (c) makes recommendations to management based on these analyses, and (d) updates and processes schedule runs on a quarterly basis.

SCHEDULING PROJECTS AND ALLOCATING RESOURCES

Figure 1 shows the CPM process that the Seattle Engineering Department uses to allocate resources for the 130 or more projects in process at one time. A step-by-step explanation follows.

Step 1—Project Planning

One of the great advantages of CPM is that planning for how a job will be done is separated from scheduling when the job will be done. In the first step, the engineer responsible for a project develops an arrow diagram for a logical sequence of work.

Every function that will be complete prior to construction of the project is reduced to detailed work units called activities. Typically, these include numerous reconnaissance and design functions, gathering of soils and survey information, right-of-way and easement acquisition, procurement of construction financing, holding of hearings and public meetings, obtaining necessary approvals, and advertising and awarding a construction contract.

Best results are obtained when activities are small rather than large and all-inclusive. For example, one lengthy activity to cover drawing, checking, and revising base plans would be better represented by three or more activities, shorter in duration, covering the same duties.

Once activities have been defined, the project engineer then specifies the necessary activity sequence. He usually shows the sequence of activities in the form of an arrow diagram. Upon seeing his project as an arrow diagram, he may wish to change some of his original assumptions regarding the number of activities or order of occurrence.

The project engineer then estimates the time and manpower required to complete each activity. The manpower required is specified by craft, i.e., engineers, draftsmen, survey crews, and by the units in each craft (the number of persons of each type to be utilized). The duration estimate for each activity is in workdays. In making his estimate of time required, the engineer takes into account historical data on the productivity of his personnel, sick leaves, and vacation time. His time estimate is then long enough to absorb nonproductive time. This time estimate information should be added to the arrow diagram.

Step 1 applies mostly to projects not previously scheduled. For projects that have been included previously, the project engineer might only review the arrow diagram, remove activities that have been completed, and make revisions to activities that remain. In any case, every project that will be included in the scheduling run is reviewed by the engineer.

Step 2—Create the Activity File

In step 2, node numbers are assigned to the nodes on the arrow diagrams, and all the information from the arrow diagrams (node numbers, activity name, and time and manpower requirements) is coded in a required format and compiled into a data file, called the activity file, for the computer run.

This file presents one of the restraints on the magnitude of the scheduling and resource allocating system. The number of activities in the file is limited by the available node numbers. Nodes may be numbered from 1 to 4,000. The computer identifies activities by their respective beginning and ending nodes (I and J nodes), and each activity must be uniquely defined. Additionally, the numbering of nodes must be such that all the projects are tied together in one master arrow diagram network, and there must be only one entrance and one exit for this network. In the experience of the Seattle Engineering Department, these limitations place the maximum number of projects that could be included in the file at approximately 150 to 160 projects. The concept is not limited, only the particular process now used. Earlier in its development, the system was limited to 1,700 activities; it was increased and could be again if necessary.

When all the activities have been entered into the data file, the file is sorted into proper order and is then ready for input to the CPM program.

Step 3—Create the Control File

A control file must be created before the program is run. This file contains the information necessary to support the scheduling and allocation of resources and to produce the reports. The file consists of five separate parts, which

1. Specify which reports are to be printed;
2. Delineate the total resources available to accomplish the projects;
3. Specify the calendar date on which the reports will start, the name of the report such as departmental schedule, and a heading date to appear on each page of the reports;
4. Are actually a 5-year calendar, the inputs of which include the starting year of the calendar, the number of working days per week, abbreviations for the months, and a matrix that establishes the actual working days, i.e., designating the nonworking weekends and holidays; and
5. Specify which crafts will be grouped together in the craft report in order to provide a unique listing for each section head and give the title for each grouping.

Step 4—Add Priority Data to the Projects

The program for scheduling and allocating resources is set up in six phases. To add priority data to the projects requires that an initial run of the program through its first and second phases be made.

The first phase of the program tells the computer which data and control files to use and how much core storage will be required and generally sets the stage for the rest of the run. This phase also checks for data errors. If errors are found, they are listed and the program aborts.

The second phase analyzes the multiproject network in the activity file as if it were one large project and finds the early and late start, early and late finish, and the total float for each activity. At the directive of the operator, a listing of this information for the last activity in each project is obtained. The critical path duration of each project can be found by listing all the last activities.

Priority data are added to a project by altering the total float on the critical path. Normally, the total float along the critical path is always zero. However, when all projects are in one network, float on a project's critical path will be inversely proportionate to the duration of the project. Therefore, the critical path of only the longest project in the network will have the zero float.

Figure 2 shows this condition. The solid lines represent the critical path durations of projects A, B, C, and D (the noncritical activities are not shown), and the dashed lines represent float time.

It is seen then that only project C, the longest project, has zero float along its critical path. The critical paths of shorter projects in this network have float.

The engineering department management, through a priority committee, assigns a relative priority to the projects. The priority of a project is shown in the program by making the total float along the critical path the same as the priority number. This is done by adding an activity at the end of the project, called the completion restraint, so that the highest priority project has the longest duration. This activity has a duration, but it requires no manpower.

Figure 3 shows how this works. CR represents the duration of the completion restraint.

For convenience in later use of the output, the priority number is also added to the name of the completion restraint activity. Therefore, the activity name, Completion Restraint 12, indicates the project with a priority of 12.

The program is stopped at the end of the second phase. The durations of the completion restraints are calculated and added to the activities in the activity files. These completion restraints play an important part in the remaining phases of the program, which are now ready to be run.

Step 5—Schedule Projects and Allocate Resources

The program is started again at phase one because it is not possible to restart the program at any other point. Calculations using the new data are made in phase two.

Phase three is the resource allocating or manpower scheduling phase. It uses the critical path analysis from phase two to allocate resources and schedule activities according to the following rules:

1. Start an activity on its earliest start time.
2. Start critical activities, identified by least float, first. If two activities are equally critical, start the one with shorter duration first (the theory being that a longer activity has a better chance than a shorter one of making up "lost time"). If the craft called for is unavailable, use an alternate if one is specified. Stop a noncritical activity that is in progress to start a critical activity (the most recently started activity is the first one stopped).
3. Start noncritical activities.
4. Delay starting activities if resources are unavailable. If more than 400 activities, ready to start, are waiting at one time, the program will abort.

This process can be likened to a manual process in which there is a listing of activities, sorted in order of their early start, that are examined day by day.

On the first day only the activities that have an early start on day 1 are considered. Activities are scheduled by allocating resources to activities having highest priority (least float) first. When either all the activities that can start that day have been scheduled or the available manpower has been completely utilized, scheduling for the first

Figure 1. CPM process used for scheduling and resource allocation.

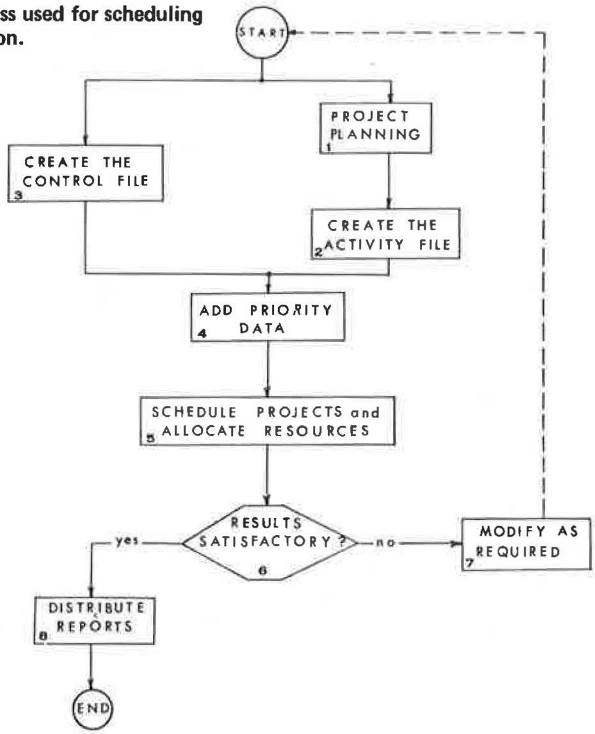


Figure 2. Float time as related to duration of project.

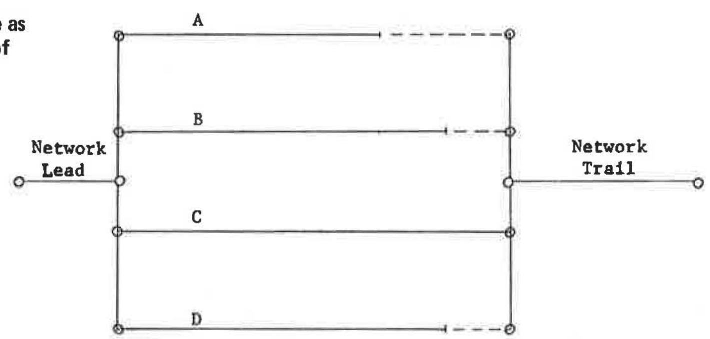
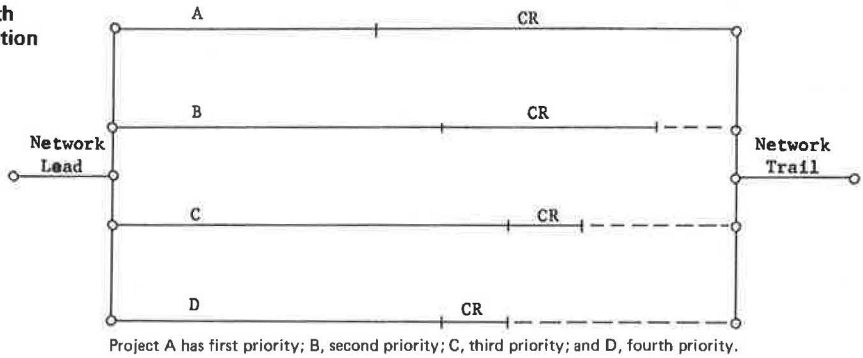


Figure 3. Critical path duration plus completion restraint.



Project A has first priority; B, second priority; C, third priority; and D, fourth priority.

day is complete. Activities that were not started are placed in a waiting table. These activities lose a day of float (and thereby become more critical) for each day they remain in the waiting table. On the second and succeeding days, the activities that will finish on that day are first located, and the manpower is returned to the pool. Next, the activities that have an early start of that day, together with the activities in the waiting table, are considered for scheduling. After the first day, if the required manpower is unavailable, the activities already in progress are examined to see whether a low-priority activity can be interrupted to utilize the manpower on a high-priority activity. When the list of activities has been completely reviewed, scheduling is complete.

The decision rules ensure that work will be done as soon as possible. They also place any float after an activity where it can be used in case the time required has been underestimated. And, because activities are started in order of their priority, resources are allocated according to the priority of the managers.

When all the activities have been scheduled, phase three is over. The remaining three phases sort the information from phases two and three and set up the files necessary to produce the reports.

Steps 6 and 7—Examine Results for Acceptability and Modify as Necessary

The results are examined by department management to determine their acceptability before any information from the program run is distributed. Basically, this is to accept or reject the projected occurrence of important project milestones. If the important dates for one or two projects are unacceptable, it may be possible to manually adjust and reschedule these projects. If, however, the dates for many projects are unacceptable, changes in the activity or control file or both are made, and the program is rerun.

Step 8—Distribute Reports

The following reports can be produced by the program: critical path report, manpower schedule, project report (item report), craft report, craft usage graph, and time-scaled arrow diagram (for each project, as scheduled). These reports make up the departmental schedule.

The critical path report (Fig. 4) is a listing of the network analysis. All the activities are listed in order of their total float. This information is useful in analyzing the allocation of resources and estimating what would happen if there were no resource constraint.

The manpower schedule (Fig. 5) is a listing of the resource allocation. This report includes all activities in the network, listed chronologically in order of workday, and tells the reader which activities are started, interrupted (delayed), and finished on each workday. This report is, in effect, a master schedule. By comparing the total float of an activity shown in the manpower schedule report with the total float shown in the critical path for the same activity, we can find how much later than the earliest possible start the activity was actually scheduled.

The project report (Fig. 6) is a sorting of the manpower scheduling information by project. All the activities in one project appear together, listed chronologically. One column of this report shows the date an activity starts or is delayed; another column shows the total float of an activity at the time it was scheduled. This report is the most useful to the project engineer in planning his day-to-day work.

Information is sorted by craft number as directed by the control file in the craft report (Fig. 7). Usually all the crafts from one work section are grouped together chronologically. The craft report shows the manager at a glance the projected work load for his section.

The craft usage graph (Fig. 8) is a character plot produced by the printer. The graph shows how many people of a craft are working on a given day, but not which activities are being worked on. A graph can be produced for crafts with 34 or fewer people in them. The graphs cover only 120 or 240 workdays, even though the data may be available for longer periods. The + characters indicate the total people available; an X indicates the number assigned that day.

Figure 4. Critical path report.

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PROJECT NO.	JOB DESCRIPTION	I NODE	J NODE	DURATION IN DAYS	EARLY START	LATE START	EARLY FINISH	LATE FINISH	FLOAT
0	NETWORK LEAD	1	2	0	0	0	0	0	0
5	PIPE AND APPURTENANCE DESIGN	2	1413	8	0	0	8	8	0
5	FINAL DESIGN	1413	1414	4	8	8	12	12	0
5	FINAL REVIEW	1414	1415	2	12	12	14	14	0
5	SUPERVISOR REVIEW	1415	1416	2	14	14	16	16	0
5	ESTIMATE AND TRAFFIC SPECIFICATNS	1416	1420	20	16	16	36	36	0
5	PREPARE SPECIFICATIONS	1420	1421	10	36	36	46	46	0
5	***BPW APPROVE PLANS & SPECS***	1421	1423	10	46	46	56	56	0
5	ADVERTISE FOR BIDS	1423	1424	10	56	56	66	66	0
5	***AWARD CONTRACT***	1424	1425	10	66	66	76	76	0
5	BEGIN CONSTRUCTION - MERCER STREET	1425	3802	0	76	76	76	76	0
5	COMPL REST 1 MERCER STREET 1	3802	3999	1123	76	76	1199	1199	0
0	NETWORK TRAIL	3999	4000	0	1199	1199	1199	1199	0
1	ORDER SURVEY	2	683	1	0	1	1	2	1
1	SURVEY PROPERTY ADJUSTMENTS	683	684	3	1	2	4	5	1
1	ADJUST PLANS	684	685	15	4	5	19	20	1
1	APPRAISE	685	708	22	19	20	41	42	1
1	NEGOTIATE	708	709	50	41	42	91	92	1
1	NEGOTIATE	708	710	50	41	42	91	92	1
1	DUMMY	709	710	0	91	92	91	92	1
1	LOGIC DUMMY	710	711	0	91	92	91	92	1
1	FILE SUIT	711	712	10	91	92	101	102	1
1	SERVE SUMMONS	712	713	15	101	102	116	117	1
1	LEGAL DELAY	713	734	44	116	117	160	161	1
1	ORDER OF NECESSITY	734	741	1	160	161	161	162	1
1	LEGAL DELAY	741	751	16	161	162	177	178	1
1	PRE-TRIAL CONFERENCE	751	753	5	177	178	182	183	1
1	LEGAL DELAY	753	758	22	182	183	204	205	1
1	TRIAL ROY ST PHASE I	758	762	5	204	205	209	210	1
1	PAY AWARDS	762	763	25	209	210	234	235	1
1	LEGAL DELAY---MOVE OUT TIME	763	769	30	234	235	264	265	1
1	BEGIN CONSTRUCTION	769	3806	0	264	265	264	265	1
1	COMPLETION RESTRAINT 2 ROY ST PH I	3806	3999	934	264	265	1198	1199	1
75	FILE SUIT	2	2928	1	0	2	1	3	2
75	SERVE SUMMONS	2928	2930	5	1	3	6	8	2
75	LEGAL DELAY	2930	2932	44	6	8	50	52	2
75	ORDER OF NECESSITY	2932	2934	1	50	52	51	53	2
75	LEGAL DELAY	2934	2936	16	51	53	67	69	2
75	PRE-TRIAL CONFERENCE	2936	2939	5	67	69	72	74	2
75	LEGAL DELAY	2939	2941	22	72	74	94	96	2
75	***TRIAL***	2941	2942	5	94	96	99	101	2

Figure 5. Manpower scheduling report.

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PROJECT NO.	DATE	WORK DAY NO.	JOB STATUS	JOB DESCRIPTION	I NODE	J NODE	DURATION	CRAFT NO.	MEN REQD	TOTAL IN CRAFT	JOB FLOAT
	APR 24, 1972										
21		39		FINISH CONTRACT PLANS	1068	1069	7	5	1	2	26
72		39		FINISH STUDY PIPE ROUTING	3110	3130	7	31	1	15	112
26		39		FINISH MAP ASSMT AREAS	593	594	6	17	1	0	44
70		39		FINISH CALC ASSMT RATES 2	3061	3063	3	19	1	2	87
75		39		FINISH MAKE PRESENTATN TO DESIGN COMM	2892	2896	2	26	1	2	38
56		39	START	COMPUTE INDIVIDUAL ASSESS	201	202	2	19	1	3	24
21		39	START	DEPT & PLANNING REVIEW 2	1069	1070	15	22	0	0	26
12		39	START	LANSC CONTRACT PLANS	2055	2056	7	5	1	3	29
75		39	START	REVISE LAYOUT POAN	2896	2899	2	26	1	3	40
26		39	START	PREPARE PRELIM ROLL	594	595	6	18	1	2	44
101		39	START	MAP ASSMT AREAS	1762	1763	3	17	1	1	48
36		39	START	FINAL PUMP STA DESIGN	2385	2440	66	31	1	16	65
	APR 25, 1972										
24		40		FINISH INK DRAWINGS	434	438	25	32	1	7	8
111		40		FINISH PLANS SPECS ESTIM	90	91	20	5	1	2	6
15		40		FINISH DIVERTER OR PARK DESIGN	377	378	18	10	1	4	77
4		40		FINISH PREPARE PRELIM ROLL	1988	1989	12	18	1	1	118
37		40		FINISH PIPE & APPURTENANCE DESIGN	2	2584	10	31	1	15	109
5		40		FINISH MAKE REVISIONS	1417	1418	2	31	1	14	5
14		40		FINISH DRAINAGE REVISIONS	2781	2783	2	31	1	13	103
42		40		FINISH DRAW GRADE PLANS	1840	1841	2	14	1	0	119
5		40	START	DRAFT REVISIONS	1418	1419	2	32	1	8	5
5		40	START	CHECK REVISIONS	1418	1421	1	31	1	14	6
111		40	START	PLANS SPECS ESTIM	91	92	15	4	1	7	6
24		40	START	DEPARTMENT REVIEW	438	440	20	22	0	0	8
36		40	START	COORD LOC-IMPR ON PLAN	2385	2426	60	10	1	5	21
78		40	START	PRELIM PLAN	1221	1223	10	5	1	3	31
34		40	START	PIPE DESIGN	605	2404	54	31	1	15	101
222		40	START	DRAFT BASE PLANS 2	2	3343	34	31	1	16	106
4		40	START	CALC UNITS & PUT ON ROLL	1989	1990	1	16	1	1	118
42		40	START	EW	1841	1844	1	15	1	1	119
	APR 26, 1972										
6		41		FINISH PREPARE PSE ESTIMATE & SCOPE	2	878	40	26	0	3	18
7		41		FINISH COMPLETE CONTRACT DRAWINGS	2	3665	40	1	1	8	30
36		41		FINISH REVISE EIS E	2	2374	40	27	1	10	43
75		41		FINISH PREPARE NEW TRAFFIC DATA	2	2876	40	36	1	0	65
245		41		FINISH ESTIMATES AND SPECIFICATIONS	2	3573	40	11	0	7	118
16		41		FINISH REQUEST R/W APPROPRIATION	476	1562	40	40	0	0	187
128		41		FINISH RECEIVE COMMENTS ON DRAFT EIS	969	971	35	20	0	5	31
290		41		FINISH PAY AWARDS	319	320	25	21	0	3	13

Figure 6. Item report.

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PROJECT NO.	DATE	WORK DAY NO.	JOB STATUS	JOB DESCRIPTION	I NODE	J NODE	DURATION	CRAFT NO.	MEN REQD	TOTAL IN CRAFT	JOB FLOAT
37	MAR 1, 1972	1	START	DRAFT BASE MAPS	2	2582	0	31	1	16	143
37	APR 11, 1972	30	START	PIPE & APPURTENANCE DESIGN	2	2584	10	31	1	16	109
37	JUL 24, 1972	102	START	CHECK BASE MAPS	2582	2584	5	32	1	8	42
37	AUG 1, 1972	108	START	FINAL DESIGN	2584	2585	5	31	1	16	46
37	AUG 8, 1972	113	START	FINAL REVIEW	2585	2586	5	31	1	15	46
37	AUG 10, 1972	115	START	INK DRAWINGS	2584	2587	20	32	1	8	34
37	AUG 15, 1972	118	START	SUPERVISOR REVIEW	2586	2587	5	31	0	13	46
37	SEP 8, 1972	135	START	DEPTL REVIEW	2587	2588	20	22	0	0	34
37	SEP 11, 1972	136	START	ESTIMATE	2587	2596	15	11	1	7	59
37	OCT 6, 1972	155	START	REVISIONS	2588	2589	2	31	1	11	34
37	OCT 11, 1972	157	START	CHECK REVSIONS	2589	2591	1	31	1	12	35
37	DEC 1, 1972	191	START	DRAFT REVSIONS	2589	2590	2	31	1	11	0
37	DEC 5, 1972	193	START	DUMMY	2590	2591	0	0	0	0	0
37	DEC 5, 1972	193	START	**BPW APPROVAL - PLANS	2591	2592	10	22	0	0	0
37	DEC 19, 1972	203	START	COMPUTE & CHECK AREAS	2592	2593	2	16	1	1	0
37	DEC 21, 1972	205	START	MAP AREAS	2593	2594	2	17	1	1	0
37	DEC 26, 1972	207	START	PRELIMINARY ROLL	2594	2595	2	18	1	1	0
37	DEC 28, 1972	209	START	CALC UNITS & PUT ON ROLL	2595	2596	1	16	1	1	0
37	DEC 29, 1972	210	START	CALC ASSMT RATES	2596	2597	5	19	1	1	0
37	JAN 8, 1973	215	START	COMPUTE INDIV ASSMTS	2597	2598	2	19	1	1	0
37	JAN 10, 1973	217	START	MAIL NOTICES	2598	2599	25	19	0	0	0
37	FEB 15, 1973	242	START	**PRELIMINARY HEARING	2599	2600	1	19	0	2	0
37	FEB 16, 1973	243	START	PREPARE SPECS	2600	2601	15	11	1	1	0
37	MAR 12, 1973	258	START	**BPW SPEC APPROVAL	2601	2602	10	22	0	0	0
37	MAR 26, 1973	268	START	ADVERTISE	2602	2603	15	22	0	0	0
37	APR 16, 1973	283	START	**BPW CONTRACT AWARD	2603	2604	20	22	0	0	0
37	MAY 14, 1973	303	START	BEGIN CONSTRUCTION	2604	3960	0	22	0	0	0
37	MAY 14, 1973	303	START	COMPLETION RESTRAINT 139	3960	3999	897	0	0	0	0

Figure 7. Craft report.

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WATER DESIGN

PROJECT NO.	DATE	WORK DAY NO.	JOB STATUS	JOB DESCRIPTION	I NODE	J NODE	DURATION	CRAFT NO.	MEN REQD	TOTAL IN CRAFT	JOB FLOAT
13	MAR 1, 1972	1	START	FINALIZE ROOF SHAPE	2	1528	10	7	1	1	27
45	MAR 1, 1972	1	START	DETERMINE PIPE LOCATION	2	616	65	6	0	0	84
98	MAR 1, 1972	1	START	DRAFT 20 BASE MAPS	2	2622	35	7	1	2	97
82	MAR 1, 1972	1	START	DESIGN	2	1630	20	7	1	3	109
104	MAR 1, 1972	1	START	TRANSMIT PH II CORRIDOR TO R/W	2	2802	0	6	0	0	132
103	MAR 1, 1972	1	START	PUT TOPOG ON BASE MAPS	2	2803	25	7	1	4	132
98	MAR 1, 1972	1	START	DESIGN WATERMAINS PH 1	2	2623	20	6	1	1	137
103	MAR 1, 1972	1	START	SIZE PIPELINE	2804	2805	10	6	1	2	157
13	MAR 15, 1972	11	START	WORK WITH CONSULTANT	1528	1532	10	7	1	4	27
105	MAR 15, 1972	11	START	MAKE REVISIONS	2861	2862	10	7	1	5	39
103	MAR 15, 1972	11	START	DESIGN SOOS CREEK CROSSING	2805	2808	15	6	1	2	162
94	MAR 29, 1972	21	START	WM DESIGN	1661	1662	2	7	1	3	81
13	MAR 29, 1972	21	START	GRADING PLAN	1532	1534	15	7	1	4	27
82	MAR 29, 1972	21	START	DEPT REVIEW	1630	1631	10	7	0	4	109
104	MAR 29, 1972	21	START	DETERMINE MOST ECONOMICAL ROUTE	2814	2815	10	6	0	1	132
103	APR 5, 1972	26	START	FINISH TOPOG	2803	2806	10	7	1	3	132
103	APR 5, 1972	26	START	DESIGN PIPE AT SR515	2808	2809	10	6	1	1	162
42	APR 11, 1972	30	START	WM DESIGN	1836	1838	1	7	1	4	105
104	APR 12, 1972	31	START	START R/W BASE PLANS	2815	2818	20	7	1	4	132
13	APR 19, 1972	36	START	CONSTRUCTION ROAD	1534	1536	20	7	1	2	27
98	APR 19, 1972	36	START	DESIGN PH 2	2622	2625	20	7	1	3	97
98	APR 19, 1972	36	START	PRELIM CIRC & CHECK PT I	2623	2624	10	7	1	4	122
103	APR 19, 1972	36	START	LOCATE PIPELINE ON PLANS	2806	2807	10	7	1	5	132
103	APR 19, 1972	36	START	DESIGN PIPE AT FAIRWOOD RES	2809	2811	15	6	1	1	177
128	APR 26, 1972	41	START	FINAL REVISIONS TO WIDENING PLANS	972	973	5	10	0	5	31
								7	0	5	
98	MAY 3, 1972	46	START	DRAW PROFILE SHEETS	2622	2637	50	7	1	4	154
98	MAY 3, 1972	46	START	REVISIONS PH I	2624	2627	5	7	1	5	122
103	MAY 10, 1972	51	START	DRAW PIPELINE PROFILE	2807	2810	20	7	1	4	127
13	MAY 17, 1972	56	START	PIPING & VALVING PLAN	1536	1538	30	7	1	3	27
98	MAY 17, 1972	56	START	PRELIM CIRC & CHECK PT II	2625	2626	5	7	1	4	107
98	MAY 24, 1972	61	START	MAKE REVISIONS PH 2	2626	2627	5	7	1	4	107
69	MAY 25, 1972	62	START	WM DESIGN	3025	3027	2	7	1	5	110
125	JUN 1, 1972	66	START	WM DESIGN	1813	1815	1	7	1	4	102
45	JUN 1, 1972	66	START	REVISE PLANS	616	617	10	7	1	5	84
98	JUN 1, 1972	66	START	**BPW PLAN APPROVAL	2627	2631	10	7	0	5	107
103	JUN 8, 1972	71	START	DRAFT DESIGN DETAILS	2810	2811	30	7	1	4	127
13	JUN 29, 1972	86	START	FLOOR SLAB & DIV. WALL DESIGN	1538	1540	40	7	1	3	27
13	JUN 29, 1972	86	START	COORDINATE SEWER RELOCATION	1538	1539	10	6	1	1	57

The time-scaled arrow diagram is now only partially produced by the program run. A card deck of each project report is generated by the program. This deck, when used with a plotter, generates a time-scaled arrow diagram of each project as scheduled. The diagram shows activities as solid lines, float or slack time as dashed lines, calendar dates, project name, node numbers, activity names, craft codes, and numbers of people. The diagram is printed at a scale of 1 in. equals 5 days (Fig. 9).

USES OF THE SCHEDULE

The schedule in its final form provides a management tool, useful in both day-to-day and long-range planning. The project report, craft report, and craft usage graph show the line managers a way that projects can be completed on time with judicious use of available resources. When the actual design status is compared with the project report, project progress can be measured and requirement changes that may affect this progress can be assessed.

These reports also are a credible, factual method of predicting the dates of important events throughout a project's life. This type of information is valuable not only to the internal organization but also to citizen groups, other city departments, and state and federal agencies. Often, as a part of an interagency agreement, a schedule for accomplishing the design of a project is required. The project report is well suited to meet this requirement.

Often managers ask, "How and where can the organization take on more work? How can the most important projects be accelerated through design? Where will personnel transfers result in more efficient use of manpower? How would completion dates be affected by letting another firm design some of the projects?"

The critical path report, project report, craft report, and craft usage graph can provide a factual basis for answering these questions. The critical path and project reports show how and where additional resources could accelerate the completion date of a project. The craft report and usage graph show which crafts are and which are not fully utilized. If personnel transfers are possible, the critical path and project reports show which activities could most use additional manpower. Because unscheduled special requests always arise, scheduled full utilization of a craft for long periods of time indicates that activities, and therefore projects, are probably being delayed because of insufficient manpower resources. Reducing the number of projects being done by fully utilized crafts will accelerate the completion of remaining projects. The critical path and project reports can provide a measure of this acceleration.

In long-range planning, the schedule provides an aid in programming money, evaluating overall manpower needs, and preparing a plan to meet a future volume of work.

The project report predicts a completion date for the preconstruction phase of a project, i.e., the date on which construction financing will be required. The schedule then can be used to plan for the requirements from each funding source.

The capital improvement program (CIP) for the City of Seattle shows a 10-year plan for all the capital improvements to be made by all the departments in the city. The CIP shows the project names, cost estimates, funding sources, and year of expenditure. For the engineering department's portion of the CIP, the departmental schedule is used for programming funds in the proper year. Once the funding sources have been determined, we can obtain the requirements from each source by weeks, months, quarters, or years as desired.

A measurement of the manpower needs in each craft can be made by using the critical path report. By using the early start date for each activity, we can plot the usage graph that would result if unlimited manpower were available; but unlimited manpower is an uneconomic and impractical, if not impossible, condition. However, such a plot is useful in making comparisons in related skill groups. For example, the plot may show that the number of structural draftsmen required is approximately equal to two and a half times the number of structural engineers. This assumes that supervisors are correct in their evaluation of both skill level and time required to do a task. If the schedule is representative in both types and volume of work usually done, management can then use the plot to establish the numbers of each craft to be employed. Also, the size of a craft

Figure 8. Craft usage report.

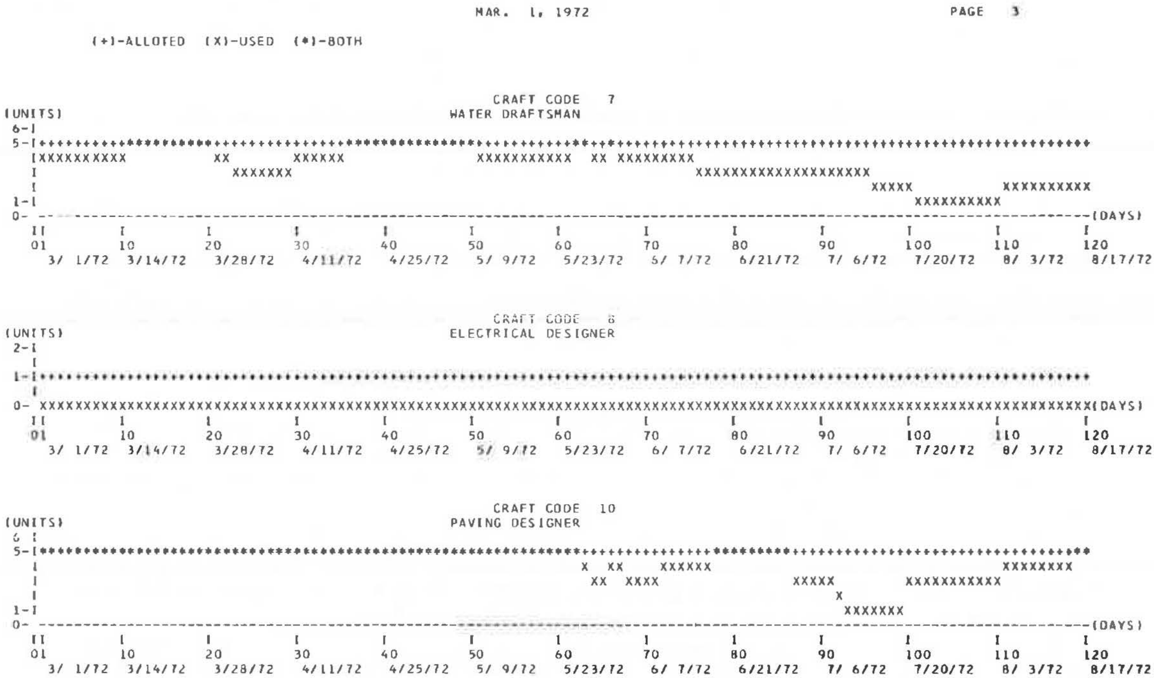
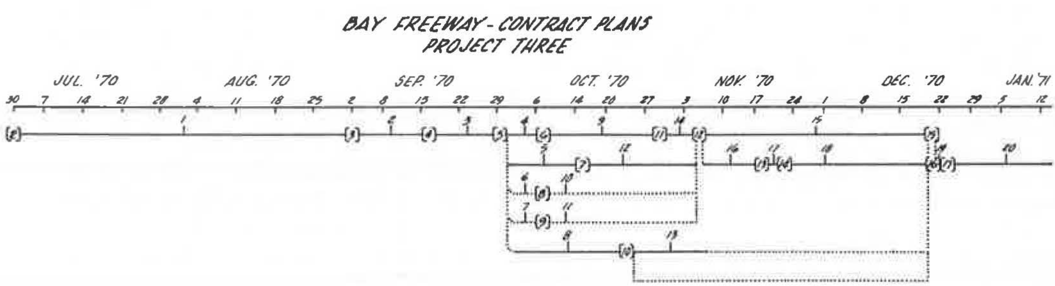
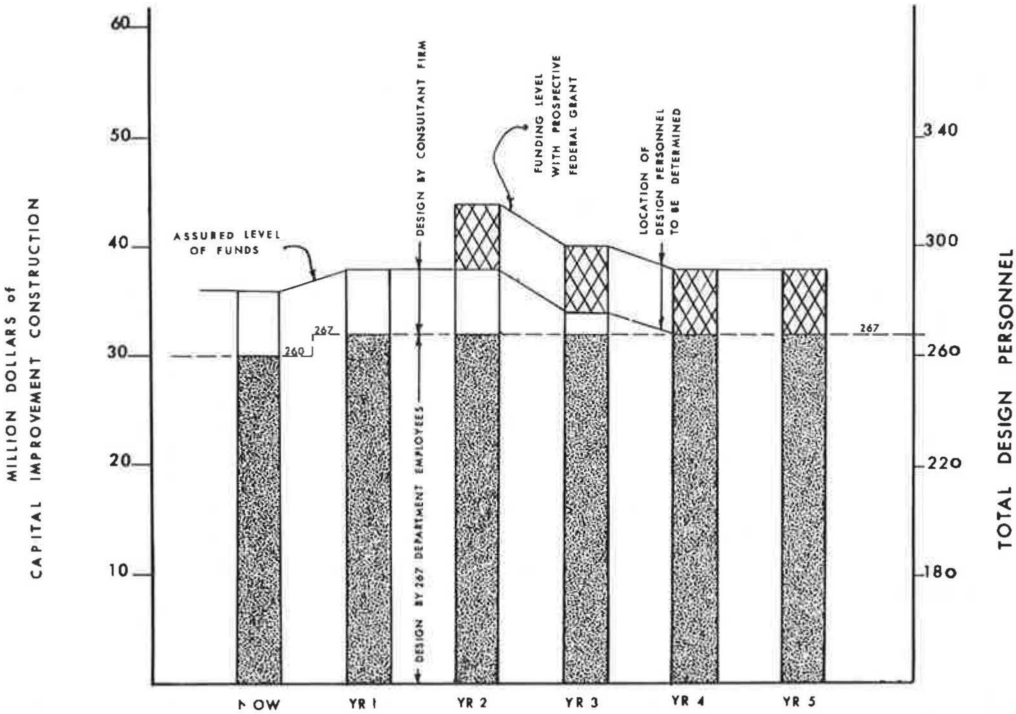


Figure 9. Time-scaled arrow diagram (original scale: 1 in. = 5 working days).



1. Prepare Design Criteria
2. Design Commission Approval
3. Design Paving & Widening
4. Access Design
5. Finish Paving & Widening
6. Lighting Design
7. Layout & Check Drainage
8. R/W Title Check
9. Landscape Design - Trees
10. Draft Lighting
11. Draft Drainage
12. Draft Paving & Widening
13. Calculate R/W Areas & Appraisal
14. Draft Landscape Design
15. Specs & Est.
16. Check Design
17. Make Revisions
18. Department Review
19. Final Revisions
20. Board of Public Works Approval

Figure 10. Personnel requirements for design of capital improvements.



may be established so that the craft would be fully utilized by activities starting on its early start for a period of 6 months. The activities delayed on that basis might result in full usage for, say, 1 year, at which time new projects would be undertaken.

By relating numbers of personnel to total dollars of construction contracts, we can begin to prepare for fluctuations in the number of projects or construction dollars available. For example, if with the current manpower resources an average of $30 million in contracts is designed each year and if inflation is estimated at 7 percent per year, in 5 years the same manpower could design $42.09 million in contracts. If projections of funds available are generally consistent with the ability to design projects, it could be assumed that current personnel levels are adequate for the next 5 years. Projects that come about through the development of any unexpected funding sources could be expected to be designed by a consulting firm. Figure 10 shows how such an analysis might be presented graphically. The solid portion of the bar indicates that approximately $32 million per year in construction contracts would be designed in-house with the addition of seven people. The portion between the solid and the XX portion of the bars would be let to consultants for design. If in the first year the prospective federal grant proves to be a reality, the department may wish to reevaluate the manpower requirements using the CPM system and perhaps increase the in-house staff.

ACKNOWLEDGMENT

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