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The Critical Path Method

CPM techniques of management control apply to mapping projects.

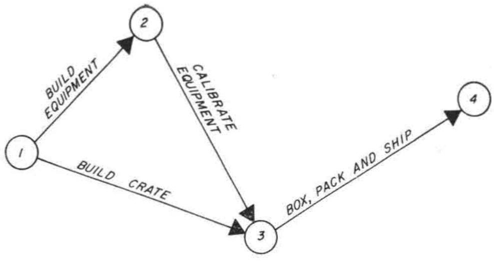

FIG. 1. A simplified network diagram illustrates one of the first steps in a critical path analysis.

INTERNATIONAL AERIAL MAPPING COMPANY has found it convenient, economical, and practical to use the Critical Path Method (*CPM*) as a management tool on photogrammetric projects. This network model system provides a diagrammed display of all project activities and improved project planning and scheduling, thereby giving continuous management control for the duration of the project. Where schedules need compressing, it provides data for activity analysis to save this time at the least cost.

International began using this method in 1963. On more complex projects digital computers were employed to set up the *CPM* schedule and for project monitoring. For the average project a *CPM* system has been evolved which supplies management the desired data without using a computer in a simple, easily operated form. Department supervisors at International use the *CPM* schedules to project their work loads which in turn provides us the data for determining our resource limitations.

Properly used, the networks model method gives management:

- Full project duration and cost data.
- Earliest feasible start and latest permissible completion time for each project activity.
- Identification of critical activities. (An activity is critical if a delay in its timing would cause the same delay in project completion).
- The critical path or paths for the project. (A critical path is a chain of critical activities extending in time from project start to completion; the sum of critical path activity durations equals the project duration; a project may have more than one critical path).
- The amount of latitude or "Float" available for non-critical activities. (In general, "Float" may be considered to be the difference between the time available and the time required to complete an activity.
- Provides the basis for preparing the estimate, project cost accounting and progress reporting. (Used for reporting progress the status can be seen at a glance, insuring that essential activities will not be overlooked).
- Where schedules need compressing, it serves to display the critical activities thus avoiding overtime pay and other crash costs on non-critical project activities.

A SIMPLE PROJECT will serve to illustrate the fundamentals of arrow diagramming a network model. (Figure 1). The rules for establishing a network are:

★ Arrow length is governed only by convenience and need for clarity; it does not indicate the importance or duration of an activity.
★ Arrow direction has no vectorial significance; it merely indicates the general progression of time.
★ The start or termination of an activity is an "Event" and is represented by a circle. All activity arrows must begin and end in "Events."
★ Arrows originating at an event indicate activities that can begin only after all activities terminating at that event have been completed.

Generating an arrow diagram is partly a trial and error process. The most useful equipment is a good eraser. Three questions that help to plot activities are:

1. What can be done at the same time that this activity is being performed?
2. What must be done before this activity can be started?
3. What can't be started until this activity is completed?

Using these rules and questions and exam-

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ining each activity in Figure 1 establishes that:

- Activities 1–2 and 1–3 can be done at the same time. None of the activities must be done before them and Activities 2–3 and 3–4 can't be started until 1–2 and 1–3 are completed.
- For Activity 2–3, Activity 1–3 can be done simultaneously. Activity 1–2 must be done before it, and Activity 3–4 can't start until Activity 2–3 is completed.
- For Activity 3–4, no activity can be done simultaneously. 1–2, 1–3 and 2–3 must be done before it and no activity depends upon its completion.

In planning a project, the first step is to establish a breakdown of the project into activities. The principles of network diagramming are used in defining these activities. The organization of the activities and the diagram must be closely examined during the planning stage. Does it contain the right amount of detail for the person who will use it. Are there too many minor details which could be lumped into one major task? On the other hand, does the diagram gloss over details which must be monitored if real control is to be maintained?

ABSTRACT: *The Critical Path Method (CPM; PERT) for scheduling and project monitoring has the same advantages for photogrammetric mapping as it does in other industry. The system provides a display of all the activities for project planning, and for continuous management control for the duration of the project, as well as data which may be needed for compressing work schedules at least cost. Graphic network models help identify the critical elements of an operation, and show how they can best be modified or rescheduled as the work progresses in order to overcome unexpected delays, or take advantage of unexpected early completions. The elements include aerial photography, control surveys, photogrammetric bridging and adjustment, stereo plotting, mosaics, drafting, editing, etc. A computer is used to prepare a Monitor Report that shows project status.*

TO DEMONSTRATE the application of *CPM* methods to a photogrammetric project, the writer chose to develop a network model for the "Sample Estimate" listed in Section 7.3.10, Volume 1, pages 344 and 345 of the Manual of Photogrammetry. This is a fictitious project based on the experience of one of the authors of this chapter of the manual. The best basis for preparing a list of *CPM* activities is the same as that for preparing a time and cost estimate which is to partially quote Chapter 7.3.9 of the manual "a body of accurate data reflecting past experience. To build up such a body, an organization should have a sound cost-accounting system." The other factor to consider is the resources, equipment and personnel, available for assignment to the project. For the purpose of this demonstration, in view of presenting a practical problem, the following resource limitations have been assumed:

One aircraft crew.
9 survey personnel. One 3-man party and one 6-man party; or three parties consisting of three men each.
1 universal plotter for bridging—16 hours a day (2 shifts).
2 plotters full time—32 hours a day (2 shifts) with a third plotter available for limited assignment.
16 draftsmen.

The sample estimate sets the schedule limitations which are:

- Fly early May (before the trees grow leaves).
- Delivery date: December 31 (our demonstration uses the year 1966 to show schedule dates).

THE DAYS CONSUMED by an activity in this developed *CPM* demonstration are derived by using the times in the "Sample Estimate," converted to calendar days on the basis of a 5-day, 40-hour work week. The one exception to the 5-day week is the aerial photography activity which, in practice, is accomplished in good weather, regardless of the week day. A 5-day week is used in this initial effort to generate a suitable schedule. Overtime pay rates, training programs, subcontracting, and other crash cost means are only considered when it is not otherwise possible to develop an acceptable schedule.

Because generating an arrow diagram is a trial and error process, the initial attempt is generally a simple diagram of the major tasks. This simple diagram is along the se-

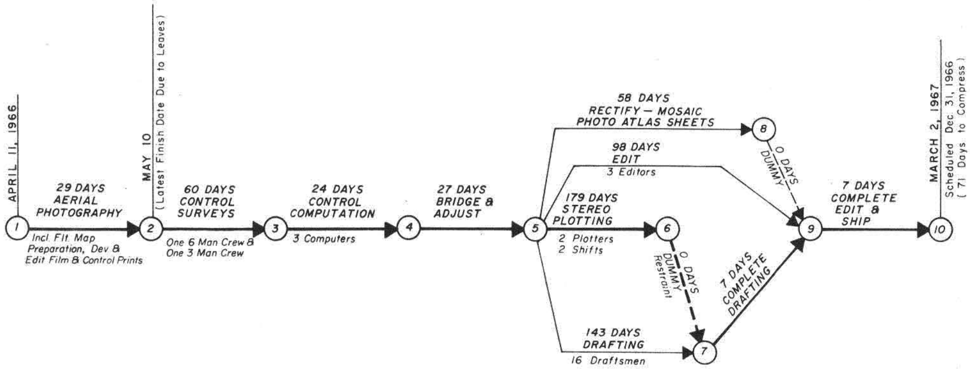

FIG. 2. The *critical path* is shown by the heavy line.

quential completion of activities usually envisioned for a photogrammetric project; aerial photography, control surveys, control computation, bridging and adjustment and simultaneously stereo plotting, drafting and photo atlas sheets followed by completion of edit. (Figure 2).

Activity 8–9 in this diagram is a dummy arrow. This device is used to avoid two activities with the same event numbers. The dummy arrow, 6–7, is used coupled with Activity 7–9 as a lead time restraint to indicate that stereo plotting must be completed seven days ahead of the completion of drafting.

THE CRITICAL PATH of the diagram, Figure 2, is displayed by the heavy line. The sum of the days along this path, 333 days, is the project's duration. Adding 333 days to the starting date, April 11, 1966, sets the completion date as March 2, 1967. This completion date, 71 days beyond the project delivery date, makes it mandatory to review the project planning in order to compress this schedule. Faced with this problem, one would review the plan for more expedient methods. Typical questions we might ask are:

Would the use of Tellurometers reduce the schedule time and cost for Activity 2–3?
How much time and cost would the use of a digital computer save on Activity 3–4?

We chose, however, to solve the schedule compression problem caused by the resource limitations assumed for this network development demonstration without changing the samples; specified times or methods. A satisfactory schedule was developed by more consideration of two of the previously mentioned questions that help plot activities:

What can be done at the same time that this activity is being performed?
What must be done before this activity can be started?

FIGURE 3 IS THE *CPM*-network model developed for this fictitious project. The schedule developed meets the required delivery date without use of crash costs and does not exceed the assumed resource limitations.

The critical path of Figure 3 is indicated by

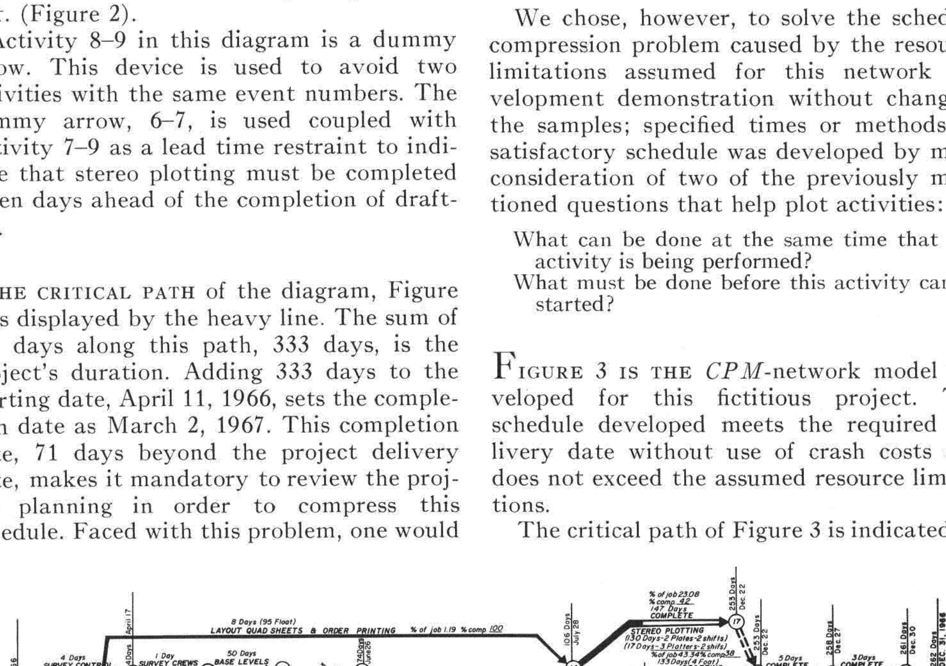

FIG. 3. A network model of the Critical Path Method for a sample project.

the heavier lines. The event dates shown are the earliest starts. The estimated calendar days required to complete an activity and the number of days of float on noncritical activities are listed above the activity description. The latest starting date can be obtained by adding the days of float to the event date. Activities along the path, Events 1 through 6, are shown as critical with "no Float" to assure that the photography is completed prior to tree leafage. Activity 8–9 is also shown critical with "no Float". This is a means of providing five days to complete the computations following completion of all surveys.

Simultaneous accomplishments of the control surveys and aerial photography was made possible by dividing the control surveys into base levels, Activity 5–7, base traverse, Activity 5–8, and then later accomplishing the control ties by side shots to the selected horizontal and vertical photo-identifiable positions, Activity 8–9. By *CPM* rules, Activity 6–8, photo control prints, restricts the start of Activity 8–9 until the aerial photography is accomplished. This division of the control activity also allowed the simultaneous accomplishment of the survey control computations, Activity 8–11 and the side shots to HPT's and VPT's, Activity 8–9.

The bridging, stereo plotting, drafting and mosaicking activities were each divided into Begin and Complete activities. This allowed the compression of the schedule by accomplishing bridging at the same time stereo plotting was being implemented except for the five-day lead provided by Activity 11–12. This division also provided the necessary lead times between stereo, drafting and edit.

It was necessary to plan on using the third plotter for the limited period of 17 days on Activity 14–17 to effect this schedule.

FURTHER COMPRESSION of the schedule would only be possible by crash costs. If this had been necessary, the *CPM* network indicates the critical paths where overtime costs or sub-contracting would shorten the total project length. This method avoids crash cost expenditures on the non-critical activities. A glance at Figure 3 indicates that, within the imposed resource limitations, further effective compression would be possible only along the paths from Events 5 through 11 and Events 12 through 18. A cost study could then be readily made to find out where the schedule could be compressed at the least cost.

The per cent of the job represented by the activity has been placed along each activity as well as a space for reporting the percentage completed. This is a very convenient method of reporting progress and it provides the accounting department the accurate information necessary for company reports. The network paths are double lined by making this line solid when the task is completed or by making a representative percentage solid. The status of the project is displayed instantly.

The planned resources, equipment, and personnel are listed for the key tasks. This furnishes department heads with the information to plan their equipment and personnel assignments. The listing serves as the basis for determining resource limitations on future *CPM* schedules from accumulative work load schedules. Table 1 is an example of a *CPM* activity listing for the sample project. The direct costs were abstracted from the sample estimate and the activity percentage computed from the total.

FIGURE 4 SHOWS A *CPM* schedule prepared on a more complex project for the Galveston District of the Corps of Engineers. Mr. George Mayfield of this District implemented *CPM* methods as a required part of contracts on their photogrammetric projects. The complexity of this project stemmed from the numerous activities and a contract requirement which divided the project into Areas 1 and 2 with different completion dates. This division required a schedule with a duplicate listing of many of the activities with different starting and completion dates. You will note that the upper portion of the *CPM* network is generally the schedule for Area 1 and the lower portion is the schedule for Area 2.

International used the General Electric Project Monitor and Control Method, GE-225 CPM/PROMOCOM system, on this project to compute the *CPM* schedule and for project status reporting. This program, using normal duration and cost, as well as crash duration and cost, computed a series of schedules from normal duration through an all "Crash" schedule. This permitted selection of a suitable schedule at the least cost. Once a *CPM* schedule was selected, a calendar-dated schedule was obtained through the use of the set-up program. Calendar dating was selected on a 5-day week; however, we at our option could have selected a 6- or 7-day week.

The monitor reports provided periodically up-to-date project status reports which

TABLE 1

PROJECT ACTIVITIES; COST, DURATION, EQUIPMENT, PERSONNEL

	Activity	*Cost*	*Duration (Calendar Days)**	*Percent of Project*	*Per-son-nel*	*Major Equipment*
1–2	Planning, Scheduling, CPM	Overhead	3	0.00	1	
1–3	Survey Control Research & Order	9.00	4	0.01	1	
2–4	Flight Map Preparation	4.00	1	0.01	1	
2–14	Layout Quad Sheets & Order Printing	945.00	8	1.19	1	
2–15	Layout Mosaic Boards	35.00	1	0.04	1	
3–5	Survey Crew Mobilization	275.00	1	0.35	9	2 vehicles—survey equipment
4–6	Aerial Photography	1,940.00	23	2.44	2	180 Cessna—6″ distortion camera
5–7	Base Levels	2,797.00	50	3.51	3	1 vehicle—self leveling level
5–8	Base Traverse	4,028.00	36	5.06	6	1 vehicle—Theodolite
6–8	Photo Control Prints, Dev. & Edit Film	141.00	5	0.18		Laboratory facilities
6–10	Diapositives	1,062.00	14	1.33	1	LogEtronic Printer
6–26	Photo Index & Delivery Contact Prints	93.00	3	0.12		Laboratory Facilities
8–9	Side Shots to HPT's & VPT's	2,126.00	19	2.67	6	2 vehicles, Theodolite, Level
8–11	Survey Control Computations	1,250.00	24	1.57	3	
9–11	Demobilization	275.00	1	0.35	9	
11–12, 12–13	Bridge—Compute—Adjust	4,575.00	27	5.75	3	One Universal Plotter—2 shifts
12–14, 14–17	Stereo Plotting	18,380.00	169	23.08	4	2 shifts on 2 plotters for 152 days
					6	2 shifts on 3 plotters for 17 days
12–15, 15–22	Mosaic Templates	660.00	30	0.83	1	
14–16, 16–18 18–19	Drafting	34,512.00	148	43.34	16	
16–19, 19–20	Edit	5,177.00	108	6.50	3	
15–21, 22–23	Ratio Prints	175.00	8	0.22	1	
21–23, 23–24	Mosaic Assembly	305.00	15	0.38	1	
24–25	Mosaic—Copy—Reproduce—Mount	342.00	5	0.43		Laboratory Facilities
20–26, 25–26	Pack & Ship	500.00	1	0.63	1	
		79,606.00		100.00		

* 5-day week, 40 hours, converted to calendar days.

resembled the original calendar-dated schedule. The monitor output is designed to retain the schedule and deadlines originally set up and, at the same time, display the results of actual progress and the weighted earnings. This is accomplished by:

- ◑ Retaining scheduled start and finish dates.
- ◑ Basing latest start and latest finish dates on the scheduled project completion date.
- ◑ Adjusting earliest start and earliest finish dates to show the effect of actual progress on the project.
- ◑ Calculating "float" as elapsed working time from earliest finish to latest finish. "Float" may be negative. The schedule is set back by the magnitude of the negative float.

FIGURE 5 ILLUSTRATES the first page of a monitor report on this project. The upper right hand corner contains the key information regarding the overall status of the project. The status column flagged an activity "overdue" if all preceding activities were finished and it had not started even though it was not yet scheduled to start or the activity was not finished by the earliest finish date.

The week's "float" entries indicated the overall punctuality or delay. A negative float meant that unless immediate correction action was taken the whole project would finish late. The Early/Late entry measured how close the schedule was being followed. The Gain/Loss entry measured the activity with respect to the amount of duration time actually used against the time scheduled.

On other projects the Bendix G-15 CPM/PERT system has been employed for *CPM* computations, and similar programs are available on many digital computers. *CPM* was originated in 1957 by Remington Rand Division of the Sperry Rand Corporation for E. I. DuPont de Nemours & Co. The management consulting firm of Booz, Allen and Hamilton developed the original PERT system for the U. S. Navy Special Projects Office in 1958. Since that time, both methods have been modified, each borrowing the best features of the other until the distinguishing features are blurred and their vocabularies overlapping.

IN SUMMARIZING International's experience using *CPM* for scheduling and project monitoring, it is believed that all the advantages of this system are as applicable to photogram-

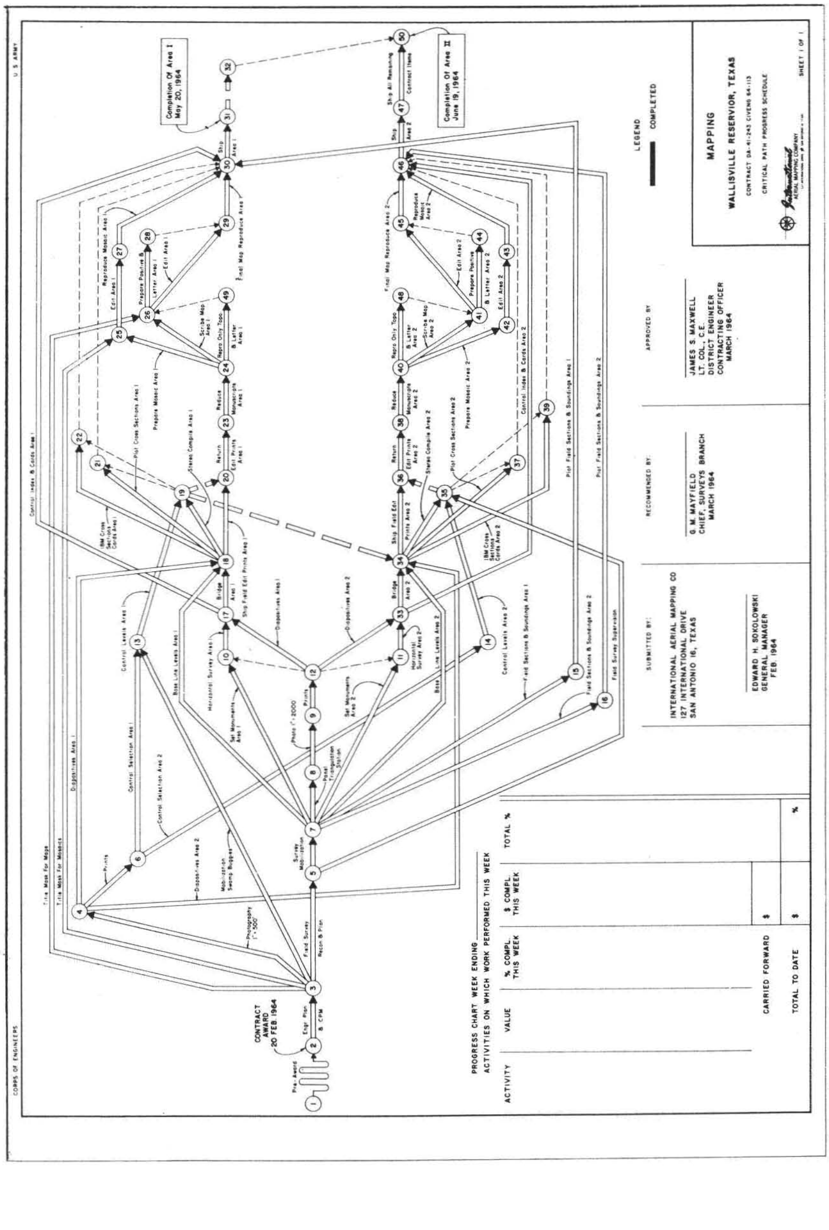

FIG. 4. A critical path schedule for an actual project.

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                                     SPECIAL MONITOR COMPLETION REPORT                                  PAGE   1
WALLISVILLE RESERVOIR PROJECT                                         INTERNATIONAL AERIAL MAPPING CO      RUN DATE FEB 25, 1964
                                                                                         SCHEDULED PROJECT FINISH= 14JUL64
                                                                                          EXPECTED PROJECT FINISH= 08JUL64

  OPTIONS-  PUSHED FULL        RESORT KEY  IJ                    EFFECTIVE  21FEB64  PROJECT STATUS,    AHEAD      4 DAYS

ACTIVITY    STATUS     DURATION                 START DATES                      FINISH DATES            WK/DA      EARLY  GAIN  SL
  I    J              SCHED  USED        SCHED  EARLIEST  LATEST       SCHED   EARLIEST  LATEST        FLOAT       LATE  LOSS  IP

  1    2               0/0    0/0                                        03FEB64  FINISHED 03FEB64
           PRE-AWARD                            WEIGHTED VALUE    -NONE     PERCENT COMPLETE 100%

  2    3               0/4    0/4                                        07FEB64  FINISHED 07FEB64
  101      ENG PLAN FH PLAN + CONT DA           WEIGHTED VALUE $ 2,800     PERCENT COMPLETE 100%    WEIGHTED EARNING $ 2,800

  2    32   OVRDUE     0/0              03FEB64  03FEB64  14JUL64        03FEB64  21FEB64  14JUL64     +20/2              -2/4
           DUMMY                                WEIGHTED VALUE    -NONE

  3    4               1/2    1/3                                        18FEB64  FINISHED 18FEB64
  202      AERIAL PHOTOGRAPHY                   WEIGHTED VALUE $ 2,340     PERCENT COMPLETE      %

  3    5               0/2    0/2                                        11FEB64  FINISHED 07FEB64                 +/2   +/2
  303      FLD SURVEY RECON + PLAN              WEIGHTED VALUE $   300     PERCENT COMPLETE 100%    WEIGHTED EARNING $   300

  3    13              1/0    0/2                                        14FEB64  FINISHED 17FEB64                 -/1   -/1
  306      3 MOR SWAMP BUGGIES + DRIVER         WEIGHTED VALUE $ 1,220     PERCENT COMPLETE 100%    WEIGHTED EARNING $ 1,220

  3    25              0/3              07FEB64  STARTED  19FEB64        12FEB64  24FEB64  06JUL64     +19/0      -1/3  -1/3
           PREP TITLE + BDR MASK MOSA           WEIGHTED VALUE $    34     PERCENT COMPLETE  50%    WEIGHTED EARNING $    17

  3    26              0/3              07FEB64  STARTED  19FEB64        12FEB64  24FEB64  03JUL64     +18/4      -1/3  -1/3
           PREP TITLE + BDR MASK MOPS           WEIGHTED VALUE $    34     PERCENT COMPLETE  50%    WEIGHTED EARNING $    17

  4    6    OVRDUE     1/0              18FEB64  STARTED  10FEB64        25FEB64  21FEB64  INFINITY               +1/1   +/2
  202      PROCESS FILM-EDIT-CONT-LIN           WEIGHTED VALUE $ 2,180     PERCENT COMPLETE  95%    WEIGHTED EARNING $ 2,071

  4    18   OVRDUE     2/0              18FEB64  18FEB64  05MAR64        03MAR64  06MAR64  19MAR64     +1/4                -/3
  215      2 PREP 1 #500 DIAP AREA 1            WEIGHTED VALUE $ 1,496

  4    34   OVRDUE     2/0              18FEB64  18FEB64  14APR64        03MAR64  06MAR64  28APR64     +7/2                -/3
  215      2 PREP 1 #500 DIAP AREA 2            WEIGHTED VALUE $ 1,040

  5    7    OVRDUE     0/2              11FEB64  07FEB64  22MAY64        13FEB64  25FEB64  26MAY64     +13/0              -2/0
  303      6 FLD SURVEY MOBILIZATION            WEIGHTED VALUE $ 3,725

  5    35             14/0              11FEB64  STARTED  07FEB64        19MAY64  15MAY64  02JUN64     +2/2       +/2
  303      1 FIELD SURVEY SUPERVISION           WEIGHTED VALUE $ 6,664     PERCENT COMPLETE  17%    WEIGHTED EARNING $ 1,133

  6    13              0/3    0/4                                        28FEB64  FINISHED 20FEB64                 +1/1  +/4
  409      CONT SELECTION AREA 1                WEIGHTED VALUE $   480     PERCENT COMPLETE 100%    WEIGHTED EARNING $   480

  6    14              0/3    1/0                                        28FEB64  FINISHED 21FEB64                 +1/0  +/3
  409      CONT SELECTION AREA 2                WEIGHTED VALUE $   320     PERCENT COMPLETE 100%    WEIGHTED EARNING $   320

  7    8               0/2    0/0                                        17FEB64  FINISHED 08FEB64                 +1/0  +2/3
  304      3 PANEL USC+GS TRIANG STA            WEIGHTED VALUE $   890     PERCENT COMPLETE 100%    WEIGHTED EARNING $   890
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FIG. 5. A page of the Monitor Report for an actual project.

metric projects as they are to those of the heavy construction industry where it is so widely acclaimed. The projects have estimates and activity patterns which parallel those of this industry with only the nomenclature changing.