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INTRODUCTION TO PROJECT LOGIC PLANNING

Berkeley, California

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INTRODUCTION TO PROJECT LOGIC PLANNING

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I. INTRODUCTION

Over the past several years considerable work has been done in developing methods for the management of large-scale projects. The approaches to the problem have been varied, ranging from the development of elaborate bar charts to the use of sophisticated statistical analyses.

In 1956, a study was commenced by the Integrated Engineering Control Group of E. I. du Pont de Nemours and Company to find methods for using electronic computers as an aid in the planning of complex projects. From this early work there have developed two principal computer methods for the processing of project-planning information. The first is the Critical-Path Method (CPM), now widely used in the planning of complex business projects such as those found in the construction industry. The other is the Program Evaluation and Report Technique (PERT) developed for the planning and control of large government contracts.

Our initial work with the Critical-Path Method was limited to relatively small projects for which the logic diagrams contained only one or two hundred activities. The data were processed by means of an IBM 650 computer, using the IBM LESS program. After this program had been used for the planning of several projects, it was found that CPM showed promise for planning larger projects.

As the projects we were working with became larger, we were confronted with three principal problems:

1. Limits on the number of activities (arrows) in the project.
2. Problems in renumbering events.
3. Problems of relating working time with calendar time when not all craft and personnel were working the same number of days per week or the same number of shifts per day on the project.

In view of these problems we decided to use a larger and more flexible computer program. We soon found that there was no existing program for a medium-size computer that would solve our basic problems. In view of our requirements, a unique approach providing a solution to the problem was conceived. The new technique allows for more and randomly numbered node points to be used and also provides for an exact relationship of working time with calendar time. Once the basic technique had been conceived, expert

assistance was obtained from the Accounting Department Programming Group in the development of the new computer program.[1] The name PROLOG (short for project logic) has been given to this LRL version of the Critical-Path Method.

The PROLOG method for project planning has now been in use at LRL on an evaluation basis since February 1962. Two major projects currently using this technique to plan and schedule operations are ASTRON (fusion power device) and the major Bevatron improvement program. The results from both of these projects have been gratifying, and indicate that use of the PROLOG method of planning will be extended to include other areas of work at the Laboratory.

II. PREPARATION OF THE PROJECT LOGIC DIAGRAM

The application of the PROLOG method is dependent upon the preparation of a logic network called an arrow diagram. This is simply a graphical representation of the sequence of jobs or activities within the project. The arrow diagram is actually the plan for the project and, by necessity, must be prepared by those persons who have the responsibility for planning the overall project. These persons are normally senior project engineers and coordinators who have a broad understanding of the project. The arrow diagram may be prepared in rough form by one or more of the above persons, but in any case the initial preparation should be done by a group small enough to work from the same piece of paper.

In preparation of an arrow diagram the following general conventions have been developed. An example of an arrow diagram is shown in Fig. 2.

a. Each activity (job) in the project is represented by an arrow.
b. Each arrow is connected to one or more arrows at a node that is represented as a circle and called an "event."
c. The tail of the arrow represents the start of an activity and the head represents the completion of an activity.
d. The length of an arrow has no significance; the arrow shows only the progression of time and the direction toward an "event."
e. All activities leading into an event must be complete before an activity leaving that event can start.
f. Each event is identified by a unique number.
g. Each activity arrow is identified by its pair of related event numbers.
h. The network may begin or end at more than one event, but all paths through the network must be continuous.
i. Loops within the network are prohibited.

In the preparation of a project logic diagram, the following three questions must be answered for each activity in the project:

1. What jobs must be completed before this job can start?
2. What other jobs can be done at the same time as this job?
3. What jobs cannot be started until this job is done?

[1] Sylvia Hutchison, one of our most experienced programmers, played an important role in developing the computer logic associated with the relationship of working time to calendar time.

Examples of the graphical representation of the logical sequence of activities are shown in Fig. 1.

We normally start the preparation of the diagram with a list of those activities we know must be done. As we assemble these jobs into a logic network, we ask the above three questions for each activity and fit it into the network in its proper position. It makes little difference where you start the network. Some prefer to start at the end and work backward; some start at the beginning and work forward; and others start in the middle and work in both directions.

The important thing to remember in the preparation of the diagram is to correctly show the flow of work through the project. Since this is not a vector technique, the lengths and directions of the arrows have no significance other than to show the accomplishment of work with the passage of time. It is best to ignore time durations and estimates of job effort at this point and, instead, concentrate entirely upon the logical representation of activities in the diagram.

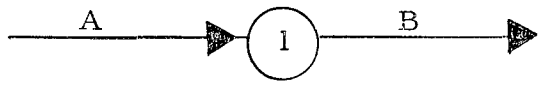
After the diagram has been drawn, time durations and manpower requirements are added to the network. We should at this stage assume that most jobs use the number of men that can do the job most effectively. For example, the job of splicing high-voltage cables would normally require two men and if more were used they would tend to get into each other's way. In many types of work past experience will readily provide the estimates both for duration and for number of men required.

Once the diagram has been drawn, we have a complete plan for the overall project. The sequence of activities is then available for everyone associated with the project to study. The value of this diagram as a communication tool cannot be overlooked. The project can now be discussed in terms of specific activities, and those participating in the discussion are certain of exactly which jobs are being examined. Our experience has shown that if the Project Logic diagram is used for no purpose other than for the communication of thoughts, the effort required to prepare it is more than justified. This, however, is just the first of the many benefits that can come from the PROLOG method.

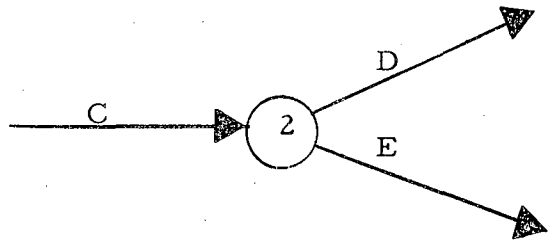
III. DETERMINATION OF THE PROJECT DURATION AND THE ACTIVITY FLOAT

Once the PROLOG diagram has been made and time durations have been estimated for each activity, we can determine the shortest length of time required to complete the project.

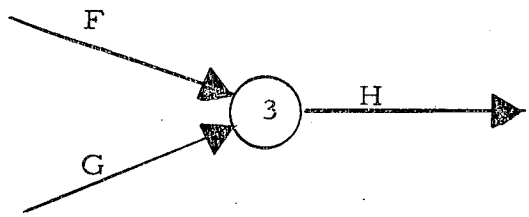
In the PERT method, scheduled times for the achievement of key events are used as milestones against which calculated completion times are measured in terms of statistical probability. Hence, we refer to the PERT method as being event-oriented. In PROLOG and other versions of the Critical-Path Method, activities are diagramed in their logical sequence, and only after this planning phase are times associated with activities. Hence, we refer to the Critical-Path Method as being activity-oriented.



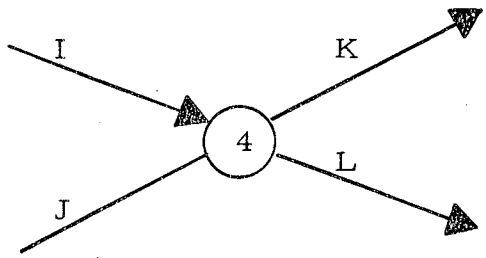
Activity A must be complete before activity B can begin.



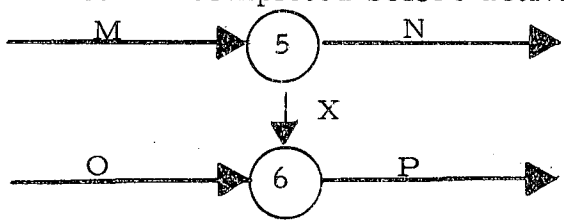
Activity C must be complete before activities D and E can begin.



Activities F and G must both be complete before activity H can begin.



Activities I and J must both be completed before activities K and L can begin.



Activities M and O must be complete before activity P can begin. Only activity M must be complete before activity N can begin. The arrow X, called a dummy, is used only to represent a restraint but is not an activity itself.

Fig. 1. Graphical representation of the logical sequence of activities.

To show how PROLOG is used to determine project duration and to further show how network data can be analyzed, let us examine the sample diagram shown in Fig. 2. We can see that there are three paths leading from event 1 to event 8. These paths are through events 1, 2, 3, 6, 4, and 8; through 1, 2, 7, 6, 4, and 8; and through 1, 2, 5, 4, and 8. The length of time required to cover these paths would be 11 days for the first, 15 days for the second, and 10 days for the third. We see then that the longest chain of sequential activities has a duration of 15 days. This particular path is called the critical path and each activity along this path is a critical activity. Since the project cannot be completed until all component activities are completed, it is seen that the length of the critical path determines the shortest possible duration of the project.

If any activity lying on the critical path were to be assigned a longer duration, we would find that the project duration would increase. If we examine the other two paths, we find that the first path of 11 days' duration could be lengthened by 4 additional days without increasing the project duration of 15 days. Similarly, the second path of 10 days' duration can be extended by 5 days without increasing the project duration. The length of time an activity can be delayed without delaying the project completion is called <u>float</u> or <u>slack</u>.

In the mathematical model developed for solving network flows, we find that we can calculate the earliest time at which any given event can be completed and also the latest time at which any event may be reached without exceeding the limits of the project duration. In order to determine the earliest event time, we examine all the chains of activities leading to the event and determine the time required to travel along the longest chain. Since all activities leading into an event must be completed before any activities leading out of the event may start, we find that the length of the longest path of arrows leading to an event determines the earliest time at which activities leading from the event may start. This calculated value is the <u>earliest event time</u> and is given the notation T_E.

Once the project duration has been calculated, we can work backward along the various paths through the network and subtract the duration of each activity along the chain from the total project duration. The lowest value obtained by examining each chain of arrows leading backwards into an event determines the latest time at which the activities leading from the event can start without increasing the project duration. This calculated value is the <u>latest event time</u> and is given the notation T_L.

Now we have determined time limits for any activity within the project. We know that the activity cannot start until the earliest event time (T_E) for the event from which the arrow leaves and, also, that the activity must be completed before the latest event time (T_L) for the event to which the arrow leads. This time interval is the available time in which the activity must be accomplished. We see that the relationship is

$$\text{Available time} = T_L - T_E.$$

Knowing the length of time available for accomplishing a given activity and also the duration of the activity (D), we can now determine how long the

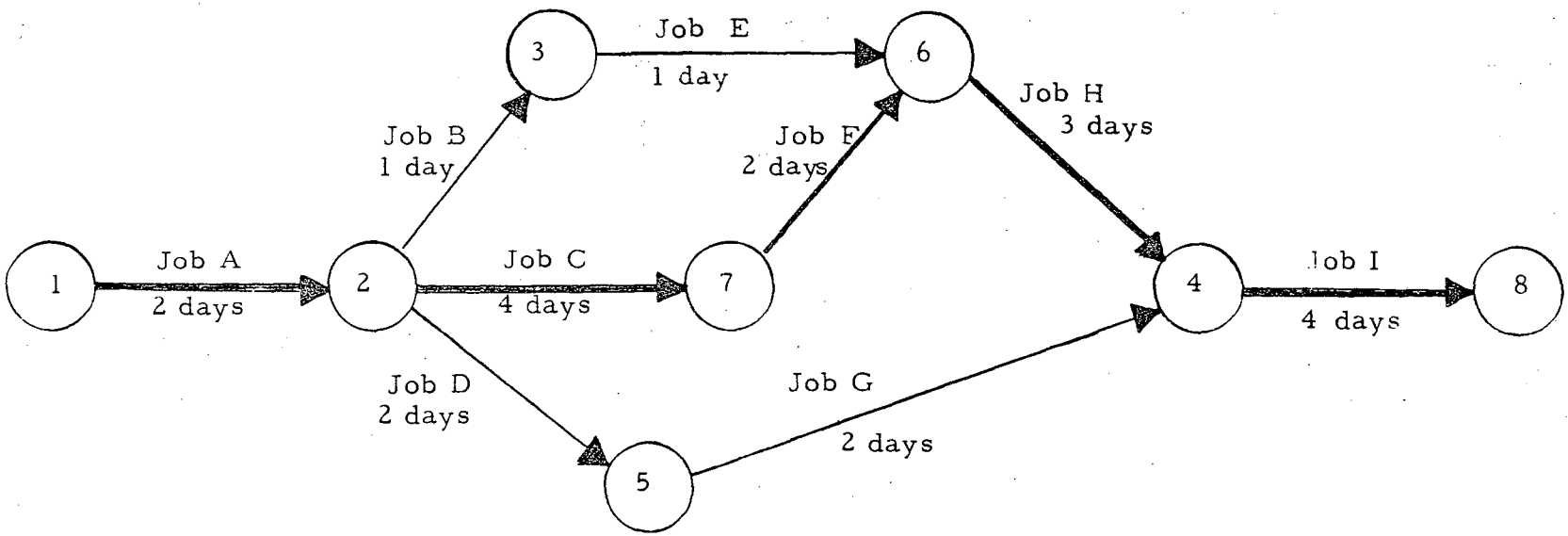


Fig. 2. An example of the sequential arrangement of activities within a project. This is commonly referred to as an "arrow diagram" or "Project Logic diagram."

activity can be delayed without delaying the overall project duration. The difference between available time and activity duration is called total float (TF) and may be expressed as

$$\text{Total float} = \text{Available time} - \text{Activity duration}$$

or

$$TF = (T_L - T_E) - D .$$

Since there are many activities within the project, we associate each with its corresponding event numbers. The beginning end (tail) of the arrow representing an activity is called the i end and the completion end (head) is called the j end. To show the total float for any specific activity within the project, we must expand the notation used above to

$$TF_{ij} = T_L^{\,j} - T_E^{\,i} = D_{ij} .$$

The above expression says that the total float for the activity lying between events i and j is equal to the latest event time for the event at the head of the arrow, minus the earliest event time for the event at the tail of the arrow, minus the duration of the activity. By similar means a great deal more information can be developed through the use of network analysis. We see that the information developed relates to each activity within the project, and this is what is meant when it is stated that CPM is activity-oriented. PERT, on the other hand, is concerned principally with the probability of reaching a given event by a given time, and hence is said to be event-oriented.

IV. COLLECTION AND PROCESSING OF DATA

After the arrow diagram has been prepared, it is necessary to obtain estimates for the duration of each activity in the project. These estimates are based upon the length of time it is expected the job will take when a fixed number of men is used. It should be noted at this point that activities such as the delivery delay time for purchased materials can also be shown in the arrow diagram and can be assigned a time duration.

The estimated durations are entered onto a data sheet along with other data and then forwarded to the Data-Processing Department for processing by means of the PROLOG computer program developed for use at this Laboratory. Estimating of an activity duration is often difficult because of the lack of any previous experience or because of unknown factors. It is recognized that these durations may not be exact, but in reality no other person can give a more accurate estimate than the project engineer responsible for the performance of the job. If later these estimates prove to be in error, the revised duration can be entered into the computer data, and the actual effects of the change in relation to other project activities will quickly become apparent. This ability to change estimates to fit the current facts and to quickly evaluate the effects of these changes equips the project management with a powerful tool for taking positive action based upon facts.

The LRL PROLOG Program and its Limitations

The current program for processing CPM data is based upon the use of an IBM 1401 Computer with an 8,000-character memory and magnetic-tape units. The limitations and features of the program are:

1. There may be no more than 999 events (nodes) in the arrow diagram, but there is no limit on the number of activities within the project.
2. Events do not have to be in numerical sequence but are subject to the limitations that
   (a) the same number may not be used more than once,
   (b) event numbers must be between 001 and 999 (numbers can be skipped if desired),
   (c) the last event in the network must be the highest-numbered event used in the diagram.
3. Any number of arrows can be placed between the same pair of event numbers to show different crafts working concurrently on the same job.
4. The project duration can be expressed in units such as days, weeks, or months so long as one unit of time is used consistently.
5. The duration can be expressed in terms of man-shifts, so that differences in the number of shifts per day for each craft involved are taken into account in calculating the project duration. (For example, if a job is completed at the end of the day shift, the job following in sequence is calculated as starting on the swing shift if craft people are normally available. If no swing-shift people are available for that particular craft, the program skips to the next normal work shift to calculate the elapsed duration of the sequence of jobs.)
6. The maximum project duration cannot exceed 999.9 units of time.
7. Account numbers to which job costs are to be charged may be included in the data.
8. Job-Order serial numbers may be included in the data.
9. A code for the person responsible may be included in the data.

Input-Data Format

For the project data to be understood by the computer it is necessary that the information known for each activity in the project be prepared in a standard format so that tabulating cards can be keypunched. To illustrate the method for input-data preparation an arrow diagram for the design and construction of a research magnet is shown in Fig. 3. This diagram shows the logical sequence and duration (in weeks) for each activity in the project. The data sheet for this diagram is shown in Fig. 4 and includes the following:

Card Columns	Symbol	Description
1-3	i	Beginning event number
4-6	j	Ending event number
7-8	CC	Craft code, which may be alphabetical or numerical
9-12	D	Activity duration, expressed in units and tenths of units
13-14	NM	Number of men required by the activity
15-16	SB	Shift-basis code (see Data-Processing Department for details)
17-22	J. O. Serial	6-digit Job-Order serial number
23-24	PR	Initials of person responsible
25-26	ID	2-digit designation assigned to the project
27-32	Account	6-digit account number
33-64	Job description	32-character description of the activity
75	--	"X" punch to identify data card

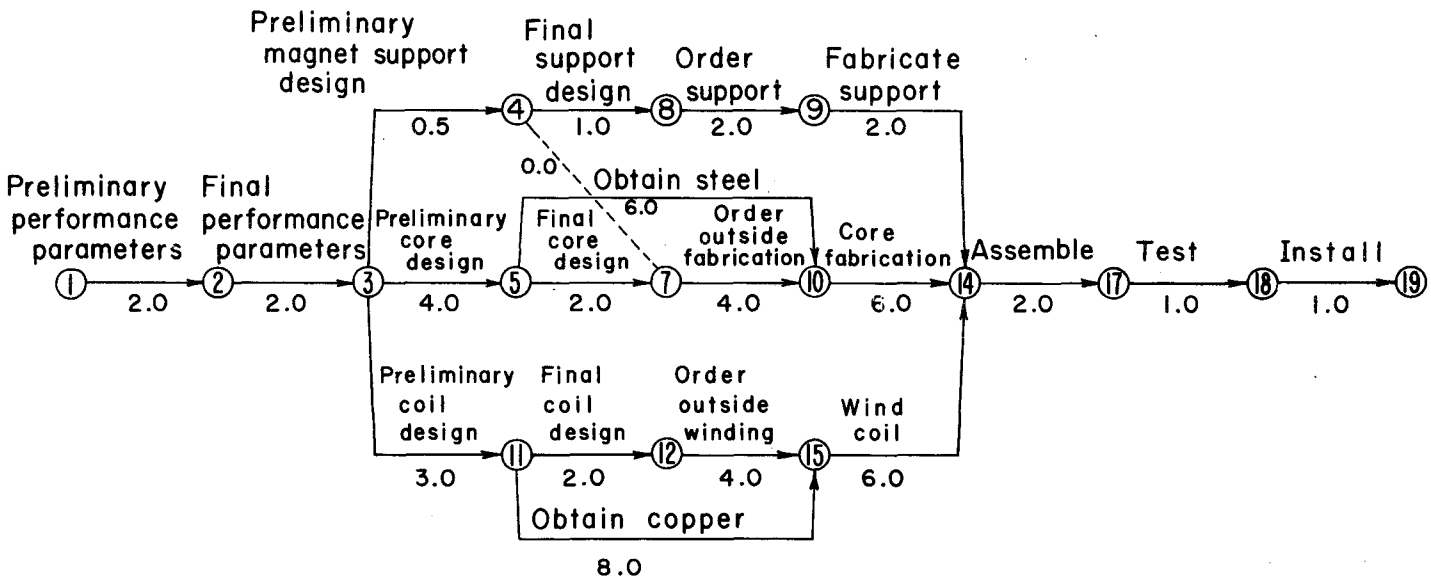


Fig. 3. Arrow diagram for the design and construction of a research magnet, showing the sequence and time duration for each activity. (Durations are shown in weeks.)

PROLOG DATA SHEET

PROJECT IDENTIFICATION: RESEARCH MAGNET PROJECT

PAGE 1 OF 1

i	j	CC	D	NM	SB	J.O. SERIAL	PR	ID	ACCOUNT	JOB DESCRIPTION
1-3	4-6	7-8	9-12	13-14	15-16	17 - 22	23-24	25-26	27 - 32	33 - 64 X PUNCH (11) ALL CARDS IN COLUMN 75
001	002		0020		37			06		PRELIM PERFORMANCE PARAMETERS
002	003		0020		37			06		FINAL PERFORMANCE PARAMETERS
003	004		0005		37			06		PRELIM MAGNET SUPPORT DESIGN
003	005		0040		37			06		PRELIM CORE DESIGN
003	011		0030		37			06		PRELIM COIL DESIGN
004	008		0010		37			06		FINAL SUPPORT DESIGN
005	007		0020		37			06		FINAL CORE DESIGN
005	010		0060		37			06		OBTAIN STEEL
007	009		0000		37			06		JOB DEPENDANCY
007	010		0040		37			06		ORDER OUTSIDE FABRICATION
008	009		0020		37			06		ORDER SUPPORT
009	014		0020		37			06		FABRICATE SUPPORT
010	014		0060		37			06		CORE FABRICATION
011	012		0020		37			06		FINAL COIL DESIGN
011	015		0080		37			06		OBTAIN COPPER
012	015		0040		37			06		ORDER OUTSIDE WINDING
014	017		0020		37			06		ASSEMBLE
015	014		0060		37			06		WIND COIL
017	018		0010		37			06		TEST
018	019		0010		37			06		INSTALL

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Fig. 4. PROLOG data sheet for arrow diagram of research magnet project shown in Fig. 3.

Computer Output Listings

After the computer program has processed the input data, various listings of the output data can be prepared. There are several sequences in which the information can be presented in order to make it meaningful, and some of the ways in which the output data have been arranged are as follows.

1. i-j Listing

This listing is sequenced by the order of the "i" nodes of each arrow in the diagram. The computer output listing for the sample project diagram is shown in Fig. 5. It is a master tabulation of all the jobs within the project and contains all the input information on the input-data cards as well as the calculated values for start times and floats. The following information appears for each job:

(a) earliest start time,
(b) latest start time,
(c) earliest completion time,
(d) latest completion time,
(e) free float (the length of time an activity can be delayed without delaying the earliest start time of the following job), and
(f) total float (the length of time an activity can be delayed without increasing the total project duration).

2. Person-Responsible Listing

The information contained is identical to that in the master "i-j" listing, but it is arranged so that all the jobs for which each project engineer or coordinator is responsible are grouped together and arranged in order of their earliest start times. This listing allows the individual project engineer to get current status information on his jobs without having to search through the entire listing.

3. Craft-Code Listing

This is similar to the "Person Responsible" listing except that in this case the jobs are arranged by craft in the order of their earliest start times. A supervisor using this list can see all the jobs requiring effort from a given craft and, at the same time, find out when this effort will be required and how important each job is with respect to other jobs in the project.

4. Earliest-Start-Time Listing

In this the jobs are arranged by their earliest start times. This arrangement gives project management a quick picture of those jobs that can be started now. It is a useful tool for the project management to use for allocating their available resources (men, equipment, money, etc.).

5. Total-Float Listing

The jobs are arranged in sequence of ascending total float. Here again is a management-type listing that can give the project management an overall picture of where the critical areas of the project lie. With this type of information available, problems can be anticipated and changes can be made in the overall project plans to eliminate the troubles long before the work progresses to that point.

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ARROW I	ARROW J	CC	DURATION	NM	SB	J.O. SERIAL	PR	ACCOUNT NUMBER	JOB DESCRIPTION	START TIME EARLY	START TIME LATE	COMPLETION EARLY	COMPLETION LATE	WEEKS OF FLOAT FREE	WEEKS OF FLOAT TOTAL
001	002		2.0		37			-	PRELIM PERFORMANCE PARAMETERS	.	.0	2.0	2.0	.0	.0
002	003		2.0		37			-	FINAL PERFORMANCE PARAMETERS	2.0	2.0	4.0	4.0	.0	.0
003	004		.5		37			-	PRELIM MAGNET SUPPORT DESIGN	4.0	15.5	4.5	16.0	5.5	11.5
003	005		4.0		37			-	PRELIM CORE DESIGN	4.0	5.0	8.0	9.0	.0	1.0
003	011		3.0		37			-	PRELIM COIL DESIGN	4.0	4.0	7.0	7.0	.0	.0
004	008		1.0		37			-	FINAL SUPPORT DESIGN	10.0	16.0	11.0	17.0	.0	6.0
005	007		2.0		37			-	FINAL CORE DESIGN	8.0	9.0	10.0	11.0	.0	1.0
005	010		6.0		37			-	OBTAIN STEEL	8.0	9.0	14.0	15.0	.0	1.0
007	004		.0		37			-	JOB DEPENDANCY	10.0	16.0	10.0	16.0	.0	6.0
007	010		4.0		37			-	ORDER OUTSIDE FABRICATION	10.0	11.0	14.0	15.0	.0	1.0
008	009		2.0		37			-	ORDER SUPPORT	11.0	17.0	13.0	19.0	.0	6.0
009	014		2.0		37			-	FABRICATE SUPPORT	13.0	19.0	15.0	21.0	6.0	6.0
010	014		6.0		37			-	CORE FABRICATION	14.0	15.0	20.0	21.0	1.0	1.0
011	012		2.0		37			-	FINAL COIL DESIGN	7.0	9.0	9.0	11.0	.0	2.0
011	015		8.0		37			-	OBTAIN COPPER	7.0	7.0	15.0	15.0	.0	.0
012	015		4.0		37			-	ORDER OUTSIDE WINDING	9.0	11.0	13.0	15.0	2.0	2.0
014	017		2.0		37			-	ASSEMBLE	21.0	21.0	23.0	23.0	.0	.0
015	014		6.0		37			-	WIND COIL	15.0	15.0	21.0	21.0	.0	.0
017	018		1.0		37			-	TEST	23.0	23.0	24.0	24.0	.0	.0
018	019		1.0		37			-	INSTALL	24.0	24.0	25.0	25.0	.0	.0

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Fig. 5. Example of computer printout for project diagram.

6. Other Listings

Various other arrangements have been used, and--in addition--the output data have been processed further to show such information as (a) how many men of each craft would be required during each time period throughout the project, or (b) how many man-shifts of effort would be charged to each account classification. The variety of reports that can be derived from the basic project information is virtually unlimited and offers an interesting area for future investigation.

Updating the Project Data

The PROLOG technique can give valuable information to management, but this information is only as good as the data fed into the program. It is therefore imperative that the logic diagrams be kept current and that job estimates be reviewed on a periodic basis.

Our experience has shown that weekly or biweekly updating is quite effective. The burden for this updating rests upon the persons responsible for following a given sequence of jobs through the project. The person responsible is normally not the individual actually doing the work, but instead is more likely to be an engineer or coordinator. Our practice has been to provide such a person with a list of all those jobs for which he is responsible. By simply marking this sheet in red pencil he can indicate changes in duration or in number of men assigned, or any other changes necessary to show an accurate picture of the current job status.

The corrected listing sheets are then returned to the person having responsibility for maintaining the arrow diagrams. He, in turn, notes the changes on a copy of the master listing and completes the cycle by forwarding it to the Data-Processing group for an updated computer run.

V. SUMMARY

The fundamental technique of Project Logic Planning as it has been used at the Laboratory is simple and can be understood by anyone responsible for project management.

A project manager who has grasped the fundamental principles involved can construct his own PROLOG diagrams for projects in which he is involved. The output data could easily be computed by hand for small networks, but the process can be greatly speeded by use of the computer.

Our objective in designing the PROLOG technique has been to provide a means through which those persons responsible for getting a task done can do their own planning. They, in turn, receive information showing how their task relates to the rest of the project. PROLOG is a method for providing timely information to those persons who are in a position to apply timely corrective action to prevent trouble from developing.

Our experience to date indicates that we have accomplished this objective. In addition we have found PROLOG to be both an effective tool in long-range project planning and an effective means for communication of project-planning decisions.

This work was done under the auspices of the U. S. Atomic Energy Commission.

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