

Final  
copy  
mark

# Helps You Solve Production Problems

Versatile management tool simplifies analysis of complex plant problems. By graphically studying your projects, you can achieve optimum operating conditions—and save money

MOST PUBLICIZED of new management tools to appear in recent years is Critical Path Scheduling (CPS). In '56, Du Pont proclaimed the success of its new scheduling technique known as the Critical Path Method. About the same time, the U. S. Navy was trying out a similar technique for project control called PERT (Program Evaluation and Review Technique). Since then, new versions and refinements have appeared.

Current broad acceptance of CPS may be attributed to two reasons: It simplifies analysis of complex situations, and it is versatile. And from a practical viewpoint, CPS saves money.

## Just What Is CPS?

Critical path scheduling is a way of thinking. It involves the application of appropriate techniques for an orderly analysis of a problem (1). Although the techniques may be grounded in higher mathematics, specific applications appear quite simple, even obvious.

The first step in applying CPS is to draw a picture of the project you are considering. The picture portrays the project as a collection of arrows where each arrow represents a component or activity involved in the project and points forward in time. Arrows are linked together to show the sequence of activities needed to complete the

project. Manipulation of the arrows allows you to consider various ways of conducting the project.

When satisfied that the arrow network reasonably approximates the project, you convert it to a time scale by assigning an estimated duration for each activity. For a complete analysis, the resource requirements (manpower, equipment, materials, etc.) also should be estimated for each activity.

With this information, plus some cost data when needed, you seek an optimum balance between time and resource allocations. The resulting management decision can take a tabular form, or even better, a graphical form which facilitates improved communications.

As illustrated in the food industry example below, only simple arithmetic is involved. However, on a big project, many arithmetic operations will be necessary. Hence, a computer can be helpful.

## Using CPS in Production

So far, most of the CPS applications to industrial production have been associated with new construction, remodeling, or with shutdown maintenance. However, wherever a situation exists that involves many diverse but dependent components to be integrated within time limitations, CPS is an appropriate tool (3). Possible uses

of CPS for production can be divided into three categories:

**1. Specific applications**—CPS as applied to a particular situation which is not likely to occur again in the same form.

These include major projects such as significant modifications of plants or production lines and maintenance or overhaul of key areas.

CPS is employed primarily to coordinate activities for maximum utilization of existing resources and available time. Unlike new construction, this means that plant activities other than the project itself must be considered in the scheduling. Because of the complex relationships likely to be encountered, common computer programs usually may be employed profitably.

In published reports of specific applications, claims are made of the cost being reduced by 25% and more because of the use of critical path methods (2). Particularly for shutdown maintenance, the reputation of CPS is well established. Its utility for long range planning should be apparent. Feasibility studies, disaster planning, and developmental programs are other types of projects within this category.

**2. Re-occurring applications**—CPS as applied to situations which are expected to be repeated occasionally in approximately the same form.

J. L. RIGGS and R. D. LANGMO

School of Agriculture and Agricultural Experiment Station, Oregon State University, Corvallis, Oregon

## Table I. Activity and Restriction List

*For the preparation of a corn processing line  
in a multi-product freezing plant.*

Activity	Prerequisite to:	Est. time in days	Crew needed
A Review equipment & establish repairs	B, I, M	3	2
B Disassemble huskers & cutters	D, E	11	3
C Processing green beans	K, L, P	—	—
D Repair huskers, install 2 new drives	O	60	2
E Repair cutters	Operate	40	1
F Order ensilage bunker material	G	7	—
G Build ensilage bunker	H	30	2
H Extend waste conveyor to bunker	Operate	4	2
I Subcontract cob saw repair	J	60	—
J Install cob saw	O	2	1
K Hook up steam & cooling water	O	1	1
L Transfer motors & lights	N	2	4
M Order belts	N	7	—
N Install belts	O	2	2
O Test run, adjust & wash down	Operate	2	4
P Prepare receiving & freezing facilities	Operate	2	2
OPERATE			

Here, the emphasis is on assignment responsibility and operational control. Certainly the preplanning, analysis, and time considerations which characterized specific applications remain pertinent. But because of the familiarity inherent in repetition, the greater need is for improved regulation.

The first step in exploring recurring situations is to determine if the existing way of doing things is optimal. An arrow network used for such a survey functions as a flow process chart or man-machine chart on a system rather than operations level.

Criteria for optimality could include one or more of the following conditions: crew size, make-up of the crew, supervision responsibility, machine or product priority, material availability, time and space restrictions, or other factors dependent on management decisions.

The decisions made during the first planning step are then portrayed graphically. The resulting time chart is completed by noting appropriate assignments on it. In this form it serves as a preplanned program for the accomplishment of a given mission.

Each activity on the chart should be accompanied by all the informa-

tion germane to it—updated as the conditions of application change. By insertion of relevant dates, the chart can be either a record of past performance or a map of an anticipated undertaking.

### 3. Dynamic applications — CPS as applied to simultaneous or continuing situations where conditions are subject to abrupt change.

Dynamic applications have a promising potential but little current usage. They are applicable to custom situations rather than mass production. Their function is more of accounting than of analysis. The value of CPS in short-term situations subject to modifications is that it promotes man-machine allocations, material

component procurement, work assignments, and product status reports.

For example, consider a company which produces on order six different products, each available in five sizes. Average production time per product is three weeks. A time chart can be constructed for each size of each product. The required resources associated with all activities are noted on the time chart. Besides the resources previously mentioned, lead times and machine indexes should be included.

When an order for a product is received, the schedule clerk extracts a folder containing itemized (equipment, materials, shop drawings, etc.) resources and the time chart for that product. Orders are placed for materials, parts, and assemblies according to the lead times indicated. Worker and machine assignments are made by meshing current production with the required work shown on the time chart.

The urgency rating of the new work is indicated by the amount of scheduling leeway (called "float" in CPS terminology) available to the activities. This float reflects both the producer's capabilities and the customer's promised delivery date.

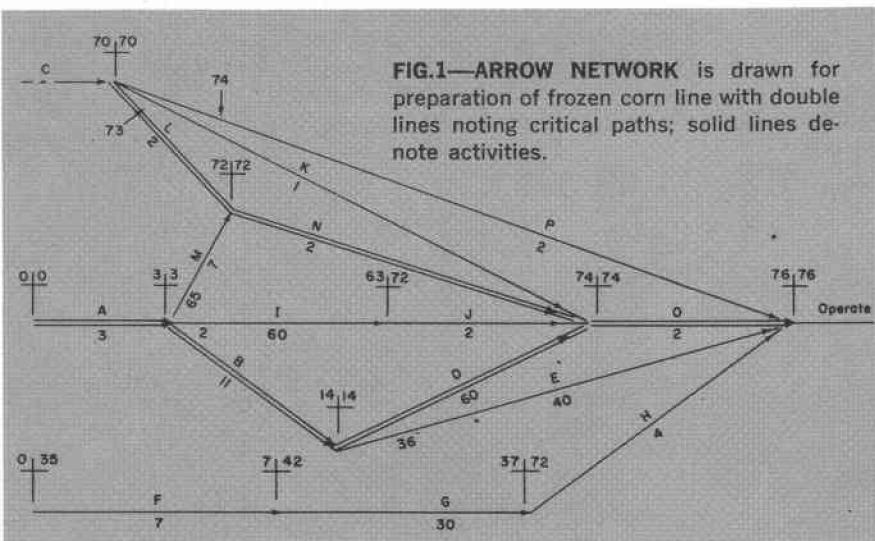
A time chart can accompany the product physically as it progresses through the production process. At designated check points the amount of material, manpower, and machine time used to accomplish activities are recorded. These values can be inscribed on the chart or on activity punch cards. Daily tabulation of the charts or cards provides a current status report. The completed record of the finished product can serve as an accounting document.

## CPS Applied to Frozen Food Line

Most techniques of critical path scheduling can be shown when CPS is applied to the problem of setting up a frozen-corn processing line. Such an operation occurs annually in a relatively small freezing plant which processes several commodities. Two primary products move through the plant in large volume: green beans and corn.

Though the end of the green-bean season often overlaps the beginning of corn, the two products cannot be run simultaneously since a single freezing tunnel and several items of equipment must serve both lines. There must be a minimum downtime for changeover from one product to the other.

The decision to apply CPS in this



**FIG.1—ARROW NETWORK** is drawn for preparation of frozen corn line with double lines noting critical paths; solid lines denote activities.

case was made by the plant manager. He directed the plant supervisor and maintenance foreman to gather the information essential for CPS application (4). The foreman described activities necessary to prepare the corn line. He provided data on time and crew size based on past experience and records.

### Orientation and Preplanning

Activities were then listed in their approximate order of occurrence. This order was not exact since some activities could be performed simultaneously and others could change in sequential position without changing the end results.

To establish a clear relationship between activities, a restriction list (shown in column 2 of Table 1) was established. The list shows which activities must immediately precede others. For example, C (processing green beans) must be completed before the start of K (hook up steam and cooling water), L (transfer motor and lights), and P (prepare receiving and freezing facilities).

### Network Diagram

The combined activity and restriction list is the only information needed to take the next systematic step: the construction of the arrow network. The network provides an intermediate step to establish conditions that permit later construction of a time chart. Convenient symbols with specific

definitions simplify the construction of the network. Several of these are demonstrated in the example (Fig. 1). Activities are represented by a solid line terminating with an arrow. Time is not related to a linear scale (e.g., K requires one day and is longer on the chart than D which takes 60 days to complete). For clarity, activity crossovers should be limited. Construction of a rough draft will usually eliminate them.

Each arrow should have the activity description above it and the estimated activity duration below it. A point in time that denotes an end or beginning of an activity is referred to as an event and is represented by a T-bar. As noted on the network, each T has the function of displaying the earliest start of an activity on its left and the latest start on its right.

Early starts are obtained by adding activity times from left to right across the arrow network. As shown, the start entry is  $^0T$  for A;  $^{3T}$  for I (the duration of activity A); and the start for J is  $^{63}T$  (the duration of I+A).

When several activities converge, the longest sequence determines the early start time for the next activity beyond that point. In the case where D, J, N, and K must all terminate before O can start, the largest accumulated total is 74 days ( $A+B+D$ ).

Late starts are readily obtained by beginning with the end activity at the right and working left, subtracting each individual activity

time from the preceding event. Starting with 76 days as the end time for corn line preparation, the latest start time for H is 76-4 or 72.

If two or more activities converge toward the left to an event, the earliest of the late starts is placed in the T. This situation occurs where D and E converge to activity B. At this event, the earliest of the late starts, 14, is on the right bar of the  $T^{14}$ . The latest start for E, 36 in this case, is placed just under the start of the E line. This graphic condition shows the planner that he has some freedom in scheduling the start of an activity such as E.

### Critical Path Identification

The critical path is that sequence of activities which possesses no leeway in scheduling. It can be identified by following activity arrows through the Ts which have the same numbers on both bars (or sides of the T). This indicates that early and late start times are the same at these events.

Activity arrows on the critical path are double lined as shown in Fig. 1. The critical path moves by activities A, B, D, L, N, and O. The part of the path that starts with L is restricted by the time at which C (process green beans) ends. The termination of C also dictates the earliest start time for K (hook up steam and cooling water) and P (prepare receiving and freezing facilities).

Since C is not a part of corn line preparation, it is indicated on the network with a dotted line. As shown on this chart with the present allocation of resources, a minimum of six days downtime is needed between the end of green-bean processing and the start of corn-processing.

At this stage of planning, management may wish to consider whether or not 76 days is more or less time than may reasonably be devoted to preparation of the corn line. Changes in the allocation of manpower and other resources would result in modifications in the network.

Changes may even establish a new critical path. For example, if activities B and D, which are on

the critical path and require a total of 71 days, were reduced to 60 days, a new critical path would move through activities A, I, J, and O with a total operating time of 67 days. Opportunities to balance resources with time requirements will become more evident as information established in the arrow network is converted into a time chart.

### Time Chart for Corn Line

Examination of a time chart for the corn line (Fig. 2), reveals several features that simplify the interrelationship of activities and their position in time sequence. As with the arrow network the solid lines denote activities and the double lines represent the critical activities.

Linear distance is now related to time as established by the scale at the bottom of the chart. If meaning is enhanced, calendar dates may be placed on the scale. Events are distinguished by specific points in time recorded under the carets ( $\wedge$ ), that are placed between activities. Vertical lines show dependencies as in the cases of M and I that cannot start until A is complete, and also N that requires the completion of M.

Lines with short dashes represent float time which presents the opportunity for some maneuverability in scheduling. Activity E has float time between the 14th and 36th days and could be started at any time within that period. F has 35 days of float. G may or may not have 35 days of freedom to start, depending on when F is actually completed. A similar restriction exists for H.

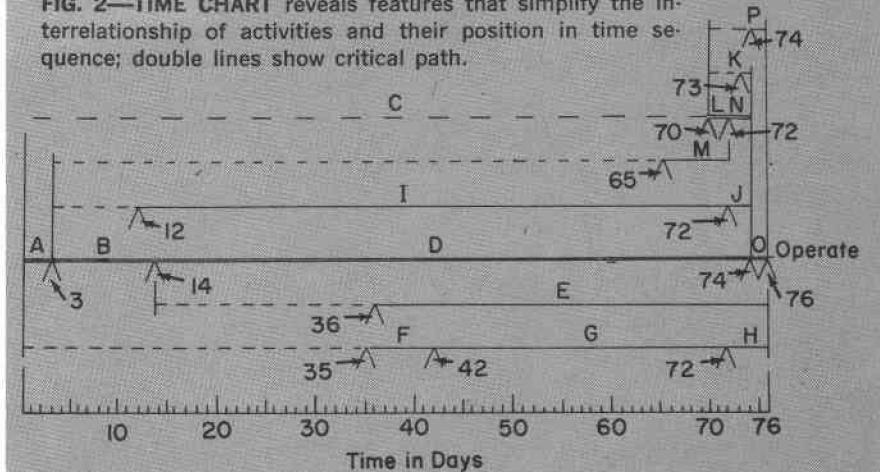
The line with long dashes depicts C (processing of green beans) which, as noted in the network, must be completed before activities L, K, and P can start.

### Resource Decisions

Organization of the schedule of activities in the manner thus far developed adds to simplicity and precision in selection of alternative resource distributions and ultimate specific decisions.

If required, you may construct modified time charts to accommo-

**FIG. 2—TIME CHART** reveals features that simplify the interrelationship of activities and their position in time sequence; double lines show critical path.



date such conditions as: a need for compressed preparation time, a reduction in maintenance crew, or changes in equipment delivery dates and adjustments in harvest periods for the crops concerned. If several alternatives are being considered in terms of cost, project-cost tables can be designed to assist you in their selections.

A study of Fig. 2 demonstrates that a maximum number of activities are in progress during the six days before the corn line starts. Crew requirements shown in Table 1 indicate nine men are required for all activities on days 71 and 72. Rather than hire more than the six men normally available for change-over, you may take advantage of available float time by moving activities I, J, E, F, G, and H to earlier start dates.

It is not necessary to advance M (order belts) since this is an order delivery time with no manpower needed until belts are installed at activity N. Order times I and F must start earlier to avoid interference with man-time activities that are moved to the left.

In addition to reducing the work load peak near the end of the preparation time, the redistribution of float time will provide a more uniform work load over the total 76-day period.

If material costs were high in a situation of this type, an analysis of your cost would be advisable. Any savings through a better distribution of labor would have to more than offset the increased cost

of idle money invested in materials installed before the minimum time needed for the project completion.

### Continuing Benefits

Once established, an effective time chart will be useful in future preparations of the corn line. Modifications can be made in the chart to conform to new requirements of each season.

Experience has proven that not least among the advantages of CPS is its communication ability which strengthens the understanding of a project by participants. A time chart with a simple legend of symbols used and activities fully identified can be interpreted readily.

All levels of your operation team from top management through supervisors, subcontractors and line-workers have a constant picture relating the progress of all activities toward project completion. Usefulness of the time chart extends through the completion period of the preplanned project.

In the event that last minute changes in schedule occur, their impact on the total remaining operation can be graphically demonstrated, quickly assessed, and subjected to appropriate action.

### BIBLIOGRAPHY

1. Critical Path Planning and Scheduling, Mathematical Basis, J. E. Kelley, Jr., *Operating Research*, 9, 296-320, May 1961.
2. Critical Path Scheduling, Charles J. Lynch, *Product Engineering*, 32, 37, 92-6, Sept. 18, 1961.
3. A Case Study of CPM in a Manufacturing Situation R. G. Odom and E. E. Blystone, *Journal of Industrial Engineering*, 15, 6, 306-310, Nov.-Dec. 1964.
4. A Working Manual for Critical Path Scheduling, J. L. Riggs and C. O. Heath, Harbs Co., 1963.