Management of large scale computer program production

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ABSTRACT

This paper describes a management/computer interactive system for the planning and control of the development of computer software programs on a large scale.

Linked planning (PERT type) networks are used to represent the basic information model. This composite network is formed within the computer from individual networks using computerized library techniques. The model then represents the overall definition of the projected work load.

This information model is then manipulated by varying both the planning data (resources available, etc.) and scheduling parameters. Multi-project scheduling methods, using advanced resource allocation procedures, are then employed to rapidly obtain basic planning information (manpower loading, completion dates, costs, etc.).

These basic concepts are established within a framework of a flexible system which responds to changes in product requirements, resource availability levels and project priorities. The interaction between management and the computer based network planning system enables the work to be effectively planned and provides a sound basis for subsequent control.

INTRODUCTION

The management of large scale computer program production poses special problems which are not readily solved by manual methods. The large volume of planning data involved, the technical complexity of the end product, the uncertainty and variability of the time and resource estimates and the vulnerability to external constraints make it essential that computer driven methods of project management are employed.

The system described was developed for in-house use by International Computers Limited in an environment where several hundred programmers and systems analysts were engaged in the development of a multiplicity of computer programs. The integrated computer based systems evolved over a long period in response to increasing work volumes. Network planning (PERT) techniques were used for many years to schedule projects individually. However, the separate treatment highlighted the need to consider the various tasks collectively against a common manpower pool and development of the system proceeded to this goal. The principal stages in development are shown in Figure 1.

As the number of projects increased so did the variety of questions which management was called upon to answer. With a mixture of firm and tentative projects on hand, estimates of costs and timescales were requested for new items about which only the barest details were known. Answers to the first questions inevitably had to be hedged with qualifications regarding the assumptions made, and these invariably sparked off a series of further questions of the "what if" variety where changes in these assumptions were postulated.

Some fast, flexible, but reliable system was required to provide this information and it was from this necessity that the present methods developed. Included in the work groups were staff who had developed PERT programs, and there was an awareness of the potentiality of the technique. It was not surprising, therefore, that network planning should be selected as the basis for a scheme for scheduling and controlling the work of the whole activity.

THE PLANNING PROBLEM

A number of complex computer programs have to be produced using pre-determined manpower and computer time availabilities. The individual computer programs are required to be finished in a defined priority sequence, and there are interdependencies between different programs and also some external constraints. The various computer programs (some 50/60 in number) have similar production characteristics, but the work force is also required to undertake some additional work of a dissimilar nature.
(maintenance of previously completed programs, technical support, preparation of manuals etc.). Some tasks can be considered as firm commitments, others are only tentative proposals for which production capacity must be reserved. The resulting workload is a mixture of these ingredients. This overview of the planning problem is shown diagrammatically in Figure 2.

The number of projects to be scheduled varies as time proceeds. As work in progress is completed, tentative proposals become firm commitments, new work items are added, state of dependencies change, availability of manpower alters (transfers and resignations, etc.).

Superimposed upon this constantly changing variety of work and resources is the infamous problem of estimating the work content of computer programming tasks. There can be few tasks for which it is more difficult to assess in advance the time scale by which a given number of persons achieve specific objectives. Uncertainty in the original estimates is therefore a significant factor in all planning decisions.

From this morass of indefinite and sometimes conflicting detail, project management needs to forecast certain highly significant information:

(a) Who should be working on what job and when?
(b) What will be the forecast completion date?
(c) What will it cost?

In connection with the allocation of jobs to people, certain basic limitations of human adaptability have to be borne in mind. Pre-eminent among these are:

(1) The need to make use of experience—an Operational Research Scientist may stumble through an accountancy routine but an accountant may not be so successful in O.R.

(2) Continuity of employment on the same task improves performance—changing individuals rapidly from job to job is invariably detrimental to progress. It is the nature of programming that it is possible to actually progress backwards by inappropriate actions.

Network planning is an obvious planning tool to employ in these circumstances. The breaking down of the overall task into individual activities minimizes the estimating error, and the computer calculated time analysis, resource allocation and costings enable the multitudinous elements of this particular jigsaw puzzle to be re-assembled with comparative ease.

The well tried methods are, however, not in themselves sufficient, as preparation of individual networks and estimates for each job is a problem and special techniques of network construction from pre-stored libraries are employed. Similarly, the established methods of resource allocation need special treatment to observe the relative priorities attached to individual projects and to ensure the (more efficient) continuity of work on similar jobs. To accomplish this, a form of multiproject/residual resource scheduling is employed.

The main features of this system are now described.

THE PLANNING SYSTEM

General approach

The general system flow is shown in Figure 3. Here it will be seen that there are two inputs (firm commitments and enquiries) and one principal output (quotations). Between
these two extremes the planning system is an interaction between management, planners and a network processing system.

Central to the system is the "master network" which holds (in computer store) the events and activities of all work (firm and tentative) which is currently in the system. This is a multi-project network and it defines all project relationships, external restraints and relative priorities, as well as carrying time, resource and cost data appertaining to all stored networks.

The master network is maintained by adding and subtracting projects with the master network updating program. New sub-networks (one for each project) are added, either after being built up from the network reference library held in computer store, or from direct input of new material. Library networks are usually employed at the tentative stage when little is known about the project and personalized networks are submitted when the work has been studied in detail.

As the library methods means that a considerable part of network creation and editing takes place out of sight within the computer, network diagrams are not available in the usual way and it is necessary to provide methods of visually checking the created network that will subsequently be submitted for processing. The system therefore provides for networks to be output on a digital plotter for this purpose. Comprehensive coding is built into the library of sub-networks so that selected portions can be examined in this way.

Network analysis is carried out in the normal manner and a series of resource allocations are performed. Usually both time limited and resource limited allocations are carried out with graded project priorities being applied by means of a residual resource scheduling technique. The results of selected allocations are then costed.

The main print outputs utilized are a key event date etc. A typical example of a library network is shown in Figure 4.

When a satisfactory set of results have been obtained, the responsible manager finally "interprets" the computer prognostication into a "quotation" which is dispatched to the enquirer.

In this description emphasis has been placed on the role of the manager in this cycle. The computer system only acts as a tool of management and does not automatically produce computer printed results which are followed blindly. The system acts as an extension of the manager's intellect; he manipulates it, he makes the major planning decisions, and he authorizes (and is responsible for) the results. Some features of the system are now described in more detail.

Network creation

In order to perform network planning it is first necessary to have a "network." This self-evident truth can, however, be qualified for computer processing to say that the necessity is for a "numerical representation of the network."

This modification, which acknowledges the nature of computing, is the basis of network library techniques. In this method, a number of module networks are reduced to digital form and stored on magnetic media (discs or tape). They can be recalled on command and edited with a minimum of effort on the part of the planner. The manipulation of library networks is shown diagrammatically in Figure 4.

In the system described, all computer programs are divided into "modules" and the overall network for the project is formed by combining a series of sub-networks, each representing a module. A library of standard module networks has been established to cover the main type of product encountered, e.g., large, medium, small, short (intensive working) timescale, long (low resource) timescale etc. A typical example of a library network is shown in Figure 5.

The planner selects the best combination of library networks and combines them together with linking dummy activities. During the selection of library networks, the planner will consult with production management to confirm the choice and identify any changes which are necessary. The library network is completed with time and

Figure 4—Network creation
resource estimates and thus changes to these may be necessary as well as the addition or deletion of activities.

Sometimes the changes will be of a "blanket" nature (i.e., increase all durations (and/or resources) by x percent) or only to specified activities. One convenient change is the addition of a "hammock activity," so called because it "swings" from end to end of the network. An example of a hammock activity can be seen in Figure 7 (between events A3-D3). No duration is specified on a hammock activity but a resource applied to this can be spread evenly over the project duration on a rate per time unit basis or given as a fixed amount, for the whole project.

Certain events on the module network are identified as "key events" for the purpose of summarizing the project time plan. These key events correspond with the same events on the "master network." This relationship is shown diagrammatically in Figure 5. Although the master network exists internally within the computer in full detail, it is summarized for management use. This relationship between module networks and the Management Summary Network is shown in Figure 6.

The Management Summary Network is, in fact, a skeleton of the Master Network which in turn represents the entire collection of sub-networks and exists for the purpose of providing management with a reference chart of all projects being analyzed simultaneously. The system is, therefore, multi-level in concept and the Master Network, together with a key event date report (from the computer analysis), provides a convenient reference for higher management. Key events are, of course, also the major milestones for reporting progress.

It is perhaps a weakness of the library technique of network creation that it is necessary to maintain a record of the changes made to library networks and some of the visual impact of the planning diagram is lost. One answer to this difficulty is the use of digital plotter output to recall the network as it stands after modification.

**Digital plotter output**

The manner in which digital plotter output can be used in the system is shown in Figure 4, and an example of digital plotter output is shown in Figure 7. (This sample has been simplified for illustration purposes.) Here the library network shown in Figure 5 has been modified to add the Hammock Activity (connecting events A3-D3) representing a supervisory overhead uniquely chargeable to this module. Points of interest from this illustration are that different types of line (continuous, broken and chain dotted) are used to represent activities, dummy activities, and hammock activities. Also different event shapes are used to identify start events, end events and key events.

When one has become familiar with the somewhat stylized representation produced by the digital plotter, a considerable amount of useful information can be quickly assimilated from these diagrams.

**External dependencies**

Computer program development work can seldom be carried out in complete isolation from external factors. This means that the work schedule must be constructed in a way which takes account of all external dependencies (or constraints).

Typical of these are completion date promises already made, dates of availability of specifications, special software or special hardware from customer or other work groups. This information is entered on the appropriate events, either as early or late imposed dates in the normal way.

**Work scheduling technique**

Operational managers who have used computer based resource allocation for the construction of work schedules will know that problems arise if blind obedience is given to the computer printed page. Computer programs have an infinite capacity for devising intricate work schedules yet sometimes miss the obvious. For example, no computer program will detect that a few hours overtime, worked in the weeks preceding an individual's three week holiday,
could save three weeks on a project completion date by releasing a critical dependency, or how activities can be shortened by further sub-division of work in time critical areas.

Scheduling is, therefore, an interactive process between the manager who innovates and the resource allocation program which merely calculates. Without the aid of a computer the manager/planner is forced to think the whole problem through. Computer assistance is not sufficient reason to give up thinking altogether, and the thoughtful manager can bring individual style to the resulting work schedules even when computer programs are used for resource allocation. This interaction between the manager and the computer program is a feature of the system. The established methods of planning network scheduling have been described in general but in this system several additional methods are employed to control the determination of the work schedule.

Work priorities

Firstly, the master network is brought up to date and checked out for data errors. All external dependencies are defined and time and resource calendars (holidays and overtime etc.) are established. Next the various projects are assigned to priority groups. Work already started and having near completion dates are given second priority. New committed work of a nonurgent nature is the third priority, and tentative work is allocated to the second priority group. In the scheduling process the priority groups (each containing several projects) are treated as separate projects which are scheduled against a common pool of resources. All projects in the first priority are scheduled in their entirety before those in the second priority are considered, and thus first priority projects obtain first claim on the available resources. During the scheduling of the first priority items, the resource availabilities are diminished by the extent of the quantity allocated and the remainder is passed on as the availability for the second priority projects. A similar procedure is followed for each successive priority category.

The process is termed “residual resource allocation” and is shown diagrammatically in Figure 8. It produces schedules which reflect the manner in which computer programming projects are conveniently run. By changing the priority associated with individual projects dramatic alterations to the resulting work schedules can be effected.

Work continuity

Computer programming requires intense concentration and the most effective way of employing the specialist skills
involved is to establish a work group and then to minimize the distractions until the task is completed. Within the work scheduling program individual network activities, groups of activities or even whole networks can be designated "non-splittable" and thus maintain a cohesive effort on particular projects.

The scheduling decision

At first sight, the decision to schedule would appear to be a simple comparison between the resources required and the resources available at a particular point in time. In practice, however, the scheduling decision is surprisingly complex as it depends upon more than just resource availability. The condition of the other segments of the activity schedule must be considered as must the effect on the project end date of any scheduling delay. In the method described, this process is systemized by employing decision tables for the scheduling decision. The scheduling decision in respect of each activity is made by calculating various factors about the activity and looking up the decision (whether to schedule or delay) in a decision table which contains the appropriate decision for the situation defined by the calculated factors. This process is shown diagrammatically in Figure 9 and an extract from a typical decision table is shown in Figure 10. According to the resources available and the information obtained from this decision table, an activity is then either "scheduled" or "delayed." In this context "delaying" means leaving for scheduling at a later date.

The use of decision tables in this way provides an heuristic approach to the scheduling problem in that known successful decision patterns can be recorded (by means of a decision table) and then subsequently re-used for the production of further work schedules. Thus, empirical experience can be encapsulated within the computer program at the discretion of the manager. The decision tables can, of course, be referenced separately and thus the manager has another method by which to steer the formulation of work schedules into patterns acceptable to him.

Management information

Both "time limited" schedules and "resource limited" schedules are prepared and the most commonly used print outputs at the planning stage are key event schedules and resource histograms. When they are found to be unsatisfactory, "problem modification" takes place. In this the planner and manager hold discussions on alternative variations to the network, resource availabilities, scheduled dates and priorities. Integration of management and the network planning system is greatest at this point and the flow of information is shown in Figure 11. In this interactive process, management skill is employed in suggesting acceptable variations to data and the planner’s knowledge is used to anticipate the effect of changes. Several alternatives may be set up in this way and put collectively to the computer program and the resource allocation process repeated until satisfactory solutions are found.

Cost planning

When a satisfactory work schedule and utilization of resources has been achieved, the PERT Cost module is
CONCLUSION

The system described has established its worth as a management tool over several years. The number of projects controlled by the system at present is over 60 and collectively they represent a total value exceeding £3 million.

The planning of computer program production is a difficult task in which unforeseen pitfalls abound. Therefore, no claims are made for the automatic production of work schedules which can be followed absolutely. Similarly all calculated results are “vetted” and often “adjusted” before being offered for commitment. This qualification is, however, in no way intended to denigrate the system, but to accept that the unforeseen is unknown and allowance must be made for it.

It is a premise of this paper that the system is a tool of management—not a management system. The materials of the planner’s craft are quantitative estimates of future activities and probable logical sequences. The manager must shape them as he can.

What is, however, claimed is a way of harnessing the advantages of network planning, and through its disciplines the unique power of the computer, for the better management of large scale computer program production.

REFERENCE
