employ. A planner, having been shown what is the critical path, can often think of ways to modify the network and shorten the critical path without extra cost. The advantages of his skill and experience are not fully effective if this stage is mechanized. Moreover, the data requirements for such extensions considerably exceed those of basic PERT, since all of the information which might be needed must be provided at the outset although much of it may in fact never be used.

Despite these objections, the field is an interesting and expanding one and there is little doubt that some PERT extensions will find application in specific areas. For the present, however, it is clear that most British companies have still to experience and master the very real difficulties of collecting full planning data for basic PERT before proceeding to more sophisticated methods.

Acknowledgements

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Resource allocation and multi-project scheduling (RAMPS)—a new tool in planning and control

By S. Lambourn

This paper gives a general description of the new network analysis technique known as RAMPS. The input and output of the computer program are described, and some indication is given of the computational procedures. An outline of the present uses of RAMPS is given, together with an indication of future applications.

The network analysis description of an operating problem will be familiar to users of PERT (p. 297). Two of the main limitations of PERT are its inability to consider more than one project, and its disregard, in the schedules produced, of the availability of resources. Managements always have a multiplicity of projects to complete on time, and are always concerned with the allocation of their resources in the most economical fashion. RAMPS is a computer-based technique which gives a solution to this general problem. It represents a major break-through in this area since it is now possible to produce, in one operation, work schedules which have taken into account the limited availability of resources.

The general problem

The planning and control of a large organization is always a complex operation. The functions of forecasting, research and development, design, purchasing, production, finance, personnel, and others are all involved, and each element of work has to be dovetailed into a coherent program in which the minimum of resources are wasted and end products are completed on time. This complexity is aggravated by the fact that events rarely work out according to program, and the knowledge of work ahead is imperfect, with the result that revisions are continually necessary.

RAMPS input

The characteristics of a situation in which RAMPS may be used may be enumerated as follows:

(1) There are one or more projects, each of which has its own desired completion date, and all of which have to be completed using the same basic set of resources.
(2) The penalty for delayed project completion may be expressed as a cost.
(3) The work to be done in each project may be described in network chart form where each job appears as an arrow, the heads and tails of which converge at points called *events*. See Fig. 1.

(4) For each job the resources required to complete it can be described in terms of manpower, machine power, materials, or money. These descriptions include resource type, combination of resource types where applicable, the amount required of each resource per unit of time, the total amount of each resource required to complete the job, and the cost of interrupting the job once it has been started.

(5) Several rates of resource utilization may be specified, together with their associated efficiencies. In general, the most efficient application of resources to a job is usually specified, together with levels above and below this where a measure of inefficiency may be introduced.

(6) Each resource may be described in terms of the number of units available in each time period, the cost per unit per time period, the extra numbers of units which may be made available through, for example, overtime and sub-contracting per time period, and the cost per unit per period of this extra availability.

Output presentation

The schedules produced by RAMPS give the indicated completion date for each project, together with two types of schedule showing the detailed period-by-period allocation of resources in bar-chart form. The first type shows all jobs within each project, and is thus suitable for managers concerned with individual projects. The second type of schedule shows all jobs within each resource, and is intended for resource management. Examples of each of these two types of schedule for projects similar to that shown in Fig. 1 are given in Figs. 2 and 3.

Computational procedure

The first computation which RAMPS makes on its input data produces a float-time for each job, based on the desired completion time for each project. The program then moves forward in equal time periods until the desired total number of time periods have been covered. At each time period the system examines all jobs available for allocation to each resource in turn. If the total work available is less than the availability of resources, then all the jobs are allocated. If the total work available exceeds the level of resources available, the various feasible combinations of allocations are evaluated by cost, and the minimum cost combination is chosen. The rules under which costs are associated with each combination are very flexible, and reflect the operating criteria of management. These will include the conflicting requirements of minimum project costs, completion of projects on time, and minimization of idle resources. In most cases a combination of these will be required, and provision is made for weighting each of these items.

Schedule improvement

The schedules produced by RAMPS may sometimes be unsatisfactory and require improvement, and examination of the schedules will indicate how improvements may be made. For example:

(1) Projects are not shown as being completed on time. The cause will usually be a bottleneck in resources over a limited area of the schedules, or a desired completion date which is earlier than the earliest date at which the project could be completed with unlimited resources.

(2) Unacceptable levels of resource idleness are indicated. If this is widespread it is an indication that the general level of resource availability is too high and that it should be reduced.

(3) A combination of 1 and 2 above. A change should be considered in the cost evaluation factors.

In such cases the procedure is to make data changes and produce fresh sets of schedules.

Using RAMPS

RAMPS is a management tool which may be used either for control purposes, or for simulation, or for a mixture of the two. As a control tool the system will

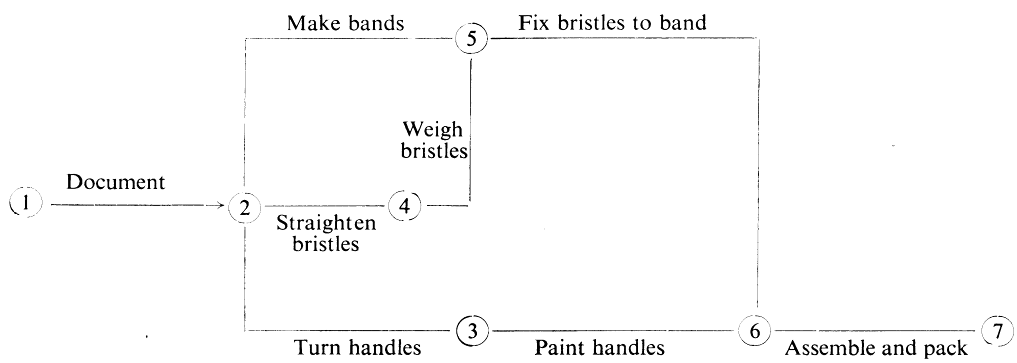

Fig. 1.—Example of project network for a batch of paint brushes

PROJ15 LARGE BRUSH, SMALL BATCH

AVAILABLE START DATE= 29
DESIRED COMPLETION DATE= 49
INDICATED COMPLETION DATE= 46
DELAY COST AT £ 5=£

	TASK	RESOURCE		RATES NORMAL	CRASH	S.O.	WORK	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
PROJ15	JOB A	1 2	DOCUMENTS				1																				
	JOB A	RCLERK		1 10																							
PROJ15	JOB C	2 4	STRAIGHTEN BRISTLES (LARGE)				8																				
	JOB C	RBRISL		2 20	4 30			2	4																		
PROJ15	JOB B	2 3	TURN HANDLES (LARGE)				5																				
	JOB B	RTURNS		1 10	2 20			2	2																		
PROJ15	JOB D	2 5	MAKE BANDS				1																				
	JOB D	RBANDS		1 10										1													
PROJ15	JOB E	4 5	WEIGH BRISTLES (LARGE)				15																				
	JOB E	RWEIGH		5 50	2 20	10 100					5	5	5														
PROJ15	JOB G	3 6	PAINT HANDLES				4																				
	JOB G	RPAINT		1 10	2 20						2	2															
PROJ15	JOB F	5 6	BRISTLES TO BAND (LARGE)				40																				
	JOB F	RFASTN		10 100	4 40	20 200								10	10	10	4	10									
PROJ15	JOB H	6 7	ASSEMBLE AND PACK (LARGE)				25																				
	JOB H	RPACKS		5 50	10 80	2 15												5	5	5	5	5	5				

PERIODS 31 THROUGH 50

Fig. 2.—Example of project schedule

RFASTN ASSEMBLERS

TASK	RESOURCE	RATES NORMAL	CRASH	S.O.	WORK	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
JOB F	PROJ11	10 100	4 40	20 200																					
JOB F	PROJ 7	10 100	4 40	20 200																					
JOB F	PROJ10	10 100	4 40	20 200																					
JOB F	PROJ 8	10 100	4 40	20 200																					
JOB F	PROJ 1	10 100	4 40	20 200																					
JOB F	PROJ 9	10 100	4 40	20 200																					
JOB F	PROJ 2	10 100	4 40	20 200		20	20	20	20																
JOB F	PROJ13	10 100	4 40	20 200																					
JOB F	PROJ12	10 100	4 40	20 200																					
JOB F	PROJ16	10 100	4 40	20 200																					
JOB F	PROJ14	10 100	4 40	20 200		10																			
JOB F	PROJ 4	10 100	4 40	20 200							20	20	10	10	4	10	20	20	20	10					
JOB F	PROJ15	10 100	4 40	20 200								10	10	10	4	10									
JOB F	PROJ17	10 100	4 40	20 200									10	10	10										
JOB F	PROJ 3	10 100	4 40	20 200											10	10	10	10	10	10	20	20	10	20	20
JOB F	PROJ18	10 100	4 40	20 200																10	10	10	10		
JOB F	PROJ19	10 100	4 40	20 200																			10	10	
JOB F	PROJ 5	10 100	4 40	20 200																					
JOB F	PROJ20	10 100	4 40	20 200																					
JOB F	PROJ 6	10 100	4 40	20 200																					
JOB F	PROJ22	10 100	4 40	20 200																					
JOB F	PROJ21	10 100	4 40	20 200																					
JOB F	PROJ23	10 100	4 40	20 200																					
JOB F	PROJ24	10 100	4 40	20 200																					
	TOTAL REQUIRED					30	20	20	20		20	30	30	30	28	30	30	30	30	30	30	30	30	30	20
	TOTAL AVAILABLE					30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
	TOTAL IDLE						10	10	10	30	10				2										10

PERIODS 31 THROUGH 50

Fig. 3.—Example of resource schedule

be run at the end of each control period, when the achievement in the last period and the growing knowledge of the work ahead are used to produce a completely revised set of schedules. As a simulation tool the effects of a variety of different courses of action may be evaluated.

In operational control applications the use is usually of the combined control and simulation variety. The short-term schedules produced are distributed to the operating departments, and used in the day-to-day control of operations. The schedules for periods further ahead are somewhat more tentative, and show potential difficulties sufficiently early for remedial action. The opportunity to simulate improvements in these areas occurs at the end of each control period. RAMPS may be used as a control tool in a wide variety of situations, ranging from those in which projects networks are very numerous but trivially small, to those in which the networks are highly complex and relatively few. This range is well illustrated by two current applications in the United States. One of these is in the control of maintenance and new-construction labour in a large chemical plant, and other is in the control of batch production of paint. In the first of these the main operating difficulty centres around the problems of work measurement and the time which individual jobs will take. In the second example the problem is one of maintaining the overall utilization of labour and plant at the same time as delivering batches of paint on time. Other examples of potential applications include the manufacture of, for example, office machinery, where the use of RAMPS will make it possible to by-pass the concept of lead time which is associated with each operation. Lead time is often many times greater in magnitude than the operation time itself, and the prospect here is one of a significant reduction of overall process times, stocks, and work-in-process. In processes involving a relatively small number of projects of high complexity, such as the building of ships and aircraft and chemical plant, where the progress of work cannot be controlled by the use of labour incentives based on measured work, the advantage of frequent schedule re-appraisal is obvious.

The use of RAMPS as a simulation tool has applications in the design of new-plant layout in machine shops, and in the design of production lines. In these situations a number of design proposals may be tested and evaluated.

Changes to the RAMPS computer program

The computer program for RAMPS which is now available at C-E-I-R's London Computer Centre is written for the IBM 7090. Its capacity is for about 700 jobs, 60 resources, and 6 projects, although any one of these may be increased at the expense of the others. This program may be used for field trials of the RAMPS system in almost any situation, but it is recognized that those wishing to use RAMPS for internal control and simulation purposes will require modifications to this system. The nature of the varied contexts in which RAMPS will be used is such that the concept of the large-scale, highly flexible, general-purpose system is not likely to be valid. Modifications to the existing program will include the following.

(1) An extension to the present capacity.
(2) A facility for varying the availability of resources in time.
(3) A facility for updating an existing master file containing project and resource information.
(4) The provision of cost-budgeting print-outs.
(5) Program rewriting for other computers.
(6) Integration with other data-processing procedures.

The installation of RAMPS as a planning and control tool

The change of an organization's procedures for planning and control is invariably a major undertaking. Once a technique has been selected, a large problem remains in the training of all personnel who will be involved in the use of the new procedures. One of the major difficulties is usually in obtaining the adequate feed-back of achievement from the operating departments which is essential if control of operations is to be achieved. The installation of a RAMPS control system will therefore run along the following lines:

(1) *Pilot exercise.* A limited area of operations will be selected for a pilot scheme; project networks will be drawn, data collected, and the first computer runs will be devoted to discovering how best management's operating criteria may be reflected in the system.
(2) *Specification for RAMPS system.* As a result of the pilot exercise and a detailed investigation of the organization's planning and control needs, a specification will be drawn up of the desired RAMPS system. A financial estimate will be made at this point of capital expenditure and running costs.
(3) *Modifications to the existing RAMPS system.* Programmers will write and test the new version of RAMPS.
(4) *Installation of the new system.* This phase will include the training of all personnel who will be involved in the new system, the drawing of project networks and collection of data for all projects, and a period of parallel running with the existing control system.

Conclusions

RAMPS is a major breakthrough in planning and control because it produces quickly, in one operation, optimized schedules of work for many resources involved in many projects. Potential applications for the system exist in a very wide range of situations, and the benefits from using RAMPS will be a closer realization of management's objectives in completing projects on time, of completing them at minimum costs, and of the reduction of idle resources.

Summary of discussion

Mr. K. Smith (*IBM* (*U.K.*) *Ltd.*): I do not wish to take time describing more four-letter word systems, but thought it might be interesting to describe a typical use of project-planning techniques. The problem was the relining of a furnace at Imperial Smelting Works, Swansea Vale, and the main object was to achieve optimum use of the available resources to achieve shortest time for the relining operation.

The network diagram involved 400 events and was run on an IBM 7090. Each morning at 9 o'clock the previous day's achievements were telephoned to Newman Street and the project rescheduled using the Resource Scheduling Program. As a result of using these methods the company were able to reduce the relining operations from ten to eight days at a cost of several hundred pounds of computer time and they say they will always control such operations in the same way in future.

Other uses by IBM include installation planning and product development. I notice that Mr. Robinson indicated that his company also uses PERT for the latter purpose. May I ask what is the reaction of his development engineers when they find their particular activity lies in the critical path?

Mr. F. D. Robinson: I think the short answer to this is that the engineers frequently know when they are on the critical path anyway, but they do not always realize quite which parts of their activities come under this heading. You cannot always lay on any more capacity in this kind of thing. What you do get out of the PERT run is information about which bits of the engineering must be closely tied down; this may, for example, relate to engineers planning their holidays forward, making sure that people who are available are there at the right time. You get added information about when you can really expect the thing to be operational. You then have it within your power to ensure that the customer is not suddenly disappointed at the end of the project. But I agree that you cannot put a quart into a pint pot.

Mr. A. P. Amiry (*United Steel Co. Ltd.*): Has Mr. Robinson any experience of using PERT on O.R. projects in his own department?

Mr. Robinson: Yes, but we have not done this very formally or in detail. I have tried on some O.R. projects to sketch the network and you do come up here against one of the profound difficulties in all of these network techniques. If you cannot predict time estimates this does not ruin the whole thing. Rough time estimates will serve to give you an idea of where the critical path lies and you can refine them as you go along, but if you cannot define the shape of the network then you are in difficulty. This does happen on a number of O.R. projects. I think on research projects generally it is difficult to define the form of the network. On something like the *Polaris* development, which is the classic one, there was a lot of research and they did make out. I think the basic distinction here is between research which does or does not incorporate a lot of human feed-back. On an O.R. project I think that everybody involved in this business would agree with me that the shape of the project can be changed entirely by a meeting at which some important person suddenly goes "cussed" on you, and when this kind of thing is likely to happen I think that the network is unlikely to remain realistic throughout the project.

Dr. W. Hackett (*English Electric Aviation Ltd.*): I wish to take up the problem of very large networks mentioned by Mr. Robinson. In English Electric Aviation Ltd. we expected to be faced with the prospect of processing a heavily cross-linked network entailing several tens of thousands of activities. This necessarily would entail sub-division into a number of sub-networks. In a heavily cross-linked network, sub-networks are never likely to be completely discrete; there will be points where information or hardware must be fed from one sub-network to another. This means that the time scheduling of the other sub-networks will generally not be independent of the time scheduling of the other sub-networks.

So far as we were able to ascertain from the published literature, and talking with experts from the U.S.A., the customary procedure for linking sub-networks was by "manual connection." In view of the magnitude of the problem we have developed a technique whereby the processing can be achieved entirely by computer, and by a computer of medium size such as DEUCE. It is hoped to publish this study shortly.

Mr. J. E. Sachs (*ICT Ltd.*): Is either system suitable for machine shop scheduling, and what is the relationship between investigation and doing the network program, particularly on RAMPS, which seems very complicated?

Mr. S. Lambourn: RAMPS is very suitable for machine shop scheduling. In this case each end product for the shop becomes a project and the operations on it have to be described in network terms. These networks may in some cases be very simple. Each machine, or group of machines, becomes a resource, and the schedules produced by RAMPS give the machine loadings and expected completion dates for each end product. The adaptability of RAMPS to the operating criteria of the machine shop management exists here as elsewhere.

The present RAMPS computer program is written for the IBM's 7090, and is available for use by anyone. In time, we expect this program to be adapted in many ways—extensions in capacity, specialization for use in limited situations, rewriting for other computers, integration with other data-processing systems, and so on. The initial systems analysis, program writing, and testing took some twelve man-years of effort, but modifications to the system should not take as long as this.

Given a suitable RAMPS program, the work involved in collecting data in input form for it will vary widely. I would not imagine that data collection from a well-run machine shop would offer many difficulties. The operations to be performed on each end product and estimates of machine time for each operation would be available from the planning office, as would information on resource availability.

I do not agree that RAMPS is very complicated. In fact, I suggest that it is no more complicated than existing production planning and control procedures using clerical methods, and that it is very much more effective in use. The difficulty is that RAMPS uses some new and unfamiliar logical ideas as well as computers, and the answer to this problem lies in persuading people to make the effort to understand these differences, and to learn how to use this new and sharper tool. I am afraid that it has not been possible in the limited time today to give you more than a brief indication of the potential of this system.

Mr. Robinson: One or two of Mr. Sachs's points related rather to PERT than to RAMPS, so I should like to answer also. On the question of the size of the job that you schedule, PERT was originally designed for developing the *Polaris* missile, and we have all heard this many times, so I do not think one needs to worry too much about the upper size of the job being too big, particularly with the partitioning device which enables one to break down one big network into smaller ones. I do not think that anybody in his right mind would use PERT for scheduling a machine shop. Machine shop scheduling is a very special problem in its own right, and, moreover, the amount of common ground between different machine shops varies a good deal. This problem is not a general one and certainly PERT is not the tool for this. When it comes to a question of data requirements, certainly on PERT the data requirement is relatively small, but, even so, obtaining the data and the difficulties of obtaining time estimates in a reasonably short space of time for all the things you want from these busy people whose activities you are trying to save, is an operation to be considered; and I think that it is not until you have actually attempted this, that you can appreciate the difficulties of doing so. There *are* difficulties; they are not insuperable; we think they are well worth surmounting, but they do exist.