Critical path analysis and the civil engineering industry

D. H. WADE

Mr W. B. Jepson, University of Manchester Institute of Science and Technology

Mr Wade's Paper confines itself to the 'civil engineering industry', whatever that may be, but it would seem to exclude building. Certainly the research effort in related fields at the Department of Building in the University of Manchester Institute of Science and Technology would not permit concurrence with his conclusions.

42. The Writer recalls a remark attributed to J. E. Mahoney in which, referring to 'pertability', he suggested the following favourable factors for the adoption of PERT and similar techniques:

(*a*) an inflexible task sequence;
(*b*) speed of more importance than economy;
(*c*) resources queueing for tasks.

43. The suggestion is that departure from a situation characterized by these factors increases the effort necessary to apply such techniques. Certainly where tactical flexibility, an emphasis on low cost, and the need to deploy limited resources are in evidence, the pursuit of network techniques throughout a contract seems to be achieved rarely. In housing, where the latter two factors are particularly inapplicable, the line of balance technique is being introduced, and it may well be that civil engineers too will be increasingly more analytical and selective in their choice of operational research techniques as working situations and certain inadequacies in network methods are found to be related. The recorded response to Mr Wade's questionnaire does not indicate any great awareness of this option.

44. One has the impression that less regard has been paid than might have been the case in building to the physical difficulties of updating: perhaps simpler networks with a relatively large volume of work in the activities reduce the problem. The direct effort of the builder tends to diminish as the job proceeds, specialist sub-contractors, whose work is often not billed let alone defined by activities, tend to become increasingly important. Again this may be less marked in the work to which Mr Wade refers.

45. It could well be that, simply by being the first technique to come forward which, through its characteristic of applying a unique reference to each activity, offered a relationship between effort and resources and cost, the ramifications could have outgrown the foundations. We should perhaps have started with a rational codification of activities which would have assisted cost control and its feedback and yet left freedom of choice between a number of planning techniques.

Mr L. K. Hale, Planning Engineer, Richard Thomas and Baldwins, Ltd, Llanwern

This Paper on critical path analysis in the civil engineering industry is of particular interest to students of CPA, since to the best of my knowledge it is the first attempt at collecting the opinions of users rather than advocates of the method.

47. The answers to the questionnaire did show that a confused state exists in both consultant and contractor organizations regarding the use of bar charts and network

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diagrams. In my experience it is unwise to use both, and no advantage is obtained by converting network data to bar charts, if the basic planning has been carried out by network. This seems to be at variance with Mr Wade's findings, but providing steps have been taken to educate site staff in the use of networks beforehand, difficulties need not be experienced. Indeed, the increased flow of detailed information provided by a network which is not apparent from bar charts has been recognized and appreciated by the users. Where networks are large and particularly unwieldy, it is current practice to produce section or department networks for site staff showing incoming and outgoing dependencies, which are part of and easily compared with the main network. These have been found to be satisfactory for recording progress and are quickly and easily produced.

48. There is a general feeling amongst older engineers that networks are complex and particularly difficult to understand, and this has been encouraged by the unsatisfactory presentation of network diagrams by some planners, who insist on introducing non-standard symbols and devices. As a user of CPA networks produced by many contractors and subcontractors, it is becoming increasingly apparent that a great deal of individualism exists in network production. Far too many symbols and terms, known only to the planner and his associates, find their way into networks intended for a wide distribution, with the result that frequent consultation with the key is necessary before the logic of the network can be fully understood. There is a pressing need for the use of standard symbols and presentation so that it is immediately acceptable to all levels of management without the need to convert to the more traditional form of bar chart, which tells the story in a less satisfactory way.

49. Certain answers to the questionnaire were surprising and somewhat depressing. The fact that 20% of the sample felt that CPA had brought no benefits to their long-term planning is very significant and appears to defy explanation, if their CPA has been applied correctly. More especially, the news that a similar number felt that knowledge of the critical activities was of little help in maintaining progress does indicate that these organizations are failing to obtain even the minimum benefits from the system. Perhaps the most startling reply was that 34% felt that CPA had not saved them overall contract time, since this is obviously the field where CPA scores over other forms of presentation, with its excellent early warning indicators that activities are lagging.

50. One great advantage of CPA which the questionnaire did not cover was the ease by which claims for contract delays can be verified or determined, using the data supplied by the networks. The effect that a time delay on one or two activities has on the contract as a whole is far better analysed and assessed by CPA than by any other method.

51. It was disappointing that so little information was forthcoming on the use of CPA with cost control techniques, since it is obvious that time and cost are so essentially bound together. Engineers have often been criticized in the past for their lack of enthusiasm in the cost control field, and it would appear that this would be a good opportunity to set up a comprehensive system under the control of the engineer which would re-establish his reputation in this field.

52. Mr Wade's Paper does indicate that the industry has yet to take CPA completely to its heart, but it does appear that enthusiasm for the method is growing and its implementation with cost control techniques could materially benefit the engineer and add to his prestige in management.

Mr P. Ciaran O'Kane, Department of Business Studies, Queen's University of Belfast

The Author is to be congratulated on carrying out this survey. The results, with one or two exceptions, show that the advantages and benefits claimed for CPA and other

network based methods of planning and control do occur in practice. This will come as no surprise to many but it is to be hoped that the solid evidence produced by Mr Wade of the practical advantages to be gained from the use of network analysis will encourage its use in those organizations which have not felt, until now, that they had much to gain from its use. No method of this kind can have any hope of success unless every single person associated with the project in any kind of managerial role is convinced of its value. The Paper should be of great value in helping those engineers who have not had practical experience of the CPA method in assessing the practical worth of this technique.

54. It was interesting to note that some firms found the PERT approach more useful than simple CPA. In the literature it often happens that PERT gets passing mention only. Yet if, as some of the firms in the survey claim, single time estimates can be 30% and more in error it would seem that the use of PERT might well lead to further improvements in planning. It would at least force some thought to be given to the estimated probability of achieving completion dates.

55. It is appreciated that if a reasonable response is to be obtained to a survey of this kind, the questionnaire has to be restricted in length and all of the questions one would like to ask can not be included. Some points not included in this survey but which might well form part of some follow-up research are indicated below.

56. It is sometimes claimed that the advantages to be gained by a small firm in adopting techniques of this kind are greater than those gained by a larger firm. The argument is that although CPA does not do any of management's thinking for it, the results of its thoughts and decisions are displayed in a clear and logical manner. Therefore network based planning does not require the same amount of intuitive skill and experience as more 'old-fashioned' methods of planning. However, this is exactly the kind of expertise that one is more likely to find in the larger rather than the smaller firm, and therefore the use of techniques like CPA should give a greater marginal increase in efficiency in the case of the latter. An analysis of the responses to this survey on the basis of the size of firm would be interesting, as it should show if this argument has any basis in fact.

57. In the case of the consultants in the survey it would have been of interest to know to what extent these techniques have been adopted to the planning of design work and with what results.

58. Network analysis appears to be the only example of modern quantitative decision making aids which has been adopted by the civil engineering industry to any large degree. It would be well worthwhile to find out why this should be so. Does the fault lie with the industry in not finding out what techniques have been developed by operations research people, etc., or is it that techniques of this sort are not really applicable to the engineering situation?

59. It seems, from the results of this survey, that the question of how to deal with costs has not yet been satisfactorily solved. Most of the respondents did not use the time–cost trade-off technique. I feel that the reason for this lies in the technique itself. Further research into improving the handling of costs in a network would appear to be indicated.

60. Finally I feel that it is a very sad comment on the training of people in the civil engineering profession to say that it requires up to two years to familiarize them with the use of this basically very simple technique. The fault cannot be said to lie in the mental ability of engineers, as most of them can quite easily become very competent in the theory and use of much more complicated techniques in, say, design work. Could it be that this is a question of the mental orientation of the people involved? An engineer's basic training tends to lead him to label such things as design as 'real engineering', and management as something less. The only real cure for this is to introduce management into engineering degree courses and to convince young engineers that a great deal of their working lives will be concerned with questions of management and that this is very much a part of real engineering.

DISCUSSION

Mr M. StC. Baird, Civil Engineering and Overseas Division John Laing Construction Ltd

Mr Wade is to be congratulated on his Paper, which shows that critical path analysis is now more widely used in the civil engineering industry. I would, however, like to make the following comments.

62. In § 8 one of the comments made by the consultants was that in the future the contract conditions will require CPA with or without the support of bar charts. At the present time, before a contractor commences work on site he is generally required to provide the consultant with a statement showing the method by which it is intended that the job will be constructed. No mention is made of the amount of detail required and I wonder what detail will be asked for (from the contractor) if CPA is made obligatory.

63. The statement in § 13 that activity durations are assessed in conjunction with bonus targets, requires further comment. As a general rule bonus targets only apply to productive operations and for planning purposes; an easement must be included in the bonus target to allow for work to be carried out on essential non-productive operations. The use of the bonus targets to assess the output of plant is not sufficient in itself, as some allowance must be made to indicate the efficiency ratio at which the plant could reasonably be expected to work.

64. In comparing CPA with PERT, it would appear that in the construction industry more use will be made of CPA for the following reasons.

(*a*) CPA being actively orientated, it is easier to list activities than events; the event may represent the conclusion of very many activities;
(*b*) float will be more meaningful to activities rather than to events;
(*c*) in CPA it will be easier to speed up the schedule.

65. Referring to § 16, an additional method by which a time allowance can be made for contingencies is by the use of the four week calendar month for planning. This will provide a built-in safety factor of 8%.

Mr P. H. D. Hancock, Senior Projects Systems Engineer, George Wimpey & Co. Ltd

I would like to add something to what the Author says in § 5 about the criteria used for deciding which jobs are suited to CPA. Harm has been done to people advocating CPA as the cure for all ills, when it is in fact a precision tool only suited to certain types of job. In place of size and 'complexity', I would suggest the following related but more precise criteria for jobs suited to CPA.

(*a*) the benefit from CPA warrants the cost;
(*b*) the job has a high proportion of time-bound as opposed to resource-bound work;
(*c*) the task sequence is relatively inflexible;
(*d*) the proportion of repetitive work is low.

67. It is wrong to think that only large jobs are worth controlling by CPA. The real criterion is whether the cost of CPA control is justified by the benefits yielded. CPA is basically a tool for controlling project duration and there are many small projects or small parts of large projects where the cost of CPA control may look large compared with the value of the work being controlled, but it is tiny compared with the rewards in money, prestige or goodwill for time saved and the corresponding penalties for time lost. Significantly CPA was first developed on two types of work which fit this description, i.e. space projects and process plant shutdowns. Admittedly space projects are also large projects, but a process plant shutdown is a textbook example of a small job where the cost of CPA is repaid many times over in benefits from time saved.

68. Secondly, since the most startling payoff from CPA is usually in terms of time saved, it is necessary to decide how much of the job is 'time-bound' (like a process

plant shutdown), and how much is really 'resource-bound' in the sense that economic use of men and machines is more important than earliest possible completion. In OR terms a time-bound job is one where resources queue for tasks and the tasks are therefore mostly started as soon as their network predecessors are complete. In a resource-bound job the tasks queue for the resources so as to ensure that men and machines are kept continuously and usefully occupied. A time-bound job is a sequencing problem while a resource-bound job looks rather like a queueing problem. Time-only CPA is a solution to the sequencing problem, and therefore it is not surprising that it has achieved some notable successes on time-bound jobs. Equally, it is not surprising that one hears rumours of notable failures where time-only CPA has been tried on resource-bound jobs. Many jobs are a cross between the two extremes and computerized resource levelling does extend CPA's usefulness into many real-life situations where one tries to balance speed against economic use of resources. Nonetheless, on most contracts, the need to use resources economically comes first most of the time, and even resource levelled CPA does not provide, except by accident, that constant reservoir of tasks queueing for resources which every good site agent aims at in order to ensure that his men and machines have a steady flow of work in spite of the inevitable unforeseen hold-ups. No clear dividing line can be drawn, but it does seem that the more the planning is dominated by resources the less useful CPA (as we know it at present) is likely to be.

69. It is also necessary to decide whether the job by its nature *imposes* the task sequence or whether the managers have to *choose* one before a net can be drawn at all. Flexible jobs containing many choices of task sequence are much more difficult to control by CPA. On such jobs, when an operation starts in the field it may be obvious to everyone that there is a task sequence that is better than the one which was agreed upon when the net was drawn up, so the agent decides to depart from the planned sequence. This makes nonsense of the original network, but no planner should complain provided the decision really is the best one for the job. CPA can cope with these situations but they require extra effort and are often hard to recognize till they are upon you. So the more of them there are the more it is useful to consider whether it is worth trying to control the job by CPA network at all or whether a simpler, quantitative control by bar chart, s-curve or line of balance would be better.

70. The final criterion is how much repetition there is. Many types of construction have a large element of repetitive, cyclic or 'long-line' work. Such work lends itself to work study and method study in the planning phase, and simple quantitative control in the progress phase. The more repetition there is in a job, the less likely it is that CPA will be worthwhile for progress control, though it may still be of value in developing the initial broad overall plan. One of the respondents supports this view in his reference to large housing schemes at the end of § 38.

71. Having tested a job by these four criteria it is worth considering two factors which apply to every construction job:

(*a*) CPA may well be valuable in the design and procure phases of jobs whose construction phase is not judged suitable for CPA;

(*b*) CPA is valuable for *preplanning* many jobs which are better *controlled* by simpler means.

72. Design, by its nature, has rather inflexible task sequences and is time-bound rather than resource-bound in the sense that drawings are needed by certain dates and designers can be switched from job to job in a city office more easily than men and machines from one remote site to another. Also, design is mostly one-off rather than repetitive. Again, procurement planning is mostly needed on the one-off special items, and these are time-bound and inflexible parts of the plan in the sense that certain pieces are needed on site by certain dates and no substitute will do. Moreover, for the main contractor such bought out items are not resource-bound because the

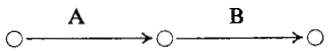
supplier is not normally competing with the work on site for resources such as skilled men.

73. In addition, CPA may not always be suitable for progress control on jobs where it has been a valuable help in preplanning for two main reasons:

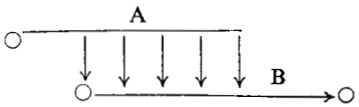
(*a*) the flexible task sequences already discussed are easy to cope with at planning stage, but more difficult in progress control;

(*b*) for preplanning one can simplify so as to produce a clear-cut net of manageable size, whereas for progress control the net has to be as realistic as possible; this usually means it has to be much more detailed.

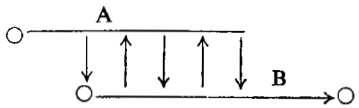
74. The commonest example of control requiring more detail than the original plan is the problem of 'blurred edges'. When preplanning the job, two tasks can be shown to be related thus:



However, when task B starts in the field it often becomes clear that the true relationship is more like this:



or even this!



Such situations produce an inexorable pressure to make the net more and more detailed as the job unfolds.

75. Moreover, they are often difficult to spot, or at least define, until they arise in the field. Detail and last minute alterations to the net both cost money and quite often it is better to dodge the problem by keeping the original net as a 'thought plan' only, and controlling the job by, for example, a bar chart which shows A and B as two overlapping bars with an informal interdependence which cannot be communicated to the computer but which is well understood on site. Of course, it may sometimes be worthwhile spending money on great detail. This depends on the cost–benefit criteria already discussed.

76. The four suggested criteria are summarized in Fig. 7 by which the 'pertability' of a job, i.e. its suitability to PERT/CPA planning and control, can be assessed by answering four questions of equal weight. This is a difficult subject and this chart is not put forward dogmatically as the final answer but as a basis for discussion. A typical problem is that any job being tested may have very different ratings under the four heads, and many jobs must fall into a sort of grey zone where success depends less on the choice of planning tool than on the will and skill with which it is used.

Mr I. Nicholson, A. M. Carmichael Ltd

It is evident from the consultant's comments in § 8 of the Paper that a considerable number favour the compulsory use of CPA in the execution of civil engineering contracts. I feel that this policy is unlikely to achieve the desired aim of increased productivity for reasons which will be obvious from the following comments.

Question	Answers for 0% rating	'Pertability' rating: % 0 50 100	Answers for 100% rating
What is the planning budget?	*Detailed control not warranted* Budget 0·1% or less of total project value	Typical jobs	*Detailed control required* Budget 0·5% or more of total project value
Is the job time-bound or resource-bound?	*Resource-bound* Smooth resource curves essential Plan develops round resources Tasks queue for resources		*Time-bound* Speed is the essence Irregular resource curves justified Plan develops round tasks Resources queue for tasks
How inflexible is the task sequence?	*Unlimited choice of sequence* (Both in preplanning and in day-to-day control during construction)		*No choice of task sequence* (In preplanning) No scope for day-to-day changes in sequence to obtain best progress
How much of the work is repetitive?	*Wholly repetitive* Production run type of job Suited to work study, method study and production control techniques		*Wholly one-off* Each task unique Needs preplanning and progress control of individual tasks

Fig. 7. Chart for estimating how well suited a job is to PERT/CPA planning and progress control

78. Contractors will tend to construe this policy as an attempt to encroach on their prerogative to execute the project virtually as they wish within the broad outline of the present bar chart programmes.

79. It must be remembered that most clients are only investing in one capital project being executed by a particular contractor at any one time, whereas the contractor is investing in several projects for several clients. This means that consultants look to CPA to control a series of individual projects, whilst contractors must integrate several CPA programmes into overall company planning. This may mean deploying resources between several contracts in order to attain maximum profitability, a position which may not necessarily be foreseen at the preparation of the individual CPA programmes. I would suggest that this condition could give rise to serious disputes on site, particularly in building projects where large numbers of subcontractors are employed.

80. Since it is the contractor's overall profitability that determines subsequent prices, anything that is likely to make overall control more difficult can only increase risk and therefore produce higher prices. This higher risk factor, combined with the additional costs of implementing CPA which itself could be in the order of $\frac{1}{2}\%$ of the tender sum, will give rise to a very real increase in costs for very intangible benefits. Surely it is unwise compulsorily to enforce something that has an infinite cost–benefit ratio.

81. Having said this, however, it is obvious from most of the comments that CPA has many advantages to all concerned and it only remains to decide how best it may speedily and voluntarily be accepted by the majority of contractors.

82. May I suggest that this would be best done by the encouragement of time–cost optimization techniques, for this alone can give tangible savings in project durations and costs. Without time–cost optimization, CPA is only a mathematical model of how the project is going to be carried out anyway. Although it does ascertain the relative importance of the individual activities systematically and not intuitively, this in itself does not lead to time or cost savings.

83. There are, however, three main objections to the use of optimization:

(*a*) contractors generally have no say in the duration of contracts;
(*b*) no computer programs exist which will carry out optimization;
(*c*) it is difficult for contractors to crash certain sections of a project by working additional overtime without employing men on needless overtime in other sections.

There is no doubt that contractors can overcome the last two of these objections, provided that they are given the incentive to optimize contract durations. I would suggest that this is best done by permitting contractors to give two tender sums, one for the optimum duration and one for the minimum duration, both of which durations would be specified by the contractor. Clients would then select the tender sum and duration which best suited them, having regard for the availability of finance and the sum of money which they normally ascertain as an estimate for liquidated damages.

84. In conclusion I would like to say that I believe it is more advantageous to carry out optimization manually with a lesser number of activities, than to carry out computerized resource levelling on a larger number of activities, a stage which should in any case be carried out after optimization. I have found that the complete process can be carried out at an approximate rate of 3–4 activities/man hour.

Messrs J. G. S. Hind and A. J. Faulkner, The Cementation Co. Ltd

Not all of the problems involved in successively instituting CPA methods of programming have been brought out by the questionnaire and the selected replies. The main problems as we see them are these:

(*a*) lack of a clear management policy;
(*b*) lack of detail when the first network is being prepared for a project;

(*c*) restrictions embodied in the earlier CP methods;
(*d*) the length of the preparation period;
(*e*) the high effort required to update and absorb changes;
(*f*) the problem of including contingencies in the activity duration times and resource figures;
(*g*) the need for support staff even after extensive training is given.

Points (*d*) and (*e*) require some further explanation.

86. The established preparation periods for medium to large projects are as follows

(*a*) first acceptable network for sequence and time analysis: 2–3 weeks;
(*b*) first acceptable resource output: a further 2–3 weeks;
(*c*) updating turn-round (including bar charts output based on networks): ½–1½ weeks.

For CPA methods to be generally accepted these times must be halved.

87. It is necessary to include an allowance for contingencies in the time and resource figures used to compute the overall project or sectional project durations; otherwise false time durations and resource demand figures are produced for overall planning, provisioning and progressing purposes. However, those overall figures which include contingencies are misleading for detailed weekly planning, daily scheduling of resources, and on the spot progressing.

88. The way to overcome all these problems is by applying the following suggestions:

(*a*) there must be a management policy laid down for the application of networks;
(*b*) the management, the practitioners and support staff must be given proper training in the techniques of network programmes;
(*c*) there has to be a planned implementation programme which follows quickly behind training;
(*d*) from top management down the updated network programmes must be studied along with other performance and cost information;
(*e*) there must be facility for condensing the network based bar charts (by sub-network or standard activity methods) for senior management reports (this in turn reduces size of schedules);
(*f*) the format of all other tabulations must be suitable for direct use on site;
(*g*) regular updating must be practised, preferably coinciding with monthly reports;
(*h*) this updating routine must be simple, inexpensive and quick;
(*i*) net and not gross figures should be used for detailed weekly planning, etc., so that those involved have the correct 'target' figures in mind during the execution of the works;
(*j*) the network method adopted must be a flexible one allowing changes to be made in the earlier stages and throughout with the minimum trouble.

89. The precedence method of constructing a network programme is gaining adherents because of its flexibility and adaptability. In fact, within the precedence convention both network and bar chart methods of constructing a programme of work can be applied, due to the inclusion of not only a 'finish to start' relationship but also 'start to start', 'finish to finish' and the combination of the latter two.

Mr J. F. Woodward, University of Stirling

The Paper, including a wide range of statements from a large number of organizations, stimulates comment on almost every paragraph.

91. From the figures quoted it appears that rather fewer than half of the companies approached use CPA in any form. It is reasonable to assume that even where

a firm does use CPA it will be only on certain projects, and therefore the proportion of projects planned using CPA is fairly small. Does the Author have any figures on this basis?

92. One of the fundamental advantages of network planning not highlighted in the Paper is simply the fact that the actual drawing of a network will of itself give the planner an excellent insight into the project. For this reason it is important that the network be drawn by the person or persons responsible for the management of the project. Two of the common cries heard are 'we don't have time for CPA' and 'we don't have enough information for CPA', but these statements are not a condemnation of the technique but of our often rather vague approach to project management. Surely before embarking on a construction project we should make time to place it in detail and also ensure that sufficient information is available to make such planning realistic.

93. Some of the statements quoted bear out the fear that CPA is widely misunderstood and misused. Network planning is simply an information system which enables a clear picture of a project to be presented so that it may be effectively and efficiently planned and progressed. The technique is basically very simple, and very simple applications can be beneficial in almost any project. The method may be made more sophisticated where conditions justify this, but care must be taken that CPA does not become the end instead of the means.

94. A much more detailed study of the results of the questionnaire backed by appropriate onsite investigation into the application of CPA could give very valuable assistance in the wider and more effective introduction of the technique into the construction industry.

Mr D. H. Wade

Mr Jepson's remark that the Paper is restricted, since it refers to the 'civil engineering industry', was I assume a rhetorical statement. I can assure him that this description was meant in its widest sense. In fact most of the contractors returning the questionnaire described themselves as building and civil engineering contractors.

96. Most of us have our guiding principles, from which we decide what technique we should apply either to frame out a structure, or in this case to adopt CPA or not as our planning tool. Those replying to the questionnaire showed that they had carefully appraised the situation as to what constraints to apply when planning a project. Obviously if the physical and safety constraints on their own lead to a flexible plan, the opportunity of imposing resource, cost and management constraints becomes possible. There are projects which tend to be of a repetitive nature; under these circumstances CPA is not the best planning tool to adopt.

97. There are of course physical difficulties in up-dating, but the volume of this task can be diminished by deciding initially on the constraints to apply. The problem of obtaining the necessary information from sub-contractors at an early date in order to draw an effective network is of course a problem. The best solution I can suggest is that sub-contractors should be made to understand more readily why information is required from them at an early date by introducing them to the disciplines of CPA.

98. Finally I do agree that there were initially perhaps too many claims made by a few as to the value of CPA. However, I am convinced that most people have now placed CPA in its true perspective and agree that it is one of the best methods to emerge for presenting planning efforts.

99. I am in complete agreement with the comments of Mr Hale, regarding the use of bar charts and network diagrams within one organization. This only really complicates matters, and makes extra work where the activities listed are the same. The establishing of an acceptable means of presenting the information of a network analysis to the client, the consultant, and the contractor is a difficult problem, and time will be necessary to achieve workable agreements. A lead to the solving of this

problem could well be achieved in a similar manner to that of the solving of some of the quantities problems in 1933 by the Committee on Engineering Quantities.

100. Regarding the question whether a saving on project time had been achieved with contracts planned by CPA, perhaps the relative infancy of the method allowed only 20% of those replying to give a definite reply to this query, or due to conservatism, under 'certain' circumstances, the contracting industry felt reluctant to be too quick to reach a final conclusion.

101. The observations of Mr Hale that claims for contract delays can be verified or determined with greater ease and with greater accuracy using the data supplied by the network, is of course true. I personally was disappointed also that the use of the time–cost trade-off technique had as yet so few advocates. At the present time, of course, there are the difficulties of the existing billing system and the possible labour difficulties of crashing some sections of the work and not others.

102. In reply to Mr Ciaran O'Kane's remarks; regarding the variation of 30% on some activity durations specifically mentioned by one consultant, this variation was only on certain activities of an extremely uncertain nature. Provided of course that such activities are away from the critical path, the project duration will not be affected. Should this type of variation exist on one of the critical activities, the project duration will vary, but not by the same percentage. As mentioned by both the contractors and the consultants, where activity time assessments are difficult, a more detailed network can help to solve the problem, or as Mr O'Kane mentions, PERT can often be the most rational means of establishing a duration time.

103. Whether the smaller firm has more to gain from CPA than the larger firm, I can only mention my own opinions. The fact that CPA is really another method of communication means that anyone responsible for any type of organization should have this facility available to improve his communications. Should, of course, the stage be reached that the firm expands, then the communication of ideas is of the utmost importance.

104. Some consultants specifically stated that their own organizations were planned by CPA, but I have no specific figures available on this aspect. From my personal experience, however, I know of a number of projects within large organizations, not of an engineering nature, which were planned by CPA. The fact that CPA was developed to assist the internal organization of E. I. Duponts, highlights the fact that CPA is basically a management tool.

105. Although the adoption of operational research was not investigated in the survey, here again I am aware of both consultants and contractors now employing this technique to assist them in arriving at reasoned conclusions.

106. Regarding the question of the time–cost trade-off technique, I feel that the failure to utilize this facility at the present time lies in the present system of the billing of engineering contracts. When it is possible to abstract billed items directly onto a network analysis, this facility will, I feel, become more commonly used.

107. Finally, I would like to say in reply to Mr O'Kane that at the University of Sheffield basic management principles are taught to the civil engineering students. Time for a full detailed understanding is not available, but it is hoped by this policy to whet the young engineer's appetite when he subsequently enters industry.

108. The first four points raised by Mr Hancock are facts which I appreciate always need consideration when deciding whether to adopt a critical path analysis, and I should like to add some comments myself on these topics.

109. The formation of a network analysis does cost money. The argument for spending money to produce a network is whether it will be recovered in time saved, plus a bonus, if at all possible. Provided this is so, no one would dispute that a network analysis should be made. It should be remembered that a network analysis is primarily a planning tool and secondly that the monitoring and updating of the network should be done regularly if the true benefits are to be realized from the analysis.

110. Time-bound and resource-bound projects do exist, and the real criterion for the need to carry out a network analysis is that if all the resources of the organization executing the project are profitably employed at all times, the network analysis is unnecessary. Should, however, some resource, whether it be men or machinery, be inoperative through lack of available tasks, then a network analysis should be prepared. This statement can only usually be realized in practice when an abundance of experience of previous projects of a similar nature exists.

111. Thirdly, when there is a great deal of flexibility in the method by which the job should be executed, then a network solution can easily appear to have little value. Under these circumstances top management decisions should be made, or the network should be prepared in consultation with the agent who will be running the project. Resource loading in phase with other projects will also often reduce the flexibility of the network and finally, the network should be updated shortly after the start of the project, when constraints or opinions are adequately appreciated, in order to remove the flexibilities.

112. With regard to the question of repetitive work, I agree that work study and method study come into their own as offering the best solution for problems of this type. Provided that it is realized that a network analysis is ideally suited to projects which have a definite starting and finishing point, wasted time can often be avoided.

113. To deal more generally with the other points raised by Mr Hancock, remembering that CPA is fundamentally a planning tool, the monitoring of projects by s-curves and bar charts (where dependencies are not given), can be equally as effective as a network. Some of the advantages of the network solution for dealing with contingencies are lost, but the more simplified method of recording progress can be advantageous.

114. The method of dealing with activities which are neither completely consecutive nor in sequence was of interest, and appears an effective method of displaying this problem pictorially, the procedure outlined apparently being able to be used whether the network solution is placed on a time scale or not.

115. Finally, from the figure suggested as an aid to those deciding which planning procedure to adopt, I was pleased to note that, assuming a uniform spread of various projects over the figure, over 50% of the cases would warrant a network solution.

116. Mr Nicholson's comments regarding the possible compulsory use of CPA in the execution of civil engineering contracts, will, I am sure, be in agreement with most people's opinions on this matter. The fact that no project, whatever its nature, will be 100% effective if it has not the capable and enthusiastic support of all concerned, is well known by everyone. Critical path analysis, and the additional facilities it offers, has benefits for all parties in certain projects; the only occasions when additional costs arise should be when circumstances favour one party more than the other. The reasons for making CPA the required planning technique to be adopted by the contractor are that: (*a*) for planning any project as the dependency relationships are shown in CPA, the forward planning must be more effective than the normal bar chart procedure; (*b*) the consultant must feel that with CPA he is better able to protect his client's interests.

117. I completely agree with Mr Nicholson when he says that time–cost optimizations are where the real benefits of CPA are to be obtained, his suggested procedure for introducing this system being the most rational approach for implementing time–cost optimization. Does not Mr Nicholson feel that those contractors reluctant to adopt CPA have not perhaps fully investigated all the facilities it offers? Possibly the proposal of some consultants to introduce CPA forcibly might be beneficial.

118. The experience of Mr Nicholson regarding optimization and resource levelling is, of course, of interest. The use of manual or computer methods when adjusting networks for certain constraints is usually a choice of the individual.

119. The point raised by Mr Baird, regarding the provision of a CPA programme by the contractor as a necessary requirement of the General Conditions of Contract, and the detail demanded by such a requirement, could be extremely important particularly when costing a project. As none of the replies specifically gave the detail required by Mr Baird, I am only able to say that some of the firms replying talked of networks with activities numbering 1000 or more and that their programme was placed on a calendar time scale. This I feel shows that those firms who have accepted CPA are attempting to derive full benefit from the method, regardless of their contractual obligation in this matter.

120. As regards the comment related to the method of assessing the activity durations in conjunction with bonus targets, I appreciate there are problems produced by adopting this procedure. The comment was included, however, to help those people dealing with activity duration problems to become aware of the methods found helpful by others in similar organizations.

121. CPA versus PERT is perhaps one of those problems in which, as regards civil engineering construction projects, the only real solution is a compromise. The activity durations on difficult tasks are perhaps better assessed by the PERT three-level time estimate, whereas an activity orientated network does show a better pictorial plan. It may be of interest that my personal experience of teaching CPA is that people being introduced to network analysis often find it easier initially to draw a network with the activity description on the event.

122. Planning a four-week calendar month will give an 8% contingency allowance, and is, of course, another way of hiding float within the network for possible delays.

123. The seven points raised by Messrs Hynd and Faulkner which they feel the questionnaire failed to answer, are pleasing to myself.

124. I hope they will agree with me if I say that many of us have come to appreciate more fully all the problems of project control since the introduction of CPA, and that at least some of the questions they raise were perhaps initiated from the discipline that CPA imposes on the planning engineer. Many points were not included in the original questionnaire for the sake of simplicity, and to avoid asking too much from those to whom the questionnaire was circulated.

125. Their experience of the time required for the preparation of a network, checking of the resource loadings, and subsequent up-dating of the network will I am sure be of interest to others. The procedure they adopt to allow for various contingencies at the planning stage and subsequently for site by 'target' figures will also be of interest.

126. Some of the solutions they offer to the seven points they raise make me wonder if they have been able to implement their solutions, and if so how this was done.

127. Regarding the precedence method of constructing a network diagram, I feel that this procedure can complicate the clarity of a network, particularly for those not too familiar with the system.

128. Mr Woodward's comment that the number of projects planned by CPA is fairly small is not what the Paper intended to convey, nor the facts as given. Of the respondents 6% used CPA alone, and 52% of those engaged on construction projects used bar charts developed from a network analysis. As 32% still use bar charts exclusively, this means that the ratio of CPA planned contracts to bar chart planned contracts, is now in the ratio of approximately 2:1. Some of those replying also stated that, once the network techniques had been adopted to plan projects, this procedure was then used for all their projects; some others gave a value to this statement of 90% of their work.

129. Of those replying 92% agreed with Mr Woodward that the logical discipline demanded by CPA had been found beneficial in their organizations. Many of those mentioned the point raised by Mr Woodward, that the persons responsible for the actual management of the project should be consulted when the network is first drawn. One of the contractors stated that 'CPA must be a team effort between

planning staff, management, surveyors, site staff, etc., or like any planning technique it becomes useless'.

130. The fact that CPA is no substitute for good site management, but can assist the efficient site, is fully appreciated. Unfortunately, it was not possible to visit all the sites of the firms returning the questionnaire, this being one of the reasons for circulating the questionnaire. However, quite a number of sites where CPA is in use have been visited, and a personal appreciation of CPA improved, but detailed factual information is inadequate to further the information already provided in the Paper.