The Examination of possible Causes of the Lack of Success in the Application of Programming Techniques to Building Sites

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Summary

This work summarizes a series of studies by the author on concepts and difficulties involved in the use of programming techniques in building projects, in particular on house building sites of repetitive nature. It comprises mainly a throughout review of the literature, with some contributions stemming from the practical research work being undertaken at the Department of Civil Engineering, University of Leeds on activity's duration and precedence, as observed on three house building sites.

The report aims to examine possible causes of the lack of success in the application of programming techniques in building companies. These possible causes of the lack of success were sought in the following areas:

- the difficulties associated with the implementation of programming techniques in building companies;
- the applicability of the technical concepts introduced by the programming techniques. The following concepts are critically reviewed: activity's definition, activity's duration, precedence relationship between activities, sequence of work on house building sites of repetitive nature, resources required by the activities, productivity modelling, estimation of activity's duration and resources required, trade-offs between durations and resources required, total level of resources allocated to the project, and the setting of objectives criteria;
- the complexities of the programming problem: the inherent complexities of the problem and the added complexities introduced by updating and other possible managerial functions, like stock control, cash flow, and methods study are discussed.

The differences between the theoretical approach suggested by the programming techniques on the above areas, mainly in terms of the technical concepts, and the evidence obtained from the observation of the work on building projects are highlighted.

Finally, the report concludes about the relative influence that each of the aspects could have had on the lack of success in the application of programming techniques. Suggestions are made on how to use the techniques while solutions to the problems refered to are not found. The problems related to activity's durations and updating are singled out as the most important possible causes of the lack of success in the application of programming techniques. Greater research effort in these areas and the exploration of the capabilities of the programming techniques in dealing with time-related aspects, as opposed to their use to perform other construction management fuctions, are suggested as the course for action in the near future.

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1. Introduction

The simplest of the programming techniques, that is bar charts, were introduced at the beginning of this century. It can be said that the scheduling of activities in a project has been a well researched area during the last 40 years. The development of operational research techniques during the Second World War and the advent of the network techniques (CPM and PERT) at the end of the 50's markedly increased the potentialities associated with project programming.

The new programming tools attracted a great number of research workers in the areas of Operations research, Computing and Civil Engineering. The rapid development of research in this area and the increased capability and availability of computers made it possible to forecast that the programming techniques would introduce revolutionary approaches to almost every area of management (planning, estimating, cost control, bidding, bonus payment, motivation, inventory, contractual claims, etc. (Antill and Woodhead).

The research effort undertaken in the 60's considered that the network planning techniques could be

applied undistinctly to the whole industry. The Construction Industry was not treated specifically, even in research work done at Civil Engineering Departments. During the first years of network use, the building process was considered a good example of a deterministic approach to the planning problem, while research projects would be a good example of a probabilistic approach (Antill and Woodhead).

During the 70's various papers questioned the use of network planning techniques in the Construction Industry and other project industries (Mehra, Davis-1966, and Ling). The use of the techniques was restricted to large firms, and mainly to the planning stage. Little use was made of them during the running of the projects. The theoretical great advantages of the use of network planning techniques to manage the overall process of construction were not being used (Popescu).

The situation did not change in the late 70's. The author decided to investigate some causes of this apparent failure of the programming techniques in changing the face of management applied to the construction industry.

The author decided to study possible causes of the lack of success in the application of programming techniques

to the construction industry. The causes can be sought at various levels, involving either the technical aspects of the techniques, or the managerial changes that they require.

This work summarizes a series of reports by the author dealing with great part of the technical concepts and difficulties associated with the use of programming techniques in building projects. It looks in particular to house building of repetitive nature. It comprises mainly a throughout review of the literature, with some contributions from the practical research work being undertaken by the author on the production characteristics (activity's duration, precedence, and resource requirements) of three house building sites. Data for this latter research work has been gathered by the Building Research Establishment using an activity sampling package, and kindly made available to the author. The BRE great contribution and encouragement to this work is deeply acknowledged.

It was found convenient to study possible causes of the lack of success in the application of programming techniques divided in the following areas:

- the implementation of programming techniques in building companies;

- the technical concepts involved in programming; activity's definition, activity's duration, precedence

relationship between activities, sequence of work on house building sites of repetitive nature, resources required by the activities, productivity modelling, estimation of activity's duration and resources required, trade-offs between durations and resources required by the activities, total level of resources allocated to the projects, and setting of objective criteria;

- the complexities of the planning problem, and the added complexities of the updating requirements.

Each of the above topics and their subdivisions is planned to be treated in separate reports. For example, "The Analysis of Activity's Duration, Precedence and Sequence of Work - Graphical Software to enhance the printed Output from the Building Research Establishment Site Activity Analysis Package" report issued by the author on January 1982 deals with the analysis of durations found to be far greater than would be expected just considering the labour content of activities divided by the number of men assigned to the job, and the overlapping of supposedly preceding stages of work, as observed on three house building sites.

The report called "Some Causes of the Variability of the Level of Labour Resources assigned to Building Sites Programmes of Work", issued on February 1982 reviews quantitative and qualitative evidence found on the

literature on the losses and variability that can be expected in the number of man-hours daily available on site.

These two reports showed that the approaches normally used in programming techniques had not been able to model adequately the production characteristics of some building sites. For example, activity's duration are normally calculated by dividing labour content by the number of operatives assigned to the job, precedence between activities is usually of a head and tail type, and the total level of resources available on site is normally taken as deterministic by the programming techniques. The reports provided evidence about the lack of direct relationship between activity's labour content and durations, the overlapping nature of the precedence relationship, and the stochastic losses that can be expected in the total level of resources actually available on site. These discrepancies between the concepts of duration estimation, precedence definition, and setting of total resource levels could be causes of the lack of success in the application of programming techniques.

Moreover, this present report purports to show that apart from the discrepancies mentioned in the last paragrah, the problems associated with the implementation of the programming techniques, the modelling inaccuracy of

other technical concepts, and the complexities of the programming problem itself are all causes that could be behind the lack of success in the application of the scheduling techniques. The whole research project also envisages to select and modify techniques that could solve or accomodate the problems that nowadays are hampering further development in the application of programming tools.

The last chapter, dealing with summary of results, conclusions and suggestions for further work, tryes to evaluate critically the relative importance of all the problems affecting the mentioned lack of success. Recommendations are made on the course of action in the application of programming techniques while the difficulties associated with the technical concepts are not solved.

2. Some Causes of the Lack of Success in the Application of Programming Techniques to Building Sites

Some shortcomings of the application of programming techniques that have led to the slow down on research work in the area, a state of general criticism, and lack of confidence regarding their benefits are discussed in this chapter.

In this analyses of the possible causes of the lack of success in the application of programming techniques to building sites, a chronogical form of discussion is being presented. First, management should consider the problems associated with the implementation of the programming techniques in the company. After that, some trial applications of the techniques will be done to program the work on new projects. During these first programming experiments, management and programmers will face the difficulties associated with the technical concepts, as described in the previous sections. As these trial projects go into construction, the company will experience the problems related to the updating issue. After a number of projects, the staff in charge will probably become convinced of the complexities of the programming issue, as discussed in the last section of this report.

2.1 The problems associated with the Implementation of Programming Techniques in Building Companies

First of all, it can be said that the techniques were oversold to the industry. They were considered capable of revolutionary innovations on management without the necessary feedback of trials experiments of their application. Building companies adopting them were expecting great results immediately, which were not produced. The first attempts to use any new technique are decisive. The success or failure at these initial stages will command its future establishment as a company routine (see Popescu and Borcherding).

It is also worth of mention the difficulties with the introduction of the programming concepts at the various levels of the company. Programming techniques were understood as a tool that once used would produce good results: in fact they are a process, requiring the involvement of a great number of participants in the project, inside and outside the building firm. For example, the new techniques introduced modifications in the way in which activities were normally carried out on site, restricting the scope for decisions by foremen and workers. There are some evidence that the techniques were not

explained to foremen and site agents, or understood by them. High levels of management did not participate in the introduction of the new techniques in the company: in general they were preoccupied only with the end results of them.

The real interest in the techniques and the major effort for their introduction were confined to the medium level of management staff (site managers, production engineers, and white collar personnel in charge of controlling the progress of work on site). The techniques really did not go to the sites, they remained to be applied, discussed and played with at the company's main office (Adrian-1974).

Generally it was felt a lack of production information data to feed the programming models. The programming techniques implicitly called for the parallel application of work study, method study, and feedback of production information from previous sites. Few companies were able to introduce jointly both programming techniques and production data management information systems. On the other hand, there has been no great development in research work trying to obtain more accurate sets of data to be used in conjunction with the programming techniques. There is a clear disparity between the capabilities of programming

techniques and the quality of data available inside the building firm, or even gathered at building research organizations.

The successfull application of the programming techniques to each new project requires production-related information in connection with the technical concepts discussed in the next section.

2.2 The Applicability of some Technical Concepts involved in the Programming of Building Sites

2.2.1 Introduction

The so called technical concepts involved in the use of programming techniques are the definition of activities, the estimation of activity's durations and resources required, the definition, or estimation of the total level of resources required at each time period, and the setting of objectives to be achieved during the construction phase of the project.

The review of the literature showed that only part of the concept of resources required by the activities was sufficiently investigated by research work, that is, only the aspect of the variability in the resources required by the activities (or complete building units) is well documented in the literature (see Bishop-July 1965, Forbes, Lemessany and Clapp, Pigott, Price, Shanley, Shipley, Walker-1970 and 1971).

The other technical concepts introduced by the programming techniques have been used and accepted by

programmers and construction management research workers without evidence of their applicability stemming from building sites.

The importance of challenging these concepts is illustrated by the fact that when the network programming techniques were introduced in the late 50's, building projects were considered deterministic as far as the duration of activities and the resources required were concerned. The work of the authors cited above and others showed that activity's duration and resources required in building projects are also stochastic. The change of approach, from the deterministic case to the stochastic one, made the programming of building works a more realistic exercise. Unfortunately the other concepts like precedence between activities, objectives criteria, existence of time/cost trade-off curves were neither challenged nor investigated in great depth by practioners or research workers in the area.

It was decided to undertake an analysis of several concepts involved on site programming. The causes of lack of success in applying programming techniques to building sites could be related to difficulties associated with the practical aspects involved in the application of these technical concepts, or with the obtention of production data to support them.

This section will examine the concepts listed below:

- definition of activities;
- activity's durations;
- precedence relationship between activities;
- sequence of work on house building sites of repetitive nature;
- resources required by the activity;
- productivity modelling;
- estimation of activity's duration and resources required;
- trade-offs between durations and resources required by the activities;
- total level of resources allocated to projects throughout the project duration;
- setting of objectives criteria.

As already mentioned in the introduction, each of these aspects is treated in greater depth in separate studies by the author. The ideas contained in these separate reports are summarized here. The various concepts are grouped according to the contents of the reports.

2.2.2 The Concepts of Activity's Definition, Duration, Precedence and Sequence of Work

Authors like Fine and Forbes (1977) showed the difficuties associated with identifying activities or operations on site. Pigott observed the discontinuity of work in the operations; the workplaces were visited several times by the trades concerned in order to finish particular tasks. Forbes (1977) reported that due to discontinuity more than 300 operations were observed on sites where theoretically just 100 were programmed and needed.

Several authors proposed to estimate activity's duration by dividing their labour content by the size of the gang assigned to the job (see, for example, Barroso-Aguillar-1973, Butcher, Halpin and Woodhead-1972, and Preston), or by correlating linearly the activity's labour content to its duration (Duff-1980). No evidence supporting these two approaches of correlating linearly duration to labour content was found in some reports of productivity studies on site dealing with a similar relationship, that is, total cost or labour consumption and total project duration. The author did not find such direct relationship between labour content and activity's duration on the three housebuilding sites he is studying.

It was observed on particular sites that the operations were performed in parallel rather than in sequence as the programmes of work would recommend. Hall and Ball, and Roderick reported respectively the analyses of bridge construction and a one-off commercial building where this happened. The author observed the same phenomenon on the three house building sites he is investigating at the moment.

Apart from this parallelism, the precedence relationship between activities is not absolutely rigid. For example, painting and floor tiling are activities that can be rearranged either as preceding or suceeding in order to produce a better scheduling; the need for windows to proceed with the dry trades could be overcome by management decisions like the use of temporary plastic cocoons. Its is clear that this flexibility in terms of activity's precedence should be taken into account in order to optimize the scheduling of activities.

Finally, the various trades did not follow the same sequence of work from block to block on the sites observed by the author. For example, the dry-linings stage of work was tackle in a different order than the decoration stage. The precedence relationships and the principles of the Line of Balance Method (see Lumsden) would dictate that

the use of the same sequence of work by all trades is the more rational way of programming and performing the various tasks of the project.

The variability of activity's duration is discussed in the next section, since it has been associated with the variability in the quantity of resources required by the activities.

2.2.3 The Concept of Resources required by the Activities

The variability of operatives output on construction sites is very large. Similar activities, undertaken by different contractors on different sites are subject to a coefficient of variation between 30-40 % in terms of the amount of resources required (Gates and Scarpa-1971, and Bishop-1965).

Variability within a construction firm should be less and it is considered to have a coefficient of variation between 10 and 30 % (Bishop-1965,and Walker-1971).

The range of resources required by similar activities on a construction site is very large. Shipley reported a range 1:10. Fine (1975) gave an example related to pile driving with a range also of 1:10. Bishop (1968) found that ranges of 1:4 were common on building sites observed by the Building Research Establishment during the late 40's and the 50's.

Carr and Brightmann, Roderick, and the author came to the conclusion that the deployment of labour resources to

the activities or stages of work followed a "s" curve. Similar "s" curves have been used to represent the allocation of resources to the project as a whole.

The review of the literature showed that resources required by the activities are undoubtelly stochastic. The variability poses complicated problems to the estimation of resources required based on previous experience (Fine-1975): resources required by the activities on previous projects are only a sample of values from a distribution with a unknown average, standard deviation, and prcbably a very large range of values.

If activity's durations are obtained dividing labour content by the number of men assigned to the job, the high variability in resources required automatically dictates a high variability in durations. So far the variability of durations has not been treated separately from the variability of resources required. There are no quantitative information about the range of variability of activity's duration that can be expected other than the great number of works dealing with the probabilistic nature of resources required.

The fact that productivity on some projects is variable and its prediction is innacurate, as it will be seen later, led to development of stochastic programming models. These models, like PERT and simulation models, are able to predict the most likely completion times of the project and the probabilities of overrun, once final completion dates are set. Their major shortcoming is that they provide only information about the completion date of a project, without giving any guidance about the timing of intermediate milestones. In other words, it is not possible to decide upon the dates of intermediate milestones with the information provided by these stochastic models: once intermediate milestones dates are decided upon by the programmer, the constraints within which the model was originally run are not valid any longer. Usually, PERT and simulation models do not have constraints related to the intermediate due dates.

Britney, for example, showed that the project programmer should take the activity's durations greater than the most likely one, if the cost incurred in achieving also intermediate milestones is to be minimized. PERT uses the most likely duration as the activity's duration. Jewell indicated that the optimal scheduling of activities in an stochastic environment depends not only on the variability of activity's duration, but also on the amount of extra effort that is necessary to input to the project to recover

from scheduling deviations, making sure that intermediate due dates are reached. The simultaneous accomplishment of intermediate and final due dates is part of the complexity of the programming issue, that will be dealt with in a further section of this report.

The problem of defining the intermediate milestones is of particular importance in the construction industry, relying on a great number of external participants, like subcontractors, materials suppliers, public authority connecting services, etc.. Conwell suggested that at the strategic level, management should be preoccupied only with the definition of the intermediate milestones of a project. Detailed planning of works and the use of programming techniques should be confined to the tactical and operational levels of management. Further discussion on the importance of defining correctly the intermediate due dates will be found in the section dealing with the complexities of the planning problem.

2.2.4 The Concept of Productivity Modelling

The variability usually found in the activity's duration, in the amount of resources required, and in the level of resources available on site could theoretically be modelled by factors affecting productivity like weather, size of contracts, workmanship, amount of supervision available, incentive schemes, motivation, etc..

Some factors were already exhaustively investigated in the literature, as it is the case of the weather (see Benjamin and Greenwald, Clapp-1966, Grimm and Wagner, and Smith and Rawlings). Difficulties associated with the use of factors to model productivity are given below.

It is relatively easy to quantify the influence of weather on productivity, but Clapp (1966) showed that it should be looked at in five different angles (decreased productivity, increased absenteism, decreased number of hours in the working week, increased time spent on repair work, and decreased productivity on alternative jobs while external work is disrupted by bad weather).

The so called Learning Phenomenon requires specific conditions on site in order that it could develop. Forbes (1977-1), Gates and Scarpa (1972), and the Committee on Housing, Building and Planning, ONU, said that learning would occur only in the presence of good management on site, continuity of work, and a sufficiently large number of repetitions.

The influence of the number of hours spent on supervision had been the object of works by Walker (1972), and Logcher and Collins, but no undisputed statistical evidence was found, due to the relatively small amount of supervision hours spent on various sites. Probably it will never be possible to get more than qualitative evidence about the level of supervision to be used a project and its influence on productivity.

In general, studies about factors affecting productivity are not conclusive, there is little information published, and results obtained by different others are hardly comparable. It is doubtful if a sufficiently large number of cases could ever be obtained to draw statistically significant conclusions about the influence of particular factors. Different factors affecting productivity can occur simultaneously, introducing additional complications in the statistical analysis. For example, repair work can be caused

by bad weather, lack of supervision, lack of skill, high level of workmanship required by the client, or purely by accident.

Some of the factors affecting productivity can be related directly to individual crews or operations. It is the case of the use of equipment, operatives training and skills, subsoil conditions, overtime and incentive schemes. Others can be related only to productivity as a whole, like absenteism, labour turnover, safety, the disruptive effect of constant variation orders, repair work, etc. Weather influences the progress of work on site both at the level of the activity's productivity and at the level of productivity associated with the whole site (Clapp-1966).

Factors affecting productivity can influence different participants of the construction process. For example, the influence of supervision and motivation can be considered at the operative level, at the foreman level, at the site engineer level, up to the client and construction company managerial level. Likewise, financial constraints imposed by government action will be felt by the building company itself, by the client, suppliers, designers and subcontractors.

Difficult site access and subsoil conditions, repair work, and variation orders tend to increase the labour content of activities. Other factors affecting productivity like incentive schemes, motivation, and training may increase the output of operatives. Weather, absenteism, and unbalanced crews can be expected to decrease the operatives' output. Architect's and authority's approvals, labour and materials supply, and lack of good programming of works tend to delay the building process, without necessarily increasing the cost of the project, if management could succesfully deviate resources to other projects. The modelling of productivity is made more complex by these different ways in which some factors influence the building process.

Carr developed a simulation model capable of incorporating the influence of factors affecting productivity in the calculation of activity's durations. The crux of the matter is the obtention of reliable quantitative values to be used as the factors modifying the activity's durations in order to make the simulations realistic.

Kellog introduced the concept of hierarchy of factors affecting productivity. His approach is designed to look at the construction industry productivity in a broad macro-economic sense, but it could easily be extended to the

modelling of productivity on site. The hierarchical approach seems to be a sensible way of dealing with the great number of factors affecting productivity and their relative importance. It could be suggested that only the most important factors affecting productivity should be investigated and used in production modelling, accepting the fact that a good part of the variability of productivity on site, which would be caused by minor factors, cannot be adequately explained due to the lack of statistical feedback information.

Variations in productivity can be controlled or reduced using the knowledge derived from the study of factors affecting it. Nevertheless, in practice there will be always a residual variability represented by partially uncontrollable factors like weather, client variation orders, and subsoil conditions.

Baldwin investigated the ranking given by architects, contractors, and engineers to several causes of delay in the construction industry. Attendance of subcontractors, weather, and labour industrial relations problems were given the three top ranking positions. No other classification of factors affecting productivity or causing delays was found in the literature.

Several authors showed that "good management" is the reason behind the correlation of some site indexes and productivity. Low non-productive time, development of the learning phenomenon, good safety records, worker's motivation, the successfull application of incentive schemes, the willingness to work under bad weather conditions, good quality of work and prompt repair of defects, the use of improved methods of construction, and the successfull use of programming techniques were observed to occur simultaneously with good management practices. In this sense, good management would occupy one of the top positions in the hierarchy of factors affecting productivity. It went without saying the difficulties of defining what is understood by good management, and how a good management factor could be established to model productivity.

The learning phenomenon could represent a set of factors affecting productivity that are related to the continuity of work on site, like bad weather, labour turnover and absenteism, materials shortage, equipment failure, and subcontractors attendance.

2.2.5 The Concept of Estimating Activity's Durations and Resources Required

The process of estimating durations and resources required was found to be innacurate by some research workers. The review of the literature points out case in which:

- activity's durations were underestimated by 20 to 50 %, that is, real durations are between 25 and 100 % greater than initially estimated (Kidd and Morgan, King and Wilson, King et alli, and Roderick);

- resources required by the activities were underestimated by 20 to 50 % (Ashworth-April 1980, and Roderick);

- apart from those biases, it was found that estimating techniques were not able to predict actual resource content of activities with a coefficient of variation oetter than 20 % (Ashworth-April 1970, Fine (1970), and McCaffer). These coefficients of variation were obtained using normal analytical estimating techniques by Ashworth and historical methods by McCaffer;

Fleming and Ashworth (March 1980) found that labour constants published in estimating books were not reliable sources of information on resources required by the activities. Fleming showed that despite the technical evolution of the construction industry during the years, the labour constants published in estimating books books did not change systematically during the last century. Ashworth (March 1980) compared the information produced by some estimating books and pointed out the different unit rates given to identical tasks by the different sources of information.

2.2.6 The Concept of Time/Cost Trade-off Curves

Problems associated with activity's durations and resources required (costs) were investigated in the previous sections. Now it is worthwhile to examine the concept of time/cost trade-off curves, that calls for the estimation of several pairs of activity's duration and associated costs. These curves are represented by convex decreasing functions relating direct costs to perform one operation to the corresponding durations. Sometimes a convex increasing part of the curve is added to represent increased costs with large durations. The time/cost relationship could also be represented by isolated points rather than curves.

When first introduced, the Critical Path Method had two major advantages over traditional programming techniques like the Gantt Chart:

a) the technical precedence relationship between activities could be displayed graphically in an easily understandable form. The precedence relationship between activities also provided a suitable algorithm for the calculation of project total duration, activity's start and finish dates, and activity's floats;

b) the time/cost trade-off curves would be able to summarize the influence of several important decisions influencing the construction process, like the choice of method of construction, number of crews assigned to each operation, overtime work, etc. The curves also provided the mathematical relationships needed to optimize the scheduling of operations.

The review of the literature showed that research work done so far failed to investigate the real nature and shape of the time/cost trade-off curves on building sites and other projects in general. This view is shared by Davis (1966): up to 1966 he did not find any research work dealing with the practical aspects and the proof of existence of these curves. Elvers (1971) doubted that companies would ever prepare these curves; the preparation of single cost and duration estimates is a major task in itself, and several accurate estimates would be necessary to produce each activity's time/cost trade-off curve.

The author investigated the literature dealing with the following aspects associated with the concept of time/cost trade-off curves:

- changes in the method of construction;
- different crew sizes and crew compositions;
- overtime work;
- incentive schemes;

- use of subcontractors;
- resource mobilization costs;
- resource idleness costs;

The review of the literature concluded that only under special circumstances it is possible to draw activity's time/cost trade-off curves. Some of the interesting points raised by different authors supporting this view are reported in the next paragraphs.

The building company would be able to consider different methods of construction only if it is fully acquainted with them, otherwise it would incur the costs of becoming familiar with a new technique. The costs involved in the use of a new technique are not really known until some experience is obtained with their use on site.

Pigott showed one example where only a restricted number of crew compositions and sizes produced shorter durations with greater number of men assigned to the job. Some large crews were totally unproductive, costing more and apparently taking more time to complete the operations than smaller crews.

Kappaz and McNally reported the contraproductive effects of overcrowding the work place in the cases in which a greater or multiple crews are employed to decrease the duration of a job.

Blough and McGlaum emphasized the lack of net production gains in some projects where overtime was used continuously for more than 7 days. Moreover, they stressed that due to the problems associated with industrial relations on site, it is not possivel to put only some trades and activities on overtime work.

Incentives schemes in fact originate increasing cost/time relationships, that is, decreased durations would be theoretically obtained with decreased costs. If this is true in practice, incentive schemes are not able to produce the classical decreasing curves generally associated with time/cost relationship. Again, incentive schemes cannot be used only with particular trades and activities, if labour-related problems are to be avoided.

The true costs of subcontracting are not easily calculated due to the difficulty of enforcing prices and durations agreed upon in the contractual documents, if any. Variation orders, which are the rule in the construction

industry, not the exception, help to decrease the lawful implications of prices and durations set on contracts. Pigott showed that subcontractors were undoubtelly more productive than the main contractor own labour on three sites analysed. However, they were responsible for the discontinuity of work on site, making irrelevant, timewisely speaking, the productive gains in terms of man-hours.

Time/cost trade-off curves obtained from the consideration of resource mobilization costs (Cullingford and Prideaux), or resource idleness (Danoon, Fine 1977-1, Fine 1977-2, and Kauffold) can only be applied to the whole process of construction, not to individual activities.

As a conclusion, it can be said that the difficulties in applying the concept of time/cost trade-off curves to the programming issue are related to the problem of calculating accurately the real costs and durations associated with the factors listed above, like change in the production methods, use of different crew sizes, overtime work, etc..

2.2.7 The Concept of the Actual Level of Labour Resources available on Site

Once the site programmer decides about probable activity's duration and resources required, the next step is the definition of the total level of resources to be made available on site. The required level of resource on site can be obtained in two different ways. It could be set as a function of the already scheduled activities and their resource requirements, or it can be imposed by external considerations. Cullingford and Prideaux proposed a model to optimize the resource profile of a project before actually scheduling the activities and defining their durations and resource requirements. Gates and Scarpa (1976) suggested to define the resource profile based on practical experience and past records.

Resource Scheduling techniques are used to allocate a limited quantity of resources to competing activities, thus defining their start and finish dates (see Rickard, and ICL-PertDisc). Resource Levelling is used to smooth peaks and valleys in the resource histogram previously obtained by just aggregating the resources required by individual activities. Optimization techniques call for the simultaneous use of Resource Scheduling, Resource Levelling and Time/Cost Trade-off techniques (see Kauffold).

Up to now, research work has been considering the resource levels associated with building projects as deterministic parameters. Any variability in the actual level of resources available on site was theoretically modelled by the variability in activity's duration or resources required. The author proposed in his report about resource levels on building sites to separate this two causes of variability: causes of productivity variation related to resource fluctuation should be separated from causes of productivity variation intrinsic to the nature of the activities.

The author identified labour absenteism and labour turnover as two causes of variability in the actual level of resources available on site. The review of the literature showed that very little is know in quantitative terms about these two common features of building sites. Staggering figures were presented by some authors; for example, Bishop (1968) stated that the labour force could be 50 % larger or smaller than in the day before. Average losses in the number of man-hours available due to absenteism was found to be as high as 8 % in some projects.

Barroso-Aguillar (1973) considered that the magnitude of absenteism deserved the application of a linear programming technique to allocate the variable number of workers that turn up daily.

Two other absenteism-related problems were identified. Firstly, Pigott concluded that the discontinuity of work on site was caused by subcontractors working simultaneously on various sites, always looking for 'snags-free runs of work' and moving from site to site as soon as production difficulties were presented.

Secondly, a NEDO report (1976) dealing with industrial plant construction showed that on average 10 % of the daily working day was lost due to late arrivals and early departures to and from the work place (not necessarily to and from the site). The author found some similar qualitative evidence on the sites he studied. His observations also suggested that the distribution of resource availability during the day followed a complicated pattern. The existing evidence indicates that resouces should not be considered available on a constant basis throughout the working day.

Another source of variation in the actual level of resources available on site is the non-productive time found on building operations. Non-productive time was consistently found to be in the region of 20-50 % (Forbes-1968, 1971, 1977-1, 1977-2, Logcher and Collins, the NEDO report-1976, and Stewart and Torrance). Obviously non-productive time could be included in the estimates of the

labour constants, but Forbes (1977-2) suggested that it should be treated as a global figure, as a particular characteristic of building sites or building companies. If this is the case, non-productive time would be better considered at the level of an aggregate figure, like the total level of resources available on site. Despite the evidence that non-productive time is a characteristic of each particular site, Bentley showed that non-productive time varied with different types of activities within a site. It could also be expected to vary throughout the project duration, daily, weekly, monthly, or according to the season of the year (Clapp-1966 and Pigott).

2.2.8 The Concept of Objective Criteria

Construction sites programmes of work can be obtained by several different methods, ranging from network techniques to simple contractual arrangements between the participants of the building process. Schedules of work can be differentiate by the attainment of certain management objectives. These management goals are the objective criteria used to compare different schedules.

The objective criteria are generally related to quantifiable measures of the construction process, but there is no theoretical problem to extent their evaluation to the whole lifecycle of a project, from design to utilization. Subjective and qualitative measures can also be introduced as the objective criteria.

Some objectives are not easy to transform in monetary values. It is the case, for example, of the policy commitment of some building companies of handing over the projects they undertake always on due dates, whatever the difficulties they might face. This good completion record that the company could offer to prospective clients probably would be associated with a higher markup margin at the tendering stage. Complex risk analyses would be called in

to help transform this subjective criteria of handing over projects always on time in quantifiable measures. To the best of the author's knowledge this approach was not yet tryed successfully by research work.

According to Fendley, the most common objective criteria are the ones related to:

- project duration (deterministic and probabilistic view);
- resource utilization; level of resources required to undertake the project, fluctuation in resource requirements, and resource idleness;
- number of projects or activities being undertaken simultaneously.

Lichtenberg stated that all this measures of the quality of projects are genuinely correct, but that they are in fact sub-objectives to be attained during the construction phase. He said that up to now one of these sub-objectives has been taken as the more important one, and the others abandoned. The real objective would be a weighted measure of all sub-objectives. Some other authors also proposed this weighting technique but without solving the problems associated with the subjectiveness of how to set the weights to the various objective criteria being considered simultaneously.

Lichtemberg tried to transform into cost elements all aspects related to a set of objective criteria. Project duration, resouce utilization, work inventory, and other factors like overtime, mobilization costs, etc. would be represented by their cost implications over the project construction. The objective criterion would become solely the minimization of total present project cost. The main criticism is that this technique would eventually require the consideration of the whole management problem (supply of materials, personnel administration, client and contractor relationship, cash flow analysis, site productivity, etc.) within the programming technique. This encompassing approach, despite the fact that it is theoretically sound, will be shown unpractical later on this report.

Another major difficulty associated with the concept of programming objective criteria is how to evaluate their effectiveness in terms of the intermediate and final results obtained during the construction phase. Bromilow (1969) showed that project durations were on average 49 % greater that stated in contractual documents, but projects using programming techniques had durations only 1 % greater than initially agreed. It was not possible to distinguish the effectiveness of good schedules as opposed to bad schedules (or the effectiveness of schedules capable of attaining good and bad measures of a particular objective criterion). The most important factor in order to achieve

final due dates was to have a programme of works, no matter how it was obtained.

Studies by the Environmental Research Group of the University College - London - (1974) came to the conclusion that building project durations were a function of the state of the construction activity. Depressed markets led to long project durations, while booming markets led to the rapid conclusion of projects. The positive effect of programmes of work in keeping project within the contractual periods was not reported.

Authors like Gates and Scarpa (1976), Handa et alli, Kleinfeld, Lemassany and Clapp, and W. N. Perry suggested that resource profile curves could be obtained by historical methods rather than by resource aggregation used in conjunction with programming techniques. This means that advantages and disadvantages associated with particular resource profiles on site could have been achieved either by the use of the programmimg technique itself, or by the natural tendency of projects to follow specific resource profile patterns.

Other objective criteria like resource mobilization costs and resource idleness were found to

depend respectively on the state of activity in the construction industry (Soeterik), and on the quality of management (Forbes 1977-1, Logcher and Collins, Miller-1977, and Smith and Rawlings), rather than on the characteristics of the programme of work.

The information provided in the preceding paragraphs leads to the conclusion that the objective criteria normally set to programmes of work are not able to distinguish between good and bad schedules. This could be so mainly due to three reasons: firstly because it is difficult to evaluate the influence of a particular schedule on the success or failure of the construction phase of a project; secondly because some of the objective criteria are influenced by a great number of outside factors, not only by the characteristics of the schedule; and thirdly, because generally the case is for multiple objectives and not for single ones.

2.3 The Complexity of the Programming Issue and its Relationship with other Areas of Management

2.3.1 Introduction

The programming issue has a complex mathematical nature, even not considering related aspects of management like cash flow, incentive schemes, cost estimating, etc. (Davis - 1966). It is generally accepted that the exact or optimal programming techniques are of little use to the scheduling of construction work, due to the restricted number of variables that they can handle (Butcher, Burt, Dressler, Preston, and Shaffer). The optimization obtained using these exact techniques can be considered in fact a sub-optimization, because a great number of variables are left outside the programming models.

Great part of the research effort in network programming techniques was devoted to the optimal methods like linear programming, dynamic programming, backtracking methods, and stochastic programming. The results of this research effort bear very little relationship with the construction programming problem.

Resource Levelling and Resource Scheduling, time/cost trade-off analysis, scheduling to satisfy different objective criteria, factors affecting productivity and resource usage on site, stochastic nature of the building process, etc. are all important aspects of the programming problem that should be considered in a greater or lesser extent in each particular project.

Furthermore, due to their own nature, the programming techniques, especially the ones based on network concepts, could be used to help perform several management functions like project cash-flow, pay-roll, cost accounting, calculation of contractual claims and the like. Building companies are in general undertaking a great number of projects; there is no theoretical difficulty in modelling a number of simultaneous projects.

The simultaneous modelling of all the above aspects results in a huge combinatorial problem, perhaps proibitively expense to be dealt with by computer simulation, needless to say by the exact mathematical methods. In practical terms, the number of variables that can be handle is limited by the computing facilities available, by the objectives of each company, or by the time taken to prepare the necessary input data. Some examples of research work trying to put together programming

considerations and other aspects of management are reviewed in the next section.

The programming problem should be hierarchized in its strategic, tactical and operational aspects, and each aspect should be considered on its own. Harris and Evans (1977) reported some experience with the management of construction sites using programming models and strategic and tactical decisions. Borcherding said that policy, strategic and tactical decisions by management help to simplify the programming problem.

Several examples can be given on how decisions at a higher level might help to simplify the complex programming problem. For example, the implications of the time/cost trade-off curves in the scheduling of activities on site can be made simpler if one of the main sources of these trade-offs, that is, overtime work, is ruled out by strategic or even policy decisions. Authors like Blough and McGlaum showed the totally detrimental effects of overtime on productivity.

The productivity improvements caused by the Learning Phenomenon (Gates and Scarpa-1972) can be disconsidered if the company decides tactically to undertake

two projects in the same area, using the same pool of labour to tackle the jobs, as it is common practice. The discontinuity of work caused by the constant movement of the operatives from one site to another would almost certainly prevent any improvement in productivity due to learning (see the Committee on Housing, Building and Planning Report - "Effect of Repetition on Building Operations and Processes on Site").

Patterson, recognizing the sizeable computing cost involved in the programming techniques, investigated methods of previewing the performance of different scheduling heuristics. Instead of applying a number of different heuristics to a specific project and incurring the cost of this computing exercise, he thought it would be better to apply only the heuristic with the best chance of attaining near optimal results.

The problem of costs of implementation and use of the programming techniques remains open to discussion. Ling, summarizing the work of other researches and reported practioners experience, said that the programming costs during the pre-construction and construction phase were in the region of 1 to 2 % of the total project costs. Authors like Lumsden, Patterson and Rickard claimed potential cost benefits of the application of programming techniques in the

region of 5 to 20 %. If this is so, there is a great scope for more and more effort to be applied to the issue of programming the construction of projects. The ever increasing availability and capacity of computers indicates that the costs involved in programming site works would tend to decrease in the future. With this increase in computing facilities, more and more of the complexities involved in programming could be tackled in a cost effective way.

Unfortunately the experience accumulated in scheduling applied to manufacturing industries and research projects cannot be directly used in the construction industry, due to the singularity of its programming problem. Each of these areas of application of programming techniques has special characteristics.

Research projects are totally stochastic in nature, in general no previous experience is available on durations and resources required. Availability of resources is not a problem, if the prospects of the research project are good. The total project duration is generally the most important objective criteria to be attained.

Manufacturing industries, producing great quantity of goods with unitary low values as opposed to the relative

high value of the construction industry product, face a more deterministic process and a more controllable environment. Once the production process is started, the flow of work should be smooth, making the intervention of management unnecessary in the short run. Resources and deadlines are absolutely defined and should be respected. The most important objective criteria is the achivement of minimum production costs.

In the construction industry, the environment is partly uncontrollable, some experience can be gained from previous projects but each project is unique, and the process was shown to be stochastic in nature. Costs and completion times are regulated by contracts. Theoretically they should be equally important as objective criteria, but Bromilow (February 1971) and R. Harris showed that clients are more preoccupied with keeping the total costs within the budget that with sticking to fixed project durations.

However, the most important distinction between the programming problem in the manufacturing industries and in the construction industry is that in the latter there is a group of personel constantly available on site, or at the building company office, whose job is to intervene in the construction process, correcting deviations from the schedule. This potential use of the management presence on

site should be explored in the initial programming stages. Kauffold classified the programming techniques according to their suitability to the various types of industries, but did not pay attention to this particular presence of management in the construction industry case.

Some research work, while recognizing the stochastic environment of project programming, used the concept of "average" results obtained using a specific technique in a number of simulations. Projects are such in the construction industry that the contractor will not face a sufficient number of repetitions to take advantage of "average" results. In the manufacturing industries the number of repetitions is larger, and the company can rely on average simulation results to decide upon the applicability of particular techniques. In the construction industry the programmes of work should be sufficiently robust to overcome problems caused by the great number of variations in productivity, delays and deviations from schedule that could occur. The programme should be optimized to produce a sufficiently good result in terms of the objective criteria, whatever the conditions to be faced during the project construction.

This concept was firstly introduced by Fendley. A good example is the change of objective criteria as the

project is being built. At the tendering stage, the achievement of due dates is of paramount importance to the client. As the project progresses, it could happen that the amount of variations orders or the irregularity of payments by the client is such that the initial contractual commitments in terms of due dates are meaningles, and the contractor could change to the objective criteria of minimizing his overall costs. The initial programme of works should not impose severe constraints to the rescheduling of site works taking into account this new objective. Some programming techniques, like the ones introduced by Pritsker, are able to consider a whole range of circumstances that could be expected to arise during the project construction phase. Nevertheless, these techniques are still not able to incorporate probable changes in the objective criteria.

After the following section, this report returns to the examination of the robustness of the initial programme of works in face of the updating of the schedule and site management. The compromises between decisions at the programming stage and possible updating actions are further discussed.

2.3.2 Some Examples of Research Work incorporating other Management Aspects into the Programming of Construction Sites

Abdulmajid related the programming of house building projects to the availability of resources, like tradesmen and bricks, at a macro-economi level. It is clear that the resources available as a whole in each region should be related, among other factors, to the time taken to built the project. In other words, the programming of activities for each individual project should somehow consider the present use of construction resources at the regional level. As a corollary, it can be said that in vertically integrated building firms, that is, the ones dealing also in the area of supplying or producing building components, it is necessary to determine at what level the programming of works should be optimized. The programming could be considered at the whole company level, or only at the construction division level.

Barroso-Aguillar (1973) related the problems of scheduling of activities and stock control of materials on building sites. The modelling complexity is great even at this level of integration of different management functions. Barroso-Aguillar opted for optimizing the scheduling of activities and then, given that schedule, optimize the stock

of materials. This approach led to the suboptimization of this two aspects taken together.

Paulson (1971, 1975) tried to explore at its fullest extent the capabilities of modern man-computer systems. The whole process of construction management, including production feedback, estimating and scheduling of activities, methods improvement, and the analysis of the time/cost implications of different methods of work would be made possible by powerful computer facilities, data storage, and other office equipment. This research project was partially abandoned in recent years, probably due to the costs of developing this complete managerial information system.

Moavenzadeh considered the progress simulation of tunnel construction, taking the physical characteristics of each section of rock being drilled as stochastic variables. The amount of computer effort, given by the number of repetitions needed in the simulation exercise, showed the practical difficulties of including more and more variables in the programming of works on site. Moavenzadeh did not include the trade-off between greater rock exploration costs before the start of the project and the benefits to the schedule of a more accurate knowledge of the rock drilling characteristics. This trade-off between greater costs

incurred in getting information about the site and improved accuracy of the information is suggested by Bjornsson. The consideration of this trade-off would add a new dimension to the programming problem.

2.3.3 The Updating Problem

2.3.3.1 The Decision of when to update a Project

After the analysis of the applicability of some technical concepts to the programming issue, prospective new users of the scheduling techniques should consider what sort of problems can be expected in the updating of the programmes of work, and in the collection of site production feedback data.

It was already mentioned in this report that the application of the programming techniques to building sites was considered a good example of a deterministic approach, that is, once activities and resources are scheduled, no substantial discrepancies between what is planned and what will really occur on site should be expected.

The review of the literature showed Nutall (1965) as the first researcher using a stochastic approach to the programming of building sites. From that time on, observations of building sites have shown that variations in productivity, deviations from schedule, project overruns, stoppages and breakdowns are the norm and not the exception

in the building industry. Frequent updates are necessary to bring the project back on schedule. schedules.

Streeter said that it is not always necessary to intervene in the project at each updating if progress on site is not matching the programme of works. The cost of collecting feedback data and stopping on-going activities in the case of resources being diverted from them, prevents the use of very frequent updates and interventions. Elvers proposed a function to represent the cost of intervening in the normal flow of the project. In fact, the updating corresponds to a new programming of works, with practically the same amount of effort in terms of clerical staff, computer time, and communication to and acceptance of the new schedule by the participants of the building process.

The type of personnel involved in the updating effort is different from the type of personnel involved in the initial programming. At the initial stage it is more likely that the programming department, or the estimating department, is in charge of applying the techniques to the new project; as the work progresses on site, it is wiser to let personnel directly involved with the day to day running of the project to perform the rescheduling of activities and resources.

It is not easy to determine when the programme of works requires an updating. Kappaz stated that the majority of disturbances and deviations from schedule are small and could be individually accomodated in the floats available. It is necessary to measure the deviations from the schedule on a cumulative basis to decide if a management intervention is needed. Critical Path Techniques, for example, will not show the disruptive effect of delays in the activities outside the main critical path.

Elvers and Ferdows examined the question of when to update a project. Elvers found that for each project a particular strategy should be followed. Ferdows found that more frequent project updating does not always improve project performance, measured in terms of average project completion slippage, average resource idleness, or average number of projects being worked simultaneously. Resource idleness was found to increase with more frequent updating in the majority of cases studied.

Furthermore, the set of management tools available at the updating periods is not as complete as in the initial programming period. Thus the whole reprogramming process becomes more constrained. Construction methods and site management style are already implemented and would not be easily changed. For example, incentive schemes should

preferably be in force since the start of the project; overtime work requires a very careful timing and management should face the possibility of using it until the completion of the project, once the workers realize their bargaining position; the employment of more labour resources should consider the added mobilization costs and the matching of old and new crew's production rates.

Any corrective action taken by management takes a period of time to be implemented. Site management can hardly afford the implementation period if the project is already running behind schedule.

Several contractual commitments are assumed during the course of the project: for example it would not be easy to reschedule delivery dates of important components, or to convince the client about a tighter schedule of payments. As the end of the project comes nearer, the scope for action decreases (Elvers). The relationship between early programming of works, site management, and the updating issue is explored further in the section below.

2.3.3.2 The Relationship between Updating, Site Management and the Early Programming of Works

Generally, it has been observed the lack of emphasis on the close relationship between early programming of works, site management, and the updating issue. For example, the following aspects are not highlighted in the literature: any costs incurred to obtain feedback data to programming models could also be partly allocated to the cost of improving general management on site; more effort allocated to programming at the pre-construction stage could determine less costly management during the project execution. This last proposition suggests an analysis of the trade-offs between greater programming costs now or greater management costs later.

Authors like Barroso-Aguillar (1973) made a distinction between programming techniques applied to the project before construction starts, and management techniques used to solve the day to day allocation problems on site. The former would be used to set the milestones, due dates, and objectives to be achieved, while the latter would just optimize the daily allocation of resources, within the framework given by the previous scheduling.

The milestones, due dates, and contractual arrangements based on the information provided by the early programming of works will represent constraints to site management during the construction of the project. It can be suggested that all arrangements made using information derived from the early programme of works should not represent severe constraints to the management of the project, whatever variations in productivity, delays and deviations from the schedule could reasonably occur.

The scheduling techniques used at the early programming stage can be successfully used again during the construction stage, as part of the set of tools available to site management to put the project back on schedule. Nutall (1965) compared in a simulation exercise the end results of two different styles of site management; in the first, a programme of works was followed strictly; in the second one, with no programme, the foreman decided which activity to schedule next based on a heuristic rule of thumb. This latter style of management provided better results in terms of the achievement of due dates and smaller project duration. The rule of thumb used by the foreman could had been used to establish a programme, before the project started on site. Unfortunately he did not investigate what would happened in the case the foremen had used the heuristic decision rule within a previously established schedule framework.

One of the reasons preventing the consideration of the early programming of works and site management as similar problems is the difference in the quality of information at the pre-construction stage and during the construction phase. It can be said that at the pre-construction stage the uncertainity about the building process is at its maximum, but the site programmer has a great deal of flexibility in terms of programming; during the construction phase the certainity about the building process increases and the scheduling flexibility decreases.

The early programme of works is done when the information is in its worst form. More often than not, the design is not yet concluded. During the construction stage, data used to update the schedule could benefit from the production feedback gathered in previous weeks.

Moreover, as already mentioned, the personnel that usually perform the programme of works in the pre-construction phase and the personnel that would be involved in the rescheduling of activities are different; the first programme is done by the programming or estimating department; the reprogramming or management of works on site should be done by personnel most directly invclved with the day to day running of the project.

Abernathy, after finding that the accuracy of estimates can improve during the construction phase of a project, recommended an adaptative strategy on scheduling and updating:

> "Action taken on early information (that is, less accurate information than the information obtainable towards the end of the project) may degrade overall project performance rather than improve it. By adaptative strategy we mean the particular pattern of rescheduling action that is pursued over the lifecycle of a project. The objective of the strategy is to minimize the sum of (1) the cost of rescheduling, (2) the costs of inappropriate scheduling action resulting from the use of poor estimates, and (3) the costs of foregone opportunities to make inexpensive corrections at an early period. It is appropriate to think in terms of strategies rather than optimal scheduling since the derivation of optimal schedules is frustated by the presence of an unknown component of bias (optimistic bias in estimating, real durations are far greater than estimated)".

This suggestion by Abernathy introduced a new avenue for the development of research works in the area of programming. However the mathematical formulations for such approach are not straightforward. Biemer and Sielken, Burt, Britney, and Jewell produced interesting introductory research work in this area.

3. Summary of Findings, Conclusions and Suggestions for further Work

3.1 Summary of Findings

Every aspect looked at in this research work showed important discrepancies between the theoretical approach used by the programming techniques anc realities faced on site or at the building company office. These discrepancies went from the difficulties in accepting the new techniques at the various levels of the participants involved in the project, as opposed to the hopes for their easy acceptance, formulated during the introduction of the more powerful programming techniques in the late 50's, to the lack of evidence from building sites supporting the technical concepts. It should not be forgotten also the theoretical approach used in updating, that is, each updating can be transformed in a totally new programming problem, while it has been shown by these report that updating is a more constrained and complex problem.

In this sense, all difficulties associated with programming dealt with in this report are potential causes of the lack of success in the application of scheduling techniques to the building industry.

It is the case now of discussing the relative importance of the various aspects as causes of the lack of failure in the application of programming techniques.

3.2 Conclusions

It has been generally accepted in the liteature that the use of programming techniques have not been capable of achieving the desired improvements in the management of construction projects due to the lack of communication to and involvement by the great number of participants in the building process. The difficulties associated with some technical concepts, like for example the estimation of activity's duration, have not been made responsible for the apparent failure of the application of programming techniques. This view is not supported by the author, that believes that the difficulties associated with the technical concepts came second only to the lack of change in the managerial structure and procedures inside the building company as probable causes of failure in the use of scheduling tools.

It is possible to make some distinction in the way in which the lack of modelling capability of the technical concepts affects the programming problem. As it will be discussed in the following paragraphs, the problems related to the activity's duration and definition, and the setting of objectives criteria can be considered of fundamental importance, while the problems related to precedence between activities, variability in the resource requirements, and

the variability in the total level of resources available on site can be overcome in a number of different means using the present programming techniques.

The overlapping noted in the precedence relationship between activities can be considered as an extra flexibility in the schedules, to be used at an operational or tactical level. Strategically the schedules can be drawn disconsidering great part of the overlapping between activities, thus leaving some room for recovering from schedule deviations by means of tackling simultaneously otherwise preceding and succeeding activities. This use of overlapping is probably already practised on building sites.

The problem of variability in resources required by the activities is already well documented in the literature. Building companies could start using the coefficient of variation published by various authors, until they develop their coefficients, based on feedback data from their own sites. It is important to note that Fine (1977-2) suggested that the reduction of the coefficient of variation of activity's duration and resources required is more important than the reduction of activity's costs, in terms of the cost implications of the schedules of work.

The variability in the total level of resources available daily on site, and the difference between the programmed level and the actual level caused by, for example, non-productive time, can be incorporated in the variability of activity's duration and resources required, and in the labour constants, respectively. This is believed to be the traditional approach used so far by the programming techniques. In his report dealing with the matter, the author did not recommend this approach. However, it is sensible to say that at this moment in the development of the programming techniques there are more important factors related to technical concepts deserving research attention. The traditional approach can still be used. Its unique shortcoming is that the production characteristics of the activities are made solely responsible for the deviations between planned schedules of work and the actual progress on site, avoiding the examination of possible causes of discrepancy at the level of the whole site, as it would be possible if the variability in the level of total resources available is treated separately.

Difficulties in modelling productivity should be examined in conjunction with the variability in activity's duration and resources required, as far as possible causes of the lack of success in the application of programming techniques are concerned. In ideal circumstances, the perfect modelling of productivity through the use of factors

influencing it, would reduce greatly the variability in these two aspects. If it is accepted that the reduction in the variability of activity's duration could be related with greater chances of succesfull application of programming techniques, it is recommended to follow the following course of action. Only the more important factors affecting productivity should be used to reduce the variability in activities duration and resources required, leaving unexplained great part of the variability caused by minor factors. The practical difficulties in collecting and analysing data to study the influence of minor factors suggests that it would be better to abandon the search for an explanation to every variation in productivity.

Primarily, the programming techniques were devised to examine the time-related aspects of the project, as final handing over dates and intermediate start and finish dates of activities. The incorporation of the consideration of resources required, and hence costs, was made afterwards. As the report showed, more recently some tentative research work tried to incorporate more and more aspects of management in the programming issue. The programming techniques are still in their initial stages of development and utilization, despite the fact that their most important representatives, CPM and PERT, had already almost 25 years of utilization. Therefore, it is possible to suggest that the programming techniques should be used solely to examine

the time-related aspects of the project while the conditions for a more systematic approach to the whole management problem are not bring about by research work.

In this sense the whole question of estimation of resources required, variability in resources required, and modelling of resources required can be kept outside the programming problem. Laing introduced the idea of "one problem, one type of tool", after discussing how to estimate resources required in construction projects. This idea of separating the resource requirements from the schedule of operations was totally opposed by Skoyles, who tried to introduce the concept of "Operational Estimating". The fact that this new approach of estimating was not accepted by the industry could mean that the building companies were not yet ready to consider simultaneously activity's duration and resources required. During the initial stages of development in construction management, different techniques should be used to perform different functions.

Accepting the fact that the programming techniques should be used initially only to investigate the time-related aspects of the projects, and that average activity's duration and their variability could be obtained, the problems associated with the precedence relationship, variability in resources required, variability in the total

level of resources available on site, and productivity modelling should not in the future be related to the lack of success in the application of programming techniques.

Previously, it was suggested that among all the possible causes of the failure of the programming techniques, the difficulties in evaluating the implications of different objective criteria choosen by the programmer could be one of the more important sources of problem. It was shown that the attainment of certain objective criteria, like minimum project duration, minimum resource idleness, etc., are not only influenced by the characteristics of the schedule, but by broader aspects of site management and macro-economy. Shortsighted appraisals of the production process achievements of similar projects under different schedules would relate the objectives attained (or not) to the programming techniques initially used to produce the schedules. Failure to arrive at the optimized objective criteria values obtained during the programming stage would be wrongly blamed on the scheduling technique.

In fact, the whole question of how to evaluate the cost consequences of different schedules, after the project is completed, is much more complex. Possibly the application of research work to the evaluation of the contribution of different schedules to the attainment of the management

goals that can be set is beyond the capabilities of the building research organizations, due to the great number of projects that should be constructed under controlled conditions.

The ideas presented so far showed that from the set of problems associated with the so called technical problems, only the problems related to activity's durations can be rationally blamed for the lack of success in the application of programming techniques. Some of the problems can be, and probably are being, overcome, like the question of overlapping precedence. Other problems, like the ones caused by the uncertainities about activity's resource requirements are more akin to cost estimating than to time-related techniques. Finally, objectives criteria cannot be rationally blamed for the lack of success in the application of the programming techniques, due to the difficulties in correlating objective criteria, different schedules, and results obtained.

Bishop (1968) and Bromilow (1969) claimed that the simple existence of a schedule, independently of its characteristics, was sufficient to improve substantially the site organization and the attainment of objective criteria. In order to be of any use to site management, the schedule of works necessarily needs to have some resemblance to the

way activities are being performed on site. Two aspects are of fundamental importance to create this resemblance. First, the programmed activity's durations should be such as to adequately represent the actual durations that would occur on site. Only in the case in which the schedule of work is obtained externally to programming techniques, using for example contractual arrangements, it is possible to drop the requirements of accurate durations for the succesfull application of programmes of work. Second, updating exercises should be carried out during the course of the project in order to bring the schedule on line with the progress of work on site, and vice-versa

Therefore, the proper consideration of activity duration and updating are directly related to the similarity between programmes of work and actual progress, and hence to the meaningfulness of the schedules to construction management. Conversely, lack of updating and activity's durations with no relationship to the time taken to perform tasks on site, can be blamed for the lack of meaning of schedules of work to the running of building sites.

The lack of updating and the complexity of the updating issue were shown as potential major causes of the lack of success in the application of programming techniques. Usually the building companies did not introduce

updating procedures and management feedback systems simultaneously with the programming techniques, probably due to the costs of this comprehensive package. If the economic advantages of the techniques are in line with what has been advocated by some research workers, the change in procedures, or even in the administrative organization of building companies, would be worthwhile.

Lumsden, for example, suggested that the application of Line of Balance programming techniques would introduce such a vigorous rhythm of work on site, that it would be better to have a material's manager at the side of the foreman, to deal exclusively with ordering, inspection, and stock control of materials being consumed at a great speed. This and other organizational changes could be brought in order to accomodate the requirements introduced by the programming techniques.

Finally, the complexities of the programming problem as such, should not be appointed as one of the causes of the lack of success in the application of the scheduling techniques. It is not possible to say that simplistic programming techniques are bound to failure, if the mere existence of schedules of work, notwithstanding the accuracy in which they were able to model the building process, were sufficient to improve the construction of some

projects, making the application of these schedules a succesfull exercise.

3.3 Suggestions for further Work

The previous section emphasized the importance of the time-related aspects of the schedules, including activity's duration and the updating issue, for the succesful application of programming techniques. The suggestion for further work are then concerned to these time-related aspects.

First comes the recommendation for a greater emphasis on the study of activity's duration, as observed on actual building sites. Great part of the research effort on programming techniques applied to construction sites should be devoted to the observation of the production characteristics of the building process. These observations using work study, time-lapse photography, or activity sampling could also produce a host of other useful information, like resources required, cperative's individual performance, influence of factors affecting productivity, etc.. It is suggested that regional or national centres should be establish to gather information on the production characteristics of building sites, imitating the succesful example of Holland (see Van den Graaf).

More effort should be dedicated to the study of the intermediate milestones in the building process. These milestones, obtained by programming methods or by other arrangements between the participants of the building project, are of fundamental importance in the coordination of building construction, characterized by the great number of participants and the long time scale of operations. Research work so far has concentrated on the study of the duration of the project, on the setting of the final hand over date. With total durations measured in years, the final completion dates are of little meaning in terms of motivating factors. The intermediate milestones are more important than the final dates for a great number of participants in the project, that, as a rule, becomes only temporarily involved in the process.

In the long term, it can be suggested that one of the first issues to be tackled by research work, after the basic technical concepts of the programming techniques are exhaustively investigated, is the relationship between the early programming of works, updating, and the daily site management.

The research work now being undertaken by the author at the Department of Civil Engineering, University of Leeds will concentrate on the analysis of activity's

duration, as observed on three house building sites of repetitive nature.

Bibliography

Bibliography

Abdulmajid, S. A. D. Resource Forecasting Models for Private Housing Projects, Phd Thesis, University of Manchester, Manchester, 1967.

Abernathy, W. S. "Subjective Estimates and Scheduling Decisions" Management Science, Vol. 18, No. 2, October 1971, pp. B80-B88.

Adrian, J. J. Modelling Construction Method Productivity, Phd Thesis, Department of Civil Engineering, University of Illinois, Urbana-Champaign, 1974.

Adrian, J. J.; Boyer, L. T.; "Modelling Method-productivity", J. of Construction Division, ASCE, Vol. 102, CO1, March 1976, pp. 157-168.

Ang, H. S. et alli. "Analysis of Construction Networks under Uncertainity", Annual and National Environmental Convention, ASCE, Kansas City, Missouri, October 1974, Meeting preprint No. 2372, October 1974.

Anthony, E. F. et alli. "Rating Project Performance by Time-Cost Quality", Proceedings of the ISA Conference and Exhibition, Niagara Falls, New York, October 17-20, 1977, Proceedings published by ISA, Pittsburgh, Pa, 1977, pp. 67-74.

Antill, J. M.; Woodhead, R. W. Critical Path Method in Construction Practice, New York, London, Wiley Interscience, 2nd. ed., 1970.

Ashley, D. B. "Simulation of Repetitive Unit Construction", J. of Construction Division, ASCE, Vol. 106, CO2, June 1980, pp. 185-194.

Ashworth, A. "The Source, Nature and Comparison of published Cost Information", Building Technology and Management, March 1980, pp. 33-37.

Ashworth, A. et alli. "An Analysis of the Accuracy of Some Builder'Estimating", Quantity Surveyor, April 1980, pp. 65-70.

Atton, W. Estimating Applied to Building - Metric Edition, London, George Godwin Ltd, 1st. ed., 1967.

Balaguru, P. et alli. "Cost and Time Scaled Networks: Graphical Model", J. of the Construction Division, ASCE, Vol. 103, CO2, June 1977, pp. 179-190.

Baldwin, J. R. et alli. "Causes of Delay in the Construction Industry", J. of the Construction Division, ASCE, Vol. 97, CO2, November 1971, pp. 177-187.

Barnes, N. M.; Gillespie, J. S. "A Computer-based Cost Model for Project Management", paper at the Third Internet, Symposium on the Practical Application of Project Planning by Network Techniques, Stockholm, Sweden, May 1972, edited by Mats Ogander, London, New York, John Wiley and Sons, 1972, pp. 37-58.

Barnes, M. "On getting paid: the right Amount", Building, Vol. 223, No. 6756, 17th November 1972, pp. 135-136.

Barnes, N. M. "Cost Modelling - An Integrated Approach to Planning and Cost Control", Engineering and Process Economics, Vol. 2, 1977, pp. 45-51.

Barnes, N. M. "Human Factors in Project Cost Control", 5th International Cost Engineering Congress, Utrecht, 1978, pp. 224-248.

Barnes, N. M. "Cost Control during Construction", Construction Industry Conference Centre Conference on Finacial Policy and Control in Construction Projects, London, 15/16th May 1980, pp. 49-54.

Barroso-Aguillar, L. F. et alli. "The Construction Project Daily Labor Allocation Problem", paper at the Third Internet, Symposium on the Practical Application of Project Planning by Network Techniques, Stockholm, Sweden, May 1972, edited by Mats Ogander, London, New York, John Wiley and Sons, 1972, Vol. 3, pp. 59-71.

Barroso-Aguillar, L. F. et alli. "The Influence of Project Work Inventory on the Daily Labor Allocation Problem", International Symposium on Systems Engineering anc Analyses, Purdue University, 1972, Vol. 2, pp.31-35.

Barroso-Aguillar, L. F. An Integrated Modelling Methodology for Project Site Management, Phd Thesis, Department of Civil Engineering, University of Illinois, Urbana--Champaign, August 1973.

Beamish, N. Statistical Analysis of Productivity in the Construction Industry, Building Research Establishment Internal Note No. 13/78, Garston, BRE, January 1978.

Beeston, D. T. "One Statiscian's View of Estimating", Building Economist, Vol. 14, No. 3, 1975, pp. 135-145.

Beeston, D. T. "Cost Models", Chartered Surveyor Building and Quantity Surveying Quarterly, Vol. 5, No. 4, Summer 1978, pp. 56-59.

Benjamin, N. B.; Greenwald, T. W. "Simulating the Effects of Weather on Construction". J. of the Construction Division, ASCE, Vol. 99, C01, July 1973, pp. 175-190.

Bennet, F. L. "Critical Path Resource Scheduling Algorithm", J. of Construction Division, ASCE, Vol. 94, C02, October 1968, pp. 161-180.

Bennet, J. "Operational Planning", Chartered Surveyor Building and Quantity Surveying Quarterly, Vol. 5, Spring 1978, pp. 50-51.

Bennet, J.; Barnes, N. M. "Outline of a Theory of Measurement" Chartered Quantity Surveyor, October 1979, pp. 53-56.

Bensasson, S.; Scoinsu, D. Computer Programs for Construction Management, Evaluation Report No. 4, Design Office Consortium, 1979.

Bentley, M. J. Production Analysis of a SEAC Mark2 Steel Frame IFE JM1 School, Building Research Establishment Internal Note No. 87/1969, Garston BRE, August 1969.

Bertram, G. "A Fair Day's Work is anything you want to be", Journal of Industrial Engineering, Vol. 19, No. 12, December 1968, pp. 592-599.

Biemer, P. P.; Sielken Jr., R. L. Incorporating Project Cost Considerations into Stochastic Pert, Institute of Statistics, Texas A&M University, College Station, Report Themis Tr-52, November 1975.

Birrel, G. S. "Construction Planning - Beyond the Critical Path" J. of Construction Division, ASCE, Vol. 106, C03, September 1980, pp. 389-407.

Bishop, D. "Labour Requirements for House Building - Advantages of Continuity of Work and Experience", The Builder, Vol. 209, No. 6374, 16th July 1965, pp. 150-154. (also as Building Research Establishment Current Papers, Construction Series No. 18, Garston, BRE).

Bishop, D. "Operational Bills and Cost Communication", Architects Review, Vol. 139, February 1966, pp. 158, 160, 162. (also as Building Research Establishment Current Paper, Design Series No. 55, Garston, BRE).

Bishop, D. "Architects and Productivity", RIBA Journal, Vol. 73, November 1966, pp. 513-518. (also as Building Research Establishment Current Paper, Design Series No. 57, Garston, BRE, 1966).

Bishop, D. The Background to Management Studies by BRS, Building Research Establishment Current Papers No. 60/68, Garston, BRE, August 1968.

Bishop, D. "Productivity in the Building Industry", paper to the Royal Society Symposium, November 1971, "Building Technology in the 80'S", Philosophical Transactions No. 272, London, Royal Society, 1972, pp. 533-563.

Bjornsson, H. C. "Learning Construction Management through Computer Simulation", International Conference on Management of Research and Education, Wroclaw, Poland, September 1975, pp. 1-20.

Blain, B. C. R. Work Study as an aid to Estimating, Institute of Building Estimating Information Service Paper No. 30, Ascot, Berkshire, Institute of Building, Autumn 1978, 9 pp.

Blough, R. M. "Effect of Schedule Overtime on Construction Projects", American Association of Cost Engineers Bulletin, Vol. 15, No. 5, October 1973, pp. 153-160.

Borcherding, J; Oglesby, C. "Job Dissatisfaction in Construction Work", J. of Construction Division, ASCE, Vol. 101, CO2, June 1975, pp. 415-434.

Borcherding, J. "Improving Productivity in the Construction Industry", J. of Construction Division, ASCE, Vol. 102, CO4, December 1976, pp. 599-614.

Borcherding, J. "Cost Control Simulation and Decision Making", J. of Construction Division, ASCE, Vol. 103, CO4, December 1977, pp. 577-591.

Bournazos, J. M. Optimization of Materials Handling Systems - A Simulation Approach -, Msc. Thesis, Department of Civil Engineering, University of Leeds, 1975.

Brett, D. "Invisible Economics", Industrialized Building Systems and Components, 3 October 1966, pp. 6-9.

Brett, D. "Where Time is Money", Building Economist, 8th August 1969, pp. 36-37.

Britney, R. R. "Bayesian Point Estimation and the Pert Scheduling of Stochastic Activities", Management Science, Vol. 22, No. 9, May 1976, pp. 938-948.

Britten, J. R. "Computerising Resource Needs", Building, Vol. 212, No. 6457, February 1967, pp. 125-130. (also as Building Research Establishment Current Papers, Construction Series Nos. 39 and 39A, Garston, BRE.

Britten, J. R. The Advantages of Time scaled Networks and Planning Frames, Building Research Establishment Current Papers, Construction Series No. 41, Garston, BRE, October 1967.

Bromilow, F. J. "Contract Time Performance - Expectations and Reality", Building Forum, Vol. 1, No. 3, September 1969, pp. 70-80.

Bromilow, F. J. "The Nature and Extent of Variations to Building Contracts", Building Economist, Vol. 9, No. 3, November 1970, pp. 93-104.

Bromilow, F. J. "Building Contract Cost Performance", Building Economist, Vol. 9, No. 4, February 1971, pp. 126-138.

Bromilow, F. J. "Contracts as Waste Generators", Building Forum, Vol. 3, No. 1, March 1971, pp. 5-11.

Bromilow, F. J. "Performance of Building Contracts in Eastern Australia", Building, November 1971, pp. 18-22, 24.

Bromilow, F. J. "Measurement and Scheduling of Construction Time and Cost Performance in the Building Industry", Chartered Builder, Vol. 10, June/July 1974, pp. 57-65.

Bromilow, F. J.; Henderson, J. A. Procedures for reckoning and valuing Performance of Building Contracts, Division of Building Research Report B3, 1974 Revision, Melbourne, CSIRO, 1974, 52 pp.

Bromilow, F. J. "The Impact of Contract Performance Research on Building Management in Australia", paper at the CIB-6th Congress, "The Impact of Research on the Built Environment", Budaspest, Hungary, 1974, Vol. 2, pp. 153-158.

Bromilow, F. J. "What is an Affordable House? Productivity and the Affordable House, a transcript of 3 papers presented at the Housing Industry Association, 12th National Convention, Canberra, Australia, April 1977, pp. 3-11.

Bromilow, F. J. "Multi-project Planning and Control in Construction Authorities", Building Economist, Vol. 16, No. 4, March 1978, pp. 208-213.

Building Industry Advisory Council of South Africa, "Timely Completion of Contracts", Building Economist, 13th June 1976, pp. 5-6.

Building Management and Marketing Consultants Ltd "Key trend Method of Project Control", Construction, (published by the Department of Environment), No. 15, September 1975, pp. 18-20.

Building Research Establishment, Project Network Analysis, Building Research Establishment Digest No. 53, 2nd Series, December 1964, reprinted with minor revisions in 1976.

Burt, J. M. "Planning and Dynamic Control of Projects under Uncertainity", Management Science, Vol. 24, No. 3, November 1977, pp. 249-258.

Butcher, W. "Dynamic Programming for Project Cost-Time Curves", J. of the Construction Division, ASCE, Vol. 93, C01, March 1967, pp. 59-63.

Butler, A. J. (editor) The Use of Cranes on low-rise high Density industrialized Housing, Building Research Establishment Current Paper No. 25/70, Garston, BRE, 1970.

Campbell, J. Y. An Investigation and Evaluation of Certain Commercially Available Computer Programs for the Construction Industry, Msc. Thesis, Loughborough University of Technology, May 1970.

Campbell, J. Y. "The Evaluation of Certain Commercially Available Computer Programs for Network Techniques", paper at the Third Internet Symposium on the Practical Application of Projecty Planning by Network Techniques, Stockholm, Sweden, May 1972, edited by Mats Ogander, London, New York, John Wiley and Sons, 1972, pp. 79-95.

Carr, R. Synthesis of Uncertainity in Construction Planning, Phd Thesis, Department of Civil Engineering, Stanford University, August 1971.

Carr, R. et alli. "Progress Model for Construction Activity", J. of Construction Activity, ASCE, Vol. 100, C01, March 1974, pp. 59-64.

Clapp, M. A. Labour Requirements for Conventional Houses (as observed in five sites), Building Research Establishment Current Paper, Construction Series No. 17, Garston, BRE, July 1965.

Clapp, M. A. "Weather Conditions and Productivity - Detailed Study of Five Buildings", Building, Vol. 211, No. 6439, October 1966, pp. 171, 172, 175, 176, 179 and 180.
(also as Building Research Establishment Current Paper, Construction Series No. 32, Garston, BRE).

Clapp, M. A. A Study of Labour Resource Requirements for Construction, unpublished paper, 7th May 1977.

Clapp, M. A. Bricklayers' Labour and Materials - A Study of Resource Inputs and Productivity, Building Research Establishment Internal Paper No. 177/78, Garston, BRE, December 1978.

Clapp, M. A. "Productivity on Building Sites", Building Research Establishment News, Spring/Summer 1980, No. 51, pp. 17-18.

Cole, L. J. R. "Applied Flowline Technology", Building Economist, Vol. 15, No. 4, March 1977, pp. 218-224.

Cole, L. J. R. "Value/Time Graphs for Building Contracts", World Construction, Vol. 30, No. 11, November 1977, pp. 40, 42 and 43.

Committee on Housing, Building anc Planning, Economic Comission for Europe, United Nations, Effect of Repetition on Building Operations and Processes on Site, Report of an Enquiry undertaken by the Committee on Housing, Building and Planning, New York, United Nations, 1965.

Cooke, J. E. "Charting the Course of Progress", Building, Vol. 239, 3 October 1980, pp. 44-45.

Cowell, A. S. T. "Events of Importance: Some Comments on Improvements to Site Programmes", Building Technology and Management, 18th September 1980, pp. 35-36.

Crandall, K. C. "Probabilistic Time Scheduling", J. of Construction Division, ASCE, Vol. 102, CO3, September 1976, pp. 415-423.

Crandall, K. C. "Analysis of Schedule Simulations", J. of Construction Division, ASCE, Vol. 103, CO3, September 1977, pp. 387-394.

Crawshaw, D. T. Project Information at the Pre-Construction Stage, Building Research Establishment Information Paper No. 27/1979, Garston, BRE, October 1979.

Cukierman, A.; Shiffer, Z.; "Contracting for Optimal Delivery Time in Long Projects", Bell Journal of Economics, Vol. 7, No. 1, Spring 1976, pp. 132-149.

Cullingford, G.; Prideaux, C. A. "A Variational Study of Optimal Resource Profiles", Management Science, Vol. 19, No. 9, May 1973, pp. 1067-1081.

Dallas, D. S. "Use of Linear Regression Analysis to establish Network Time/cost relationships", Project Manager, 2nd July 1979, pp. 2-5.

Danoon, S. A. R. The Influence of Buffers on Repetitive Operations with Statistical Variable Durations, Msc. Thesis, Department of Civil Engineering, University of Leeds, 1975.

Davidson, C. "Repetitive Operations in Building: Results of ECE/UN Studies, The Builder, Vol. 210, No. 6399, 7th January 1966, pp. 9-10.

Davis, E. W. "Resource Allocation in Project Networks Models; a Survey", Journal of Industrial Engineering, Vol. 17, No. 4, 1966, pp. 177-188.

Davis, E. W. "CPM use in Large Construction Firms: a Top Management Survey", J. of Construction Division, ASCE, Vol. 100, C01, March 1974, pp. 39-49.

Davis, E. W.; Patterson, J. H. "A comparison of Heuristic and Optimum Solutions in Resource-Constrained Project Scheduling", Management Science, Vol. 21, No. 8, 1975, pp. 944-955.

Dean, G.; White, R. F. Production Analysis of a Clasp Primary School - Mansfield Oaktree Lane First School, Project RSM, Nottinghamshire County Council, October 1979.

Department of Science and Industrial Research (Building Research) Productivity in House Building, A Pilot Sample Survey in the South, East and West of England and South Wales, August 1947 - October 48, National Building Studies Special Report No. 18, HMSO, 1948

Dietz, A. G. H.; Litle, W. A. "Education for Construction", J. of the Construction Division, ASCE, Vol. 102, C02, June 1976, pp. 347-364.

Dover, D. R. "Compact - Computer Planning and Control Technique", Conrad, Vol. 3, No. 1, 1971, pp. 29-34.

Doyle, R. C. "How Good is your Estimate", American Association of Cost Engineers Bulletin, Vol. 19, No. 3, May/June 1977, pp. 93-97.

Dressler, J. "Stochastic Scheduling of Linear Construction Sites", J. of the Construction Division, ASCE, Vol. 100, C04, December 1974, pp. 571-587.

Duff, A. R. "Control of Costs Allowances for Uncertainity", Building Technology and Management, Vol. 14, July/August 1976, pp. 19 and 45.

Duff, A. R. "New Look at Estimating the Cost of Repetitive Work", Building, Vol. 236, 20 April 1979, pp. 56-58.

Duff, A. R. "Stochastic Analysis of Activity Duration", Construction Papers, Vol. 1, No. 1, 1980, pp. 63-69.

Edmonds, G. A. Labour Substitution in Construction: A Case Study on Nigeria, Phd Thesis, Department of Civil Engineering, University of Leeds, May 1975.

Elvers, D. A. "Planning Monitoring Frequencies for CPM Projects", J. of the Construction Division, ASCE, Vol. 97, CO2, November 1971, pp. 211-226.

Environmental Research Group, University College, Study of the Building Timetable: final Report, UCERG - University of London Environmental Research Group, London, 1972, 121 pp.

Environmental Research Group, University College, The Building Timetable, part 1: The Significance of Duration, UCERG (University of London Environmental Research Group), London, February 1974, 14 pp.

Environmental Research Group, University College, The Building Timetable, part 2: The Public Sector, University College Environmental Research Group, London, February 1974, 26 pp.

Erikson, C.; Boyer, L. T. "Estimating: State of the Art", J. of the Construction Division, ASCE, Vol. 102, CO3, September 1976, pp. 455-464.

Evenwell, J. K. Productivity in the Building Industry, CSIR, National Building Research Institute of South Africa, Report 519, Pretoria, 1974. (also in Construction in Southern Africa, Vol. 19, No. 5, 1974, pp. 131, 133, 135, 137, 139, 141, 143, 147 and 149).

Farkhondeh, N. CPM-V2, Critical Path Method Version 2, Report No. 44, Centre for Computer Studies, University of Leeds, 29th October 1974.

Farkhondeh, N. Design, Implementation and Application of a Network Software for Scheduling Multiple Resource Constrained Projects, Phd Thesis, Department of Computer Studies, University of Leeds, August 1976.

Fendley, L. G. "Towards the Development of a Complete Multi-Project Scheduling System", Journal of Industrial Engineering, Vol. 19, No. 10, October 1968, pp. 505-515.

Ferdows, K. The Effects of Updating on Multi-Project Scheduling, Phd Thesis, The University of Wisconsin, 1972.

Fine, B., Hackemer, G. "Estimating and Bidding Estrategy", Building Technology and Management, September 1970, pp. 8-9.

Fine, B. "Tendering Strategy", Building, 25 October 1974, pp. 115-117, 119 and 121.

Fine, B. "Tendering Strategy", chapter No. 8 in Aspects of Economics of Construction, edited by D. A. Turin, London, George Godwin, 1975, pp. 202-221.

Fine, B. "Randomness in Construction", Symposium on Operational Aspects of Constructing Highway Bridges, Transport and Road Research Laboratory, 24th June 1976.

Fine, B. The Repetitive Process, Fine, Curtiss and Gross Ltd. Internal Report No. 4/1977, London, February 1974.

Fine, B. "Production Management", paper presented at the conference Management in the Construction Industry, 10-11 November 1977, paper No. 6, London, pp. 51-55.

Fine, B. Models of Construction Processes, unpublished paper presented at a Seminar for the Msc. Course in Construction, Department of Civil Engineering, University of Leeds, Leeds, January 1980.

Firmstone, C. J.; Skoyles, E. R. Operational Drawings and Bills - Report of their use on a Live Project, Building Research Establishment Current Paper, Design Series No. 63, Garston, BRE.

Fleming, M. C. "Pricing in Construction - The Relationship of Constants to Productivity", Building Technology and Management, December 1978, pp. 5-9.

Fletcher, A. L. The Effect of Nomination on Building Productivity and Cost, Institute of Building Occasional Paper No. 12, Ascot, Berkshire, Institute of Building, 1976, 25 pp.

Forbes, W. S.; Skoyles E. R. "The Operational Bill", Chartered Surveyor, Vol. 95, No. 8, 1963, pp. 429-434. (also as Building Research Establishment Current Paper, Design Series No. 1, Garston, BRE).

Forbes, W. S.; Cooper, H. G. "Problems encountered during the Introduction of Mechanical Plastering National Builder, Vol. 46, April 1965, pp. 380-382, 384 and 387. (also as Building Research Establishment Current Paper, Construction Series No. 16, Garston, BRE).

Forbes, W. S.; Stevens, A. J. "The First Operational Assessment of V-Bricks", PACE, January 1966, pp. 23-30. (also as Building Research Establishment Current Paper, Construction Series No. 32, Garston, BRE).

Forbes, W. S. "Some Aspects of the Measurement of Productivity in the Building Industry", PACE, Vol. 1, April 1966, pp. 13-16. (also as Building Research Establishment Current Paper, Construction Series No. 28, Garston, BRE).

Forbes, W. S.; Skoyles, E. R. "A Practical Application of Operational Bills, Part I: Preparation and Tendering Stages", Chartered Surveyor, Vol. 98, No. 9, 1966, pp. 489-493. (also as Building Research Establishment Current Paper, Construction Series No. 35, Garston, BRE).

Forbes, W. S.; Mayér, J. F. "The Output of Bricklayers", Building, Vol. 24, No. 6506, 26th January 1968, pp. 137-138, 141-142 and 145-146. (also as Building Research Establishment Current Paper No. 32/1968, Garston, BRE, 1968).

Forbes, W. S. A Survey of Progress in House Building, Building Research Establishment Current Paper No. 25/69, Garston, BRE, 1969.

Forbes, W. S. Flow Charts to Control Progress on Housing Sites, Building Research Establishment Digests, Second Series, No. 132, Garston, BRE, October 1971.

Forbes, W. S. Dimensional Disciplines and the Output of Bricklayers - a Case Study by W. S. Forbes, Building Research Establishment Current Paper, No. 34/1971, Garston, BRE, November 1971.

Forbes, W. S.; Stjernstedt, R. The Finchampstead Project, Building Research Establishment Current Paper No. 23/1972, Garston, BRE, 1972.

Forbes, W. S. "Production Cost Information", chapter No. 7 in Aspects in Economics of Construction, edited by D. A. Turin, London, George Godwin, 1975, pp. 186-201.

Forbes, W. S. Modular Bricks and Productivity: Results of full Scale Trials, Building Research Establishment Current Paper No. 16/1977, Garston, BRE, 1977.

Forbes, W. S. The Rationalization of House Building, Building Research Establishment Current Paper No. 48/77, Garston, BRE, 1977.

Forbes, W. S. Housebuilding Productivity at Ladygate Lane, Hillingdon, Building Research Establishment Internal Note, Garston, BRE, March 1980.

Forbes, W. S. The Relevance of BRE Productivity Studies to Estimating, Building Research Establishment Internal Note No. 143/80, Garston, BRE, November 1980.

Forbes, W. S. The BRE Site Activity Analysis Package, Building Research Establishment Internal Note No. 13/1981, Garston, BRE, 1981.

Fraser, R.; Evans, R. W. "Scottish House Building Performance", Building Research Establishment News, No. 54, Summer 1981, pp. 17.

Gates, M.; Scarpa, A. "Bidding Contingencies and Probabilities", J. of the Construction Division, ASCE, Vol. 97, CO2, November 1971, pp. 277-303.

Gates, M.; Scarpa, A. "Learning and Experience Curves", J. of the Construction Division, ASCE, Vol. 98, CO1, March 1972, pp. 79-101.

Gates, M.; Scarpa, A. "Conceptual RMC/Time Synthesis", J. of the Construction Division, ASCE, Vol. 102, CO2, June 1976, pp. 307-323.

Gates, M., Scarpa, A. "Optimum Number of Crews", J. of the Construction Division, ASCE, Vol. 104, CO2, June 1978, pp. 123-132.

Geddes, S. Estimating for Building and Civil Engineering Works, 2nd. Ed., London, Newnes-Butterworths, 1976.

Geisel, J. "A Method for Measurement and Analysis of Supervisory Work", J. of Industrial Engineering, Vol. 19, No. 4, April 1968, pp. 175-185.

Goodsman, R. W. Modelling the Flow of Work in Architect's Office, Building Research Establishment Current Paper No. 4/1979, Garston, BRE, 1979.

Grimm, C. T.; Wagner, N. K. "Weather Effects on Mason Productivity", J. of the Construction Division, ASCE, Vol. 100, CO3, September 1974, pp. 319-335.

Grimm, C. T. "Estimating Real Estate Development Time Lapse", J. of the Construction Division, ASCE, Vol. 103, C02, June 1977, pp. 213-226.

Hall, B. Cost Models based upon Precedence Networks, Transport and Road Research Laboratory, Department of the Environment, TRRL Bridge Construction Division Working Paper BC/3, August 1976.

Hall, B.; Ball, S. Industrial Training Report - Report on Industrial Training at the Transport and Road Research Laboratory exploring Cost Models based on Precedence Diagrams, Sheffield, Sheffield City Polytechnic, 1978.

Hall, B. RIT: A Computer Program for Simulating Construction Work, Building Research Establishment Internal Note No. 52/1980, Garston, BRE, 1980.

Halpin, D. W.; Woodhead, R. W. "Flow Modelling Concepts in Construction Management", in National Water Resources Engineering Meeting, ASCE, Atlanta, Georgia, Usa, 24-28th January 1972, Meeting preprint No. 1618.

Halpin, D. W. An Investigation of the Use of Simulation Networks for Modelling Construction Operations, Phd Thesis, Department of Civil Engineering, University of Illinois, Urbana-Champaign, 1973.

Halpin, D. W. "Constructo - An Interactive Gaming Environment", J. of the Construction Division, ASCE, Vol. 102, C01, March 1976, pp. 145-156.

Handa, V. K. et alli. "A Cost Control and Forecast Model for Building Projects", paper presented at the CIB 6th Congress, "The Impact of Research on the Built Environment", Budapest, Hungary, 1974, Vol. 2, 1974, pp. 276-280.

Handa, V. K.; Geogiades, I. F. "Joint Venture Utilities and the Construction Firm", paper presented at the CIB-2nd Symposium Seminar on Organization and Construction Management of Construction, CIB-W65 Comission, Haifa, Israel, November 1978, Session 3, pp. 3-177 to 3-198.

Hareli, M. "Optimising the Execution Sequence in Construction Projects with Repetitive Processes", paper presented at the CIB-2nd Symposium Seminar on Organization and Construction Management of Construction, CIB-W65 Comission, Haifa, Israel, November 1978, Vol. 2, pp. 217-230.

Harris, F. C. "Costing the Effects of Bad Weather", Construction (Department of Environment), No. 17, March 1976, pp. 10-13.

Harris, F. C. "Controlling Costs on Site", Building Technology and Management, Vol. 14, No. 10, November 1976, pp. 5-8.

Harris, F. C.; Evans, J. B. "Road Construction - Simulation Game for Site Managers", J. of the Construction Division, ASCE, Vol. 103, C03, September 1977, pp. 405-414.

Harris, F.; Speed Management Games for use in Construction, Institute of Building Occasional Paper No. 15, Ascot, Berkshire, Institute of Building, 1977.

Harris, F. C. Modern Construction Management, London, Granada Publishing Company, 1977.

Harris, R. "The Time Element" (part 1 and part 2), Quantity Surveyor, October 1976, pp. 49-55, and November 1976, pp. 69-75.

Heineck, L. F. The Analysis of Activity's Duration, Precedence between Activities and Sequence of Work - Graphical Software to enhance the printed Output from the Building Research Establishment Site Activity Analysis Package, unpublished paper, Department of Civil Engineering, University of Leeds, Leeds, January 1982.

Howenstine, E. J. "Productivity in Building - The Universal Enigma", Building Research and Practice--Batiment International, Vol. 3, No. 6, November-December 1975, pp. 364-371.

Hydes, W. S. Resource Allocation and Techniques of Estimating with Special Reference to Highway Engineering, Phd Thesis, Department of Civil Engineering, University of Leeds, Leeds, 1978.

Hydes, W. S. Work Measurement and Work Study, handouts for the Msc. Course in Construction, Department of Civil Engineering, University of Leeds, Leeds, 1979-1980 Session.

Institution of Civil Engineers Civil Engineering Standard Method of Measurement, London, Institution of Civil Engineers, 1976

International Computers Limited Pewter - Pert without Tears ICL Computer Package Manual, 1900 Series, London, International Computers Limited (ICL), 1972.

International Computers Limited Pert Disc - ICL Computer Package User's Manual, 1900 Series, London, International Computers Limited (ICL), 1972.

Jeanes, R. E. "Critical Path Method applied to the overall Process of Building", The Builder, Vol. 205, No. 6286, 1963, pp. 957-963, and also Chartered Surveyor, Vol. 96, No. 7, 1964, pp. 339-349.
(also as Building Research Establishment Current Paper, Design Series No. 11, Garston, BRE).

Jeanes, R. E.; Britten, J. R. "Networks Diagrams: Some Notes on Alternative Presentations", Building, Vol. 210, 10th June 1966, pp. 102-106.
(also as Building Research Establishment Current Papers, Construction Series No. 29, Garston, BRE).

Jewell, W. S. "Risk taking in Critical Path Analysis", Management Science, Vol. 11, No. 3, January 1965, pp. 438-443.

Johnston, D. W. "Linear Scheduling Method for Highway Construction", J. of the Construction Division, ASCE, Vol. 107, CO2, June 1981, pp. 247-261.

Jordan, M.; Carr, R. "Education for the Professional Construction Manager", J. of the Construction Division, ASCE, Vol. 102, CO3, September 1976, pp. 511-519.

Kappaz, M. H. "Effect of Scope Changes on Schedule - A Systems Approach", Transaction of the American Association of Cost Engineers, Florida Section, Symposium, Miami Beach, Florida, January 22-24, American Association of Cost Engineers, Miami, 1978, pp. 106-111.
(also in American Association of Cost Engineers Bulletin, Vol. 9. No. 6, November-December 1977, pp. 221-224 and 237.

Kauffold, P. V. Critical Resource Allocation in Stochastic Project Network, Phd Thesis, University of Illinois at Urbana-Champaign, December 1976.

Kellog, J. C. et alli. "Hierarchy Model of Construction Productivity, American Society of Civil Engineers Convention and Exposition, Boston, April 2-6, 1979, ASCE, 1979.
(also in J. of the Construction Division, ASCE, Vol. 107, CO1, March 1981, pp.137-152).

Kennedy, W. B. et alli. "Client Time and Cost Control with Network Analysis", Building Economist, Vol. 9, 1970, pp. 86-92.

Kidd, J. B.; Morgan, J. R. "The Use of Subjective Probability Estimates in Assessing Project Completion Times", in Communications to the Editor, Management Science, Vol. 16-A, pp. 266-269.

King, W. R.; Wilson, T. A. "Subjective Time Estimates in Critical Path Analysis - a Preliminary Analysis", Management Science, Vol. 13, No. 5, January 1967, pp. 307-320.

King. W. R. et alli. "On the Analysis of Critical Path Time Estimating Behaviour", Management Science, Vol. 14, No. 1, September 1967, pp. 79-84.

King. W. R.; Lukas, P. A. "An Experimental Analysis of Network Planning", Management Science, Vol. 19, No. 12, August 1973, pp. 1423-1432.

Kinninburgh, W. "Comparison of Times Required to Build Walls in Building Units of Various Sizes", Building, Vol. 215, No. 6543, 11th October 1968, pp. 151-152 and 155-156.
(also as Building Research Establishment Current Paper No. 77/1968, Garston, BRE, November 1968.

Kleinfeld, I. "Manpower Use in High-rise Residential Construction", J. of the Construction Division ASCE, Vol. 102, CO2, June 1976, pp. 379-383.

Klingel, A. R. "Bias in PERT Project completion Time Calculations for a Real Network", Management Science, Vol. 13, No. 4, December 1966, pp. B194-B201.

Kotiah, T. C. T.; Wallace, N. D. "Another Look at the PERT Assumptions", Management Science. Vol. 21, No. 1, September 1973, pp. 44-49.

Laing, W. M. A New Approach to Construction Management Through Building Measurement and Time Standards, Lancaster, Construction Press, 1976, 213 pp.

Langier, F. J. "Statistical Control of Time Standards", Management Science, 1963, pp. 527-541.

Latta, J. K. Case Studies to determine the Man-hours required to construct the Concrete Frames of Tall Buildings in Summer and Winter, Building Research Note No. 70, Division of Building Research, National Research Council, Ottawa, Canada, May 1970.

Lemessany, J.; Clapp, M. A. Resource Inputs to New Construcion: the Labour Requirements of Hospital Building, Building Research Establishment Current Paper No. 85/1975, Garston, BRE, 1975.

Lemessany, J.; Clapp, M. A. Resource Inputs to Construction: the Labour Requirements of House Building, Building Research Establishment Current Paper No. 76/1978, Garston, BRE, December 1978.

Lichtemberg, S. "Evaluation of the Effectiveness of Project Plans", paper at the Third Internet, Symposium on the Practical Application of Project Planning by Network Techniques, Stockholm, Sweden, May 1972, edited by Mats Ogander, London, New York, John Wiley and Sons, 1972, pp. 219-229.

Lichtemberg, S. "The Principle of Sucessive Planning", paper at the Third Internet, Symposium on the Practical Application of Project Planning by Network Techniques, Stockholm, Sweden, May 1972, edited by Mats Ogander, London, New York, John Wiley and Sons, 1972, Vol. 2, pp. 226-236.

Lichtemberg, S. et alli. "Graphical Evaluation of Project Schedules - A Computer Program for Interactive Man-computer Application", paper at the Fourth Internet, Symposium on the Practical Application of Project Planning by Network Techniques, Paris, 1974, 1974, pp. 5-16.

Ling, C. J. The Implementation and Use of Network Analysis Techniques in a Construction Company, Msc. Thesis, Department of Civil Engineering, University of Leeds, Leeds, 1976.

Logcher, R.; Collins, W. "Management Impacts on Labor Productivity", J. of the Construction Division, ASCE, Vol. 104, C04, December 1978, pp. 447-461.

Lumsden, P. The Line of Balance Method, Oxford, Pergamon Press Ltd, Industrial Training Division, 1968, 71 pp.

Mazzetti, M. An Appraisal of Industrialized Building Methods, Msc Thesis, Department of Civil Engineering, University of Leeds, Leeds, 1977.

Mehra, K. K. Introducing Critical Path Planning in an Engineering Firm, Msc Thesis, University of Manchester Institute of Technology, 1967.

Meyer, W. L.; Schaffer, L. R. "Extensions of CPM for Multiform Project Time Cost Curves", J. of the Construction Division, ASCE, Vol. 91, C01, May 1967, pp. 45-67.

Meyers, D. A. "Critical Path Computerized", The Consulting Engineer, Vol. 35, No. 2, February 1971, pp. 46-47.

McCaffer, R. "Some Examples of the Use of Regression Analysis as an Estimating Tool", The Quantity Surveyor, Vol. 32, No. 5, December 1975, pp. 81-86.

McGlaum, W. "Overtime in Construction", American Association of Cost Engineers Bulletin, Vol. 15, No. 5, October 1973, pp. 141-143.

McNally, H.; Havers, J. A. "Labor Productivity in the Construction Industry", J. of the Construction Division, ASCE, Vol. 93, C02, September 1967, pp. 1-11.

Miller, D. G. Recruitment and Turnover of Carpenters in Auckland and Wellington, BRANZ, Building Research Association of New Zealand technical paper P2, Wellington, New Zealand, 1975, 37 pp.

Miller, D. G. Productivity in House Building: the Views of Australian Managers, Supervisors and Carpenters, BRANZ, Building Research Association of New Zealand report P20, Wellington, New Zealand, December 1977, 31 pp.

Moavenzadeh, F.; Markow, M. "Simulation Model for Tunnel Construction Costs", J. of the Construction Division, ASCE, Vol. 102, C01, March 1976, pp. 51-66.

Moder, J. J.; Rodgers, E. G. "Judgement Estimates of the Moments of PERT Type Distributions", Management Science, Vol. 15, No. 2, October 1968, pp. B76-B83.

Moder, J. J.; Phillips, C. R. "Merge Event Bias Correction Procedures", appendix No. 9-5 in Project Management with CPM and PERT, 2nd. Edition, London, Van Nostrand Reinholds Co., 1970, pp. 229-239.

Moodie, C. L.; Mandeville, D. E. "Project Resource Balancing by Assembly Line Techniques", J. of Industrial Engineering, Vol. 17, No. 7, July 1966, pp. 377-383.

Morris, D. "Seasonal Effects on Building Construction", J. of the Construction Division, ASCE, Vol. 102, C01, March 1976, pp. 29-39.

Morris, D. "Economic Analysis for Accelerated Construction" J. of the Construction Division, ASCE, Vol. 103, C02, June 1977, pp. 273-286.

Morrison, N.; Stevens, S. "A Construction Cost Data Base", Chartered Quantity Surveyor, June 1980, pp. 313-315.

Naaman, A. "Networking Methods for Project Planning and Control", J. of the Construction Division, ASCE, Vol. 100, C03, September 1974, pp. 357-372.

National Economic Development Office What's wrong on Site - a Program for Change, London, NEDO-National Economic Development Office, July 1971.

National Economic Development Office Engineering Construction Performance - Report of the Corporative Construction Performance Working Party, EDC, Mechanical and Electrical Engineering Construction, London, NEDO-National Economic Development Office, HMSO, 1976, 88 pp.

National Economic Development Office How Flexible is Construction ? A Study of Resources and Participants in the Construction Process, London, NEDO-National Economic Development Office, HMSO, 1978, 90 pp.

National Electrical Contractors Association The Effect of Temperature on Productivity, National Electrical Contractors Association Report, Washington, USA, 1974.

National Electrical Contractors Association The Effect of Multi-Story Buildings on Productivity, National Electrical Contractors Association Report, Washington, USA, 1975.

Nazem, S. "Labour(staff) Turnover and its Effect on Productivity", Building Technology and Management, Vol. 7, No. 5, May 1969, pp. 114-115.

Neale, R. H. "Towards Effective Project Planning (or how to survive the Planning Whirpool)", Building Technology and Management, February 1980, pp. 9-10.

Nowak, F. "The Building Game", Architects Journal, 21st Abril 1976, pp. 789-790.
(also as Building Research Establishment Current Paper No. 49/76, Garston, BRE, July 1976.

Nutall, J. F.; Jeanes, R. E. "The Critical Path Method, 1 - Its Value in Building Design and Construction; 2 - Detailed Methods of Use", The Builder, Vol. 204, 14th June and Vol. 205, 21st June 1963.
(also as Building Research Establishment Current Paper, Construction Series No. 3, Garston, BRE).

Nutall, J. F.; Amos, E. E. "Critical Path Method Applied to Building Control", The Builder, Vol. 207, No. 6327, 1964, pp. 381-392.
(also as Building Research Establishment Current Paper, Construction Series No. 12, Garston, BRE).

Nutall, J. F. "A Study of Decision Rules for Site Control: Guidance for Foremen when Programme Changes", The Builder, Vol. 209, No. 6379, 20th August 1965, pp. 407-409.
(also as Building Research Establishment Current Paper, Construction Series No. 19, Garston, BRE).

Nutall, J. F.; "Resource Scheduling: coping with Labour Problems as they occur on site", The Builder, Vol. 210, No. 6404, 11th February 1966, pp. 311-316.
(also as Building Research Establishment Current Paper, Construction Series No. 25, Garston, BRE).

O'brien, J. J. "VDM Scheduling for High-rise Building", J. of the Construction Division, ASCE, Vol. 101, CO4, December 1975, pp. 895-965.

Oxley, R. Incentives in the Construction Industry - Effects on Earnings and Costs, Institute of Building Site Management Information Service, Paper No. 74, Ascot, Berkshire, Institute of Building, Summer 1978, 10 pp.

Patterson, J. H. "Project Scheduling: the Effects of Problem Structure on Heuristic Performance", Naval Research Logistics Quarterly, Vol. 23, No. 1, March 1976, pp. 95-123.

Paulson, B. Man-Computer Concepts for Project Management, Phd. Thesis, Department of Civil Engineering, Stanford University, Stanford, 1971.

Paulson, B. "Project Planning and Scheduling: unified Approach", J. of the Construction Division, ASCE, Vol. 99, CO1, March 1973, pp. 45-58.

Paulson, B. "Estimation and Control of Construction Labor Costs", J. of the Construction Division, ASCE, Vol. 101, CO3, September 1975, pp. 623-633.

Paulson, B. Continuing Research in the Development of Interactive Man-computer Systems for Engineering Construction Projects, Stanford University, Department of Civil Engineering Technical Report No. 200, September 1975, 68 pp.

Paulson, B. "Concepts of Project Planning and Control", J. of the Construction Division, ASCE, Vol. 102, CO1, March 1976, pp. 67-80.

Paulson, B. "Goals for Education and Research in Construction", J. of the Construction Division, ASCE, Vol. 102, CO3, September 1976, pp. 479-495.

Paulson, B. "Interactive Graphics for Simulating Construction Operations", J. of the Construction Division, ASCE, Vol. 104, CO1, March 1978, pp. 69-76.

Pedersen, H. "Network Planning of Repetitive Processes in the Housing Construction Industry", paper presented at the Third Internet. Symposium on the Practical Application of Project Planning by Network Techniques, Stockholm, Sweden, May 1972, edited by Mats Ogander, London, New York, John Wiley and Sons, 1972, pp. 381-392.

Peer, S.; Selinger S. "CPT - New Approach to Construction Planning", paper presented at the CIB-W65 First Symposium on Organization and Construction Management of Construction, CIB-W65 Comission, Washington, USA, May 1976, Session 4, pp. 156-163.

Pereira, G. L. An Appraisal of Human Factors Affecting Productivity in Construction, Msc. Thesis, Department of Civil Engineering, University of Leeds, 1978.

Perry, C; Greig, J. D. "Estimating the Mean and Variance of Subjective Distributions in PERT and Decision Analysis, Management Science, Vol. 21, No. 12, August 1975, pp. 1477-1480.

Perry, W. N. "Automation in Estimating Contractors'Earnings", The Military Engineer, No. 410, November-December 1970, pp. 393-395.

Pigott, P. T. "Some Factors Influencing Productivity in House Building", paper at the CIB-6th Congress, "The Impact of Research on the Built Environment", Budapest, Hungary, 1974, Vol. 2, pp. 269-274.

Pigott, P. T. A Productivity Study of House Building, 2nd. Impression, Dublin, An Foras Forbartha - The National Institute for Physical Planning and Construction Research - , December 1974.

Pilcher, R.; Davidson, G. "Computer Based Simulation Models for use with Construction Projects", paper presented at the CIB-2nd Symposium on Organization and Construction Management of Construction CIB-W65 Comission, Haifa, Israel, November 1978, Vol. 2, pp. 295-319.

Pilcher, R.; Oxley R. "Optimising Productivity and Cost in Repetitive Construction", paper presented at the CIB-W65 First Symposium on Organization and Construction Management of Construction, CIB-W65 Comission, Washington, USA, May 1976, Session 4, pp. 172-195.

Plant, J. J. A Survey on Labour Availability and Requirement on London Local Authority Construction Sites, Greater London Council Research Memorandum No. RM 468, London, Greater London Council, 1975, 64 pp.

Popescu, C.; Borcherding, J. "Developments in CPM, PERT and Network Analysis", J. of the Construction Division, ASCE, Vol. 101, C04, December 1975, pp. 769-784.

Popescu, C. "CPM - Cost Control by Computer", J. of the Construction Division, ASCE, Vol. 103, C04, December 1977, pp. 593-609.

Popescu, C. "CPM - Interactive Training Tool", J. of the Construction Division, ASCE, Vol. 104, C02, June 1978, pp. 157-166.

Poskus, K. K. Industrialized Building Construction:Time/cost Model; First Quarterly Results, FY-76, Construction Engineering Research Laboratory (CERL) Report No. CERL-IR-D-66, Urbana-Champaign Illinois, Construction Engineering Research Laboratory, April 76, 31 pp.

Preston, R. L. Management of Construction Resources, Phd. Thesis, Gergia Institute of Technology, Georgia, 1974.

Price, K.; Horn, A. Industrialized Two-Storey Housing, A Productivity Study, London, The National Building Agency, August 1970, 35 pp.

Pristsker, A. B.; Happ, W. W. "GERT: Graphical Evaluation and Review Technique, Part 1: Fundamentals", J. of Industrial Engineering, Vol. 17, No. 5, May 1966, pp. 267-274.

Pritsker, A. B.; Whitehouse, G. "GERT: Graphical Evaluation and Review Technique, Part 2: Probabilistic and Industrial Engineering Applications", J. of Industrial Engineering, Vol. 17, No. 6, 1966, pp. 293-301.

Rabenek, A. "Research Into Site Management", Architectural Design, Vol. 46, No. 5, 1976, pp. 275-280.

Rawcliffe, J.; Rickard, P. J. "An Algorithm for Resource Levelling", Building, Vol. 212, 20th January 1967, pp. 131-136.

Reiners, W. J.; Broughton, H. F. Productivity in House Building, Second Report, National Building Studies Special Report No. 21, London, HMSO, 1953, 37 pp.

Rickard, P. J. Resource Allocation in Engineering Construction, Phd Thesis, Department of Civil Engineering, University of Leeds, Leeds, 1968.

Roderick, I. F. "Examination of the Use of Critical Path Methods Building", Building Technology and Management, Vol. 15, March 1977, pp. 16-19. (also as Building Research Establishment Current Paper No. 12/1977, Garston, BRE, 1977.

Rossow, J. A. K.; Moavenzadeh, F. "Management Issues in the USA Construction Industry", J. of the Construction Division, ASCE, Vol. 102, CO2, June 1976, pp. 277-294.

Russel, J. H. "Progress Function Models and Their Deviation", J. of Industrial Engineering, Vol. 19, No. 1, January 1968, pp. 5-10.

Salag, B.; Silberman, H. Efficiency of Labour Input in Swedish Construction, National Swedish Building Research Summary R15, 1975, 2 pp.

Seeley, I. H. Building Quantities Explained - SI Edition, London, Macmillan Press Ltd, 1969.

Selinger, S. "Construction Planning for Linear Projects", J. of the Construction Division, ASCE, Vol. 106, CO2, June 1980, pp. 195-205.

Scheurer, T. Optimal Project Scheduling under Multiple Resource Constraints, Phd Thesis, Department of Computer Studies, University of Leeds, Leeds, 1978.

Scott, D.; Cullingford G. "Scheduling Game for Construction Industry Training", J. of the Construction Division, ASCE, Vol. 99, CO1, July 1973, pp. 81-92.

Schaffer, L. R. "Impact of Research on Management", paper presented at the CIB-6th Congress, "The Impact of Research on the Built Environment", Budapest, Hungary, 1974, Vol. 2, pp. 147-152.

Shanley, L. F. (editor) Seminar on the Bill of Quantities and the Operational Format, organized by Ann Foras Forbartha in conjuction with the Royal Institution of Chartered Surveyors (Republic of Ireland Branch), Dublin, March 1970.

Shanley, L. F.; Keaney, B. J. An Examination of Labour Content in Housing, Dublin, Ann Foras Forbartha, May 1970.

Sheppard, R. F.; Harris, F. C. "Predicting the Effect of Weather on Construction Costs", Building Technology and Management, Vol. 15, No. 7, July/August 1977, pp. 14-16.

Shipley, N. Variability in Output, Operational Research Department Internal Note n. 4/71, Loughborough University of Technology, 1971.

Shippam, R. "House Building Productivity in USA". Building, Vol. 213, 15th December 1967, pp. 127-128 and 131-132.
(also published as Building Research Establishment Current Paper No. 28/68, Garston, BRE, March 1968).

Skoyles, E. R. "Introduction to Operational Bills", Quantity Surveyor, Vol. 21, 1964, pp. 27-32.
(also as Building Research Establishment Current Paper, Design Series No. 32, Garston, BRE).

Skoyles, E. R. Examples from Operational Bills, Building Research Establishment Miscellaneous Papers No. 9, Garston, BRE.

Skoyles, E. R. Preparing Operational Bills, Building Research Establishment Miscellaneous Papers No. 10, Garston, BRE, June 1967.

Skoyles, E. R. Introducing Bills of Quantities (Operational Format), Building Research Establishment Current Paper No. 62/68, Garston, BRE, August 1968.

Skoyles, E. R. "Materials Wastage - A Misuse of Resources", Building Research and Practice, July/August 1976, pp. 232-243.
(also as Building Research Establisment Current Paper No. 67/76, Garston, BRE, 1976.

Smith, D. H.; Rawlings, B. The Effect of Weather on Building Productivity, Construction Industry Research and Information Association - CIRIA -, Technical report No. 50, London, CIRIA, June 1974, 25 pp.

Soeterik, F. W.; Foster, P. K. Time/Cost Performance of New Zealand Building Contracts, BRANZ Technical Paper P13, Wellington, BRANZ - Building Research Association of New Zealand -, July 1976, reprinted February 1979, 20 pp.

Spooner, J. E. "Probabibistic Estimating", J. of the Construction Division, ASCE, Vol. 100, CO1, March 1974, pp. 65-77.

Stacey, N. "Estimates of Uncertainity", Building, Vol. 237, 19 October 1979, pp. 63-64.

Stacey, N. "Assessing the Uncertainity of an Estimate", The Quantity Surveyor, Vol. 36, June 1980, pp. 105-107.

Standard Method of Measurement of Building Work, 5th Edition.

Stark, R. M. "Unbalanced Bidding Models - Theory", J. of the Construction Division, ASCE, Vol. 94, CO2, October 1968, pp. 197-209.

Stevens, A. J. "Activity Sampling Studies aided by the Use of an Optical Reader", Work Study, Vol. 16, No. 1, January 1967, pp. 21-29. (also as Building Research Establishment Current Paper, Construction Series No. 38, Garston, BRE).

Stevens, A. J. Activity Sampling on Building Sites: Further Experience in the use of Optical Readers, Building Research Establishment Current Paper No. 16/69, Garston, BRE, May 1969.

Stewart, W. P.; Torrance, V. B. "An Examination of Certain Relationships between Accuracy, Productivity and Site Management in the Construction of Reinforced Concrete Framed Buildings", paper at the CIB-W65 Second Symposium on Organization and Construction Management of Construction, CIB-W65 Comission, Haifa, Israel, November 1978, Vol. 4, pp. 311-326.

Stone, P. A. Building Economics: Design, Production and Organization, a Synoptic View, 2nd. Edition, Oxford, Pergamon Press, 1976, 293 pp.

Strandell, M. "Productivity in the Construction Industry", American Association of Cost Engineers Bulletin, Vol. 20, No. 2, March/April 1978, pp. 57-61.

Streeter, M. J. "Time Thermometer", paper presented at the American Association of Cost Engineers Annual Meeting, Milwaukee, Wisconsin, 26-29th June 1977, published by AACE, Morgantown, West Virginia, 1977, pp. 273-276.

Swan, C. "Labor and Materials Requirements for Housing", Brookings Paper on Economic Activity, Vol. 2, 1971, pp. 347-381.

Talbot, P. J. Financial Incentives - do they work?, Institute of Building Occasional Paper No. 10, Ascot, Berkshire, Institute of Building, 1976.

Taylor, T. E. "How Certain are you about the Uncertainity of your Estimates ?", American Association of Cost Engineers Bulletin, Vol. 19, No. 3, May/June 1977, pp. 101-102.

Thorpe, B. W. "Trends in Productivity in the Housing Industry", in Productivity and the Affordable House, paper No. 2, a transcript of papers presented at the Housing Industry Association Twelth National Convention, Canberra, Australia, April 1977, pp. 12-15.

Tindale, P. et alli. "R(esearch) and D(evelopment) in low Density Housing: The Finchampstead Project", Conrad, Vol. 2, No. 3, 1970, pp. 123-135.

Toussaint, E. "Prise in compte des Intemperies dans les Planning", paper at the CIB-6th Congress, "The Impact of Research on the Built Environment", Budapest, Hungary, 1974, Vol. 2, pp. 297-298.

Trimble, G.; Darlow, M. S. A Study to determine the Feasibility of a Line of Balance Computer Programme, Loughborough, Department of Civil Engineering, Loughborough University of Technology, February 1969.

Van den Graaf, M. P. "Richttigden voor Bouwactiviteiten", Building Technology and Management, September 1979, pp. 8-12.

Vergara, A. J.; Boyer, L. T. "Probabilistic Approach to Estimating and Cost Control", J. of the Construction Division, ASCE, Vol. 100, C04, December 1974, pp. 543-552.

Vergara, A. J.; Boyer, L. T. "Portfolio Theory: Applications in Construction", J. of the Construction Division, ASCE, Vol. 103, C01, March 1977, pp. 23-38.

Verschuren, P. "The Value of Labour Economy in the Building Industry", CIB - W65 Second Symposium on Organization and Construction Management of of Construction, CIB-W65 Comission, Haifa, Israel, November 1978, Vol. 2, pp. 335-340.

Wahab, K. A. "Manpower Requirements in a selected Number of Housing Projects in Nigeria", Building Environment, Vol. 15, pp. 33-43.

Wainwright, W. H.; Whitrod, R. Measurement of Building Work, London, Hutchinson Technical Education, 1968.

Walker, A. "Man-hours Requirements for conventionally constructed Dwellings", The Chartered Surveyor, Vol. 103, No. 6, December 1970, pp. 278-287.

Walker, A. "A Study of Variation in Output of Building Operatives", The Architect and Surveyor, Vol. 16, November-December 1971, pp. 10-13.

Walker, A. "A Study of the Factors affecting the Level of Output on certain Building Sites", The Quantity Surveyor, November-December 1972, pp. 65-68.

Whitehead, B. "Productivity in Bricklaying", Building Science, Vol. 8, 1973, pp. 1-10.

Whitt, K. J. Materials Management in the Construction Industry, Phd Thesis, Department of Civil Engineering, University of Leeds, 1974.

Wilson, P. H. Survey of Winter Working Practices in Scotland, Building Research Establishment Current Papers, Construction Series No. 20, Garston, BRE, September 1965.

Woodhead, W. D. "Achievable Improvements in Housebuilding Productivity", paper presented at The Housing Industry Association, 12th National Convention April 1977, paper No. 3, Canberra, Australia, pp. 16-24.

Young, S. M. "Misapplications of the Learning Curve Concept", J. of Industrial Engineering, Vol. 17, No. 8, August 1966, pp. 410-415.