Some Causes of
the Variability of the Level
of Labour Resources assigned to
Building Sites Programmes of Work

Luiz Fernando Heineck

Department of Civil Engineering

University of Leeds

February 1982

Summary

This report reviews some causes of the variability between the theoretically programmed and the actual level of labour resources available on building sites.

It deals in particular with labour turnover, labour absenteeism and non-productive time on building operations. The report seeks to evaluate quantitatively and qualitatively the losses in the actual number of man-hours available on site at each time period caused by these three problems affecting the construction industry. It also discusses the effect of these three aspects in the variability and uncertairity about the level of resources available on site, on an hourly, daily, and seasonal basis.

The author reports some observations related to labour absenteism and non-productive time that he made while studying the production process of three house building sites.

Ways in which the effects of labour turnover, absenteism and non-productive time could be incorporated in the labour estimates and in the programming of works on site are suggested.

It concludes that the variability in the resource levels caused by the three factors mentioned above is significant and should be taken into account. However, as the potential variability caused by these factors is less than the variability in resources required by the

activities, rescurces levels could continue to be considered deterministic, as it has been the case with several prcgramming techniques, once the resources required by the activities and their variability is increased by factors representative of the effect of labour turnover, absenteism and non-productive time.

Index

1. Introduction 1

2. Some Causes of the Variability of the Level of Labour Resources Available on Site

   2.1 Introduction 6

   2.2 Labour Turnover

      2.2.1 Discussion 12

      2.2.2 Conclusion 16

   2.3 Labour Absenteeism

      2.3.1 Discussion 19

      2.3.2 Conclusion 24

   2.4 Productive/Non-productive Time Ratios on Building Sites

      2.4.1 Introduction 26

      2.4.2 Methods of obtaining Labour Content of Activities and the Rate of Output of Operatives 28

      2.4.3 Productive/Non-productive Time Ratios 35

      2.4.4 Conclusion 45

3. Conclusions and Suggestions 50

Tables

Figures

Bibliography

1. Introduction

This report is one of a series that purports to examine different concepts used in the programming techniques applied to building projects, in particular to house building projects of repetitive nature.

The more simple programming technique, that is bar charts, were introduced in the start of this century. During the first years of the sixties the whole programming issue received a boost with the advert of network techniques. The success of the application of programming techniques, and in particular of network technicues, has not yet matched the expectations raised during their introduction.

The author decided to study possible causes of this lack of success in the application of programming techniques to building sites. These causes can be sought at the general level (macro level) or at the specific level of technicalities that the use of programming techniques involve. Examples of problems faced by the programming techniques at the macro level are the difficulties and speed required in updating, communication of the programmes to site personnel, and the necessity of involvement of a great number of participants of the construction process, both within and outsice the building company. Examples of the technical problems of the implementation of programming techniques are the difficulties associated with estimating activity's duration and resources required, defining precedence relationship between activities, setting resource histograms taking into account possible variations in the resource levels over time, obtaining time/cost trade-off curves, modelling productivity achieved on operations through the use of factors, and, finally, setting and evaluating the various objectives criteria to be achieved by the programme of works.

Each of the above topics is the subject of a special report. 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 analyses of durations far greater than would be expected just considering the labour content of activities, and the overlapping of supposedly preceding stages of work, as observed in three house building sites.

Normally the programming techniques would calculate activity's durations dividing their labour content by the quantity of resources assigned to them. The majority of the programming techniques just consider straight preceding and suceeding relationships between activities, with no possible overlapping. In fact, there is no published information about the amount of overlapping between activities that could be allowed at the programming stage. These discrepancies between the concepts of duration estimation, precedence definition and what actually was observed to occur on sites could be one of the causes of the lack of success in the application of programming techniques.

Here it is suggested that the programming techniques have not been able to model adequately the work on site. The various studies about the technical concepts mentioned above were envisaged to examine how accurately the programming approaches to these concepts are able to model the way the concepts occur on site.

This report investigates the variability that occurs on an hourly, daily, or seasonal basis in the total level of resources available on site. Generally the programming techniques consider that the level of resources allocated to a project is deterministic in nature; variations in the level of resources are dictated only by management action.

The literature on labour turnover, labour absenteeism and non-productive time on building sites is reviewed. If it can be shown that the above factors determine important losses in the available amount of labour resources on site, and if it can be shown that as these factors are not directly under control of management the losses that they determine are uncertain and stochastic in nature, it could be suggested that the discrepancy between the deterministic level of resources approach used by the programming techniques and the variability of these levels actually found on site is another of the probable causes of the lack of success in the application of programming techniques.

Thus the report deals with labour resources on building sites. It is generally accepted that labour is the more important resource in building construction, due to the fact that building is labour intensive, as opposed to civil engineering construction that is equipment intensive. The report deals with resource levels at the aggregate level, that is, total resource levels applied to the site, and not resource levels applied to individual activities.

The author has been using production data obtained from the Building Research Establishment. This data was obtained by the BRE using activity sampling methods on three house building sites with 72, 103 and 253 dwellings. Several references are made to evidence stemming from these building sites, mainly in terms of labour absenteeism and non-productive time.

The remainder of this report reviews the bibliography on the subject. It will be appreciated that the majority of works in the area give only qualitative indications of the influence of the three factors on the availability of labour resources on site, specially with reference to labour turnover.

Conclusions and suggestions at the end of this report are again put mainly in the form of qualitative statements. Special concern throughout this report is the consideration of how to incorporate the influence of the variability in the level of resources available on site in estimating and programming for building projects.

2. Some Causes of the Variability of the Level of Labour Resources Available on Site

2.1 Introduction

When simple programming techniques like Bar Chart and Critical Path Method are used, the levels of the various resources required to perform the project are obtained by summing the deterministic amounts of resources required by the individual activities, time period by time period. Once and approximate level of resources required is obtained, resource scheduling and resource levelling techriques could be used to optimize objective functions like minimum project duration, maximum resource utilization, minimum resource mobilization cost, or minimum total cost. Resource Scheduling is the technique employed if a cefinite level of resources is allocated to the project. Resource Levelling is used to smooth peaks and valleys in the resource histogram obtained by simply aggregating resources required by individual activities (see Rickard).

Alternatively the approximate level of resources required on site can be obtained by optimization of resource mobilization costs, without consideration of the activities to be performed (see Cullingforc and Prideaux), or by historical records of similar projects (see Lemessany and Clapp).

More sophisticated programming techniques incorporate the definition of resource usage by individual activities, their aggregation, resource scheduling, resource levelling and the optimization of the above objective criteria in one powerful algorithm (see Kauffold).

The aggregation of resources required by individual activities in a project is not an straighforward exercise as it might look. First of all, the activity's rates of consumption of resources and the activity's durations need to be estimated. Abernathy, Ashworth, Barnes (November 1972), Beeston, Bishop (July 1965), Fine, Fleming, Forbes, Kidd and Morgan, King et alli, Reiners and Broughton, Roderick, Shipley, and Walker (1971) showed the innacuracy, bias, variability of output rates and labour constants of the estimating process.

There is some evidence showing that activities would require resources according to a "s" shaped curve throughout their duration rather than on a constant basis as it is normally considered by the programming techniques. Roderick found this "s" shaped curve of allocation of resources to activities in the construction of an office block and warehouse for an public utility (see figure 1). Carr et alli identified this shape of curve for the formwork stage of work in concrete framed structures. In his case the formwork stage is considered as whole, without breaking it down to the various storeys of the structure. These authors observed that there was a initial low consumption of resources, increasing to a peak value, and then decreasing towards the completion of the activity or the stage of work.

The author is studying the production process of three house building sites, with 71, 108 and 253 houses; no quantitative evidence was obtained so far, but the observation of production graphs like the one presented in figure 2 suggests that the allocation of resources to the decoration stage of work in each block also followed a "s" shaped curve.

Several authors like Bromilow and Henderson (1974), Gates and Scarpa (1976), Handa et alli, Kleinfeld, Lemessany and Clapp, and W. N. Perry found that "s" curves could be used to approximate the deployment of resources (labour or capital) to the whole project construction. Lumsden demonstrated how "s" shaped curves of total resource comsumption on site can be derived from the Line of Balance programming approach, with individual activities requiring resources on a constant basis.

Without discussing further the nature of the curves representing the allocation of resources to the whole project or to individual activities, this report concentrates on the variability that occurs on resource levels available on site, once a required or desired resource histogram is programmed.

A large number of research workers in the area of civil engineering and building programming had considered that the programmed amount of resources available to be made available on site is not subjected to stochastic variations (see Carr-1971, Fendley, Nutall-1965, Paulson-1971, Patterson, Peer, and Pilcher and Oxley). Apart from deliberate efforts by management to mobilize or demobilize resources, no other cause of variation in resource levels on site was considered.

Construction Management Games like the ones proposed by Borcherding (1977), Halpin (1976), Harris and McCaffer (1977-1), and Scott and Cullingford adopted the same approach. Only the activity's durations and resources required were made stochastic; management reaction to variations in productivity and departure from the schedule of work were represented by increases in the deterministic levels of resources available on site.

It is reasonable to suggest that keeping resources available as a deterministic paramenter is the same as increasing the variability in the amount of resources required by the activities. For example, in a project progress simulation exercise two approaches could be adopted: in the first one, resources required and resources available are stochastically varied; in the second case, resources available are kept constant, with a corresponding greater variability in resources required by the activities.

After some calibration, the two project progress simulation models should produce similar results.

It is also possible to keep the level of resources available on site as a fixed value, if their availability is modelled by factors affecting productivity like weather. Clapp (1966) reported that due to the shorter working day and higher absenteeism in winter periods, the same number of tradesmen present on site represented in fact different amounts of man-hours available on summer and on winter, according to observations on five building sites. Figure 3 shows that the labour force built-up trend was not strictly followed in winter due to absenteeism when bad weather occurred.

Despite these procedures to avoid the consideration of a stochastic level of resources available on site, or even its random presence as it could be the case with subcontractors (see the works by Pigott), the subject deserves greater attention. The review of the literature did not show any research work dealing specifically with causes and magnitude of the stochastic variations in resources available on site. Rare references were found about labour absenteeism and labour turnover. These two causes of variability will be treated in the following chapter. At the end of the following chapter, the proportion of productive to non-productive time on building sites is investigated. This proportion and its variability over time could help to quantify the total amount cf labour resources actually available on site.

2.2 Labour Turnover

2.2.1 Discussion

Labour turnover is usually associated with labour market conditions (depressed, booming, etc.), with the operatives satisfaction with the management of the site they are engaged at, and with the building company as a whole.

Miller (1975) said that labour turnover is more likely to be influenced by the nature of the work, organization and management of the site, and geographical factors (workers desire to keep living in the same neighbourghood) than by low wages. This is not to say that financial aspects do not play their role in causing labour turnover. For example, McGlaum stated that overtime magnifies any labour shortage, because it determines increased labour turnover with operatives moving to contractors offering more overtime hours, and hence a better pay deal.

Talbot found that operatives generally work for the foreman rather than for the company. He also said that workers prefer to stay in the area in which they are living; if the building company gets a job in a different area, they tend to move to another local contractor.

Miller (1975) investigated the causes of labour turnover amongst carpenters in New Zealand. The reasons behind carpenters keeping their jobs for long time were:

- age over 40 years;
- married status;
- long period of work for the previous contractor;
- employment in small building companies;
- weekly earnings including bonus;
- good industrial relationship between labour and management;
- attractive tasks available on site (non-repetive tasks;

Forbes (November 1971) observed that on a particular site labour turnover among bricklayers was high due to the difficulties imposed by design and the quality of workmanship required by the client. These two factors influenced badly productivity and the workers were not able to get sufficiently high bonus to make the job worthwhile.

Swam concluded that seasonal employment and labour turnover were responsible for the low number of hours worked by the operatives during the year. He showed that the various trades in the USA worked between 600 and 1000 hours during the July 1966 - June 1967 period (see table 1). The average figure is less than 50 % of what could be expected if the workers were fully employed.

Evidence from New Zealand (Miller-1975) suggested that in periods of intense building activity carpenters did not loose money going from one building company to the other and thus missing some working days. In fact, according to the labour regulations prevailing there, this frequent transfer from one building company to another provided the opportunity for carpenters to get some extra money or benefits.

Labour turnover does not only affect the level of resources available on site, but it is directly related to productivity. Walker (1971) found that a local authority stable labour force receiving bonus incentives was able to achieve productivity levels as high as the ones achieved by the more efficient private building companies.

Miller (1975) listed several implications of labour turnover. The more important ones are reproduced below:

- each new worker employed by the company starts afresh in some point of his learning or experience curve; the worker needs to become familiar with the new tasks, and more important than that, he needs to get himself acquainted with the organizational procedures of the company and the management style on site;

- each worker released represents a loss for the company that have supported him throughout the less productive periods of his learning or experience curve;

- greater labour turnover puts more strain on supervisory personnel; if the number of supervisors remains the same, some supervisory effort is deviated from on-going activities to be dedicated to the new operatives;

- labour turnover is a constant cause of interruptions of work on site, and of disruption of balanced crews of work.

The review of the literature was not able to identify a single research work dealing specifically with the problem of labour turnover and its influence on productivity on building operations. Some authors just mentioned labour turnover figures while reporting a different subject. Nazem studied the influence of white collar staff turnover on productivity in 30 building companies. Just as an illustration, it is worth mentioning that annual staff turnover ranged from 4 % to 32 % and a definite relationship was found between high turnover and low productivity. Productivity in this case was measured by the ratio of total annual financial turnover to the number of staff personnel employed.

Talbot refered to the Banwell report where it is shown that labour turnover in the construction industry is twice as large as in the average of the other industries, but at least one third of the workers keep their jobs for more than 5 years. Talbot considered this latter fact contrary to the general belief labour turnover is exceptionally high in the construction industry.

Miller (1977) came to the conclusion that the carpenter's labour turnover in New Zealand was in the region of 30 % per year. The average for the whole set of builing companies investigatec was between 50 and 64 %, due to the fact that some large building firms had extremely high turnover rates, pushing the average upwards.

A National Economic Development Organization report on industrial plant construction (1971) found a 50 % rate of labour turnover per year on the sites observed.

Evenwell revealed South African experience with unskilled labour turnover. According to his own words "it was alarmingly high and figures of up to 50 % per year were given by some of the larger contractors".

2.2.2 Conclusion

Labour turnover determines fluctuations in the level of resources available on site and also losses in productivity.

Labour turnover rates in the construction industry could be expected to be relatively high due to the fact that at the end of each stage of work, or at the end of the project, it is usual to dispense with part of the labour force. This lack of continuity of employment has a negative influence in the productivity of the construction industry as a whole, but does directly affect the level of resources available on individual sites. This report tried to identify causes of the labour turnover that occurs while the stages of work or the project are still under construction, that is, labour turnover that occurs while the operatives are still needed.

The review of the literature did not produce quantitative evidence about this particular type of labour turnover. As the majority of the building projects takes a long time period to be built, it could be expected that the labour turnover that occurs while the operatives are still needed represents a good proportion of the up to 50 % total labour turnover rate found in some reports.

Labour turnover effects on productivity are related to the increased need for supervision, the disruption of balanced crews of work and losses in the operative's learning curve. The author proposes that the effects of labour turnover could be incorporated in the analyses of site productivity through the use of the learning concept: high turnover rates would be associated with low rates of improvement in learning curves; in the extreme case, a very high labour turnover rate would prevent any learning gains in productivity.

This review of literature was not able to indicate the quantitative influence of labour turnover in the variability of resources available on site. Undoubtelly more research work is needed in this area.

2.3 Labour Absenteism

2.3.1 Discussion

Labour absenteism gives rise to fluctuations in the resource profiles on a day to day basis. High absenteism is an indication of low site morale and bad industrial relations (National Economic Development Office, NEDO, 1976).

Very little information is available on the magnitude of labour absenteism. Bishop (1968), exemplifying the managerial difficulties faced by site agents, stated that the labour force could be up to 50 % greater or smaller than in the previous day.

Clapp (1966) showed that absenteism increased in winter months in a set of five projects observed. Projects started on spring had losses in the potentially available work-force on site of only 0.2 %, while projects started in the winter months had losses of 3.2 %. The most weather affected part of the project was the initial part, corresponding to substructure, ground floor slab, and carcassing; projects started in the winter months had their initial stages also performed in winter and hence greater losses due to absenteism.

Evenwell founc that absenteism on Mondays on some South African construction sites ranged from 5 to 30 %.

Plant reported a Greater London Council survey on labour availability and requirement on London local authority construction sites. After analysirg some 600 sites in a particular day of October 1974, he obtained the following figures: average rate of absenteism in that day was 3 %, ranging from as little as 1.56 % fcr labour employed by subcontractors to 6.6 % for workers employed by direct labour organizations within local authorities.

The NEDO report (1976) dealing with industrial plant construction indicated an average absenteism ranging from 5 to 15 % (see table 2).

McGlaum analysed the relationship between overtime and absenteism. Overtime would lead to an increase in absenteism due to two factors:

- the operatives tend to get more tired when working overtime: absences are a natural way of physically recovering from abnormal efforts;

- if building companies are fcrced into overtime due to competition for scarce labcur rescurces, the operatives would start to shop around in order to find the best "wage package" available.

Miller (1977), after studying the productivity of carpenters in New Zealand, found that one of the suggestions made by this trade to improve industrial relations with the employer would be to allow some free time during the week; if accepted, the workers would be able to solve family or personal-related problems during the week, without incurring in absences.

Pigott stated that absenteism is a cause of interruptions in the normal flow of work. In his studies, absenteism was the reason behind part of the postponing of operations and unbalance of crews. Nevertheless, he found that absenteism was responsible for only 1.3 % of the total number of interruptions on three sites analysed.

Plant, from the Greater London Council said that more absences would be expected in winter months than on the average of the whole year. He also raised the point that on summer absences could be higher than the average of the year due to the holiday season. This fact is confirmed by observations made by the author on the labour attendance on the three sites that form the data bank being used in this research work; the number of hours lost due to absenteism near the Summer, Christmas and Eastern holidays is greater than the average for the whole year; the workers tend to increase the number of days off, even at their own expense.

Shanley gave some support to the theoretical prediction that a extenced absence from site leads to losses in productivity due to the unlearning phenomencn (see Gates and Scarpa-1972, and the Effect of Repetition on Building Operations and Processes on Site, prepared by the Committee on Housing Building anc Planning, CNU). In figure 4 the total number of man-hours spent on roof timbers in block 14 was higher than in the identical block 15; the first block was completed just after the annual holidays.

In one site where activity sampling was used Forbes (November 1971) found that subcontractors did not follow strictly the official main contractor working hours. They made breaks, late arrivals and early departures to suit themselves. The author also cbserved that on the three sites being studied in his present research work the problem of absenteism was not confined to variaticns in resource levels available on a day to cay basis; it was quite frequent to observe workers calling cn the site but staying there only few hours.

The already cited NEDO report (1976) gathered information about the number of hours worked by the operatives in the active period, as cpposed to the pay period. The active period was defined as the daily period of work during which construction work should be observable. Therefore it excluded all official breaks, cfficial washing periods anc allowed travelling time from the worker's home to the site. The paid period excluded the lunch break that was unpaid but included all other breaks. The average active period was only between 84 % and 94 % of the paid period on UK industrial plant construction sites (see table 03). Similar results were reported by Stewart and Torrance: the average active period was 89 % of the paid period, ranging from 86 % to 94 % in the construction of four concrete framed structures (see table 4).

The uncertainities about the work force available daily led to to the creation of site programming models that consider the day to day allocation of labour, as suggested by Bishop (1968) and Barroso-Aguillar (August 1973). But it is worth recalling the conclusions of several authors, showing that the reallocation of labour is not done without productivity losses. Clapp (1966), Smith and Rawlings, the report on the Effect of Repetition on Building Operations and Processes on Site elaborated by the Committee on Housing Building and Planning, and Shanley (May 1970) conveyed the idea that losses in productivity due to the reallocation of labour caused by absences or bad weather could be so high as to make preferable to send workers home than to allow them to go to alternative working places. Figure 5 shows the increase in the number of man-hours spent erecting internal partitions due to the alternative allocation of bricklayers previously engaged in external work disrupted by bad weather On average, each hour worked on the alternative working place during bad weather increased the total number of man-hours spent on the job by also one hour, that is, the reallocated work had no productive effect.

Losses in productivity after reallocation of labour due to absences could be explained by overcrowding of the work places (see Kappaz, and McNally), interruptions in the individual learning curve, or simply because each time an alternative work place is temporarily tackled some time is spent on preparatory work before the task starts and on cleaning up after its temporary finish (Bishop-November 1966).

Labour absences on building sites due to union action were not yet quantified in the literature. The NEDC report on industrial plant construction (1976) stated that losses due to strikes on UK sites were less significant than previously thought, ranging from 1 to 6 % of the total potentially available number of hours to be worked per year (see table 2).

2.3.2 Conclusion

Labour absenteism represents a loss of between 1 and 10 % of the number of man-hours available on site. Daily losses or losses in particular periods, specially after and before holidays, could be higher. Losses corresponding to early departures, late arrivals, official breaks, officially agreed washing periods and travelling time should be added to the figures above; they may represent up to more 10 % of the paid period of work on site.

Thus the effect of labour absenteeism on resource levels on site could be modelled by stochastic decreases in the daily quantity of resources available, producing average losses of up to 20 % of the man-hours theoretically available throughout the project construction. The daily variations in the resource levels should also be affected by factors related to prevailing weather conditions, seasons, holidays and the characteristics of the working week (attendance before and after the weekend, and during and after the day wages are paid on site).

Continuity of work is a prime consideration when reallocating labour due to absences. Resource idleness when no reallocation is made should be compared with losses on productivity that could otherwise occur when operatives are allocated to alternative working places.

2.4 Productive/non-productive Time Ratios on Building Sites

2.4.1 Introduction

The determination of the amount of resources really available on site call for the examination of the productive/non-productive time ratios in building construction.

The fact that not all working hours spent on site are productive determires a decrease in the level of resources available. On the other hand, Bentley showed that the productive/non-productive time ratio was not constant throughout the duration of a particular project that he observed. This latter fact determines that the same level of physical resources (men, trades) would represent a variable number of man-hours actually available from time period to time period.

Before going further, it is interesting to discuss how to incorporate non-productive time in the estimating and programming processes. Resource levels could be defined by the number of operatives available on site; in this case the ratio productive/non-productive time would not affect the level of resources available. On the other hand, if the level of resources is defined by the total number of man-hours available, as it might be the case on large sites, the aforementioned ratio could be used directly to model the actual level of resources available.

Work Study and Method Study techniques include non-productive time in the labour content of activities or in the output capability of operatives and crews. Normally these techniques consider only part of the non-productive time observed on building sites, that is, they include relaxation time and personal needs allowance time. The percentage of non-productive time defined by those two allowances is generally less than 10 % (see Blain). As it will be seen later, the average .non-productive time on building sites is much larger than 10 %. Moreover, non-productive time is not directly related to the operations' characteristics but to general aspects of site administration.

If non-productive time is a function of general aspects of site administration it would be better to consider man-hours allocated to non-productive tasks as a single aggregated measure, representative of the administrative practices found on site, rather than to apportion these ineffective man-hours to the individual operations where they ocurred. A natural extension is the association of the aggregated measure of non-productive time with another aggregated measure, that is, total resources required or available by trade. This is the reason why this section on productive/non-productive ratios is included in this report dealing with the concept of variability in the resource levels available on construction sites.

Non-productive time should be allocated to building costs in one way or the other. It was considered interesting to review hereafter the various available methods of obtaining labour content and operative's rate of output; each method takes into account non-productive time in a different way. The review of the literature on productive/non-productive time ratios is made after this discussion on the methods of obtaining productivity data.

2.4.2 Methods of obtaining Labour Content of Activities and Rate of Output of Operatives

Productivity measures and the labour content of operations, stages of work, or completed building units can be obtained by several different methods that can be classified under the following headings:

a) Work Study and Method Study: These two techniques aim to establish standard labour content of operations by observing a limited number of repetitions performed under ideal circumstances and laboratory conditions. They call for the use of average qualified operatives, working under average weather conditions and using a well defined method of work. The standard labour content is obtained by adding to the basic average stopwatch time, allowances for rest, walking time, personal needs, etc.. The use of the technique is quite expensive, and it is not possible to apply it to the whole site, becau'e it would require more observers and analysts than operatives.

Observations are restricted to the periods in which some productive work is being done. Therefore non-productive time is not recorded and other ancillary times like supervision, measuring up, testing and handling are also ignored. These methods could be better defined as "Laboratory work study and Method Study", due to the restrictive requirements they made in order to be succesfully applied.

b) Site Methods: it is difficult to craw the line separating the previous methods from the ones to be described here. Again work stucy and methoc study are used, plus production card annotation, and the activity sampling method. The difference of this group of methods from the previous one is that site conditions are accepted as they are, there is no need to observe only "average operatives under average working conditions". Disruptions in the normal flow of work are also recorced.

Adrian proposed the observation of "work cycles", using stopwatch techniques or time-lapse phtography. Disturbances in the normal flow of work in each cycle are recorded under five headings:

- environmental delays: they are represented by delays or interruptions caused by weather, subsoil conditions different than expected, variation orders and design changes, preparatory work after moving from one working place to another, etc.;

- equipment delays: they are represented by delays or interruptions caused by equipment faults, maintenace, equipment working at less than maximum production rate, movement of equipment from one working place to another, etc.;

- labour delays: they are represented by delays or interruptions caused by lack of skill, waiting for another man or instructions, relaxation periods, meal breaks, etc.;

- material delays: they are represented by delays or interruptions caused by lack of materials, defective materials, etc.;

- management delays: they are represented by delays or interruptions caused by bad programming of works, like interference between operations, poor layout of operations, unbalance of crews, etc..

Several working cycles are observed and average non-delayed times and delayed times in each one of the five categories above are calculated. Therefore, labour content or cycle times of operations contain built-in allowances for non-productive time caused by factors like lack of operatives skill (repeat work), equipment faults, reduced productivity during bad weather, etc.. Nevertheless, it should be stressed that the recordings are made only wher the operations are being performed or during small interruptions; the method is not able to record, for example, time lost due to complete work stoppages, walking time, early departures and late arrivals, or tools cleaning.

The method could theoretically be extended to the observation of all operations being carried out on site. Major difficulties are the number of observers (or time-lapse photography equipments) needed and the fact that good part of the work on site is done in connection to non-repetitive tasks, or tasks that are not performed in cycles. The method would be useful to record cyclical operations like earthmoving and concreting, but it would be unpractical to record finishing operations in house building, for example.

Productivity measures can also be obtained by the annotation of production cards, as it is normal practice in the manufacturing industry. This technique was used by Shanley (May 1970) and Pigott in the productivity studies on house building sites in Ireland. Both the operatives or site observers could be in charge of filling the production cards, hence with variable degrees of reliability in the information provided, mainly in terms of non-productive time. Even if cards are filled by site observers, it is difficult to quantify the amount of time spent on non-productive activities: stopwatches and a great number of observers would be necessary if an accurate measure of the non-productive time is needed.

The activity sampling method is the last of the site methods being analysed in this report. A great research effort has being devoted to the use of the activity sampling method on building sites at the Building Research Establishment during the last 15 years (see the works by Forbes and Stevens). Activity sampling can be economically used to analyse the work on single operations or on the whole site, during brief periods of time or during the whole construction process. The totality of hours worked on site could be observed, irrespective of being productive, non-productive, ancillary, subcontracted, related or not to any particular operation or building unit being constructed, etc.. Only temporary absences from the site are difficult to quantify because the method is based on what the observer is able to see on site: it is necessary to introduce some refinements in the method to check that the activities of all operatives are recorded during each "snap" observation round, even if some operatives are not seen. It is also necessary to record separately time lost before and after the actual period of work on site, like travelling time, late arrivals and early departures.

c) Global Productivity Analysis Methods: these methods deal with the totality of man-hours spent on a site or in a particular sector of the construction industry. They do not use detailed daily recordings of how the man-hours were spent on site. Generally, the input data for these methods is the total amount of labour (or capital) spent, broken down, at the most, at the level of trades. It is difficult to correlate the labour expenditure with particular operations on site or even with groups of operations; multi-regression models can theoretically overcome this problem, but accuracy achieved is small (see Beamish).

Two different approaches can be used:

I - macro-economic: labour and construction activity statistics are used to work out rough guides of labour consumption (or capital consumption) per unit built, per square metre of floor area, or per unit of material;

II - micro-economic: instead of taking published statistics for the construction activity in one country or in one region, a group of selected is examined after its construction. Labour consumption is related to physical quantities of work as specified by the bills of quantities. A good example of this technique can be seen on the work being developed by the Building Research Establishment during the last 15 years (see Clapp-July 1965, May 1977, 1978, 1980, Lemessany and Clapp, and Beamish). Howenstine pointed out that labour content figures obtained with this method are potentially biased, because the co-operating firms tend to be the larger, more progressive and more efficient ones.

These global methods of obtaining productivity are not able to distinguish between productive and non-productive times.

Theoretically, labour content and productivity measures obtained with "laboratory methods", site methods and global methods could be made comparable by the use of allowances and a precise definition of what is being observed in each circumstance. In practice this is not achieved due to the difficulties in defining under which conditions each observation method was employed and the subjective aspect of allowances (see Bertram)

Laboratory methods, site methods, and global methods would indicate increasingly higher labour content of activities and hence decreasing productivity, because a greater proportion of ancillary and non-productive time is included from the first method to the last. Isolated measures of non-productive time are given only by some of the so called site methods. As it will be seen the majority of the non-productive time on site is spent without any connection to the on-going operations; laboratory methods and production card methods tend to record only man-hours directly spent on particular operations.

2.4.3 Productive/non-productive Time Ratios

Before examining several ratios found in the literature, it is necessary to provide some guidelines about how observed activity was classified as productive or non-productive. Reported research works differ in the classification systems adopted. Forbes has gathered a lot of experience in this respect during the last 15 years. Generally he has classified the "snap" observations of his Site Activity Analysis Method in the following categories:

A - absent;

I - not working around site;

N - not working at the work place;

W - walking;

Bk - meal breaks;

Cl - cleaning tools, sweeping up;

F1 - constructive tasks;

H1 - handling;

P1 - preparation;

Ro - rained-off: time lost due to interruptions of work during bad weather;

Rt - repeat work;

Su - supervision;

T1 - setting out;

T2 - testing;

U1 - unloading

These headings has been grouped by Forbes in three more general categories:

a) Productive work: Forbes has used the expression "making the building grow" to describe the tasks included in this group; from the list above, only F1 has been included;

b) Ancillary items (related to productive work): activities not directly related to the physical growth of the building, but necessary to make the constructive tasks possible have been included in this group. They have been further subdivided into:

- Preparatory work: handling and unloading;

- Miscellaneous: cleaning tools, sweeping up, supervision, setting out and testing;

c) Non-productive work: activities that would be recorded under the headings below are assigned to this group: absent, not working around the site, not working at the work place, walking, meal breaks (outside official hours), rained-off and repeat work; due to way in which the activity sampling method used by Forbes has been implemented on site, the number of hours allocated to the heading "absent" does not give a true amount of time lost due to absenteeism; when operatives did not come to the site at all, they were not recorded as absent by the activity sampling method.

Forbes (March 1980) found that in the 17 site studies carried out by the Building Research Establishment, typical figures for non-productive time laid between 25 and 30 %. Moreover, he proposed that as a general rule of thumb, one third of the man-hours available on site would be spent on each of the groups a, b and c above. He concluded that the way in which time is spent on site is related to organizational aspects of construction rather than to the physical quantities and difficulties of the project: only one third of the time spent on site, that is, the time allocated to productive tasks, could be directly related to the material quantities of the project.

Bishop (1968) stated that non-productive time was low on the sites studied by the Building Research Establishment during the late 40's, the 50's, and the early 60's. Figures quoted were around 10 % not exceeding 15 %. The reason behind the discrepancy between Bishop's and Forbes's conclusions is the difference in the method of productivity measuring; Bishop's conclusions were based on site productivity studies making use of production cards, while Forbes mainly used the activity sampling method.

Verschuren related the Dutch building industry experience. He divided his observations in productive time, ancillary time and ineffective time. It is not possible to conclude from his report if the activities listed in each of these groups match exactly Forbes's classification. His findings are presented on table 5. The increase over the years in the proportion of ancillary time in the activities of the construction industry as a whole was caused by the greater use of equipment; proportionally more time is spent now a days in maintaining, preparing, and moving equipment.

Stewart and Torrance studied the construction of six framed concrete structures in Scotland. They found 63 % as an average value for productive time (corresponding to productive and ancillary items in Forbes's classification). The range of productive time was 54 to 85 %.

Logcher and Collins examined the roof tiling operation in six different sites and came with productive time ranging from 40 to 53 %.

Bentley studied the school building process on a site where a CLASP system was used. He arrived at the figure of 28 % for non-productive time, but, if all subcontractors travelling time and absences are taken into account, the non-productive time figure would raise to 50 %. Work on site started actually between 8:45 and 9:15 a.m., despite the fact that the paid period started at 8:00 a.m..

This fact gives more support to the ideas presented in the section dealing with labour absenteism, where it was stated that apart from day to day absences, there are absences also during the working day.

More striking figures on the non-productive amount of man-hours spent on site stem from the NEDO report dealing with industrial plant construction (1976). Observable activities on site were grouped into:

- construction work;
- operative's movement: walking, climbing, etc.;
- miscellaneous activities: idle at the work place, talking, receiving supervision, etc.;
- "not on plot": this is a residual category in which the number of hours allocated were obtained by subtracting the number of men seen on each site observation round trip from the total work force calling in the morning.

The distribution of times between these various headings is given in tables 6 and 7. Miscellaneous time, the heading which could be expected to encompass the majority of non-productive activities, had a 32 to 42 % share of the time spent on UK sites. The figure was not markedly better in the USA sites. When miscellaneous time is added to the "not on plot" figure, the percentage of ineffective generally rose to more than 50 %. Finally, only between 14 and 40 % of the paid period of work on site was allocated to the physical growth of the industrial plant, that is, to constructive tasks.

Once more it is necessary to stress the difficulty of comparing the distribution of productive/non-productive times given by different authors. The definition of each category is not the same in any two reports; in fact, the majority of reports lack a precise definition of the categories in which the observable work on site was subdivided.

Other important production-related information can be derived from the study of the consumption of man-hours in the various productive and non-productive tasks. For example, the examination of the daily allocation of man-hours on the three sites that constitute the data bank for this research project, showed that this allocation varied considerably during the day. The total amount of man-hours allocated followed a trapezoidal curve, interrupted by tea and meal breaks, as it can be seen in figure 6, taken from the study of the largest of the three sites. The labour effort was not deployed on a constant basis throughout the day. In the early morning, the majority of effort was devoted to materials handling and work preparation. Cleaning tools and the work place occupied a significant proportion of the work in the late afternoon. The afternoon period showed greater concentration of work than the morning period. The daily period of work started later and finished earlier than officially set. Tea and meal breaks did not occur at sharply defined intervals.

These characteristics of the daily deployment of resources are potential sources of unbalance in the work of different operatives or gangs. Moreover, they represent a reduction in the number of man-hours actually available.

Bishop (1968) observed that each working session is constituted of preparatory work, constructive work and cleaning up. The continuation of individual tasks on the following day due to delays, or even because the scheduled duration is greater than one day, would represent an increase in non-productive and ancillary times. Therefore, each interruption of work contributes to modify the ratio productive/non-productive time associated with the operations.

Logcher and Collins demonstrated that a great number of work interruptions caused by tea breaks could be associated with low productivity.

Stewart and Torrance examined the incidence of non-productive time in "fill in jobs"; general labourers, for example, increased their non-productive time from 34 % to 46 % after being transferred from scheduled jobs to "fill in jobs".

Forbes (November 1971), while observing the output of bricklayers, found that substantial improvements in productivity occured with improvements in the efficiency in which elemental tasks related to brickwork, like spreading mortar, laying bricks to line, laying bricks to rule, cutting, measuring, etc. were cone, together with a more than proportional reduction of non-productive time. In another of his studies (March 1980), the decrease in the number of man-hours taken to build each house was obtained chiefly by reducing non-productive time, with a secondary contribution represented by increased efficiency while performing productive tasks.

The information contained in these two last paragraphs could be used to raise the question about the constancy of the ratio productive/non-productive time during the construction of particular sites, or throughout the years in the whole construction industry.

Verschuren saic that the Dutch building industry was able to maintain the same output over the years, with a decreasing labour force, due to mechanization and reduction in non-productive time.

Several reports like the ones by Bishop (November 1966), Forbes (April 1965, 1968, and March 1980) and Pigott showed that subcontractor's operatives tend to have lower non-productive time than main contractor ones.

non-productive times. At the Ladygate Lane site, one of the sites being studied by the author, average non-productive time was around 9 %. The majority of the work was subcontracted. On another site, where a new type of brick was being introduced, non-productive time was reduced from 30 to 18 % in the bricklayer's trade, with the introduction of an incentive scheme. It was observed on this same site that subcontrator's non-productive time occured more in connection with late arrivals, early departures and unofficial meal breaks, than in connection with idleness around the site or at the work place. In another site were brickwork was being observed (Forbes-November 1971) non-productive time was only between 0.6 % to 5 % in the various trades, reflecting the adequacy of the incentive scheme adopted.

Experiments to increase productivity on site should take into account the distribution of time between directly constructive tasks, ancillary tasks and non-productive time. Real benefits would be felt only when the problem is treated as a whole. Potentially large improvements in the efficiency in which the constructive part of the work is done, like the use of increased size of bricks, mechanical plastering, and the use of equipment in general, are made smaller when the large proportion of ancillary and non-productive time are brought into the calculations. It had been also observed that the potential improvements could be overshadowed by increases in ancillary and non-productive time, as it happened with the introduction of modular bricks (Forbes-1977), and mechanical plastering (Forbes-April 1965). In this last experiment the equipment was capable of producing 3600 sq. m. of rendering daily; after experience was gained, the practical maximum output achieved was 640 sq. m.. This output was still twice as much what could be obtained by hand plastering using the same number of men. During the first runs of the plastering equipment, 50 % of the time was spent on non-productive activities. After experience was gained, 35 % of the time was used for plastering, 30 % to repair minor faults and attend the equipment, and 45 % continued to be non-productive time.

It was already mentioned that the proportion of non-productive time depends more on organizational aspects of the site than on the physical characteristics of the activities. Under these circumstances, it could be expected that the ratio productive/non-productive time of different trades on the same site would be fairly similar. This fact remains open to discussion: Bentley, already cited, said this ratio varied from operation to operation and from trade to trade in one building site he observed.

2.4.4 Conclusion

Despite the fact that the findings of several different authors cannot be made directly comparable, due to their lack of a precise definition of what was considered as productive and non-productive time, the following general figures can be tentatively proposed.

Productive time takes in general from 50 to 90 % of the operative's time on building sites. Furthermore, the productive part of the work is usually represented by two groups of tasks; the first one is directly related to fixing, laying or connecting building materials and componentes, while the second one is related to ancillary items like handling, measuring, testing, cutting and setting up. These two groups are equally important in terms of consumption of man-hours, and each one represents roughly 50 % of the total productive time.

In general, non-productive time represents between 10 and 50 % of the time spent on site. Common figures are in the range of 20 to 40 %. Larger proportions of non-productive time are generally obtained taking the paid period as the basis for calculation, instead of the observable period of work on site. When the paid period is taken as 100 % of the theoretically working time available on site, non-productive time in connection with late arrivals, early departures and travelling time is added to the ineffective time represented by relaxation, personal needs, unofficial meal breaks, idleness at the work place and idleness around the site.

The different methods of obtaining labour constants and productivity figures would produce different values for non-productive time. Work study techniques, for example, would show a very small proportion of non-productive time, restricted to relaxation times and personal needs. Activity sampling techniques are able to record a more realistic amount of non-productive time, but they are still not able to measure on their own the totality of time lost on site.

The non-productive time figures stemming from the literature reporting the observation of various construction sites are very high, mainly after comparing with the traditional allowances recommended by work study and method study techniques. The estimating departments of building companies should make sure that their labour constants include allowances for non-productive time in order to match those high values found in practice. Alternatively, the cost consequences of non-productive time can be added as an aggregated figure at the end of the estimating process.

The high proportion of productive time spent on ancillary tasks could present some difficulties depending on how the labour constants incorporate skilled and non-skilled man-hours. Tasks like handling and unloading are usually accomplished by general labourers and trade labourers. The gang compositions (2:1, 3:2, etc.) should be balanced taking into account the proportion of skilled and non-skilled tasks in each activity.

Part of the ancillary work is difficult to measure using traditional work study techniques. Tasks like measuring, setting out, cleaning tools and the work place, testing, and receiving supervision are not usually recorded by these methods because they occur sporadically, they do not make part of a cycle of tasks. Another difficulty is that the contribution of skilled and non-skilled labour to perform the ancillary tasks could be blurred by the observation of unbalanced crews.

The ratio productive/non-productive time was shown to depend more on organizational procedures like the use of subcontractors, incentive schemes, equipment, site morale, continuity of work, etc., than on the physical content of each operation.

Improved productivity on building operations is possible with the combined effect of reducing non-productive time and more efficient use of productive time. The exact contribution of each one of these sources of productivity improvement is not known: they occured together in all cases examined.

The concept of variable resource levels available on site is related to the ratio productive/non-productive time in two different ways:

- lack of accuracy in the prediction of the proportion of the resources available that will be productive, once a given level of resources in man-hours is defined at the start of the project. Better predictions would be possible only with the knowledge, before the project starts, of the future effects of site management style, subcontractor's characteristics, industrial relations, incentive schemes, the programming technique and day to day scheduling decisions, etc.;

- variability in the ratio productive to non-productive time over the project duration. The effects of the improvement in productivity during the construction phase (learning phenomenon), the modifications on site organizational procedures, and the industrial relations climate prevailing at each month would influence this ratio throughout the construction process.

As the scope for variability in the proportion of non-productive time on construction sites was found to be very large, both the lack of accuracy in its prediction and its variability over the construction period can affect significantly the actual level of resources available on site. Non-productive time can on itw own determine a range of resource consumption (and hence of resource availability) of almost 2:1. Productivity ranges cf this order would be found comparing the resource requirements of identical activities performed with the maximun and the minimun non-productive times observed in practice.

3. Conclusions and Suggestions

Labour turnover, labour absenteism and non-productive time are causes of changes in the resource histogram available on site either in terms of daily variations or even hourly variations. The difficulties in predicting and modelling the future turnover, absenteism and productive/non-productive ratios on building sites are also a cause of uncertainity about the level of resources that would actually be available, once a desired theoretical level is set.

The problem of non-productive time spent on building operations is well documented in the literature. There are some published evidence showing the range of losses due to labour absenteism that could be expected. Very little is known in quantitative terms about labour turnover and its influence on the actual level of resources available on site. The concepts of absenteism and non-productive time somehow overlap: some part of the non-productive time observed on building sites is due to short absences of the operatives during the day, late arrivals, or early departures.

Losses in man-hours available on site due to non-productive time are higher than losses due to absenteism. In general, the former could represent up to 50 % of the paid period of work, while the latter could represent up to 20 %. A compromise should be made between those figures in order to take into account the overlapping mentioned on the paragraph above. Nothing can be said, in quantitative terms, about the losses in man-hours associated with labour turnover.

Due to the different magnitude of the losses associated with non-productive time and absenteeism, it could be expected that the variability on the level of resources caused by the former is higher than the variability caused by the latter. No information is available on the range of variability that can be found on the values of the resource histograms, after their theoretical levels are reduced by factors taking into account the losses cited above.

Labour turnover, absenteeism and non-productive time could be highly correlated; for example, just before the operative's dismissal or shortly after his admission it could be expected that non-productive time would be high. High values for these three aspects could be an indication of low site morale.

Daily programmes of work should consider the real resource level histogram likely to occur on site: resources are not available on a constant basis from the first hour in the morning to the last hour in the afternoon.

The question of how to incorporate labour turnover, absenteism and non-productive time in estimating and programming techniques is not yet answered. It seems that all these three aspects are highly related to organizational procedures on site, rather than to the characteristics of the individual activities to be estimated for and scheduled. This report suggests to associate the influence of these three aspects with aggregatec measures cf the building process. This would be the case, for example, of multiplying the aggregated resource histogram of a project by a factor representative of the losses in man-hours that could be expected with estimated values of turnover, absenteism and non-productive time. The real effects of these three items on construction schedules and construction costs, would be better quantified if the losses in man-hours available on site are made stochastic: this approach would be more coherent with the stochastic nature of turnover, absenteism and productive/non-productive time ratios.

Alternatively, resource histogram could be considered as deterministic in nature; the effect of the three aspects above would be incorporated by increasing activity's duration, resources required and the range of variability of these two measures. The reasoning behind this approach is that the losses and variability caused by the factors examined in this report, large as they may be, are still small when compared with the general range of variations in the activity's productivity found in practice. The shortcoming of this approach is the modelling of the building process at its operational level; building costs and the progress of work on site are better understood and predicted when looking at the strategic and tactical levels of the construction process.

Tables

Table 01

Average Number of Hours worked per Year by Construction Workers, by Occupation, July 1966-June 1967

Occupation	Hours worked
Skilled	1016
Bricklayers	1002
Carpenters	1014
Cement Masons	903
Iron Workers	981
Lathers	1087
Operating Engineers	1116
Plasterers	1044
Laborers	660

Table taken from

U. S. Bureau of Labor Statistics, "Seasonality and Manpower in Construction", BLS Bulletin, No. 1642, 1970, tables A17-A20. The data are for workers in Detroit, Omaha, Milwaukee, and Southern California; skilled workers figure corresponds only to the average of the trades listed in this table.

Table 02

Percentage of Construction Man-hours Lost through Disputes and Absenteeism

Type of Plant Construction	Disputes UK	Disputes Europe	Disputes USA	Absenteeism UK	Absenteeism Europe	Absenteeism USA
Ethylene Units						
UK	6			5		
France		1			na	
USA			5			5
Distillers						
UK	4			8		
Holland		0			8	
USA			7			5
Refineries						
UK plant No.1	2			na		
UK plant No.2	3				na	
Holland		0				na
Methanol Plants						
UK	2			na		
Holland		0			na	
France		0				na
Power Stations						
UK plant No.1	1			15		
UK plant No.2	0			8		
Italy		1			15	
Germany		0			na	
USA plant No.1			0			0
USA plant No.2			1			3

na = data not available

Table taken from

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

Table 03

Activity Sampling Survey - Active

Period as a Proportion of the Paid Period

	Pairs of Similar Construction Sites										
	UK1	US1	UK2 *	US2 *	UK3	US3	UK4	US4	UK5	HOL	UK6
A	386	680	176	800	180	120	143	112	161	141	85
B	8.00	8.00	8.00	9.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
C	6.45	7.40	7.10	8.50	6.55	7.40	7.00	7.40	7.07	7.25	7.07
D	84	96	90	96	86	96	88	96	89	93	89

Notes:

A - average number of men on plot;
B - paid period, in hours and minutes: the paid period excludes the lunch break that is unpaid but includes all other breaks;
C - active period, in hours and minutes;
D - active period as a percentage of the paid period

* - although UK2 and US2 are similar projects, because of the widely differing number of men on the selected plots, the figures from these projects are less directly comparable than those for the other pairs;

Table taken from:

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

Table 04

Productive Time and the Active Period as a Proportion of the Paid Period in the Construction of four reinforced Concrete Structures anc in General Contracting

(in percentages)

Reinforced Concrete Structures

Site	Productive Time (a)	Active Period (b)	Labour Efficiency (a*b)
1	66.3	88	58.4
2	60.5	89	53.8
4	53.5	86	46.0
6	71.6	94	67.3
Aver.	63.0	89	56.4

General Contracting

Site	Productive Time (a)	Active Period (b)	Labour Efficiency (a*b)
A	85.1	81.7	69.4
B	55.1	82.0	45.1
Aver.	66.5	89.0	59.2

Notes:

A - site with the highest productive time in the NBPI incuiry irtc productivity in the construction industry;

B - site with the lowest productive time in the NBPI inquiry into productivity in the construction industry;

Table taken from:

Stewart, W. P.; Torrance, V. B. "An Examination of Certain Relationship between Accuracy, Productivity and Site Management in the Construction of Reinforced Concrete Framed Buildings", paper at the <u>CIB W-65 Second Symposium on Organization and Construction Management of Construction, Haifa, Israel, 1978</u>, Vol. 4, pp. 311-326.

Table 05

Productive, Ancillary and Innefective Time

in the Dutch Building Industry from 1930 to 1970

(in percentages)

Period	Average Building Organization			Good Building Organization		
	P	A	I	P	A	I
1930-1940	49	13	37	60	12	26
1945-1960	50	22	28	70	22	8
1960-1970	47	34	19	79	11	10

Notes:

P - productive time
A - ancillary time
I - ineffective time

Table taken from

Verschuren, P. "The Value of Labour Economy in the Building Industry", paper at the _CIB W-65 Second Symposium on Organization and Construction Management of Construction, Haifa, Israel, 1978_, Vol. 2, pp. 335-340.

Table 06

Activity Sampling Survey: Percentage of the observed Labour Force engaged in the various Activities

	Pairs of Similar Construction Sites										
	UK1	US1	UK2	US2	UK3	US3	UK4	US4	UK5	HOL	UK6
A	35	40	54	38	48	65	40	50	38	67	39
B	23	20	14	21	19	16	24	10	20	13	21
C	42	40	32	41	33	19	36	40	42	20	40

Notes:

A - construction work;
B - movement;
C - miscellaneous.

Table taken from:
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.

Table 07

Activity Sampling Surveys: Percentage of the Active Period spent on each Activity by the potentially observable Labour Force.

	Pairs of Similar Construction Sites										
	UK1	US1	UK2	US2	UK3	US3	UK4	US4	UK5	Hol	UK6
A	17	24	44	28	38	57	27	32	25	43	31
B	11	12	11	15	15	14	16	7	13	8	17
C	20	24	27	31	26	17	24	25	27	13	32
D	52	40	18	26	21	12	33	36	35	36	20
Total	100	100	100	100	100	100	100	100	100	100	100
E	14	23	40	27	33	55	24	31	22	40	28

Notes:

- A - construction work;
- B - movement;
- C - miscellaneous;
- D - 'not on plot';
- E - construction work as a percentage of the paid period.

Table taken from

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

Figures

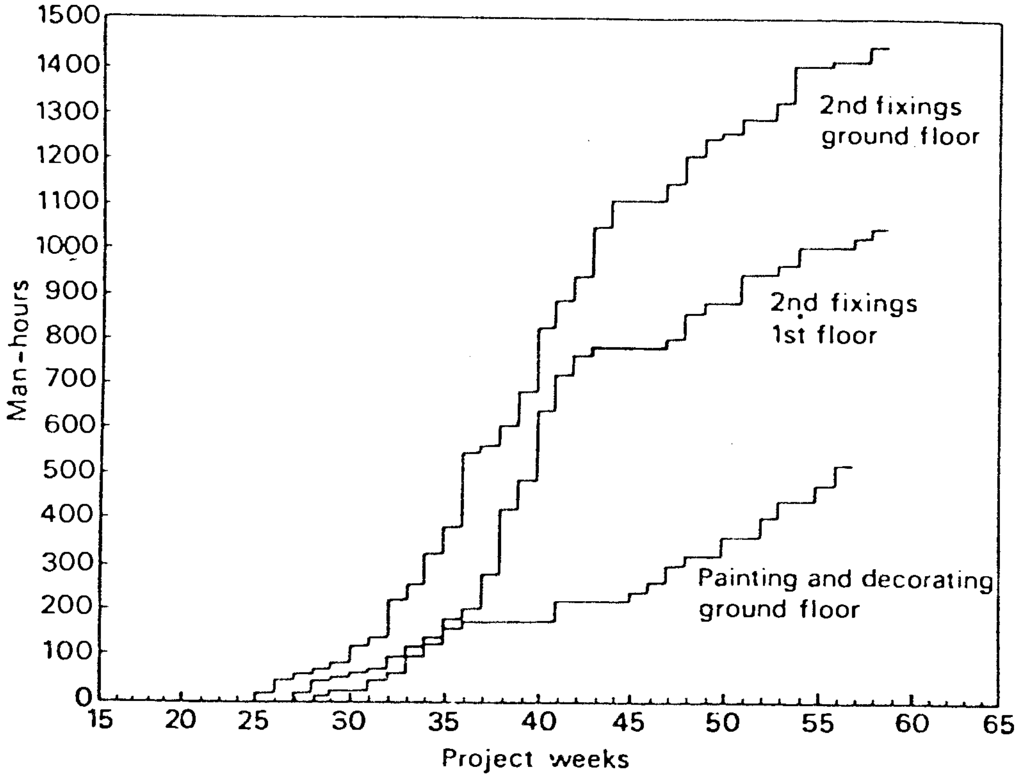
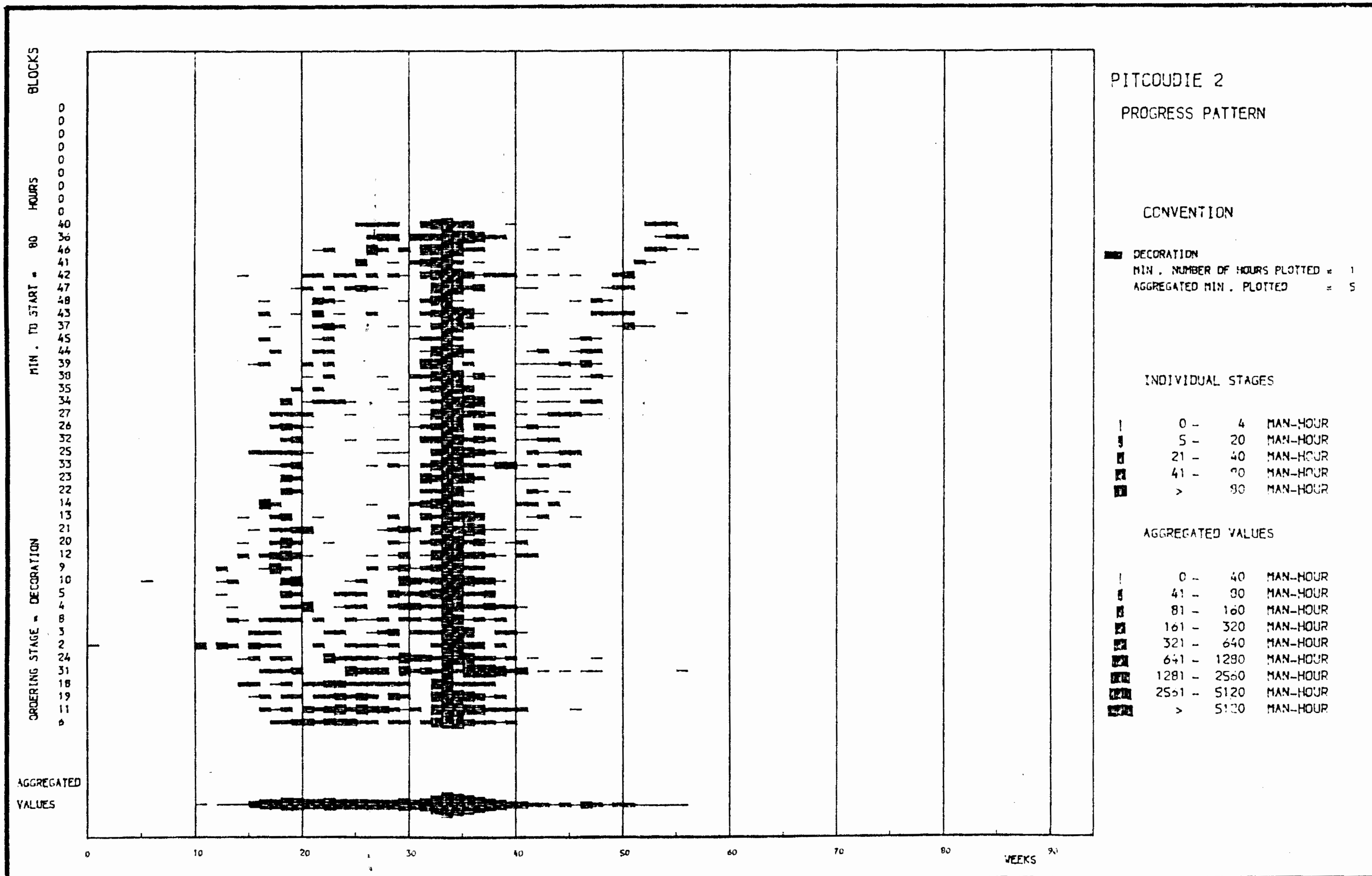


Figure 1

Cumulative Man-hour Graph for some Operations observed in the Construction of a large Office Block and a central Warehouse for a Public Utility.

Ref.:

Roderick, I. F. Examination of the Use of Critical Path Methods in Building, Building Research Establishment Current Paper CP 12/77, Garston, BRE, March 1977.



PITCOUDIE 2
PROGRESS PATTERN
CONVENTION
DECORATION
MIN . NUMBER OF HOURS PLOTTED = 1
AGGREGATED MIN . PLOTTED = 5
INDIVIDUAL STAGES
0 - 4 MAN-HOUR
5 - 20 MAN-HOUR
21 - 40 MAN-HOUR
41 - 80 MAN-HOUR
> 80 MAN-HOUR
AGGREGATED VALUES
0 - 40 MAN-HOUR
41 - 80 MAN-HOUR
81 - 160 MAN-HOUR
161 - 320 MAN-HOUR
321 - 640 MAN-HOUR
641 - 1280 MAN-HOUR
1281 - 2560 MAN-HOUR
2561 - 5120 MAN-HOUR
> 5120 MAN-HOUR
BLOCKS
MIN . TO START = 80 HOURS
ORDERING STAGE = DECORATION
AGGREGATED VALUES
WEEKS
0
10
20
30
40
50
60
70
80
90

FIG. 2

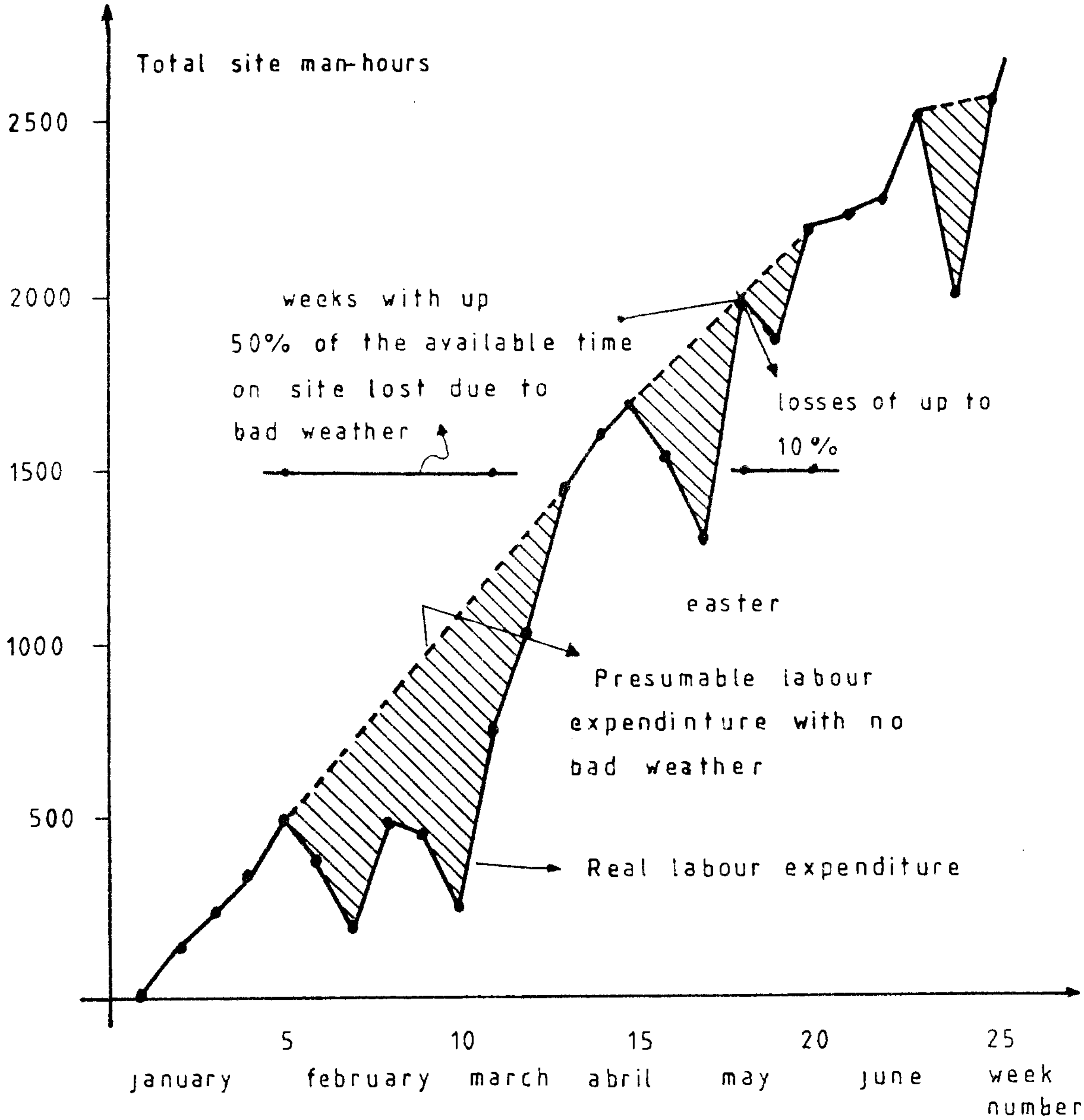
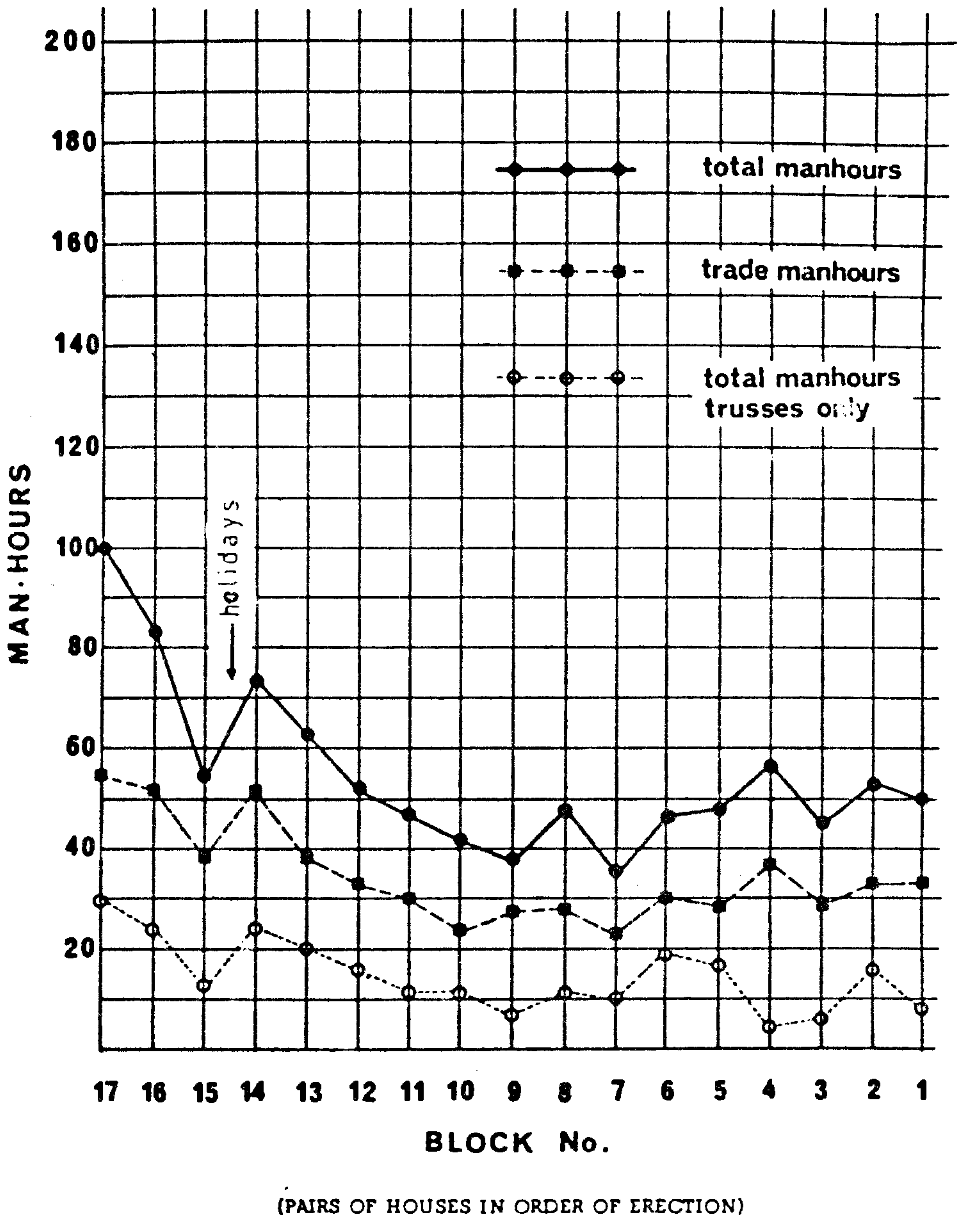


Figure 3

Relation of Total Site Time to
bad Weather Time on a Sheffield Site (1954)

Ref.:

Clapp. M. A. "Weather Conditions and Productivity - Detailed Study of Five Building Sites", Building, Vol. 211, No. 6439, October 1966, pp. 171, 172, 175, 176, 179 and 180.



TOTAL MANHOURS ROOF TIMBERS

Figure 4

Increase in Man-hours Requirements for the Stage "Roof Timbers" after the Summer Holidays

Ref.:

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

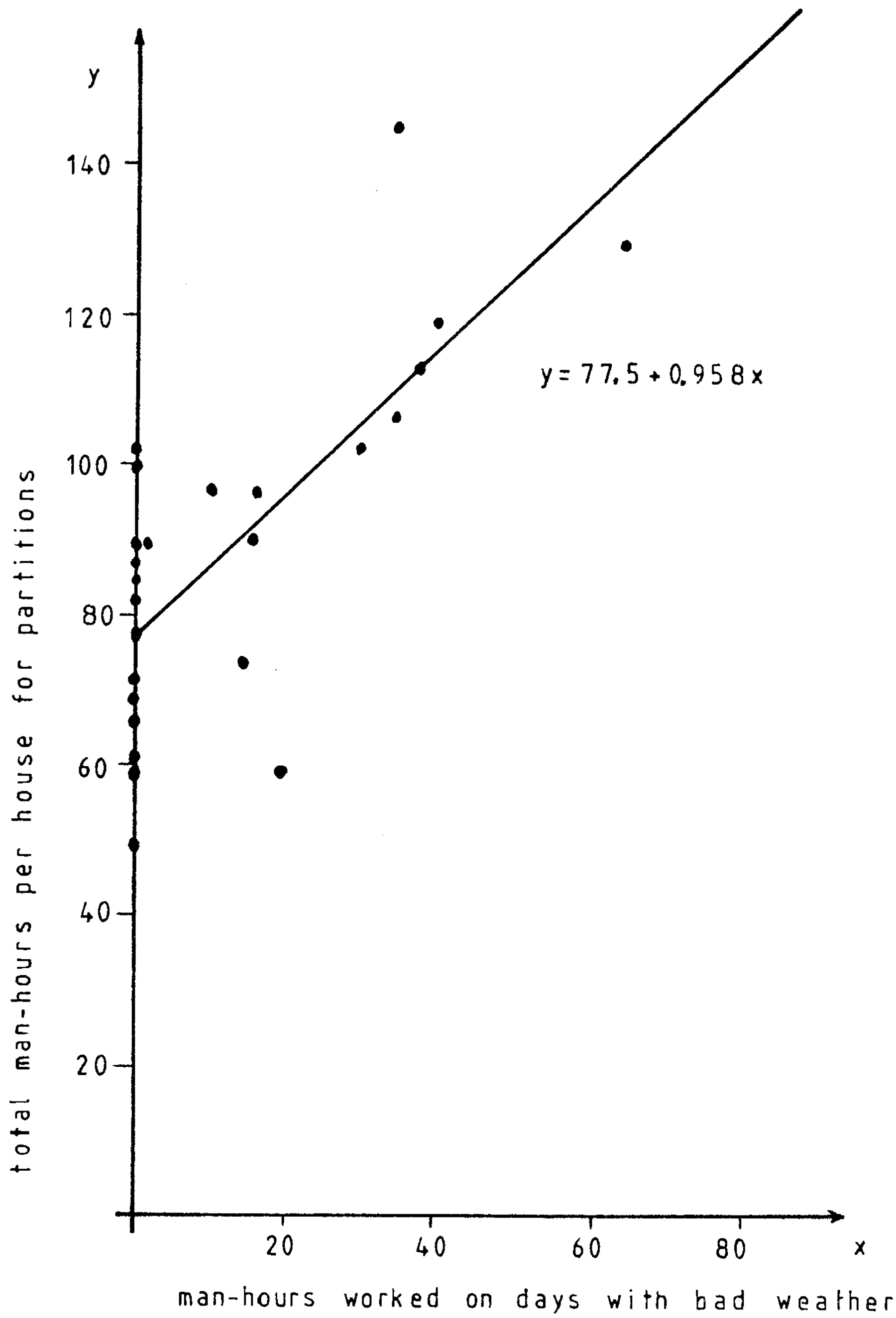


Figure 5

Effect of bad Weather on Man-hour Requirements for Erection of Partitions in Traditional Houses on a Brighton Site (1954-1955)

Ref.:

Clapp, M. A. "Weather Conditions and Productivity - Detailed Study of Five Building Sites", Building, Vol. 211, No. 6439, October 1966, pp. 171, 172, 175, 176, 179 and 180.

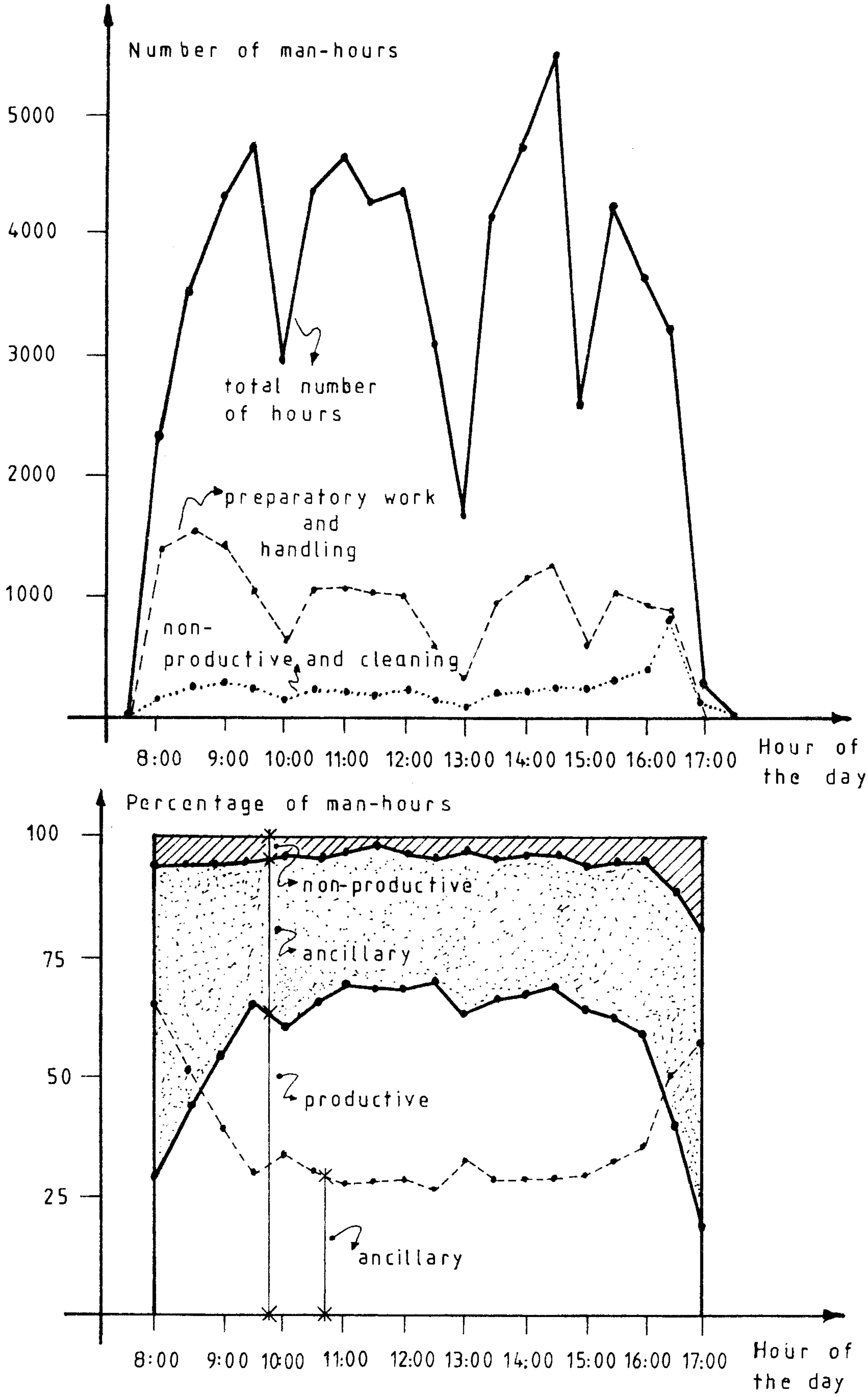


Figure 6

Distribution of productive, ancillary and non-productive times during the day

Bibliography

Bibliography

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

Adrian, J. J.; Boyer, L. T.; "Modelling Method-productivity", J. of Construction Division, ASCE, Vol. 102, C01, March 1976, pp. 157-168.

Adrian, J. J.; Boyer, L. T.; "Modelling Method-productivity", J. of Construction Division, ASCE, Vol. 102, C01, March 1976, pp. 157-168.

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 Builders' Estimating", Quantity Surveyor, April 1980, pp. 65-70.

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

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", paper at the International Symposium on Systems Engineering and 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.

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.

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. "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.

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, Autumm 1978, 9 pp.

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

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.

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, CO1, 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.

Committee on Housing, Building and 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.

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

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).

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.

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.

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

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.; Mayer, 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.

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.

Halpin, D. W. "Constructo - An Interactive Gaming Environment", J. of the Construction Division, ASCE, Vol. 102, CO1, 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.

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.

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.

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, F. A. "An Experimental Analysis of Network Planning", Management Science, Vol. 19, No. 12, August 1973, pp. 1423-1432.

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

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.

Logcher, R.; Collins, W. "Management Impacts on Labor Productivity", J. of the Construction Division, ASCE, Vol. 104, CO4, December 1978, pp. 447-461.

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

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, CO2, 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.

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.

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

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).

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.

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.

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.; 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.

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.

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

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

Shipley, N. Variability in Output, Operational Research Department Internal Note No. 4/71, Loughborough University of Technology, 1971.

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.

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 Reacers_, 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.

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.

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.

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