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Productivity in the building industry

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1. INTROUDCTION

This paper sets out to identify the best courses open to the building industry and its clients to obtain higher productivity. Although there is common ground that the concept involves the relationship between inputs and outputs, it eludes precise definition. From the standpoint of this paper productivity is taken to mean the optimum use of resources to obtain an acceptable goal, thus avoiding one contentious aspect of productivity, the relative utility of the goals obtained.

High productivity is not, of course, an end in itself. It includes wider issues including the value of the output to society, the quality of life of those engaged in the operations involved and of those affected indirectly by the activity or the outcome, or by both. Single-minded pursuit of higher productivity assumes scarce resources or at least an imbalance between the intentions of an organization and practical achievement. Social benefit from higher productivity is obtained when the resources made available by higher productivity are deployed on the next most important activity, or when work is allocated to share the benefits of higher productivity, e.g. by working shorter hours.

A paper drawing together the threads of two decades of activity by an industry and of research necessarily rests on the work of others. In an industry as large as construction, with so many active individuals and organizations, any selection will exclude much that merits inclusion, and acknowledgement will be never complete. Hence this general acknowledgement to the many whose ideas and work have contributed to this paper, in particular to my ex-colleagues of the Production Division of the Building Research Station and of the Directorate General of Development of the Department of the Environment.

2. INCREASED PRODUCTIVITY IN THE PAST TWO DECADES

Estimates of general levels of productivity are notoriously difficult (Bowley & Corlett 1970) especially when an industry's products are heterogeneous, as are those of the building industry. Moreover, the severe methodological problems set by changes in the value of the product – for example, more extensive mechanical equipment has changed the cost per unit of hospitals and universities – make difficult the interpretation of long-term trends of productivity. Indirect costs also pose methodological problems, especially in an industry composed of many subcontracting organizations, few of which are dedicated to a well-defined segment of the market

In view of these reservations, figure 1 states the indices for productivity and output for building. During the first part of this period output increased rapidly until 1964, with the exception of 1963 when the weather must have been a dominant factor, and less rapidly in the recent

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† Mr Bishop, Director of Management Services, Department of the Environment, was speaking in a private capacity, therefore the views expressed do not necessarily represent those of the Department.

past reaching a peak in 1968, with a sensibly constant output during the past six years. Productivity rose in all but two years when it remained static; in the first part of the period the average rate of increase was little over half that in the latter. Overall the performance of the building industry compares well with other industries, 5.1 % (compound) averaged for 15 years, compared with 2.6 % for manufacturing industries in general.

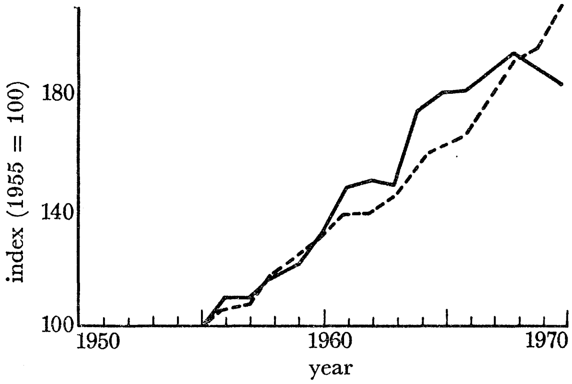

FIGURE 1. Trend of output (—) and productivity (– –) of the construction industry.

An alternative estimate of increased productivity may be obtained by comparing the on-site labour requirements for a well-defined building type such as two-storey dwellings. A properly structured survey in 1949 found that the average man-hours per dwelling were 2665, the range being 3:1 (Reiners & Broughton 1953). At that time there was considerably less variability in layout and design than is now the case – more than 50 % were two-storey, brick-built semi-detached houses, compared with 11 % in the survey mentioned below. Currently the great variability of layout and design would dictate a sample of impracticable size. In 1968, however, the Building Research Station completed a survey of progress in house building on 48 sites (Forbes 1969). In this, the sample of contractors willing to cooperate with the Station might be expected to be those more interested in improved techniques, and hence biased to the more productive sector of the industry. This may have accounted for the low average man-hours per dwelling which were about 1110, with a range from just under 600 to just over 1900 man-hours; the mid-point of the more recent survey was 1965, indicating an average increase of productivity of about 4.5 % per annum since 1949, which compares reasonably with an increase of 4.5 and 5.7 % per annum for public and private sector housing respectively, averaged for the last 15 years (Source: Construction Statistics M.P.B.W.).

Since 1945 there have been continuous efforts to improve productivity, with first one sector of the industry then another holding the initiative. Some developments directly affect only their promoter while others affect the industry at large. Experience suggests that many developments limited to one sector of the industry achieve their immediate objectives, and that more far-reaching (and the more significant) developments affecting the industry as a whole are much more difficult to achieve. This may be because measures aimed at achieving higher productivity of ‘the total use of resources’ encounter resistance – usually expressed by delay or higher costs – from those whose operations are made more difficult by the development. That is the industry resists disturbances to its equilibrium which reflects the ‘mini-max regret’ strategy of its activities. It is to be argued that the principal constraints determining these strategies are so much an integral part of the industry’s structure that a rapid gain in productivity is unlikely unless the structure is modified to relax them.

3. The industry: a system

Organizations in the construction industry exercise relatively little control over their market. Clients' requirements have to be met and buildings have to conform to their physical environment. What is to be built and when and where it is to be built is decided by clients; technical requirements and standards are usually decided by clients' professional advisers and the timing of projects may be at the mercy of planning or financial procedures. The building workload in any region fluctuates with the fortuitous conjunction of major works such as highways, electricity generating stations, hospitals, and the like. For all these reasons building is largely bespoke and the industry is less able than the manufacturing industry to mould its market, or to plan to take advantage of market trends.

Two invariable consequences of uncertainty are delay and lack of forward commitment. Taken together these depress utilization of resources, particularly those committed to fixed ends. In order to escape the consequences of low utilization, the industry has evolved a fragmented structure by specializing by tasks rather than by building types because this leads to greater continuity of work (the market for most building types, e.g. universities, fluctuates more rapidly than the market for building).

Construction involves comparatively simple techniques, widely understood by the industry as a whole. Few techniques must be operated on a large-scale for technical reasons, and the productivity of craft-based operations does not appear to be significantly affected by the size of the enterprise for which operatives work. Moreover, any contractor may choose to hire some or all of the plant and equipment needed to build, and thus reduce fixed assets. As a consequence, building organizations (professional and contracting firms) have few resources committed to the construction of any building type or any method of construction. That is, they are organizations capable of building, a factor that has led to widespread subcontracting (in design and construction), a practice that enables specialization to an extent not warranted by the size of the individual projects or by the size of many firms.

The second consequence of uncertainty is that organizations seek to obtain more work than would be required if the timing envisaged in programmes of design and construction were realized. Typically design and construction proceeds more – much more – slowly than justified by the amount of work to be completed, each organization having a stockpile of work to be drawn on when other projects are delayed. This is a remarkably successful tactic for coping with variability, especially as the industry's clients have become conditioned to relatively slow progress, and meet most of the cost of funding by way of interim payments!

These responses to variability – fragmentation, specialization and subcontracting on the one hand, and a relatively slow rate of progress on the other – have the unfortunate consequence of reinforcing variability. This is because sub-contracting, the consequence of fragmentation and lack of commitment of resources to specific ends, makes it difficult for any organization to exercise effective control. Design involves the cooperation of many specialists, some appointed by the client, some by the architect. Construction involves the cooperation of main and subcontractors; many of the latter, being nominated by the client, may look to the client rather than to the contractor for future work which must reduce contractors' ability to manage work on site, quite apart from the impact of labour-only subcontracting on the organization of site work. Moreover, the existence of a stockpile of work makes it attractive for all organizations to 'hold back', starting any activity at the latest rather than the earliest start time, so that others have completed their tasks and removed obstacles to completion, thus transferring the variability of all activities to the project. Lack of direct control and enhanced variability combine to reinforce the uncertainty of the market, to further reduce utilization and to force further fragmentation of the industry. This regressive cycle must be broken.

Also the strategy for any organization must conflict with those of others, at least to some extent. Tactics that transfer non-productive time to one's collaborators or to one's clients can be practised only within acceptable bounds. Hence, at any time, the industry probably represents an equilibrium in which the interests are all respected, apart from those who have not learned the rules of the game; clients in particular. Restated, the proposition is that the tempo of work and specialization in the industry minimizes the total cost of uncertainty and control of timing at the cost of constraining productivity.

Higher productivity requires, therefore, conditions that make possible achievement of high utilization of all resources in the industry, including those of clients. This implies better control of the timing of events so that resources may be committed with confidence. The other necessary condition, not so far discussed, is that the industry's procedures should be such that production considerations are taken into account during design of projects and of components, whether prefabricated or *in situ*. Production considerations embrace the many facets of productivity, including the more obvious features such as production methods *per se* and the tasks involved in erection, together with others such as transport, storage, and handling, tolerance control, inspection and quality control, and the incidence and difficulty of re-work when errors are put right. Currently the procedures do not make ease of site assembly an essential feature of specifications for components, hence this attribute may not bear heavily on designers in manufacturing industries. Similarly, many have commented on the consequences of separating building design from production (Bishop 1965) and there have been many attempts to resolve the problem by a number of devices including operational bills (Skoyles 1967), design–construct contracts, and design–construct consultancies. These, then, are the objectives: high utilization, better control over timing and designs for components and projects that take account of production considerations.

4. HIGH UTILIZATION AND CONTROL OF TIMING: TWO NECESSARY CONDITIONS

Utilization

Any organization, in order to make the best of its circumstances, must arrange its affairs so that the resources deployed are utilized to the maximum. No activity however efficient is economic unless utilized. Low utilization is the bogey of mechanization, of industrialization, of commitment of any resources to specific ends. Probably low utilization was the death knell of more industrialized building systems than any other single cause. Relatively few of the firms adopting or developing an industrialized building market in the hectic '60s devoted sufficient resources to marketing and sales. Significantly those still in the field have efficient marketing and sales divisions.

It is necessary to distinguish between the direct and indirect costs of production. Direct costs are those proportional to output, and indirect costs those that must be met, at least in the short term, however output fluctuates. As has been explained, the building industry has resolved the problem of uncertainty by having relatively few resources committed to specific ends, that is by having relatively high direct costs. But most measures to improve productivity run counter to this tendency by sharply increasing the proportion of indirect costs. There is often increased capital investment and a consequent increase in capital charges and process costs. Also the volume of production obtained from new techniques must be matched by efficient marketing, sales, buying, stockholding, maintenance, training, supervision and inspection, all of which increases the demands made on management and add to the indirect costs of production. Moreover, operatives trained to operate sophisticated or new processes cannot be dismissed immediately there is insufficient work to keep them fully employed.

Actual cost is the sum of indirect and direct costs. For indirect costs the charge per unit produced is generally inversely proportional to the overall utilization. Adopting a technology with a high proportion of indirect to total cost will therefore increase actual costs if the planned utilization is not achieved (figure 2); e.g. when the proportion of indirect costs is increased from 0.2 to 0.4 for an organization operating at 0.8 utilization, actual costs are increased from 1.04 to 1.07 times that if all resources are fully utilized. A relatively small increase, perhaps, but one that is likely to exceed any increase in profit stemming from committed resources.

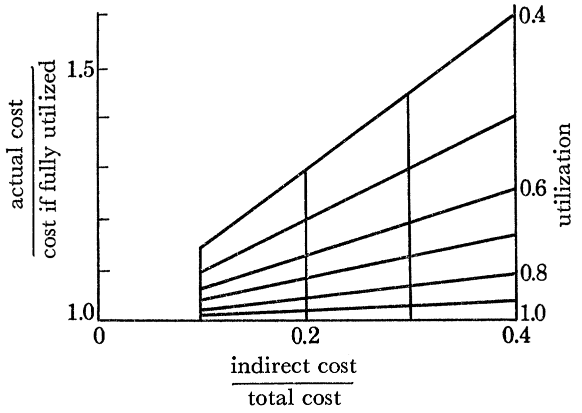

FIGURE 2. Effect of utilization on costs.

Often, however, new techniques also decrease utilization because many internal and external factors reduce output, and compensating periods during which work proceeds at a faster tempo than that intended seldom occur. Productivity is low when a new process or system is first commissioned and improvement continues for a protracted period before the target output is reached. Other factors reducing output include the time lost when a contract is delayed by clients or for financial or for other reasons or while production equipment is modified, or when construction is prevented through bad weather or delayed while cranes move from one building to another, or from one site to the next. Some external factors also restrict production; these include the effect of labour disputes, delayed deliveries of materials, and inability to obtain orders. Sometimes, and damagingly, commitment of resources to specific ends reduces the potential market so that greater effort has to be devoted to sales, thus further increasing the proportion of indirect costs, or sales fall thus decreasing utilization, or both. Whatever the cause, the consequences are the same – indirect costs rise, the ratio of the actual to the intended output reduces, utilization falls, and actual costs increase. A glance at figure 2 demonstrates the serious consequences that flow from the combined effect of increased indirect costs and decreased utilization. For example, an increase in the proportion of indirect costs from 0.2

to 0.4 combined with decreased utilization from 0.8 to 0.6 produces an increase in actual costs 1.04 to 1.27 times that if all resources are fully utilized.

Uncertainty in controlling timing

There is no need to argue the proposition that uncertainty in timing is a universal phenomenon of the building industry. In occupations as fragmented, as interwoven, as much affected by the weather as building, there is and there must be a penumbra of uncertainty surrounding every outcome; no condition is ever 'spot on'. Uncertainty has many guises, most of which affect the structure and work of the industry. Finance may or may not be available; clients may be hazy about their objectives, or modify them in mid-course; design solutions may or may not be accepted; waivers to bye-laws may or may not be given; acceptable tenders may or may not be received; availability and quality of labour may be dictated by the general level of local building activity; materials may or may not be delivered on time and undamaged; and so on. Whatever the uncertainty the consequences are the same; stages are delayed. Other resources awaiting completion of the delayed stage either accept the cost of lower utilization or are redeployed. It has not been possible to obtain coherent data about timing from a number of different sources. This would be difficult because it would be necessary to establish that the examples chosen were not 'most favoured nation' in character, and were not from a segment of the industry where the arrangements made provided adequate time for completion – as may happen with the phasing of school projects (Bodapati, O'Brian, Ortwein & Stilitz 1970). Also few data are available. Data for individual projects are qualified to an extent that narrative case studies are more appropriate than analysis. This is not that case studies have not their proper place as those thoughtful studies of projects by University College have demonstrated. What is required, therefore, is a large body of data, sufficient to lose the particularity of individual projects in the variability of the sample as a whole.

For this reason I have turned to the building contracts of the former Ministry of Public Building and Works – my parent Department. Each year about 500 building projects are let, some by headquarters directorates, some by the regional organization. In value contracts vary from £30000 to several millions; and in complexity from relatively simple local offices to large, complex and unique research facilities. Data are collected to show the delay in completion and the causes attributed for delay. It is reasonable to suppose that one measure of the control over timing is the variance of the distribution of the ratio of actual construction time to contract time. This is not to assert that one value of variance is better or worse than another, only that the variance is one description of the system in question. It might be supposed that different values for variance would be found for relatively simple and relatively more complex projects, for relatively small and relatively large projects, and for different years. An extensive analysis of data for all projects for one year,† and another of a large group of projects for several years found no significant relationship between any factor and the variance which was sensibly constant possibly apart from location. This implies that control is related to the industry rather than to technical factors. So much for an analysis of a body of data sufficiently large to represent the industry. Is there a more general method of investigating the consequences of management decisions on timing?

If progress of a building project is considered as the main sequence of stages, the many related sequences include the activities of the client, of each specialism forming the design team, of the

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† I am indebted to Mr D. Beeston of the Directorate of Quantity Surveying Development for this analysis.

contractor and subcontractors and so on (figure 3). This array of contributors, complicated though it is, omits contributing activities such as those of the local and planning authorities, suppliers, manufacturers and unions. From the standpoint of each of the supporting sequences of activities the overall control of its own activities probably matters more than the control of the main sequence (a building project from our present standpoint) e.g. it is more likely that those managing a plant hire organization have effective control over their own activities than that they are willing or able to afford to support the activities of others. It is at least plausible to assume that the more remote a contributing system is, the more likely will it be to assign low value of control to its contributions to the main sequence of events. The obvious exception to this rule is when the main sequence, by being given a 'most favoured nation status', is more important to each of the contributing sequences than are their own activities. Generally, however, prevailing conditions can be described by the phrase, 'You are on my critical path, I am not on yours'.

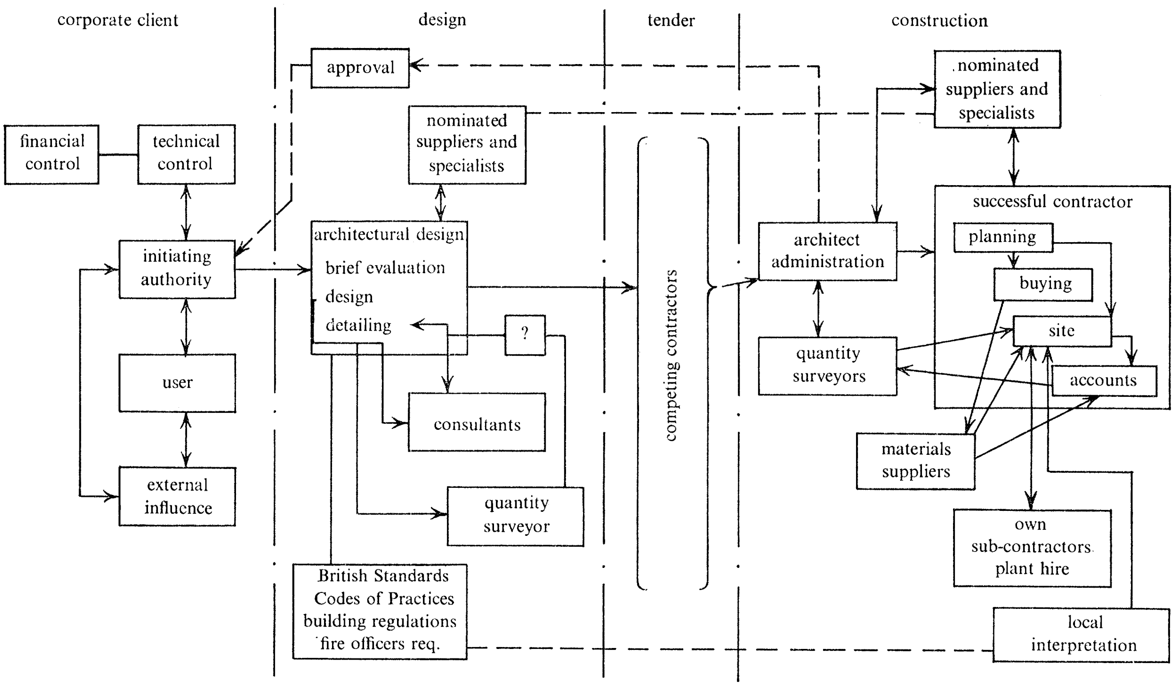
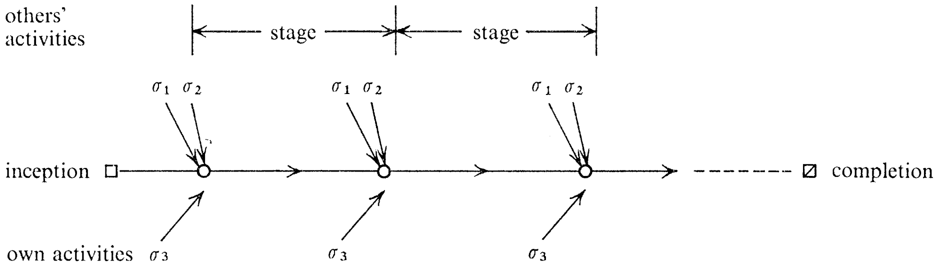


FIGURE 3. Conventional building process.

Network representation rapidly becomes too complicated for convenience. A simpler model results from considering the behaviour of a single sequence of stages, progress from one stage to the next being dependent on contributing activities by others (approval of sketch plan, completion of structural drawings, receipt of materials, completion by roofing subcontractor and so on). That is progress beyond each stage is inhibited until all contributing activities are completed and all constraints removed, not necessarily simultaneously. The advantage of this model (figure 4) is that the probability of progress depends only on the number of activities, their elapsed time, and on their variance and not on their relationship with each other or with other sequences of activities not interacting with the main sequence. This model has affinities with models of neural systems, but the analogy is not exact.

Each of the components of the model will be briefly discussed. The number of stages depends on definition; the minimum would be 7 (feasibility, final sketch plan, drawings, specification and bills of quantities, tender accepted, start on site, complete carcassing, hand-over): the R.I.B.A. Plan of Work lists 22 management activities; there would be many hundred if a stage is defined as the work that can be completed by an individual organization without a contribution from others. The following examples are limited to 12 stages – the maximum likely to be affected by any management decision. Evidence about 'completion on time' indicates that distributions are log-normal with coefficient of variation ranging from 5 to 20 % (a 3:1 range corresponding to a coefficient of variation of 18 %). Some evidence indicates that the coefficient of variation is independent of mean times (a 3:1 range is encountered in many productivity studies, whatever the level of detail), other evidence that variance is inversely proportional (the coefficient of variation is proportional) to mean times, e.g. the study of overrun discussed above. On this basis some studies were made by Mr P. Rose and other colleagues; a simple model was made to explore the outcome of management decisions. The 'control' of each activity is indicated by its standard deviation and the 'control' for each system by the probability of completing in the target time and by the proportional over-run at 0.95 cummulative probability. To keep computation within reasonable bounds some simplifying assumptions were made, including that each stage receives the same number of contributing activities, and that the 'control' for any one activity does not vary from stage to stage. For each example one activity (B) is considered as under direct control, whilst the other activitie(s) represent the contributions of others.



assumptions

(1) own activities usually have a lower variability than those of contributing activities, i.e. $\sigma_3 \leqslant \sigma_1$ or σ_2

(2) For any simulation all stages are triggered by the same number of activities

(3) for any simulation any activity has the same variability at each stage

FIGURE 4. Model of the building process.

When activities start at the earliest start time the outcome is insensitive to the number of activities or to their control except when the second of the activities has the same duration as the first (figure 5). This conflicts with experience which is that progress is likely to be delayed by non-critical authorities. In practice, of course, all organizations tend to hold back until the last moment, that is to the latest start time. This has the effect of transferring the variability of all activities to the project, so that the outcome is more sensitive both to the number of contributing activities and their control (figure 6). Hence the importance of obtaining effective authority over all organizations contributing to a project so that each can be instructed to start at the earliest start time. In a fragmented industry this will be difficult to achieve unless projects have a 'most favoured nation status'. In ordinary circumstances the independence of

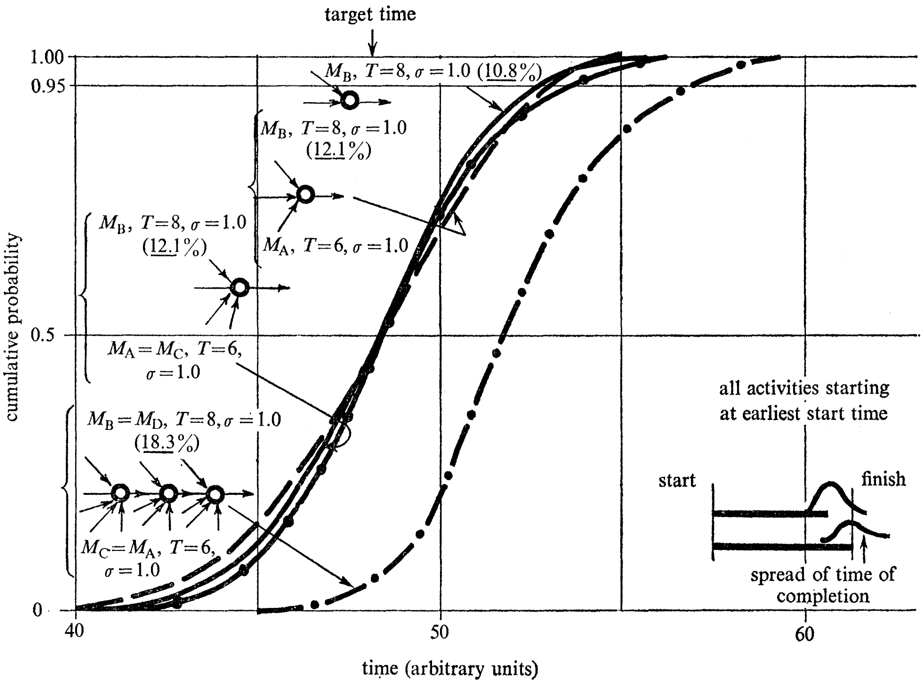


FIGURE 5. Control of timing; effect of number of activities. T, time units for each of six stages; (10.8%), percentage over-run at 0.95 cumulative probability; σ, standard deviation.

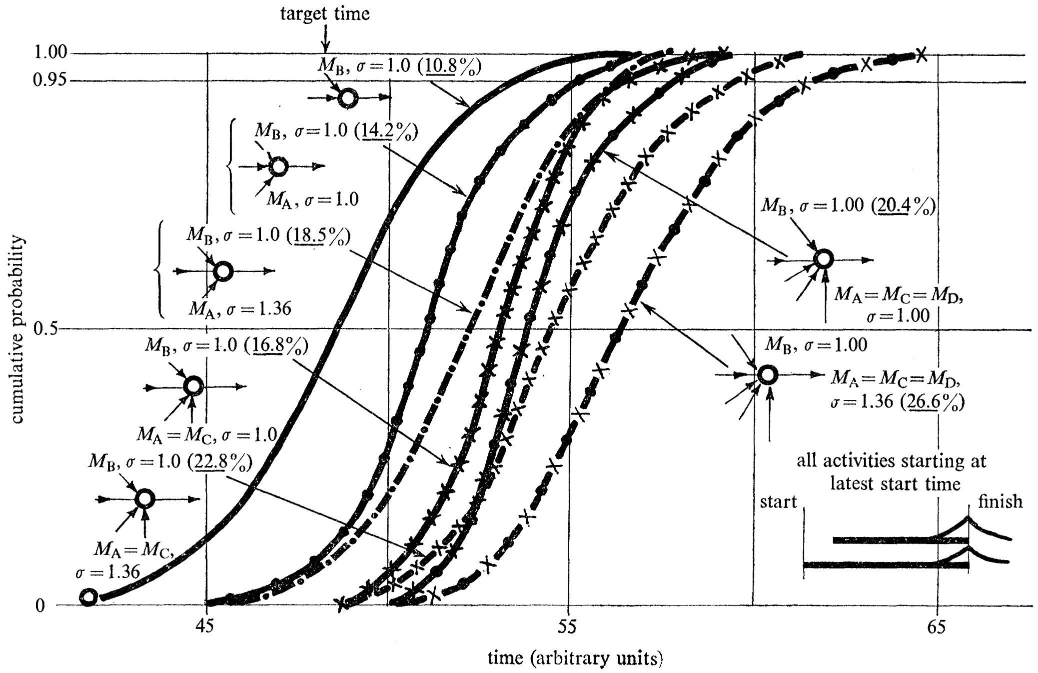


FIGURE 6. Control of timing; effect of number of activities. T = 8 time units for each of six stages for all conditions.

design organizations and subcontractors militates against effective control and other solutions must be sought.

One alternative tactic is to tighten control. In the following, all activities are assumed to start at the latest start time (resulting in a very simple model), and two standards of control are assumed, one relatively coarse ($\sigma_A = 1.36$, $\sigma_B = 1.0$) and one relatively fine ($\sigma_B = 0.68$, $\sigma_B = 0.50$). With three contributing activities (figure 7), the effect of tightening control is to reduce the over-run at 0.95 probability to one-third and two-thirds for six and twelve stages respectively, a useful improvement. In practice, however, it would be difficult if not impractical to improve the control of activities not under one's direct authority. The effect of having different degrees of control for activities within and without one's control may be seen by comparing figures 7 and 8 and table 1. That is for 12 stages almost one half the advantage of

TABLE 1

	over-run at 0.95 cumulative probability	
12 stages	$\sigma_A\sigma_C = \sigma_B$	$\sigma_A\sigma_C > \sigma_B$
relatively coarse	29.2%	35%
relatively fine	19%	23%
	36% improvement	34% improvement

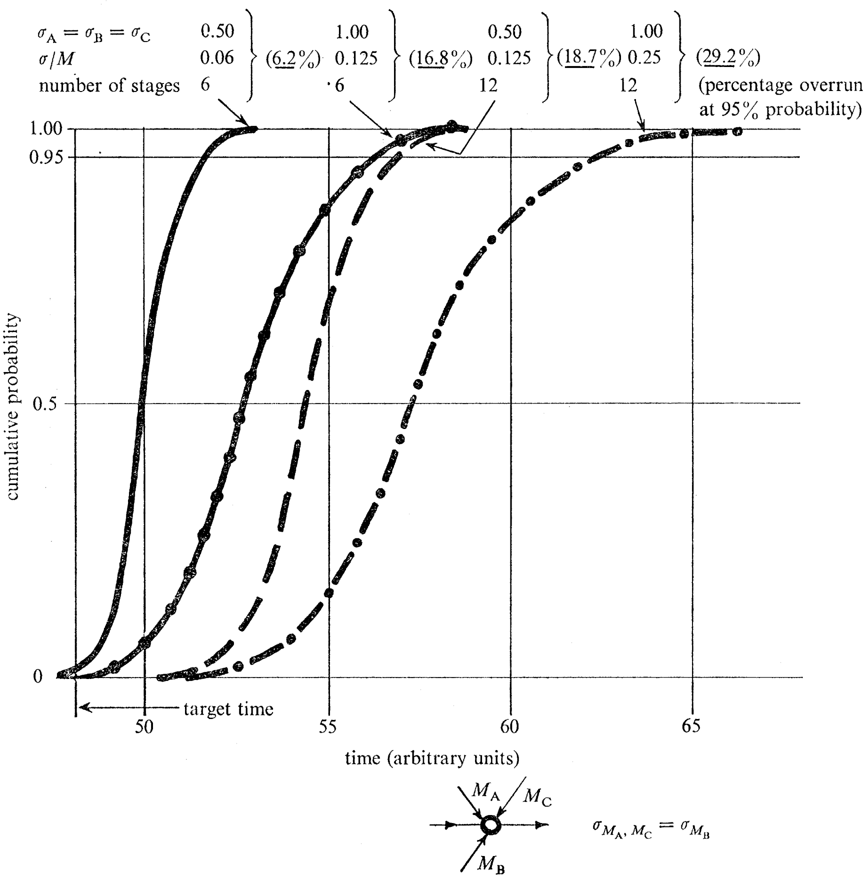


FIGURE 7. Control over timing (three activities starting at latest start time).

tightening control is lost if the control of the independent activities is less good than that of one's own (22 % instead of 36 % improvement).

Another tactic is to reduce the number of activities contributing to any stage (table 2). Here the gain is less than might be expected, and is less dependent on control.

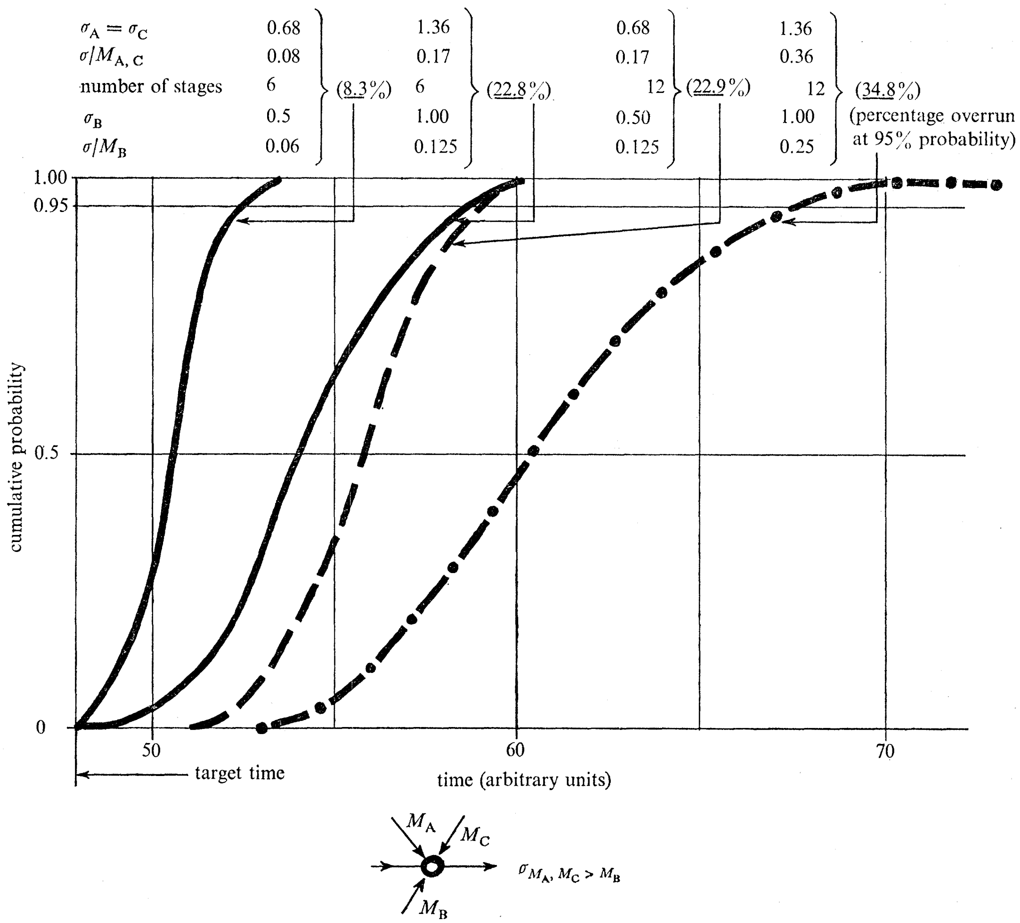


Figure 8. Control over timing (three activities starting at latest start time).

Table 2

6 stages, contributing activities	over-run at 0.95 cumulative probability	
	σ_A etc. $= \sigma_B$	σ_A etc. $> \sigma_B$
1	11	—
2	14	19
3	17	23
4	20	27

Table 3

3 activities	over-run at 0.95 cumulative probabitity			
	σ_A etc. $= \sigma_B$		σ_A etc. $> \sigma_B$	
control	fine	coarse	fine	coarse
6 stages	6	17	8	23
12 stages	19	29	23	35

A final tactic is to reduce the number of stages to achieve any goal (figure 8; table 3). For 12 stages the gain from reducing to six stages is roughly equivalent to that obtained by improving control of activities from relatively coarse to fine, and has the advantage of being independent of control because the number of stages is determined by technical factors, i.e. by the 'bittiness' of operations dictated by the design.

Clearly not too much should be read into these examples that do no more than roughly indicate the consequences of some management options. In summary these are to adopt tactics that are independent of control, whatever the organizational pattern, e.g. to reduce the number of stages and, less decisively, to reduce the number of activities contributing to each stage. Where effective control can be exercised advantage is obtained if all activities start at the earliest start time, and further advantage if control is tightened. Finally the examples decisively demonstrate the low probability of completion on time, whatever the circumstances, unless there is adequate float.

5. Tactics to improve productivity

Tactics to improve productivity of design and construction may be divided into two groups, although measures taken often combine both. The first is composed of the tactics directed at improving management, control and utilization, the second, those intended to improve the efficiency of tasks inasmuch as these are independent of their external world. Materials manufacturers, designers, contractors and subcontractors all contribute to the productivity of the industry, the largest component capable of being directly influenced by 'the industry' being site labour which probably contribute about 40 % of the output. Therefore this section takes operations on site as its starting point.

Problems of site management are determined largely by the nature, number and interrelated tasks defined by the design. By determining the complexity of site operations – both technically and operationally – design impinges directly on the management of sites as well as on the tasks performed. To some extent, given reasonable prospects of continuing work, contractors can improve productivity through mechanization, specialization, training and incentive payments. Design is not usually in their gift, therefore this section concentrates on tracing the path from the management of sites to tactics whereby designers can simplify the task of site management by producing buildable buildings. In the event, these also simplify the task of designers. The complementary tactics aimed at improving the efficiency of site operations and the management of design are discussed in appendixes A and B. Both groups are important, each tactic being a topic in its own right, but neither is central to the conclusions of the paper.

Management of sites

Work on any site may be divided into a number of operations, each operation corresponding to work that can be done by a man, or by a gang, or by plant perhaps served by one or more gangs, without interruption by the work of other men or equipment. The problem is to maintain a flow of work through the site so as to strike a balance between the rate of construction on the one hand and non-productive time† on the other. Non-productive time has many sources: one major source is when a gang can find no vacant workplace, that is when one gang is delayed by another; gang II delays gang III and gang IV delays gang V in figure 9. There are two important considerations; the general tempo of work and the number of vacant workplaces.

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† Non-productive time is one of the important factors determining utilization of resources.

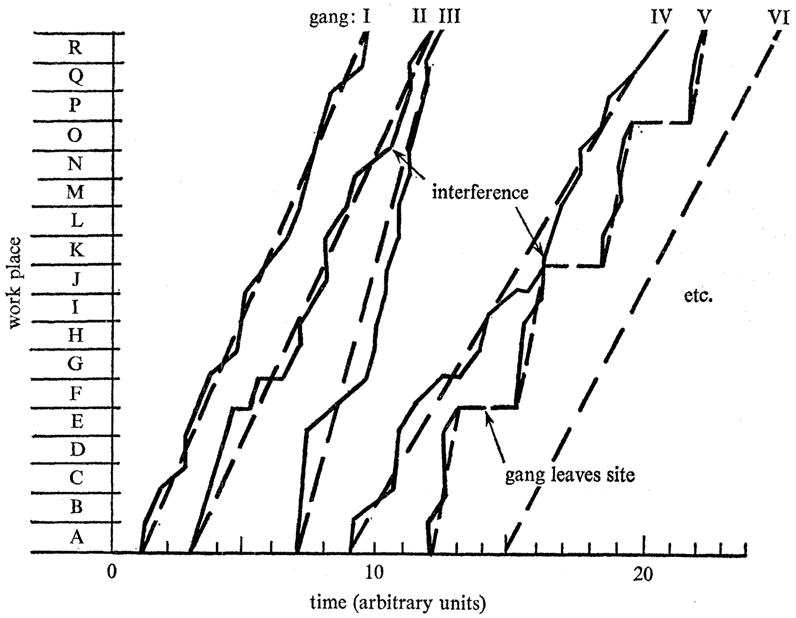

Figure 9. Flow diagram of site operations.

The general tempo of work through a site is influenced by the elapsed time for each stage when a stage is composed of several operations. Elapsed times are determined by the manning of gangs, by mechanization, and by the headway (the interval between the work of successive gangs). Greater headway creates many more workplaces than there are gangs, so that each gang is likely to find work at some workplace on completion of any task; smaller headway produces fewer vacant workplaces for each gang and a more rapid rate of building, and the likelihood of interference and non-productive time.

In practice the task of planning and controlling work on site is considerably more difficult than might be expected. Even under ideal conditions, the task of setting up and controlling an *ad hoc* organization with 30 (or perhaps 100) gangs and subcontractors is formidable. Elapsed times vary about an average, typically with a range of 1:2. Much happens to interfere with the smooth flow of work; delays occasioned by the weather, by materials not being available or by being rejected on inspection and technical hitches (breakdown of equipment and the like); uncertainty caused by inadequate detailing on the part of designers and delays while drawings are either rectified or produced for the first time. Sometimes main contractors find it difficult to achieve effective control, especially when many nominated suppliers and subcontractors are employed. Other disturbances are external to site management – decisions of building inspectors, for instance, or the cooperation of statutory authorities. Therefore the central problem of site management is not planning and programming but control, because on site one *force majeure* follows another. Therefore, although programming may accurately reflect the information then available, only exceptionally are the envisaged circumstances realized. Site supervisors must decide the way in which the labour force actually available can be deployed to workplaces in order to make the best use of the resources at hand, and to complete and open up work so that progress can be maintained in the forthcoming weeks.

One important attribute of an experienced supervisor is to size up a site to decide the appropriate tempo of work and headway and allocate gangs to the workplaces in a way that will be the most profitable. The Building Research Station has devised decision rules to assist managers to make better judgements which identify a reasonable (though not necessarily an ideal) solution (Nuttall 1965). Decision rules are not likely to supplant an experienced and able supervisor who may well make better decisions than the rules indicate. They have the advantage, however, that they are objective, calculable and teachable.

Better programming has been seen as a way of controlling work on site, to obtain reasonably rapid progress without paying the penalty of high non-productive time. A start was made on the basis of balanced gangs and of a regular rate of progress from one workplace to the next. These simple assumptions are invalidated immediately a project is encountered in which the work at each workplace differs either in character, or extent, or both. Then, even on the basis of balanced gangs proceeding at a uniform speed, the resultant programme is much more complicated if continuity of work is to be ensured; moreover, the underlying assumptions are not a good representation of practical experience, because the many factors already discussed combine to produce considerable variability in the actual elapsed time for the same work. The advent of critical path analysis gave impetus to programming and at at first appeared to offer a solution. Experience showed that network analysis is less applicable to building. Few difficulties arise for simple projects in which there are few parallel paths through the network and operations do not repeat at different workplaces. But these conditions rarely obtain, because the majority of building entails partially repetitive work, considerable overlap between operations, and uncertainty injected by many factors not within the direct control of the agent. In the event progress is seldom controlled through critical path networks – there are just too many amendments to make this feasible – unless the project, by being given a 'most favoured nation status', can draw on relatively infinite resources to ensure that every activity (critical or not) starts at its earliest start time.

Can low non-productive time and a rapid tempo of work be obtained by tactics other than by adjusting the level of resources or by altering headway? Common sense indicates, and the simple analysis confirms, the advantage of reducing the number of stages to substantially improve 'control' of the system, even if the average variability of the remaining stages is unchanged. Similarly, control is improved by reducing the number of activities contributing to one event when they are of approximately the same variability. Finally there is a substantial improvement in control if all resources can be committed at the earliest rather than the latest start date. Taken together these tactics can reduce management problems on site. They can be exploited more easily if the designers adopt 'component building', a term that does not necessarily imply factory production. It entails designing the building as a relatively small number of components whether *in situ* or prefabricated, so that each is a substantial part of the whole and can be completed by the work of one gang, preferably under the direct control of the main contractor. This reduces the number of stages (and gangs), ensuring their independence of other activities and places more work directly under the main contractor or in the hands of substantial subcontractors experienced in working with the main contractor. This is a characteristic of traditional building and a tactic well understood by early examples of industrialization. The Crystal Palace was one example. 'Easiform' and 'no-fines' construction are others. This principle was overtaken by the growing intrusion of services and by the wide choice of materials and techniques now available to designers. More recently component building has been implicit in many systems including the output of schools consortia, many 'rat-trad' home-building systems, and large panel construction.

Component building, a general strategy, is discussed in §7. The remainder of this section discusses the range of tactics open to designers leading progressively from modest attempts at standardization of details within a design office to component building dependent on the industry's acceptance of dimensional coordination, performance specifications, and fixing and jointing conventions, the latter including tolerance control.

Design tactics leading to component building

Depending on the project, design is made less complex by restricting choice, e.g. to preferred manufacturers, to standard details, to standard briefs, or in the extreme case to standard layouts. Constraint usually does not amount to prohibition of new details; designers may evolve or adopt new details where these are necessary, or more efficient, or more economic. This tactic includes a whole spectrum of activity ranging from standard details and office specifications, to catalogue building, to the type of system building so well developed by schools consortia. In essence all apply one principle, namely retaining in an explicit, systematic and usable way experience obtained on project for use on another. This can sharply reduce the apparent variability to all other members of the design team, to contractors, their operatives and subcontractors and to manufacturers.

Standardization of office details, if energetically and systematically pursued, can result in a set of well-conceived and aesthetically satisfactory details that are both easy to construct and fail-safe in performance (because with experience the unsatisfactory will be eliminated). The latter is important to clients, designers, and contractors alike and probably costs nothing. Standardization may involve a major effort to develop a system unique to an office. Alternatively, many if not all the advantages of standardization can be obtained by catalogue building, a tactic that does not introduce yet another range of specials on the market. In this, of course, offices require designers to avoid *de novo* designs by using products selected for their performance, appearance, and ability to be combined to produce a pleasing result. Some object to catalogue building on the grounds that the constraints imposed prevent clients' requirements being met satisfactorily and make good building unlikely. These suppositions are belied by the experience of many documented projects, for example the Temporary Laboratories at Cardiff by Alex Gordon & Partners. In this the architect adopted catalogue building under pressure of time; the programme, design and construction, ran smoothly, work was completed inside agreed cost limits, the job was profitable to the design team, and won an award. Of course this is not an isolated example.

Standard details and catalogue building contribute to the productivity of design offices that are relieved of the task of re-inventing the wheel and, with experience, designers may be expected to select products that perform satisfactorily. It is less likely, however, that catalogue building makes a direct contribution to manufacturers' or contractors' productivity, other than by removing unnecessary variety by not calling for specials. Manufacturers have to assume the balance of performance attributes, including price, that will be attractive to designers, and these may not include buildability, on-site productivity, and maintenance costs. The recent development of performance specifications is intended to redress the balance of initiative in the expectation that manufacturers will be better able to exploit their production techniques given requirements in the form of the required performance, usually including the costs of site assembly and maintenance. This tactic, currently practised only to a limited extent, is not going to be perfected overnight. Nevertheless, the recent experience of my Department is that tenders for acceptable components have been received at a range of acceptable prices – and designers must be presented with a range of choice so that they can satisfy the standards of each project. Incidentally manufacturers tendering for these components have found that the discipline imposed by performance specification has made them view their products in ways that will influence their development policy.

Performance specifications apply naturally to components, i.e. to significant parts of a building to which comprehensive statements of performance apply. In the United Kingdom the components have been relatively simple, e.g. windows, door sets, partitions, and flat roofing systems. In the United States there has been a tendency, led by Ezra Ehrenkrantz, to specify complex components embracing building and mechanical engineering elements such as the lighting/ceiling components of the School Construction Systems Development project (S.C.S.D.) in California.

Whatever the scale, the intention remains the same, to create conditions in which manufacturers can design components to meet the performance requirements of designers and to reduce the total cost of production, site erection and maintenance. Thus component building creates conditions likely to lead to high productivity.

Component building is, of course, a problem generating solution. Performance specifications are difficult to devise, for each statement must be matched by a statement of the tests to compare the performance of components with specified requirements. Consequently clients, designers and manufacturers must have available testing facilities on a scale not hitherto required. If tests are not to be everywhere duplicated, with the cost and delay this will entail, components will require an acceptable test certificate – hence the importance of the Agrément Board. Variety reduction, an essential concomitant of component building requires a universally accepted code of dimensional coordination, with a (very) restricted set of preferred dimensions. Designers and manufacturers will have to acquire a detailed understanding of site operations and maintenance costs. And so on. The next section considers the productivity aspects of component building; the other, albeit important, aspects are not germane to this paper.

6. Component building: a general strategy

Component building, that is use of a relatively limited number of distinct materials or elements, reduces the complexity of design and construction, and makes possible the use of performance specifications so that manufacturers can produce to meet requirements stated in performance terms. Component building by reducing the number of distinct operations can lead to more simple tasks on site, reduce queuing problems, and make possible a quicker tempo of work without the consequent penalty of higher non-productive time. There are also the incidental advantages of fewer times to order, store and deliver to workplaces. Component building is a term not restricted to prefabricated construction. Much of traditional construction is properly component building in that the same rules apply and the same advantages can be obtained from designs which employ only a few techniques, are repetitive and reduce the amount and complexity of site work.

Sometimes prefabrication opens the way to new techniques inherently cheaper than site processes. For example, production of concrete floor panels by extrusion casting or by long-line prestressing uses less reinforcement and less labour than normally reinforced concrete. In practice not many components are produced in ways that are radically different from site processes and this necessarily places a low limit on the possible savings from direct production costs. Factory prefabrication also incurs considerable indirect production costs incidental to a permanent establishment including the necessity for a sales department. Therefore it is not possible to state general rules for determining whether factory or *in situ* production is likely to be more economic; there are too many factors, including:

(i) *Relative cost of materials*. This is often a difficult hurdle because conventional materials are cheap in relation to their performance. Sometimes opportunities occur to cheapen the cost of secondary materials (e.g. prestressed concrete, cheapens reinforcement costs); in other cases moulded plastics may offer the possibility of changing the form of a component and therefore cheapening materials costs compared with conventional design. Often, however, factory production dictates standardization which can increase materials costs because a standard component must be capable of meeting the most severe of the range of conditions for which it may be used.

(ii) Relative cost of labour. In this country this means using female labour on non-shift work at least until there is equal pay for equal work. In other countries factory labour is paid less than site labour and this alone offers a considerable inducement of transfer of work from site to factory: in this country the reverse holds in some areas.

(iii) Production methods. Processes which can be used on site are nearly always cheaper when used on site. Other processes not adapted to site use, including most continuously operated processes, typically have a short cycle time and hence can be operated economically only at a large volume of production. Therefore the minimum scale of production (and hence volume of sales) are often the decisive factors (see §8).

(iv) Whether a production method combines several elements into one component. One example is the roof deck developed for the S.C.S.D. project, the components for which included the structure, the deck, weatherings, soffite and services including air-conditioning equipment and electrical services. (Hislop & Walker 1970). Subsequent to the original development contract other manufacturers joined forces to offer similar components but composed of standard or near standard parts. It seems that any loss of the advantage obtained from the integrated nature of the original solution was offset, and possibly more than offset, by the relatively higher utilization of separate organizations that served a wider market.

(v) The incidence of short-run series of specials, or for specials that can be produced only on dedicated production lines that will not be fully utilized.

Therefore the following makes no assumptions whether component building applies to prefabricated or *in situ* construction, the same considerations apply to both. Many current developments involve components, each embracing the work of several trades now built *in situ*, with the intention of simplifying site operations and reducing costs. Whether these intentions are realized is determined by the interplay of many factors. A component frequently cuts across the work of several trades removing from each some but not all of its work. Observation has shown that this often decreases productivity for the conventional work remaining, partly because the residue may consist of the more awkward parts and partly because the non-productive elements – setting up, clearing away – will not be reduced in proportion to the work omitted. Moreover, the work of each trade is composed of a group of main operations, which account for the bulk of the work done, and a large number of incidental jobs, many of which prepare for a following trade, tasks which are often fitted into the normal work sequence. Such incidental tasks are unlikely to be eliminated by substituting a component for part of a trade's work. That is, components must replace the whole of a conventional group of operations, and not demand special treatment not required elsewhere for the project.

A classic example of what can and often does happen was encountered in the *Alternative methods of house construction* experiment, published many years ago, but still valid and of vital importance to all concerned with innovation and development (N.B.S. 1959). In this 412 houses of four different types were built on five sites. Type I house was conventional with brick/brick external walls; type II had the inner leaf of the external wall and the majority of the internal walls built of plaster panels. For structural and other reasons the party-wall and the flues were built in brickwork. The intention was to reduce the work content for walling and to eliminate the bulk of plastering. In the event the manhours for external and internal walling, including plastering and trims, were roughly 15% greater for the type II house, the difference arising mainly from the excess time for erecting the panels and completing trims which was not compensated for by eliminating plastering. In part this could be attributed to the traditional work remaining being the more awkward part of the total job and in part to discontinuities introduced by the two methods of construction. For example, an outer cavity wall normally involves eight operations for damp-proof course to roof plate, whilst 16 separate operations were required for the type II house. Every change of operation was responsible for some non-productive time. In general, the greater the number of separate operations to complete any section of work, the greater was the proportion of non-productive time.

Therefore components should be designed to: (i) *reduce* the total number of individual tasks so that work on site is more easily organized, e.g. by detailing reinforcement and construction joints so that walls and floors may be cast in one operation; and (ii) ensure *continuity* of work for gangs placing components, e.g. by avoiding the interruption of work on placing external cladding panels while flashings or other jointing materials are fixed; hence (iii) *separate* the work of related gangs (a consequence of (ii)); and (iv) *make* mechanization possible, whether on or off site, e.g. by specifying flooring of uniform thickness, ensure that screeds are at one level thus making possible the use of power floats (if *in situ*) or battery casting (if precast).

These few rules are remarkably difficult to apply in practice. Even given knowledge and adequate time it is difficult to foresee the consequences of introducing a new component into a sequence of construction, e.g. inevitable tolerances on dimensions may produce joining problems, a component may require minor but essential service by another trade, a new component may produce a peaked demand for labour, designs may assume impractical standards of protection of self-decorated surfaces. In large panel construction, for example, the basic operational sequence, hoist-secure-joint, is apparently simple and independent of other activities. In practice this is seldom the case; e.g. on one scheme site observers identified more than 100 minor tasks taking 70 manhours in the stairwell complex alone, all essential to completion and all requiring the cooperation of different gangs and trades. With further development many could have been eliminated. One well-documented example of systematic development is the 5M system, launched by the then Ministry of Housing and Local Government in the early 1960s (Forbes & Tyndale 1968). Typically the early marks required the cooperation of several trades to erect the external panels; e.g. scaffolding had to be erected, dismantled, re-erected, so that flashings and cover pieces could be secured. This entailed buildings standing idle while awaiting attention from the next trade. When next developed, with the advice of information from site studies, the design was amended so that loose flashings and cover fillets were eliminated. Many minor tasks occur after components are in position, and the extent and cost of 'fitting' is seldom appreciated either by designers or by estimators. In the 5M system the original stairflight had 37 separate pieces. Activity sampling showed that although flights were fixed in 10 manhours, adjustment and fitting entailed another 20 manhours. Development produced a new stairflight equally easy to manufacture, with eight pieces which have been assembled and finished in 8 manhours (Cooper 1968).

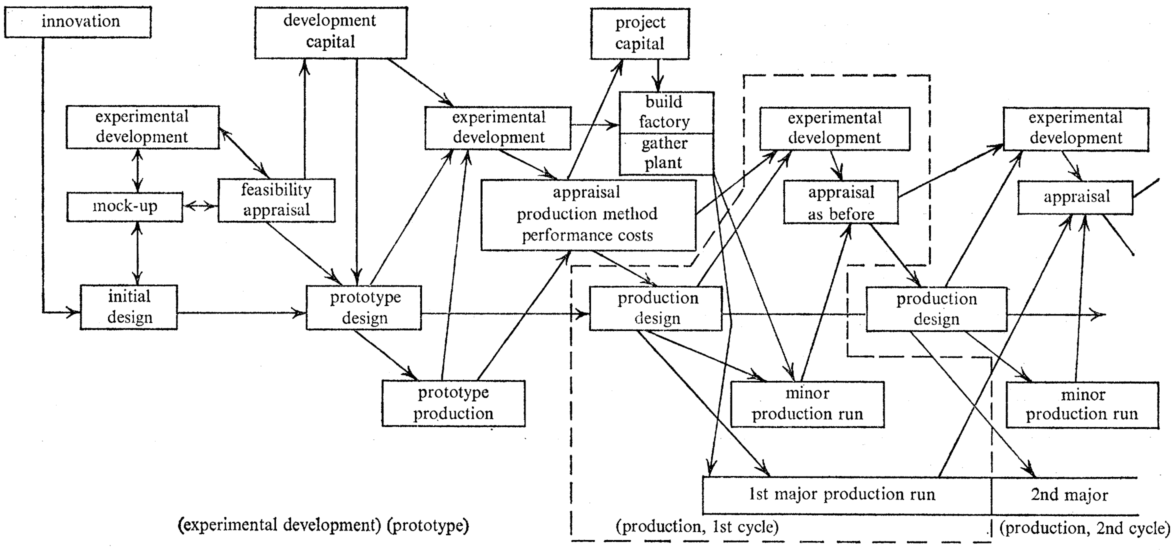

FIGURE 10. Production development.

Therefore production development is a necessary part of component building, requiring several stages before the main phase of the development commences (figure 10). First there is innovation which often stems from past experience. This is followed by a phase of experimental development in which design, mock-ups, production development, *ad hoc* experiments to settle technical features of the building and the production method, proceed iteratively until an acceptable solution is found. An essential feature of this phase is appraisal to determine the feasibility of the development from the standpoints of technical performance, production methods and cost. Only when this last is satisfied is it likely that the necessary capital will be made available. With this hurdle cleared the development now hardens into the prototype phase, involving design, production and experimental development which is likely to be expensive, even when the prototype building can be built as part of a project anyway required. Direct observation by well-established activity sampling methods (Forbes 1966) is essential if production costs are to be correctly allocated and the operational consequences of design and management known. This information is vital for the redevelopment of the system in the most promising directions. With this phase completed, it should be possible to estimate the economic viability of the system and, if favourable, to secure capital and proceed to the first production cycle.

At this stage the prototype will be redesigned to take advantage of the information already obtained, and the necessary production facilities will be provided. The main part of the first production run will be part and parcel of the ordinary commercial operations of the organization concerned, with sufficient cost feedback to establish effective control. Part of the programme, preferably a part which can be completed reasonably quickly, should be regarded as an extension of the development process. Associated with this phase will be further experimental development, suggested by ideas and problems stemming in part from the design for this phase of production and in part from the experience gained in production.

This cycle, production, appraisal, experimental development and redesign is a continuous and continuing process, important because it alone is likely to realize a substantial improvement in productivity. It will be noticed that development is not technique-dependent. Rather it requires the will and ability to invest money, technical and management skills and time, an investment which is not likely to be made unless the investors have confidence in the future of the market and in their ability to control the required resources. It is this latter point which is our last concern.

7. Markets for component building

The objectives of component building and performance specifications cannot be achieved unless supported by a market in which the industry has sufficient confidence to justify commitment of resources, financial and human. This market must be such that performance specifications do not proliferate, be sufficient to justify adequate testing faculties, and be of a kind that fosters production development. In practice only three groups have sufficient resources to create this market; the industry and its clients in concert, manufacturers or contractors acting in a quasi-manufacturing role, and clients. This is not to derogate from the professions which will influence and contribute to the market whatever the form it takes.

Inevitably much of the industry's cooperative activity to sustain its market amounts to reorganizing *de facto* procedures initiated by others. In this way the industry has responded to changing circumstance without grossly damaging established interests. Many institutions contribute to this work, and the industry and its clients are much in debt to the several hundred dedicated enthusiasts who regularly serve committees of professional institutions and other organizations, of the B.S.I., and of committees and working parties sponsored by central government. Without their considerable (and unpaid) work progress in the industry would have been more painful and less rapid. Only dimensional coordination and the National Building Specification will be mentioned because both are germane to the evolution of an industry-led market for component building.

Dimensional coordination has a respectable antiquity. For example, it was well understood by the manufacturers of cast iron structures in the mid-1800s. From the early 1950s the Modular Society, the Building Research Station and others contributed to a discussion (albeit dogmatic at times) which was brought into focus by the Component Coordination Group. This, by acting as a forum for building departments, produced a consensus of large users to provide working documents for Committee B94 of B.S.I. to publish the DC series of British Standards. Their effect is likely to be slow but certain and will make possible an orderly extension of component building. The advantages of dimensional coordination are lost if components cannot be jointed, therefore dimensional coordination has prompted the industry to pay more heed to the control of tolerances in design, in manufacture and on site.

The second example, the National Building Specification, should promote standardization of requirements and reduce the volume of unique information required for individual projects. To a man, the National Specification Sub-Committee of the Economic Development Committee thought the industry would gain from a comprehensive specification that would state proven, acceptable and desirable standards (perhaps complete with supporting details) (Carter 1969). When this expectation is realized – the first edition is being prepared by National

Building Specification Limited in collaboration with the Department of the Environment and the Greater London Council – much of the unnecessary variability of specifications can be eliminated as the industry adopts the N.B.S. for everyday usage.

What are the conditions that ensure progress is made? One prerequisite would seem to be sufficient practical experience to demonstrate a new concept as technically feasible and desirable in its own right. The second is a moment in time when a catalyst can initiate gradual acceptance of the concept, whatever that is. Often large and continuous clients are best placed to play this role by making available a programme of work for application of the development. The third pre-requisite is a neutral corner, independent of the main institutional forces of the industry but acceptable to them. So far this role has been played mainly by government, by the Economic Development Committee and by the British Standards Institution. It is surprising the industry has no mechanism for dealing with other than single or related problems. This is not to denigrate the good work of, for example, the Standing Joint Committee of the Standard Method of Measurement, or the Joint Contracts Tribunal, or the National Joint Consultative Committee. The Economic Development Committee and the National Consultative Council work at a different level of generality. In industries dominated by a few large organizations, each can evolve an integrated system of objectives and make it effective by dominating a market. In fragmented industries such as the building industry, and in the absence of an industry-broad mechanism, both manufacturers and major clients have increasingly assumed the role of dictating markets matched to their requirements.

Manufacturer dominated markets

The past two decades have seen many attempts by manufacturers or by contractors acting separately or in association to create markets more akin to those for manufactured articles. This objective, if achieved, would confer operational advantages. Given effective control of a market a producer can design an efficient and sophisticated production line matched to the technical requirements and to the predicted market. In one leap two important constraints – low utilization and uncertainty – would be overcome. So much for theory. In practice technical and commercial factors often intervene to negate these expected benefits.

The decisive technical factor is the scale of production necessary to significantly decrease production costs. Often batch production is not all that inefficient in comparison with other methods and has the advantage that the more simple production methods are more capable of producing variants or serving other markets. Secondly, production costs are only a proportion, and sometimes a low proportion, of total costs including materials, transport, marketing and other overhead costs. Thirdly, more sophisticated production methods always increase overheads and the proportion of indirect costs (Bishop 1966). Hence the advantage obtained from sophisticated production methods is often less than expected so that manufacturers are forced to integrate processes now carried out separately. As a consequence the minimum scale of operation becomes the minimum scale for the most productive stage in the integrated process, and this may be high indeed. Precast concrete flat or coffered panels may be cast alongside the building under construction or produced in a number of more sophisticated ways with shorter production cycles (see table 4). This sharp increase in the scale of operation creates an entirely new marketing problem, one more akin to customer durables than to building.

The early 1960s saw many firms launching industrialized building systems. The cumulative effect of the increased scale of production was to increase the capacity of the industry above the capacity of the market. Hence producers searched for business rather than dominated the market, a state of affairs which strengthened the hand of their clients who were well placed to insist that their special requirements were met. Therefore manufacturers and contractors selling industrialized building were forced to accept modifications which sometimes vastly complicated production. Thus, even given buoyant demand, the building market is not expansible like that for consumer durables and industrialized building has had, and is likely to have, a difficult task to secure the market necessary to maintain utilization at an economic level.

TABLE 4

method	cycle	scale of activity
site casting	weekly	1
temporary factory	daily	5
permanent factory		
steam curing	8 h	15
continuous kiln	4 h	30
continuous casting	$2\frac{1}{2}$ h	48
pressing	10 min	720

The nearest approach to a consumer market is the mobile trailer home of North America. With different constraints from planning regulations than permanent construction, this market has expanded, now accounting for 20 % of all new dwellings built for private occupation in the United States. In this country there is an expanding market for 'instant' hutting, ably exploited by several firms. In this country manufacturer or contractor domination is likely in limited markets such as industrial and commercial buildings built on open sites. These have relatively standard requirements; also clients for these buildings are as likely to be interested in price and delivery dates as in having their requirements exactly met. For other building types client preferences, site peculiarities and an erratic market are likely to combine to defeat 'total' industrialized solutions.

Manufacturers or contractors playing a quasi-manufacturing role are likely to achieve greater dominance as the volume of performance-specified component building increases. Both are well placed, either separately or in association, to design and develop components matched to a stable series of performance standards. In particular they are able to ensure that the crucial task of production development is well done. There are, however, three necessary conditions: an adequate volume of demand, confidence that this will be maintained or be increased, and the existence and acceptance of performance specifications backed by adequate testing facilities. These are the gift of clients, the group most likely to develop an effective market for component building.

Client-dominated market

Good projects start with good clients; muddle-minded clients get the projects they deserve. Hence every client should play an effective part (in the early design stages especially) by setting objectives, by stating priorities and by choosing from established ways of building. Clients with a continuous building programme can at least influence if not dominate their market. The tactic used depends on the relative importance of the work placed by a client to *all* those involved. Measures affecting only some of the resources are likely to have only a small effect on productivity, especially in the short term. Hence occasional bursts of standardization are likely to be absorbed by the industry without detectable advantage or stress. The tactics available may be divided into two groups; those which concentrate on creating a submarket and those that seek to create a wider but differently structured market for component building. They are not mutually exclusive.

Many clients create a submarket by channelling work to one or a few designers, contractors and manufacturers. In the private sector a direct and continuing relationship between client, designers and contractors raises no eyebrows (M.P.B.W. 1970*a*). In the public sector, public accountability and fair shares often dictate other methods of selection, e.g. serial tendering to improve control of building programmes and to enable the selected contractor to benefit from a continuing programme of work (M.P.B.W. 1966). That serial tendering benefits a client's organization is not open to doubt, what is more doubtful is the advantage obtained by contractors. If projects within a serial are technically similar and started so that each main operation continues from one project to another, contractors could be expected to attain higher productivity as they, their subcontractors and operatives overcome snags. In the event, projects within serials are often started at times to suit a client's convenience, or the availability of sites, and each is often separately managed and ganged. Hence the benefit obtained is likely to be confined to the client's design organization and to the contractor's head office; and the latter may be offset by the consequential perturbation when a serial contract is either won or lost.

Alternatively larger local authorities and others building frequently in a locality can create a submarket matched to their requirements by a well-defined technical policy, and a steady programme of work coupled with a sensible approach to contractual relationships. The Greater London Council's technical policy is widely recognized and available to all through its specification (G.L.C. 1971). The Department of the Environment uses a standard specification matched to an extensive schedule of rates (M.P.B.W. 1970*b*) to let measured term contracts for the maintenance of considerable but scattered Crown, Defence, and Post Office estates (M.P.B.W. 1969). These authorities and other continuous clients are well placed to reduce the unnecessary variety of building by adopting, for example, restricted ranges of choice from the DC series, the National Standard Specification when it is available, and a restricted number of standard alternatives for documentation, i.e. arrangement and content of drawings, specifications, and bills of quantities.

Clients often use standardization to improve their own efficiency, a tactic that runs through all consortium working. West Sussex County Council have combined standardization with computer applications to produce an integrated suite of procedures operating from sketch design stage onwards (West Sussex County Council 1968), similarly with the Building Industry Code developed by Nottinghamshire County Council.

When a client organization standardizes on a series of 'special' components in the expectation of reducing production costs, the volume of work for these 'special' standards is seldom sufficiently large to justify setting up special production lines, therefore the components are batch produced as are most other 'standard' standard lines. Where the annual volume is so considerable that a separate line appears justified, bunching of orders may lead to underutilized production capacity for much of the year, or to high stockholding costs, or to long delays on site. Long production runs are possible only for components produced on a national scale (Lockwood & Pedder-Smith 1969). All else is batch produced, and long runs are obtained only when variety is severely reduced. For example the consequence of reducing from 65 to 13 the number of different external wall panels for the 5M housing system was estimated to increase the numbers in a batch only from 21 to 48. Therefore, although 'special' standardization almost certainly leads to higher productivity within a client's design office, and may lead to lower prices, the industry would gain more if clients could standardize by selections from ranges of components already available, or by using performance specifications as a basis for selection of components.

Client led market for component building

Component building has the prospect of enabling clients to benefit from standardization without creating a submarket. There are two problems to be resolved; the production of an adequate range of acceptable performance specifications, and the contractural relationships best suited to component building.

Initially performance specifications were produced *de novo*, a practice that was expensive and time consuming to designers and did little to reduce variety from the standpoint of manufacturers and contractors. The task of writing performance specifications is difficult and long-drawn. Not only must the characteristics specified be sufficient and the level of performance capable of being achieved at a reasonable cost, but each requirement must be capable of being verified by tests that can be applied to prototypes and to samples drawn from production runs. Hence, quite apart from arguments based on variety reduction, clients have much to gain from a set of broadly based performance specifications meeting the majority of requirements. As far as the public sector is concerned work on this topic is being brought together by the Component Coordination Group which serves the Interdepartmental Sub-Committee for Component Coordination (D.O.E. 1970). By the analogue of dimensional coordination, it is possible that the output of this Group will form the basis for the newly formed Performance Standards Panel of B.S.I. In time, therefore, there should be a sufficient range of performance standards for practical purposes, given the continuing stimulus only large public clients can provide.

While contracts based on the Standard Form of Building Contracts may provide an adequate basis for component building, clients are experimenting with alternatives with two objectives, separately or in combination. The first is to impose a system of management on designers and contractors who then play out their roles but with the objectives and priorities of the client. The second is to bring designers and those responsible for construction into a closer relationship so that each can be influenced by the other, both to respond to the overall objectives of the client or parent organization (whether this be profit, rapid construction, avoidance of fire risks in occupied premises, and so on) and to design with construction, servicing and maintenance in mind. Of course these alternatives cover only a fraction of the work of the industry and none of the developments discussed are anything like established. Moreover some place different responsibilities on contractors and, clearly, only a limited number of contractors have the staff or experience to respond. Alternative forms of contract raise issues other than productivity and this paper is not the place to discuss, still less to evaluate them. Despite this, these variants, if pursued, would represent a significant shift in responsibility and power, the first leaving the design team with very much their present roles, the second introducing a different division between professional design and construction.

The first variant is when clients revert to what amounts to separate trades contracts that can be administered in several different ways: by a client's architect, by a management consultant, by a management group. In all, however, the client or his respresentatives are in operational control, decide priorities, and have direct access to site costs. In most favoured nation projects or for technically complex projects, or when all concerned look to the client for continuing employment, this tactic may work well. In ordinary circumstances, however, there is no immediately apparent reason why management in the direct employment of clients should be better placed to obtain effective control over resources than are main contractors. However, the data acquired from direct involvement in site management would help designers to better appreciate the interaction between design details and building operations. This latter consideration was the main incentive for the R.S.M. experiment by the Architect's Department of Nottinghamshire County Council which has as its prime objective feedback of cost and production information from site to the design office so that the future development of C.L.A.S.P. can be production orientated.

Our concern, however, is to pursue component building through performance specifications, hence the second variant of letting contracts on the basis of scheme designs and performance specifications may be more appropriate. In these a client's interests are protected by a professional team who undertake feasibility studies, prepare a brief and a scheme design to satisfy the clients' objectives including the budget for the project. On this basis, competitive tenders are sought, the successful contractor being required to select components and prepare a detailed design to conform to the scheme design and performance specification, the tender being confirmed before work on site commences. In this way a client's professional advisers are free to design or specify in detail any features of particular aesthetic or operational importance, while a direct link is forged between design and construction. The latter gives tenderers incentive to pursue standardization, to select components that are easily assembled and fail-safe in performance, and to train and retain a labour force skilled in the range of components the contractor preferentially uses.

Often firms offering this version of design and construct contracts concentrate on a single technique, e.g. long-span portal frames for industrial building or large panel construction for high and medium rise flats. In both, the proper detailing of the components is bound up with the production method, inexpert detailing leading to high production costs and poor performance. Also many shop drawings are required which are expensive, unless their cost can be borne by many uses: for example, one manufacturer of portal frames can normally assemble more than 80% of the final drawings for a project from 30000 standard details, each backed by cutting and welding schedules. Moreover, these firms are able to, and indeed must, embark on programmes of production development as experience is gained through successive projects using their components.

It is too early to assess which of these two tactics, direct management by clients or design and construct contracts, will pevail, or indeed if either will persist. Both are compatible with component building. The former may be limited to continuous clients of the industry able to work frequently with – and hence influence – a comparatively small number of component manufacturers who both make and erect components. The latter may be of more general application, especially if component manufacturers do not undertake erection. What seems certain, however, is that major clients are increasingly acting to fashion an industry to suit their objectives, and that this is likely to be component based. The direction taken will depend on the initiatives of clients, of manufacturers, of contractors and the vigour with which they pursue their ends. What is certain, however, is that the direction taken will satisfy the conditions necessary for higher productivity – better control over timing, relatively high utilization and systematic production development.

Appendix A. Measures to increase the productivity of site operations

Contractors have been responsible for a substantial proportion of the increased productivity of the industry to which mechanization, specialization, training and incentive payments have each made a contribution. Each is, of course, a major subject in its own right.

Mechanization

The productivity and cost of mechanical plant is as much affected by utilization and by control of timing as are those of other resources. Some plant, for example power tools used in direct support of manual tasks, are so much a part of the tasks they serve and adaptable that their effective cost is not much influenced by utilization. The extent to which power tools are used is probably related more to the average level of wages than to other factors. Other plant, serving many operations, e.g. transport or hoists, must remain on site substantially for duration. The cost of this plant is clearly inversely proportional to the general tempo of work, which in turn is related to the cumulative headway and the number of separate operations, that is to the extent and 'bittiness' of the project.

General purpose plant affects productivity directly to the extent that gangs have to queue for service. Too little general purpose plant can depress the tempo of work, hence productivity, for a whole site. Initially tower cranes were expected to serve several operations. Experience showed that utilization of more than roughly 60 % could be achieved only at the cost of delaying the operations served. The current tendency, I believe, is for plant to serve only one or two operations in order to maintain the tempo of work. Queue theory has been applied to some clear-cut civil engineering problems, such as face-shovels loading spoil to dumpers. There have been few published studies of this problem in building, rather surprisingly because this is a resource entirely within the gift of main contractors.

For plant dominating a single operation, costs are inversely proportional to the total work executed annually. Interference and delay affects the productivity of plant as that of any other resource. Utilization is affected both by non-productive time while plant is on site, and by the time spent in the plant yard, either because there is no work or for maintenance. Early studies by Stone (1956) showed that many items of plant have low utilization – less than 400 hours a year typically. Since then many contractors have set up plant hire subsidiaries that service all comers. In this way a high proportion of all major plant can be considered as a resource serving the industry, so that the level of utilization depends on the average level of employment of the industry, rather than on the work obtained by any contractor. This will have improved overall utilization, although utilization on site is still likely to be low because few projects outside civil engineering offer continuous or near continuous employment for plant.

Specialization

Complexity and uncertainty argue for fewer committed resources in order to reduce indirect costs to a minimum, an argument that can be met by specialization and by subcontracting, thus solving some organizational problems and generating others. Specialization leads to improved productivity. This occurs as, through experience, supervisors overcome organization problems and operatives become accustomed to familiar tasks and to working together in gangs. The reduction in manhours resulting from repetition is often masked by the influence of other factors – by bad weather or by shortages of materials for example. In conventional construction manhours for any operation usually fluctuate about an average after an effective start has been made. In one study the difference between the average labour requirements for work early in the sequence of construction and the average when a steady tempo of work had been achieved was found to be about 8% for conventional construction. The difference rose to about 12% for houses of unconventional construction and to about 33% for the new operations involved in the construction of these houses (Nuttall 1965). Often, as Burgess's account of partitioning indicates, repeated experience arising from specialization stands in the place of explicit training, and this leads to improvement (Burgess & Roberts 1964).

Specialization is closely bound up with subcontracting which ensures a greater degree of specialization than that justified by the continuity of employment possible in the industry. However, subcontracting works against the management of sites by increasing the number of gangs (often with greatly differing tempos of work) to be organized, and hence the need for headway. Subcontractors are often reluctant to visit sites except when a clear run of work is available. For example, Forbes has reported that main contractors in New York would not expect a subcontractor to visit a site unless a substantial run of work is available: three floors clear of other gangs for plasterers, and one for door hangers. Also subcontractors are more likely to hold back resources to start at latest start date, thus increasing variability, than are a contractor's own employees.

Hence the advantages stemming from specialization obtained by subcontracting are partly offset by their consequence; relatively high non-productive time or a relatively slow rate of construction. While the cost of the former falls on contractors, the substantial proportion of the cost of the latter falls on clients who meet the cost of funding by interim payments.

Training

Few firms encountered during the Building Research Station's studies of operative skills (Jeanes 1966) gave systematic training in production methods to their operatives, although some firms arranged for short courses on, for example, the use of materials, or plant operation, or safety. This was surprising because an operative's ability to work quickly determines his income and, to some extent, his employer's profits. Studies of the work of bricklayers has indicated that the output of an average operative could be increased by training in production methods (Forbes & Mayer 1968). Until recently craft courses were orientated on the proper use of materials and building construction. Skill in handling tools was considered to be a subject best learnt by being part of a production team. However, an element of production training is being introduced into trade and other courses, an important development because training of this kind may be one of the most direct ways of increasing the productivity of building and of maintenance work in particular. Those who doubt the need for training in production efficiency should re-read Burgess & Roberts's (1964) study of partitioning which contrasted the care showns by some manufacturers in detailing and marketing demountable partitioning systems with the almost total absence of training for the operatives charged with installation.

Is production training likely to be effective? To the extent which individuals or gangs work independently, probably yes, because the 'within gang' domain can be separated from the system of which they are part. This condition obtains when traditional building is carried out more slowly than the amount of work to be done would indicate, so that gangs can work relatively independently of others.

Incentive payments

Payment of incentives may be viewed as a mere expedient to obtain labour and to retain it in the face of competition from other sources. When, however, payments are related to performance, the average labour cost has been shown to be smaller than on contracts where standard wage rates are paid or where ex-gratia payments are unrelated to output. In one early survey the average labour expenditure on contracts with target bonus schemes was shown to be consistently smaller than that on contracts with standard wage rates only; the difference ranged from 10 to 29% for the various trades, the average difference being about 15%. However, these studies were made at a time when the payments of incentives was not widespread in the industry. Now, and for some time past, the majority of firms make incentive payments of one kind or another; also in many trades the work of a gang is the basis of payment rather than the work of individuals. In these circumstances the consequences of incentive payments on production are difficult to interpret. One detailed investigation of the operation of incentive schemes showed that individual firms tend to relate targets to their own average level of productivity, that is, high productivity was associated with high targets rather than with the bonus earnings of operatives (Entwistle & Reiners 1958). That is, incentive payments cannot be dissociated from the firm, its structure, its work, and the environment in which it operates.

In defined circumstances incentive payments of the conventional kind lead to a higher productivity. These are (N.B.P.I. 1968):

(*a*) Work must be measurable, and directly attributable to an individual or group. In practice, this generally means the work should be almost entirely manual, repetitive, and consist of fairly short-cycle operations.

(*b*) The pace of work should be controlled to a significant degree by the worker rather than by the machine or process he is tending.

(*c*) Management should be capable of maintaining a steady flow of work, and of absorbing at least short-term fluctuations in demand or output.

(*d*) The tasks involved should remain fairly constant through time – that is, they should not be subject to frequent changes in methods, materials or equipment.

Although too much can be made of these operational requirements and payment-by-results schemes can be applied to work that is not entirely manual and to work that is machine paced, there must be reasonable stability to ensure that the scheme negotiated can be seen to be operating in practice. 'Waiting time' payments and bargaining may dominate the scheme if the flow of work is variable. Similarly *in lieu* payments will be the order of the day if the work done differs from that described in the payments-by-results scheme in question.

Clearly the two necessary conditions, a steady flow of work and sensibly constant tasks, seldom obtain in building. Most projects have a distinct sequence of tasks, and the natural sequence is frequently altered to meet the dictates of weather, availability of labour and materials, and so on. Moreover, in both traditional and non-traditional construction there is a high premium on cooperation for in most building projects there are a large number of necessary but minor tasks which are substantially unrecorded: Forbes has found that bricklayers spend about 70% of their time on 'measurable' work and the remainder on many tasks essential to the progress of other work (Forbes & Stevens 1965). Therefore incentive payments are not a universal panacea but a tool of management to be used where warranted by the circumstances, i.e. when the task to which the incentive is to be applied is subsequently independent from others and under proper management control.

Appendix B. Measures to improve the management of design

Clients decide when and which projects are brought forward, and which are subsequently delayed; clients are important members of design teams who may or may not choose to cooperate as team members; clients decide priorities and change their minds. As long as patronage determines appointment, design teams are in a relatively weak position towards their clients and are in less control of their operations than are contractors who, by a tendering policy, may divert elsewhere work they do not seek or wish to undertake for technical or financial reasons. Moreover, the present method of appointment does not force clients to observe the discipline of deciding what they, the clients, require of their design team (a necessary part of tendering) and may appoint without a clear idea of the service they expect. This is not to dismiss the arguments for fees for professional services, but only to point out their consequences.

Design is bespoke in that few offices, public or private, systematically develop a limited range of design solutions. In a craft-based industry, using a limited range of conventional materials, this may not have produced many problems. Now backed by large technical vocabulary, each project presents a different combination of technical and organizational problems, so that situations are seldom repeated and designers find it difficult to learn from experience. Also the very variety of technical solutions means that many are used without prior experience and novelty produces its own crop of problems, during design, construction and subsequently.

Therefore design operations have all the characteristics of high variability; many participants, relationships complicated by status, non-repeating tasks, and a wide vocabulary of technical solutions. Many of the problems of the management of design are analogous to those encountered on site with gangs (single professional teams) tackling tasks (stages of design) at different work places (different projects). Management is more difficult because the inter-relationship between the work of the different professions is more subtle, shifting with each project, and the work content more difficult to define. Characteristically more time is allowed for design than is strictly necessary for the operations to be performed. A slow rate of work in any system improves control and the tactic enables organizations to accept more work than would be otherwise justified, thus ensuring reserve work if patrons do not provide new jobs and enabling organizations to quickly tackle jobs having a most favoured nation status.

An early attempt to improve the management of design was the R.I.B.A. Plan of Work (1969). Without doubt this performed a valuable service by defining the contribution from each participant for a typical building project. This, by itself, cannot reduce the inherent variability of the system, improve control, or lead to higher utilization of the resources. It can, however, provide a frame of reference when simplifying the design process, e.g. by design collaboration.

Design collaboration

One certain way of reducing complexity is to reduce the number of participants. In design this involves establishing joint design teams, with architects, structural engineers, services engineers and quantity surveyors reporting to a group manager, often but not necessarily an architect. Joint design teams magnify the problem of utilizing the different skills (solved by employing generalists) and the converse problem of having staff with sufficient competence to cope with difficult problems (solved by employing specialists). Both are aggravated when, at different stages, design requires the services of first one specialist then another. This latter consideration dictates that a joint design team tackles more than one project at a time, a practice often leading to separate specialist cells within the group thus substantially defeating the intention of joint team working.

An alternative is to confine joint team working to the feasibility and sketch plan stages of design, the formative stages that require continuous and effective collaboration from the various participants. This tactic has been taken furthest by Clive Wooster who developed a 'design collaboration exercise' as part of mid-career training given to architects, structural and services engineers, and quantity surveyors by the former Ministry of Public Building and Works. In these a composite team tackled the feasibility and sketch plan stages of a £100000 project under training conditions. Experience demonstrated that a properly balanced team of cooperative and experienced professionals (including a client's representative with plenipotentiary powers) can complete in two days (albeit long ones) stages B, C and D of the R.I.B.A. Plan for a 'typical' project. More recently, after an introduction by the then M.P.B.W.'s Professional Practice Group, the Department of Health and Social Security adopted this procedure to achieve the design of three health centres each costing about £85000 throughout the country. For each centre an administrator, a local Medical Officer, two architects, a structural engineer, a heating engineer, and two quantity surveyors backed by a Departmental approval group comprised the team. They worked together – in one room – for 2 days during which time they evolved an agreed sketch plan complete with preliminary calculations, a cost plan and the final schemes were approved on the spot by H.Q. officers of the D.H.S.S. The usual time for this work is 11 months; a difference the industry and its clients cannot ignore and one that stems from substituting one coherent team for six independent participants. In the short elapsed time utilization of the individual skills is not important, experience shows that individuals who are not busy assist others who are. Incidentally, the fee-earning capacity is roughly £120 per man-day!

A related tactic is to divide professional work into definite stages, usually three, each being tackled by different teams specializing in one stage. H. R. H. Burgess and Partners are advocates of this method of working, arguing that it is an exceptional individual who is equally interested in or competent at the whole of building from inception to completion. Some have a flair for conceptual design, others for detailed design and documentation, and others for the no less exacting rough and tumble of site supervision. This contention is an anathema to many professional people, but the experience of Burgess and Partners is that staff find satisfaction in tackling what they do best. In any case few major projects are tackled by the same team from start to finish: people move jobs too quickly for the life span of most projects.

Personnel issues and philosophy aside, the tactics of dividing professional work into three compartments (feasibility and sketch plan, detailed design and documentation, and post-contract control supervision) has operational advantages. The team for each stage can be balanced differently to match the work content of that stage; each stage can be given a budget and a programme; those in charge of a subsequent stage will not accept a project unless the previous stage is properly completed. That is the tactic improves control and is likely to ensure higher utilization of the available resources; both desirable ways of achieving high productivity.

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