OPTIMUM DESIGN AND PRODUCTION OF TWO STOREY TIMBER FRAMED HOUSING

By

R. Holmes. A.I.O.B., A.M.B.I.M.

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SUMMARY

The demand for housing in the last decade has resulted in the increase of Industrialised methods of construction. Industrialised methods have reduced manhours per dwelling from the region 1200 to 2000, to the region of 600 to 900. However, costs have tended to be higher for industrialised methods, and even though standards are better the change from traditional to industrialised has been slower than expected.

The timber framed house offers the best solution to prouctivity, since the manhour content is half that of any traditionally built house. The manhour content for timber frame housing is in the range of 500 to 800 hours for the average 3 person 5 bedroomed house. The cost per square foot or square metre is lower than any other form of housing now that Parker-Morris standards are mandatory. This means that the present growth of demand is likely to increase.

The manufacturers of timber framed housing for Local Authorities are trying to compete for orders by adopting various degrees of mass production. Hitherto there has been no data available to substantiate the production and erection techniques undertaken and this has resulted in uneconomic methods. Detailed data below shows that mass production of timber frames is unwarranted. Flow line production, which is thought to be the ultimate in manufacturing, is more costly than manual batch production. Temporary site factories are more economical than permanent factories, reducing both the cost of production and the cost of transportation.

Manual erection is not out-dated, it compares favourably with crane erection, for the present methods of design. Profits are reduced by bad planning, expensive scaffolding and inadequate allocation and control of preliminary budgets.

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INTRODUCTION

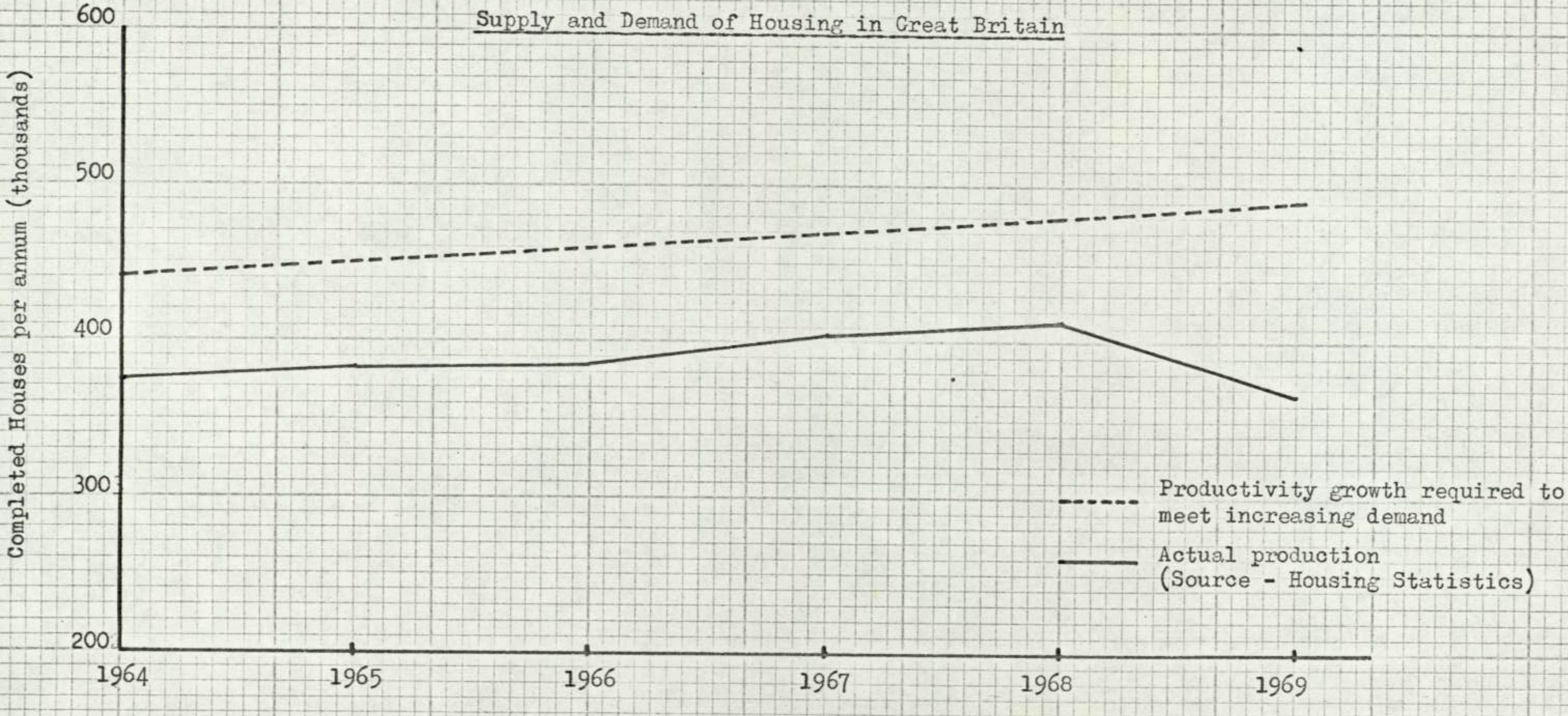
Throughout the last two decades there has been an increasing concern over productivity in housing. Many and varied are the committees which have been commissioned to look into housing, in respect of economy and speed of erection, and in spite of the many recommendations these committees have made, there has been little or no attempt to curb the rapid and unwieldy development of housing systems. Some form of housing system other than traditional construction has been necessary for many years, so that the demand in housing can be satisfied. The demand, however, is still much greater than supply and is increasing at an alarming rate, being aggravated by our economic situation, for where economic stringency is being adopted the field of building inevitably suffers.

During the period 1919-1939, a total of 4½ million houses were built in Great Britain.[1] For a similar period of time 1945-1965 a total of less than 6 million houses were built. A cursory glance at the situation shows that productivity increased some 33 percent, but the overall increase for one period over another is not significant, unless the effective demand for the same period is known. Over the period stated, 6 million houses represents only 300,000 houses per year since the war, and compared with the year 1938 when some 380,000 houses were built, it says very little for our methods of increased productivity. In fact, not until the second half of this present decade has the total annual production exceeded that of 1938. Compare this with the increasing demand for the latter part of that period which was reviewed in 1959 as being 410,000 dwellings per annum [2], which over the period 1959-1963 fell short by 713,000 dwellings[3], and one will realise that the present methods of production fall far short of the demand.

The future trends in productivity have been outlined by the National Building Agency, through its Chairman T.V. Prosser, as being 450,000 dwellings[4] per annum for 1965, growing over a ten year period by an additional 10,000 per year, the peak figure of 550,000 "to continue for whatever time is necessary to achieve full satisfaction of the housing need". The Chairman then went on to say that some 100,000 dwellings per annum would need to be provided by fully industrialized means or "new methods of building".

The housing statistics for the period 1964 to 1969 show that the proposed level of progress, (Fig 1.1) for one reason or another, has not been achieved. One might ask why, and one of the real answers would be that too much construction in house building is still done by traditional and outdated methods. The figure of 100,000 dwellings per annum by industrialised methods as yet, has not been realised. In 1964 the figure was 17,171 dwellings,[5] in 1967 the figure had risen to 49,030 dwellings, and if trends can be predicted from the quarterly statistics the figure will not rise above 100,000 dwellings per annum until 1973. (Fig 1.2) This means that more work is necessary on the promotion of 'new methods' so that the man hour total per dwelling can be greatly reduced from the present national average of 1200 man hours per dwelling. [6] To this end, the National Building Agency was appointed in 1964, and has already made significant strides towards appraising the many 'systems' so that both public and private sectors of house building can select a 'system' which will give them the best value for money, and the satisfaction of their needs.

The appraisal of housing systems is very desirable, but the terms of reference under which the National Building Agency operates,



Period 1964 - 1969

Figure 1:1

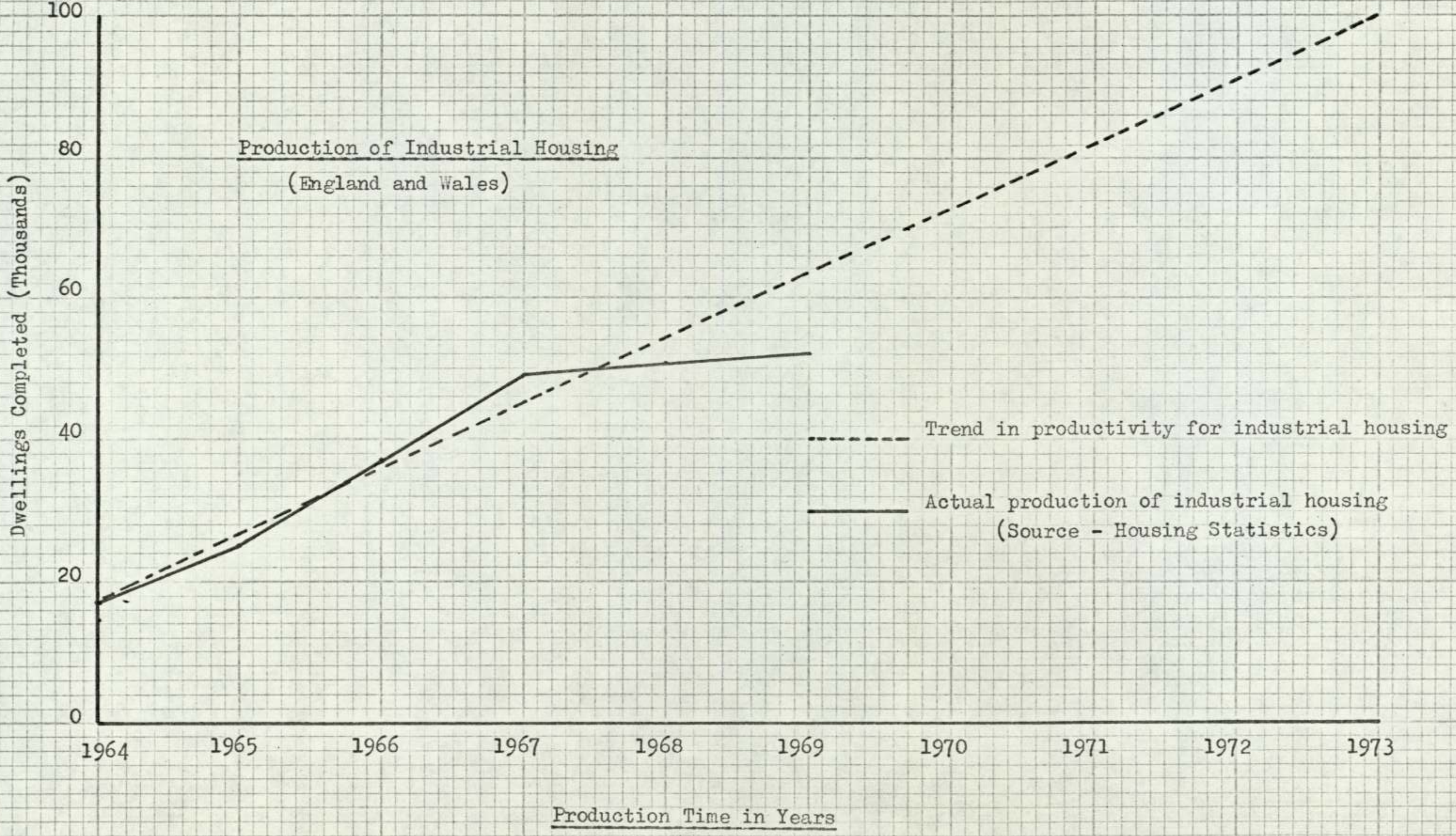

Production of Industrial Housing
(England and Wales)
Dwellings Completed (Thousands)
100
80
60
40
20
0
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
Trend in productivity for industrial housing
Actual production of industrial housing
(Source - Housing Statistics)
Production Time in Years

Figure 1:2

do not begin to answer the problem of uneconomic production of industrialised housing. Under the appraisal scheme a manufacturer gains a certificate, if he satisfies the requirements, which put him in a favourable position to tender for housing contracts. What he does not know is whether by his present methods of production he is being uneconomical. The manufacturer has been left to his own devices, to develop at will, what he thinks will be economical. The Construction Industry, as a whole, is very reluctant to pool new methods and techniques, and in spite of some interchange of staff, drastic changes in methods are rarely seen. There is an air of satisfaction in the Industrial housing sector which is partially founded on the premise that the Construction Industry has unique problems which prevent mass production as seen in other sectors of industry. The root of this problem however, goes back many years to the time when other industrial problems were being solved by mass production. Housing was never considered to be a problem, say, like that of transport, where new needs created new demands; or in the case of the motor car, where standardisation was necessary to lower the cost. The pride of satisfying individual requirements, together with the fear of unknown public reaction has hindered the vision of many architects.

In the last decade, the demand for increased productivity in housing, has created a situation where system built housing has appeared like "toadstools", all resembling a familiar shape, but varying in name, size and aesthetics. Who has ever heard of 'rationalised' toadstools or 'industrialised' toadstools? Yet such names have sprung up overnight and have been linked with housing. On reflection however, one can easily discern that the new names are equally misleading whether applied to 'toadstools' or many of the system built houses.

1.1 Rationalised and Industrialised Housing

We would do well to define the meanings of these words, so that designers could apply them when conceiving a new development. Albert Farwell Bemis states that; "Rationalisation is the process by which the flint knife became the bronze axe, the plowshare was shod with iron, picture writing became the printed page ...."(7). For a broader meaning the same author says, "Rationalisation is the ever continuing, evolutionary process by which an activity, a custom, a technique, an industry is brought up to date, into balance, into harmony - thus it becomes rational with respect to other things ....."(8).

The foregoing definition is substantiated by the World Economic Conference, which at Geneva, in May 1927 interpreted rationalisation as "the methods of techniques and of organisation designed to secure the minimum waste of either effort or material. It includes the scientific organisation of labour, standardisation both of material and of products, simplification of processes and improvements in the system of transport and marketing"(9).

In considering the last definition of rationalisation one is aware of the inadequacies of the method of construction named Rationalised Traditional (RAT-TRAD). The traditional work is certainly evident, but the scientific organisation of labour, standardisation of materials and simplification of processes leaves much to be desired. This form of construction (RAT-TRAD) had become increasingly popular in the last five years and although 'good' regarding the man hours saved against traditional housing, may become the enemy of the 'best'. It is due to half hearted attempts to rationalise, that the industry bears the label of 'learners' when comparing industrial methods with other industries. Commenting on this state of affairs H. Jerome says; "The Construction Industry is one of the last strongholds of the traditional handicrafts.

The transition from hand to machine methods was later getting under way than in manufacturing, and has reached a less advanced state".[10] Thus we are slow to start, and far too content with our progress to do justice to such terminology.

Industrialised housing is a term which embraces all housing 'systems'; indeed anything which is built other than by purely traditional methods and manages to be sufficiently different to achieve a name as a system, falls into this category. This is clearly shown by the method of housing analysis in the Ministry of Housing and Local Government Statistics.[11] Industrialised systems, comprise methods and organisation which facilitate the rapid assembly of standardised components. Such standardised components should be mass produced in order to achieve the economies required in housing. Therefore, to achieve the full meaning of the term 'Industrialised' housing, the components should be mass produced in a factory and simply erected on site. At present the only form of mass production for housing is found in multi-storey units such as Local Authority projects. In these cases the localised mass demand brings about a certain degree of mass production. This point of fact directs us away from the all embracing terminology of 'Rationalised' and 'Industrialised' and leads us to consider the narrower fields of mass production and standardisation in relation to housing.

1.2 Mass Production and Standardisation

Mass production of housing does not mean the mass production of materials. This is a defence all too commonly used by people who seek to justify the progress within the industry. Nor does the term refer to houses completed entirely in the factory, for in this country the house is not suitable in bulk or weight to total manufacture in the factory, nor to transportation for any distance. The nearest achievement of mass producing complete dwellings is that of the Canadian market, where dwellings are completed in the factory and moved to site in the form of suitable box sections.(12) This method of production has been attempted in this country (13) but has not proved popular. The room unit has become increasingly popular since the need has arisen to up-date the many pre-war houses that lack toilet and bathroom facilities, but mass production is hardly the term for the production of such units. Nearer the mark in mass production is that of 'heart units' for the services to industrialised housing.

It is inevitable that mass production has failed for private demand, since traditional houses are produced individually for individual means. The industrialised house must be made by mass production for mass demand. As stated above the present type of house is not adaptable as a unit for complete assembly in the factory. If transportation for the completed unit were practical, nothing would be gained by producing a house in the factory in the present unco-ordinated way. Therefore, the new type of dwelling required to satisfy the ever growing housing problem is not one where the process of manufacture is changed. It does not suggest merely transferring field work to the factory. The house must be given new forms and features which will embrace versatility of design, economical mass production and rapid field erection.

If one assumes that the present housing designers are unable, for various reasons, to produce house designs which will satisfy the latter requirements, then one must measure the progress towards such ends by defining 'mass production'. For if a suitable definition can be established, then the 'yard stick' for progress in mass production of housing can be established. A good definition is that of Henry Ford: "The term mass production is used to describe the modern methods by which great quantities of a single standardised commodity are manufactured .... Nor is it merely machine production. Mass production is the focussing, upon a manufacturing project, of the principles of power, accuracy, economy, system, continuity and speed. The interpretation of those principles, through studies of operation and machine development and their co-ordination, is the conspicuous task of management. And the normal result is a production organisation that delivers in quantities, a useful commodity of standard material, workmanship and design at a minimum cost ...." (14)

The above definition is enough to make all designers production conscious and bridge the gap between the design office and the production floor. It means that some smaller unit, both of design and structure, must be found to provide the optimum production environment. For while the house continues to be a choice of the individual, the principle of mass production must be applied not to the completed house, but to standardised units for it; to elements of structure that may be assembled to form any house type. Standardisation of this nature, will lead to the optimum production runs required for economy, as well as permitting variety in plan and appearance. The greatest field of potential is that of Local Authority housing, where variety has to be kept to a minimum for economic reasons. In this field, greater production and erection savings can be expected, but only when standardisation is adopted as a complete policy.

However, it must be mentioned that there are problems even with the potential market to be gained from Local Authorities. For while it has been stated that variety has to be kept to a minimum for economic reasons, it will be noticed that even a minimum demand for variety can play havoc with an order for a thousand dwellings.

If the variety of house type is as low as five per thousand dwellings then the maximum production run will be two hundred for any type (assuming an equal number for each type). Therefore the value of large contracts in respect of production runs, depends on the variety of house types, and because of this factor large contracts show little or no saving over the medium or small contract. The one exception is that of multi-storey dwellings where variety may be nil. The economies in this case are made possible by repetitive manufacture and erection of parts in great quantity. Although such economies are substantial compared with 'one off' housing, the total savings offer no real solution for low cost housing. The mass demand which would offer such a solution has not yet been created, but if such a demand was ever envisaged it must come from the Local Authorities, where the occupants have no sovereignty of choice in house design.

The above factors, which are many and varied, have long been used as reasons for the lack of progress in industrialised housing. Therefore a much closer examination is necessary in the field of industrialised housing, not of the all embracing problems, but of the problems which are common to a basic production technology; i.e. construction in concrete, steel or timber. This leaves out completely traditional technology, such as brickwork, and concentrates on the development of materials suitable for mass production and standardisation.

This research paper concentrates on the problems found in Timber Framed Housing, which is making a valuable contribution to the housing problem. With a close examination of the methods of production and erection, it is the aim of this research to show where designers need to concentrate their effort. Many of the problems are similar to those in concrete and steel, but others are peculiar to the basic material, namely timber.

1.3 Timber Framed Housing and Industrialisation

Compared with concrete and steel the timber framed house requires a much less advanced factory in respect of advanced technology, mechanisation or automation. Improved efficiency, achieved through the organisation of materials, men and jobs, often requires no more than cutting and assembly areas. The lack of general success for the 'pre-cut' house in the U.S.A. [15] is but proof of the fact that more of the work should be transferred to the factory. The development of wood-frame prefabrication shops in Canada, together with help from the Canadian Government in sponsoring timber housing, has reduced the learning period in this country.

The timber house in this country should rightly be named 'Prefabricated' for prefabrication refers to: "any process that takes basic pieces and materials of building into shops to cut and assembly them into much larger components, of sizes limited only by handling methods." [16] The name, of course, is unpopular because of the association with temporary wartime housing, and so the all embracing name 'Industrialised' appears again. So for 'industrialised' timber housing one would be more correct to say 'prefabricated', and for 'mass produced' timber housing to say 'standardised'. Standardisation of house parts is primarily a matter of dimensional control, but no such unit of measurement has been used which makes present units interchangeable. Units are at present produced in 'standard' sizes, but the sizes have no relation one to another.

The traditional framed house consisted of joists and studs, which performed the function of loadbearing and alignment of infill elements. The more recent types of panel construction eliminate the use of joists and studs as separate members, and incorporates them as composite floor and wall units. This is the first important step towards standardisation. The second step could be the uniformity of stud sizes in panel construction. These studs, which vary from company to company under the name of 2"x4" (50mm x 100mm), have to satisfy the mechanics of structure, and therefore lend themselves to a simple modular dimension. Thus all walls could be 4" (100mm), floor and roof 8" (200mm).

The process of manufacture should take place in the factory (as far as possible), and should be subject to the principles of mass production stated earlier, namely; method, economy, speed and rhythm, This does not always happen, for in the present economic situation many units are being produced by carpenters who would be otherwise employed, but their companies have tendered for the work to keep their labour force together.

Erection should be assembly, pure and simple, and it should be standardised assembly. Too much cutting and fitting is still being done on site, all this should be eliminated by scientific design. At present, the standards for raw materials dictate the standards for the finished parts. This process must be reversed if optimum standardisation is to be achieved. The finished part must dictate the dimensional standard of the raw material.

At present, many of the finishes to units or panels are applied on site. These finishes must be applied in the factory. Where this is impossible new finishes should be sought and used. Units should be of sizes that can be readily handled, and the means of connection should be semi-automatic.

These factors, which perhaps are the ultimate for timber framed houses, are by no means being adopted by manufacturers. Indeed some manufacturers are contesting the validity of such ideals by stating that they have tried them and found them to be more costly than present methods. These claims have long required examination so that industry can save time and money on development. This research seeks to provide the answers to many of the points stated.

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PART 2. HISTORICAL BACKGROUND

2.1 TIMBER FRAMED STRUCTURES - PAST AND PRESENT

"Timber was the first material to which prefabrication was applied on any appreciable scale", writes R.B. White in his book 'Prefabrication'.(17) The emphasis should of course be put on the words 'on any appreciable scale', so that a true picture is given of the earlier methods of prefabrication.

In the 14th century many cottages and barns were erected on the 'cruck' method of construction. The 'crucks' were simply hewn members, rather like 'portal frame' members, which sat on a base plate and were connected at the apex by a ridge plate. Purlins and collars were then placed in pre-determined positions to support the roof. In this type of construction which was the ancestor to the modern portal frame, the parts were usually fitted, numbered and erected in the forest prior to carting to site for their final position. Many instances are quoted in "The Development of English Building Construction".(18)

The first prefabricated house was probably that quoted by Charles E. Peterson in his article 'Early American Prefabrication'.(19) It was carried from England across the Atlantic for a gold mining project in Baffin Land. The plan was to shelter the men over winter in a 'knocked down' wooden house. The operation, however, was not successful because many pieces were lost in transportation over the ice, and two of the walls had not arrived by the end of summer. So the idea was abandoned and all sailed home, leaving the house incomplete. The year was 1578.

Later attempts were more successful - for instance the Great House of Edward Wimslow was sent and erected in Massachusetts in 1624.

This timber house was moved several times, and it is thought that parts were used in the Hooper-Hathaway house which still stands in Salem. Throughout the next century, there are many records of the prefabricated house being used as a means of providing shelter in new settlement areas.

America, with its rich supply of timber, soon took the lead in developing the timber house and the colonists were even making knock-down houses for export. In 1727, the ship 'Dromadaire' left New Orleans carrying houses ('all cut to be erected') bound for the West Indies. Old custom records quoted by Peterson (cit. above), show that New England also exported houses, first to the West Indies and then to Honolulu which provided a natural market for them. The old mission house, still standing in Honolulu was sent out by friends from Boston, eighteen thousand miles around the Horn, to arrive on Christmas Day of 1820 (20). As early as 1819 a sawmill operator was advertising in the St. Louis press that, "Those who wish to procure houses framed and put together at the mill, will have them done to order, with best materials and delivered at his landing below the mouth of the Missouri" (21).

In 1840 a Baltimore architect, John Hall, published a series of modern designs for dwelling houses. The series contained a cottage of interchangeable wooden panels, some solid, some glazed, to be bolted together at the site of erection. For convenience the parts were dimensioned to be interchangeable; "all the panels, posts and plates, being respectively of the same length, breadth and thickness; no mistake or loss of time can occur in putting them together" (22).

This idea of Hall's was very advanced for the time and can be said to embrace all that is required in the principles of full prefabrication. However, it is not a foregone conclusion that the Americans achieved first place in the design for such houses.

In 1843, in the first publication of "The Builder", sketches and plans appear for 'portable cottages' (23). The designer, a man by the name of S.W. Brookes, claims that he had, for some years, devoted time to the design and construction of portable cottages, many of which were erected in the northern parts of England. This could mean that Brookes was first to provide detailed designs for prefabricated houses, for his reason for publishing in "The Builder" was to encourage others to erect such buildings.

All these buildings were of the solid frame type, mortised and tenoned together and pinned at the joints with dowel pins. The fitting of these frames in the traditional way, required many hours of work by skilled craftsmen who were not readily available. The dearth of skilled men, the increasing supply of prepared timber and the wonderful invention of the mass produced iron nail brought into being a new structure. The new structure was the "Chicago Construction" (25) or more commonly "Balloon" frame.

2.2 The Balloon Frame

The balloon frame is but one of several systems of timber framed construction, the most common types being (a) Platform, (b) Balloon, (c) Braced. The braced system which employs diagonal braces notched into the exterior face of the studs, has largely been included under the other two headings in this country. "The principle of the balloon frame involves the substitution of thin plates and studs .... running the entire height of the building and held together only by nails ...... for the ancient and expensive method of construction with mortised and tenon joints" (26).

In practice, slender wall studs 4"x2" (100mm x 50mm) are used at sixteen inch (400mm) centres. At the base, the studs are nailed to a horizontal cill, a similar plate is fixed to the top of the studs.

For two-storey buildings, a horizontal plate is notched, or often just nailed to the face of the vertical studs to carry the first floor joists. The floor joists are nailed to the studs thus providing bracing for the frame. Roof rafters, which are commonly spaced at greater centres than the vertical studs, are nailed to the top plate. Thus a simple structure is formed which the builder can clad internally and externally with any desirable material. Ship lap boarding is commonly used for the exterior. Details of this frame and other methods of framing, produced for the timber industry in general, are available from the British Columbia Lumber Association.[27]

The first building erected by this method was St. Mary's church in Chicago, Illinois in 1833. It would appear that the name "Balloon" frame was given by scoffers who saw the erection of this church, and laughed at its light construction - that of a balloon. Walker Field in his excellent paper on the balloon frame [28] quoting from G.E. Woodward's article "Woodward's Country Homes" (New York 1869 p.151) records; "A Balloon Frame looks light, and its name was given in contempt by those old fogey mechanics who had been brought up to rob a stick of timber of all its strength and durability by cutting it full of mortices, tenons and auger holes and then supposing it to be stronger than a far lighter stick differently applied, and with all its capabilities unimpaired".

The significance of the invention of the balloon frame was not only simplicity and lightness, which led to new elegance and grace in timber construction, but also the quickness and ease of erection. It meant, says Walker Field quoting again from Woodward, "Even if a mechanic is emplyed, the Balloon Frame can be put up for <u>forty per cent less money</u> than mortice and tenon frame. If you erect a balloon frame yourself ...... it costs the price of the materials and whatever value you put on your own time". The emphasis was of course on the simplicity of erection which satisfied the desire of many who wished to build a house of their own without employing expensive labour.

So rapid and wide-spread was its acceptance (one authority [29] estimated that 60 to 80 per cent of all houses in the United States were built in this manner) that the balloon frame was of first-rate importance in American social and architectural history.

2.3 The birth of the Balloon Frame

It is strange that so little is known about the invention of such a revolutionary method of construction. Many are the accounts of this new method, the speed of erection and the low cost but no one has named the inventor of the first balloon framed building. Many authorities accepted the evidence of Siegfried Giedeon in his article in New Direction 1929. In this article Giedeon names George Washington Snow (said to be a descendant of the Pilgrim Fathers) as the inventor. However, Walker Field, in his paper (A re-examination into the Invention of the Balloon Frame) points out that the documentary evidence cited by Giedeon reduces to a statement by J.M. Van Osdel who arrived in 1837 to become Chicago's first architect. Van Osdel is quoted as saying, "Mr. Snow was the inventor of the 'Balloon Frame' method of constructing wooden buildings." Walker Field goes on to say that, "Van Osdel gives no hint of the origin of his knowledge, though doubtless he talked with Snow or with residents who vouched for Snow's connection with the balloon frame". [30] The most doubtful point to Van Osdel's claim is to do with the first erection of the balloon frame. It is on record that Father St. Cyr, (priest of St. Marys) chose Augustine Deodat Taylor, a Hartford carpenter and builder who arrived in Chicago, June, 1833, to be architect and builder.[31] Of course this does not prove that Snow was not the inventor. However, of the two men, Field points out that Taylor was much more qualified to be the inventor of the new type of timber construction since Taylor was a carpenter and Snow was a surveyor. Augustine Taylor inherited his father's carpentry business and soon afterwards began to build churches. When he settled in Chicago he built six churches. Throughout his life he was known as a builder. George Snow on the other hand was not a builder and the only instance in which Snow is connected directly with a building operation, quoted by Field, (Kimberley Papers, Chicago Historical Society) deals with the building of Snow's house. The document states the builder to be a certain John Garwin, and the style of the house other than balloon frame construction. The date of the agreement was 2nd August, 1833 - the very time when St. Mary's church was well under construction; this new evidence devastates Van Osdel's claim, for one would expect the inventor of a revolutionary method of construction to stick to his new principles instead of returning immediately to old fashioned practice. We must therefore accept the evidence placed before us by Field and accept Augustine Deodat Taylor as both inventor and builder of the "Balloon Frame" construction.

2.4 The Platform Frame

This type of construction lacks the exciting history of its predecessor, the balloon frame. Its name is simply derived from making a "platform" with wall panels and floor panels (single storey height) and using this platform to erect the second storey.(32) It was developed from the balloon frame to make erection simpler by making such a working platform, and so reduce the height of wall panels for the purpose of handling. The actual date for the innovation is not known, but by the 1860's it was a commercial proposition. (33)

Both types of construction came back to England but only in a small way. The Industrial Revolution and its effect on building, had, to a great extent, dictated the construction of the dwelling house. It may well be said that in the overcrowded conditions that prevailed in our industrial towns, it was a blessing that timber dwellings were not used. For the fire risk would have been a constant problem.

2.5 Timber Framed Housing - Period 1919-1969

After the first world war there was an attempt to revive the interest in timber framed housing when a committee, set up by the Local Government Board, began to look into proposals for new methods of construction. (34) Experimental timber houses were erected on the L.C.C. Beaconfield Estate between 1924 and 1928. These were constructed of Swedish timber and some of the wall panels were already prefabricated.(35) On the L.C.C. estate at Warling, 464 timber dwellings were erected in 1928, these were balloon frame construction,(36) However, problems with dry rot, union disapproval and the fact that there was no appreciable saving in cost, compared with the brick house, caused a setback in development. There was some demand in Scotland, where bricklayers were not so plentiful, during this period of setback. The Swedish style house built by Scanhouse Ltd., and another type built by Solid Cedar Homes Ltd., continued to be erected there until 1939. Timber houses were also gaining popularity among private owners at this time. This was due to the efforts of the Timber Development Association (now Timber Research and Development Association). One of the firms who pioneered such work was W.H. Colt, Son & Co.

The war caused great restrictions of the use of timber, and it was not till such restrictions were lifted in 1953, that full use could be made of new designs. Messrs. Spooner's of Hull, in an attempt to overcome the licensing restrictions on timber, designed a house on a very light timber framed system of 3in x 1½in (75mm x 38mm) studs. These houses were being erected shortly after the war ended.

In 1954 the Ministry of Housing and Local Government set up a development group to prepare design for houses, flats and maisonettes to be built by selected local authorities. Several local authorities participated, but costs proved to be greater than those of traditional types.(37) "In its Annual Report for the year 1955, the Ministry finally accepted the fact that, in general the local authorities preferred traditional methods and usually found them cheaper".(38) This saw the end of yet another government attempt to provide houses in quantity by alternative methods.

Further studies by the Building Research Station in co-operation with the National Federation of Building Trades Employers were mounted in 1961 and were completed in 1967.(39) This survey showed that Local Authority System built houses had the lowest man hour content of all types of construction.

The Ministry of Housing and Local Government in collaboration with the Building Research Station, is developing a 28 acre site in Finchampstead for the Wokingham R.D.C.(40) The purpose of this development is to speed up development of new forms of housing construction. Timber framed construction has been chosen for the first 170 houses.

The Scottish Special Housing Association decided to embark upon a programme of timber framed houses in July 1969. (41) This was after specialising in the "no fines" system for over thirty years. The main reason, was that small builders had the ability to erect timber framed housing, whereas only a limited number of contractors had the specialised plant for "no fines" work.

It can be seen that there is a growing interest nationally in the timber framed house, more are being erected each year. The annual growth of such housing is shown below (Fig. 2.1).

With such a change of heart toward the timber framed house, it is necessary for research to keep in step with demand, so that better economies may be achieved.

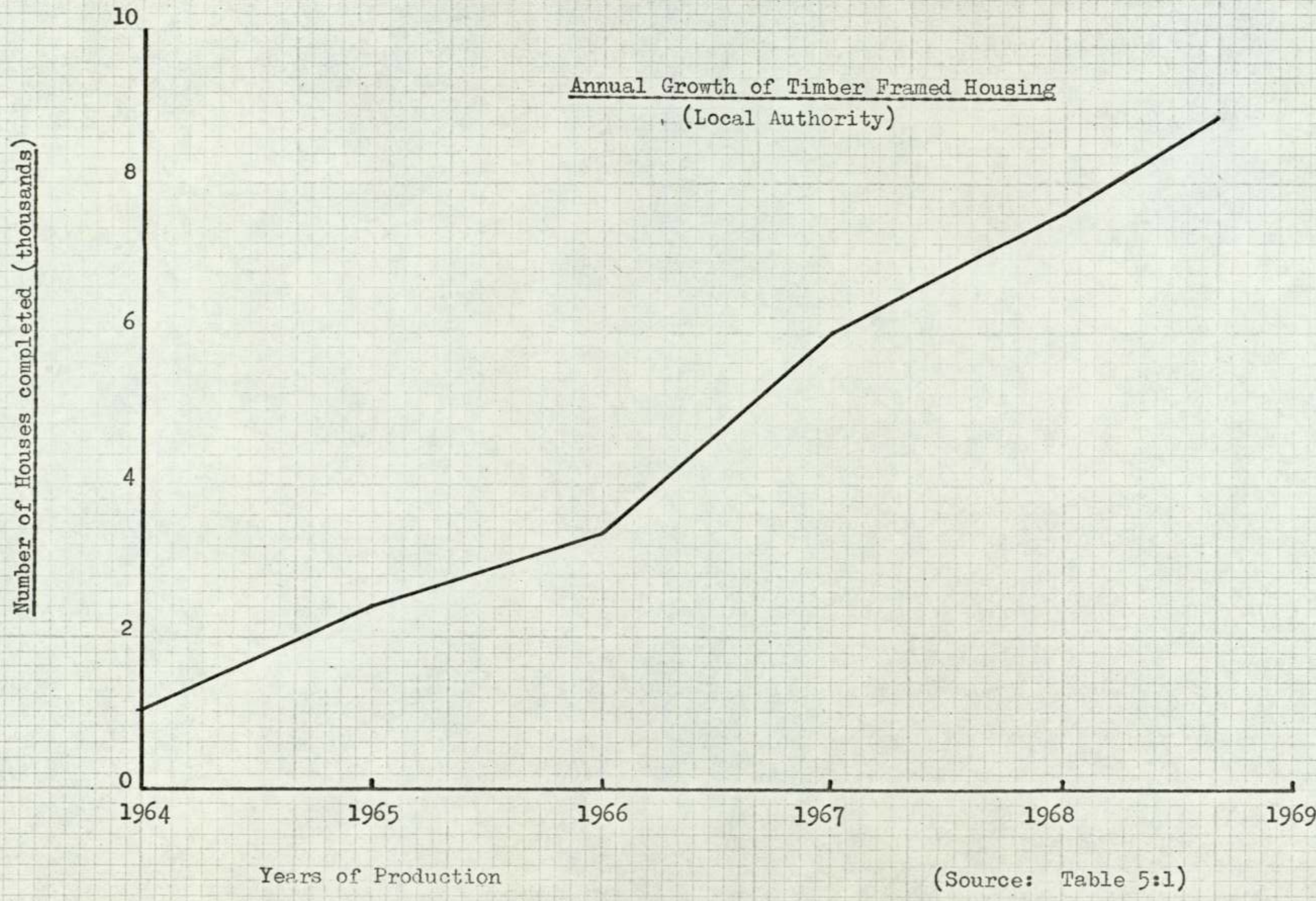
Annual Growth of Timber Framed Housing
(Local Authority)
Number of Houses completed (thousands)
10
8
6
4
2
0
1964
1965
1966
1967
1968
1969
Years of Production
(Source: Table 5:1)

Fig. 2:1

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PART 3   DETAILS OF THESIS

DETAILS OF THESIS

Research has been carried out in many industries which are involved in the manufacture of components, to ascertain optimum production methods. However, this type of research has not been carried out for Timber Framed housing in the United Kingdom. Some trends in this field have been highlighted in Canada [(1)] but they are of little value to the manufacturers and designers in this country. The pressing demand for greater productivity in low rise housing, which is required to meet government and Local Authority programmes, has made it necessary for all low rise systems to be examined. Since timber framed housing reduces site labour times from 1200 man hours for traditional types to approximately 600 man hours [(2)] it becomes necessary to examine the Production and Erection costs. The advantage of increased productivity has been offset by higher costs, on small contracts timber frames being five per cent dearer than traditional structures. A reduction in cost, by improving techniques or increasing batch sizes, must be achieved if orders are to be gained from Local Authorities.

Factual data, which will enable the timber framed housing industry to make the necessary changes in production technology or erection techniques is not yet available. The aim of this research project is to satisfy this need and provide, by means of graphs and tabulated data, conclusive information which will enable both designers and manufacturers to relate the economic batch size to production technology. This will highlight the areas where savings can be made and costs reduced.

Data was collected by means of a questionnaire (App. 1) from the majority of firms operating in this field.

This general data has been used to ascertain the present trends within industry regarding the following points:-

1. The types and systems of houses i.e. open or closed, two storey or single storey and whether the system is platform or balloon frame.

2. The geographical distribution of houses to assist in costing of transportation and probably development of temporary site factories.

3. The quantities of houses produced by firms to show the economies to be gained in mass production and to consider the possibility of sub-letting manufacturing units below certain production limits.

4. The timber used by firms for panel production.

5. The amount of work undertaken for Local Authorities and private sale.

6. The amount of brickwork or blockwork used in the structure.

7. The proportion of companies doing site works i.e. roads, sewers, slabs and pavings.

8. Factors that affect factory production of houses such as storage, erection demand, orders, factory facilities. Whether firms could raise their production without increasing the facilities.

9. Number of men and hours involved in factory production. The probably reduction of time with increased batch size.

10. The amount of space given to the various activities i.e. storage, sub-assembly, man assembly, finished components.

11. Type of plant used in factory production including handling of materials.

12. Amount of assembly undertaken in the factory showing the effect on transportation and site work. Size and weight of panels are also considered.

13. Transportation costs which are used to show the economies of factory and site production of timber frames.

14. Amount of site work including plant used and times involved in erection of units.

The information compiled from the questionnairs is backed by detailed studies of four companies who both manufacture and erect timber framed houses. The fifth company involved carried out a project in conjunction with the University in which certain problems were analysed and compared with standard methods adopted in timber framed houses.

3.1 Detailed Study

The detailed studies covered the following points:-

1. Production methods and costs

    This section covers the layout of the assembly area, type of plant and amount of prefabrication, together with a detailed break-down of production costs for each method undertaken.

The costs of production are given graphically, showing the effect of batch size on cost. A detailed description of the production methods illustrated by photographs precedes the data.

2. Erection methods and costs

The methods of erection are discussed and the actual times are shown for various activities so that comparison can be made with other methods adopted.

Graphs show the effect of increased mechanisation on site compared with reduction of man hours and the optimum size of contract is shown. The effect of improvement is shown for the major items of work on site. This shows the optimum number of units to be erected for maximum productivity.

Each site operation is fully described and times are given graphically for comparison with factory production so that the cost of increased factory prefabrication can be considered. Photographs show the various methods of site work and erection procedure.

3. Transportation of Units

The types of plant for handling the units both at source of supply and site are considered together with costs involved. The costs per mile or per unit are shown for varying mileage radii, this latter data is used to show the economics of site factories. Break-even points are shown by means of graphs for the most economical batch size for site production.

Various stages of prefabrication are also considered to show the problems of loading and the effect on transportation costs.

4. Materials

The origin of the timber used, costs involved in cutting waste and protective finishes are discussed.

The problems of using certain materials, are discussed; these have been given in construction stages.

The structural properties are not considered in the project.

5. Design Factors

Systems and component design are considered with the factors which determine the amount of prefabrication. Design consideration in erection, internal and external finishes are discussed to show where cost planning can be used effectively.

3.2 Selection of Companies for Studies

Five companies assisted greatly in the research by affording facilities so that detailed data could be tabulated. Four firms were selected on the basis of their experience in the field of timber framed housing. The fifth firm, in collaboration with the University agreed to erect a pair of proto-type houses and provide staff for monitoring the erection sequence.

Firm 'A' is a medium sized company which undertakes traditional house building as well as timber framed houses. They have been one of the leading firms in the field of timber framed houses and have gained contracts in excess of five hundred dwellings per contract. This firm make the panel units at their Midland Joinery works and erect anywhere in the country. They also make panels for other sponsors of timber framed houses. Present production is five hundred units per annum.

Firm 'B' is a large company well established in prefabrication of school buildings and offices. This company has opened a section of their production unit for producing timber framed housing panels on a semi-flow line basis. They carry out all site works as well as erection of the houses. The present output is between one thousand five hundred and two thousand units per annum.

Firm 'C' is a very large company which has specialised in housing for many years. Only recently they entered the field of timber framed houses. The main reason for choosing this company was the method of production which employs site factories instead of a centralised works. This factor gives the opportunity for comparison with other methods generally employed in the industry.

Firm 'D' is a large company which carries out work in many fields of the construction industry from joinery to building caravans. One section of the company has been developing timber framed houses for Local Authorities since the War, having designed a prototype house to overcome the timber licensing restrictions. This company has been successful in gaining valuable contracts in timber framed units and present production exceeds one thousand five hundred per annum. The method of sheathing and erection is substantially different from firms 'A' and 'B'.

Firm 'E' is another well known housing contractor who with the aid of a government grant has erected a pair of houses in timber frame construction so that direct research could be employed for further development. The University was called in to advise on the research procedure and some of the data provided has been included where comparisons are necessary. The project included some new ideas for examination so that the most economical method of erection and finishings could be established. These methods and ideas are examined in detail for their economic validity.

3.3 Procedure for data collection

The methods of production were studied first to give the background knowledge necessary to decide which operations should be factory orientated rather than site orientated.

Firm 'A' was contacted first and a detailed analysis was made on all activities in the production shop. This analysis was completed before the other companies were visited for study. The reason for carrying out this pilot study was to prove the method of data collection and so prevent the duplication of work on items which proved to be superfluous.

Data for erection was considered in parallel to production work but points arising in both fields of activity created the need for basic production analysis prior to visiting sites.

Detailed analysis sheets were prepared for the actual time spent on the activities in panel production. The time spent on machining, handling, assembly and transit to storage were recorded. Since the companies produced several house types from a series of panel types, a separate tabulation sheet was compiled for the most popular house type in demand, namely 5 person, 3 bedroom.

In firm 'A' three such house types were studied, all of which were being erected on one particular site.

The allocation of time for panel production is followed by an analysis on the prime cost of labour in panel production. The prime labour costs were plotted to show reductions gained by increasing batch size. The cost of producing sheathed panels by machine and by hand were tabulated, together with data on factory 'set-up' cost and machine costs.

After the basic data had been collected from firm 'A' the research was extended to the other firms so that data could be compared. In all cases the data is tabulated and correlated to the basic 5 person, 3 bedroom house.

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PART 4. PRESENT SITUATION IN THE MASS PRODUCTION OF OTHER TIMBER COMPONENTS

PRESENT SITUATION IN THE MASS PRODUCTION OF OTHER TIMBER COMPONENTS

In establishing the correct production technology for timber framed housing it is natural to consider other fields of mass production. Architects and designers of good repute have, over many years, compared all industrialised building technology with that of engineering technology. The flow-line production ideas which are commonplace in some industries have provoked designers to state that such methods are inevitable for housing if the industry is to keep pace with public demand. "The study of transport history (states Bemis [1]) reveals many striking points of comparison with housing. In transport new needs have created new demands. More speed and power was required than horse drawn vehicles could provide, hence the loco engine. Rapid development is a familiar story, why not the same with housing. Mass production and commerce are all ready to assist." What Bemis and others, who have made similar comparisons, did not envisage was the birth of scores of industrial type houses. The development from the old stone cottage to the factory made house has been achieved, but in such a way that mass production has played no important part.

However, mass production has played an important part in the manufacture of components for housing and these developments may be considered when looking for an answer to the economic production of timber framed houses. The components in question are windows, doors, kitchen units and trussed rafters. All are required in great quantities and even though the types available are numerous they are often produced by flow-line processes.

Within the context of mass production there are two types of production which need some amplification. This has been explained extremely well by W.L. Foster of T.R.A.D.A. in his paper on "Timber Component Production" [2]. The two types of production are Flow-line production and Batch production. The latter appearing to be the antithesis of the former, but in reality it is a system of production with its own desciplines and circumstances.

Flow-line production is the steady flow of components, in various stages of completion, moving by conveyor through work areas where operations are carried out until the component is completed. Of necessity flow-line production is highly organised where production costs are to be kept low. Materials and other resources must be readily available at every work position. The cost of preparation, in machines, buildings and overheads is usually very high. Therefore the system is suitable for large quantities of standard components.

Batch production is any method of producing a number of components where the quantity to be produced is small compared with the cost of preparing to produce. In simple terms, if the cost of preparing and organising flow-line production cannot be off-set by the quantity produced then batch production is introduced. It is possible to employ both systems, matching by batch production and assembly by flow-line.

These two production systems have their own economic circumstances and therefore deviation from the intended standard is costly. As stated above it would appear that batch production is the antithesis of flow-line, but where variety is required, and this is a common requirement, it has been shown to be the most economical way of production. This is not to imply that batch production is for very small batches, indeed cost reduction can only be achieved where the batch size permits reasonable machine runs and semi-automated assembly.

To this end designers should standardise sections and mouldings.

If flow-line production can be justified then the cost advantages are considerable and far outweigh any saving by batch production. The finishes on such production lines are usually superior to batch production methods but alteration to components more difficult to carry out due to complications inherent in machine produced articles. The components which are generally produced by flow-line methods are flush doors, windows and kitchen fitments, whereas roof trusses, glazed doors and some windows are usually produced by batch production methods.

Since batch production is commonly employed by small and medium range producers there is a tendency to assume higher costs from this sector. This conclusion may be in error, for the small producer has very low overheads and capital outlay costs. He is therefore more flexible in organisation and more likely to offer competitive prices than larger producers for certain batch sizes. This would certainly be true for the trussed rafter, where batch sizes can be as low as thirteen, a number suitable for one house. Trusses for fifty dwellings, all of the same type, would be a large order for trussed rafters yet still not large enough to justify flow-line production.

Glazed doors create the same problem; there are far too many patterns or types to justify flow-line production. The only answer would be to produce for stock, but the market demand is too flexible for this and capital tie-up would more than offset the economies gained.

The answer is determined by the demand for standardised components. Where the designer continues to specify components which vary from a standard type, batch production will continue as an economic system of production.

Window frames have created a problem for producers. The demand is high but variety almost prohibits flow-line methods. The demand for metal frames has created problems by adding to variety. Such is the problem that some window frame manufacturers have ceased to operate flow-line methods and have reverted to batch production techniques.

One of the best examples of flow line methods is that of flush door production. It has been estimated that the current demand for all doors is between 8M and 9M per annum.(3) Flush doors account for about eighty per cent of total production and internal flush doors for over seventy per cent.

These figures give every reason for considering flow-line production. Production of doors is concentrated in a few large firms with many others making relatively small quantities (Table 4.1). It can be seen from the table that the large producers account for some eighty per cent of the total doors produced. This has enabled them to set up flow-line systems and maintain a competitive position. The reason for such efficient production has been the reductions in variety. Rationalisation can be shown by examining the production of two large producers Table 4.2). A more detailed examination was made of the production in Firm 'B' and the actual production figures for all sizes of hardboard faced flush doors are shown in Table 4.3. It can be seen from the table that three sizes of internal doors account for approximately eighty five per cent of total production. The only variable is the width which can be accommodated on the flow-line without much difficulty. These figures show a production rate of over 10,000 standard hardboard faced doors per week. Over sixty per cent of these were the 6ft. 6in. x 2ft. 6in. door.

With this quantity of production it is necessary to establish the cost structure for the common sizes so that areas where economies may be gained can be examined. Table 4.4 shows the cost structure for 6ft. 6in. x 2ft. 6in. doors. In the firms quoted the area for economy is clearly shown to be materials. The direct labour cost is so low that further reductions would be hard to achieve by variety reduction or improved technology.

The actual allowable labour cost per unit can be calculated for any system and economic minimum and maximum production established. From Fig. 4.1 it can be seen that the economic minimum is 9600 doors per week and the economic maximum 16,000 doors per week. The law of diminishing returns, created by overtime working, has its effect beyond the production of 16,000 doors. The allowable cost for labour includes supervision therefore raising the percentage in Table 4.4 from seven per cent to fourteen per cent of the ex-works price. The cost graph for production is shown in Fig. 4.1. Where production due to variety reduction reaches 16,000 doors per week there is a further saving of approximately seven per cent. A seven per cent saving on the ex-works price of hardboard flush doors shows how efficiently the industry is running. Further large scale production may not be justified. A typical flow-line assembly is shown in Figs. 4.2, 4.3., 4.4, and 4.5.

This example of flow-line production has been stated to show that increasing demand and variety reductions are necessary to achieve economies. If fifty per cent of hardboard faced doors produced were 6ft. 6in. x 2ft. 6in. then the annual demand would be in the region of 2M doors of this size. By comparison the annual number of industrial dwellings in approved tenders is approximately 70,000 and the number of systems involved exceeds one hundred. This gives an average of seven hundred dwellings per system. This figure is approximately fourteen dwellings per week, hardly the demand that requires flow-line techniques.

Within the figure of 70,000 dwellings allocated in 1967 the quantity of timber framed dwellings was approximately nine per cent, over 6,000 dwellings. These contracts were awarded to thirteen individual producers, this equates to approximately five hundred dwellings per system. Only six producers were awarded contracts totalling over five hundred dwellings and no single producer received a contract totalling more than 1,000 dwellings.

Even within the contracts for five hundred dwellings there were problems created by house types. The total orders placed rarely exceeds two to three hundred dwellings of any particular type. Therefore the quantity of panels passing through a production unit at any one time prohibits flow-line techniques.

Variety reduction has been set aside to achieve interesting estate development. Producers are eager to obtain orders and therefore offer many concessions in the discipline of design and standard layout.

Until the demand for timber framed houses reaches a scale where capital expenditure in flow-line techniques is justified, the current methods of batch production are here to stay. The comparison cannot be made with the production of other timber components, for the high demand of standard components is the key factor for reducing costs. At present this factor is restricted to a few components, the best example being flush doors.

Table 4.1 Size Distribution of Door Manufactures

Size, annual output of doors †	No. of Firms
1,000,000 +	4
100,000 to 500,000	9
10,000 to 1000,000	10 to 15
Less than 10,000	about 170

† Panel and flush doors (Source BRS c.p. 32/69)

Table 4.2 Annual production of flush doors
(based on two large firms)

Production	Firm 'A'	Firm 'B'
Total No. of flush doors	800,000	1,050,000
Internal doors	720,000	1,000,000
External doors	80,000	50,000
Hardboard faced	490,000	600,000
Hardboard veneered	-	250,000
Plywood faced	310,000	200,000

(Source Firm 'A' BRS c.p. 32/69)

Table 4.3 Size variety in the production of hardboard faced flush doors (based on Firm 'B')

Size Width x Height (ins)	Percentage of orders	Production No. of doors
36in. x 78in.	0.36	2160
33in. x 78in.	5.19	31140
30in. x 78in.	)* 60.57	363460
27in. x 78in.	) 15.31	91850
24in. x 78in.	) 9.68	58070
21in. x 78in	4.78	28670
18in. x 78in	2.58	15470
24in. x 72in.	0.71	4260
48in. x 96in.	0.33	1980
36in. x 84in.	0.28	1680
33in. x 81in.	0.02	120
32in. x 80in.	0.19	1140
	100.00	600,000

* Sizes which account for 85% production

Table 4.4 Cost structure for producing standard hardboard faced door (6ft. 6in. x 2ft. 6in.)

Item	Percentage cost (ex-works price)	
	Firm 'A'	Firm 'B'
Materials	64	66
Direct Labour	4	7
Overheads & Profit	32	27
Ex-Works Price	100	100

(Source Firm 'A' BRS c.p. 32/69)

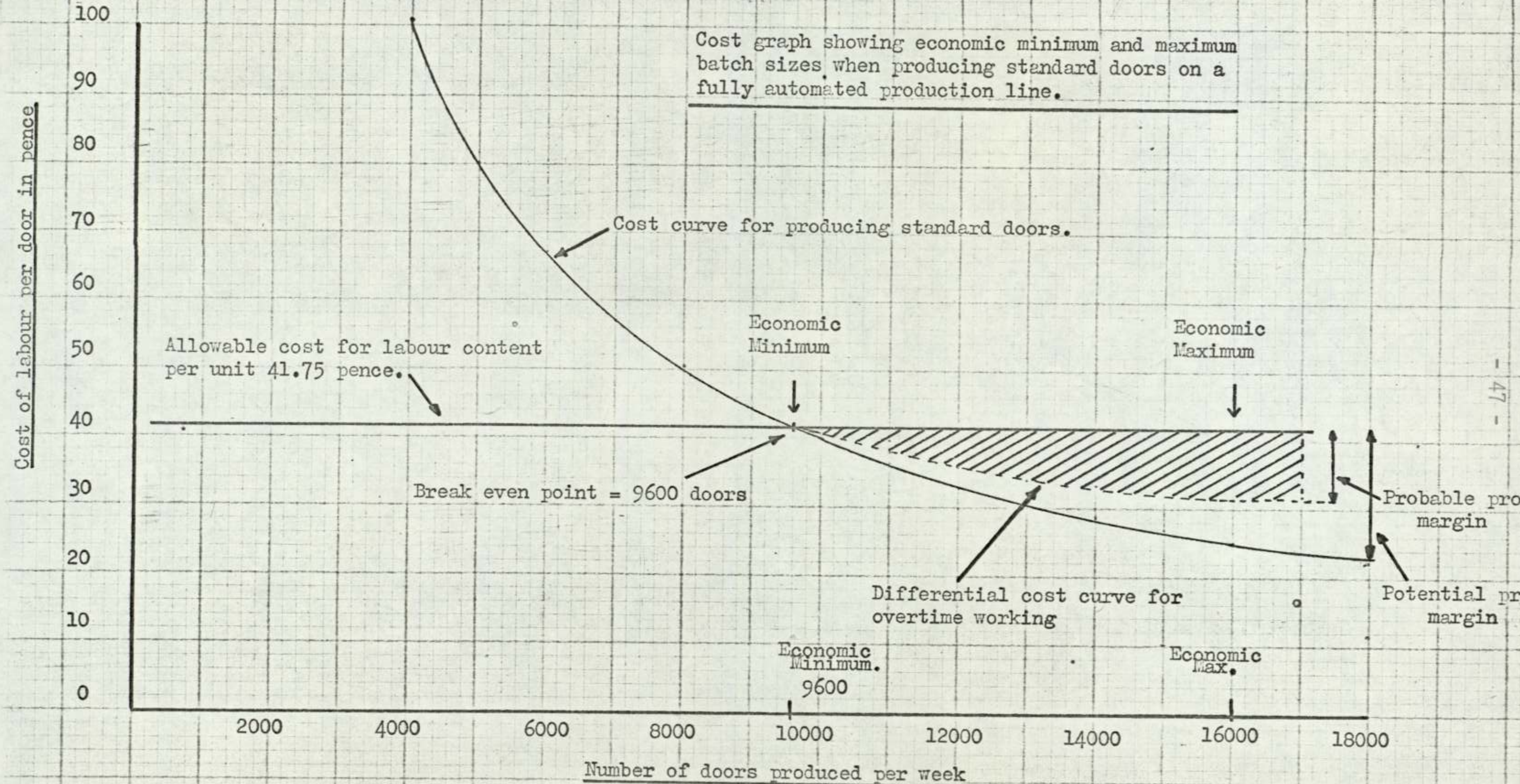
Cost graph showing economic minimum and maximum batch sizes when producing standard doors on a fully automated production line.
Cost curve for producing standard doors.
Allowable cost for labour content per unit 41.75 pence.
Economic Minimum
Economic Maximum
Break even point = 9600 doors
Probable prof margin
Potential pro margin
Differential cost curve for overtime working
Economic Minimum. 9600
Economic Max.
Cost of labour per door in pence
100
90
80
70
60
50
40
30
20
10
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Number of doors produced per week

Fig. 4.1

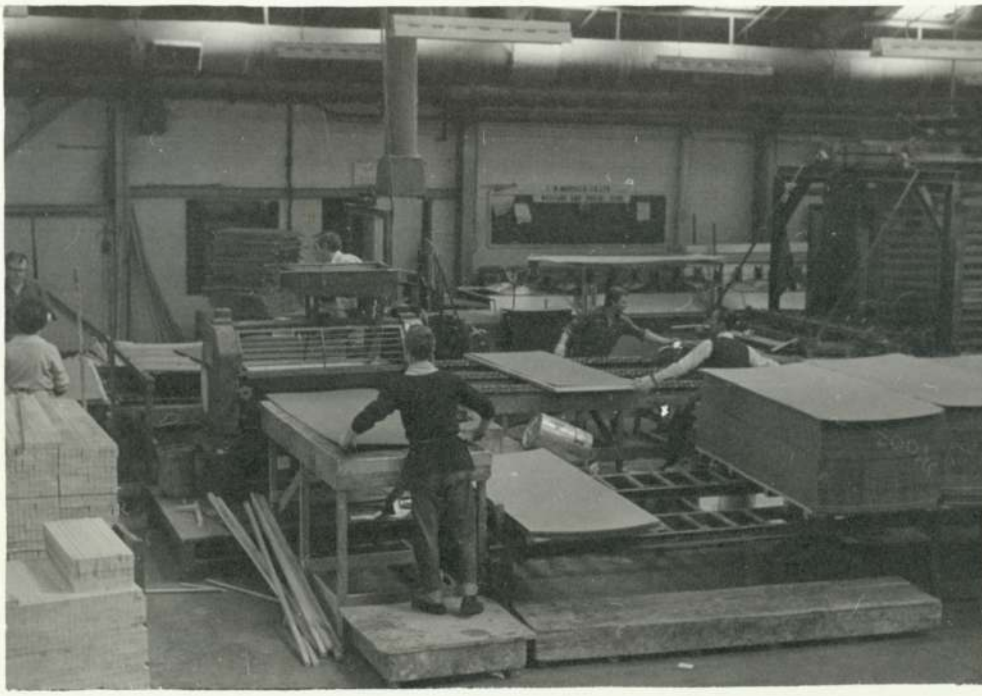

Fig. 4.2

General view of hardboard being glued and applied to cores

Fig. 4.3

Core assembly for flush doors

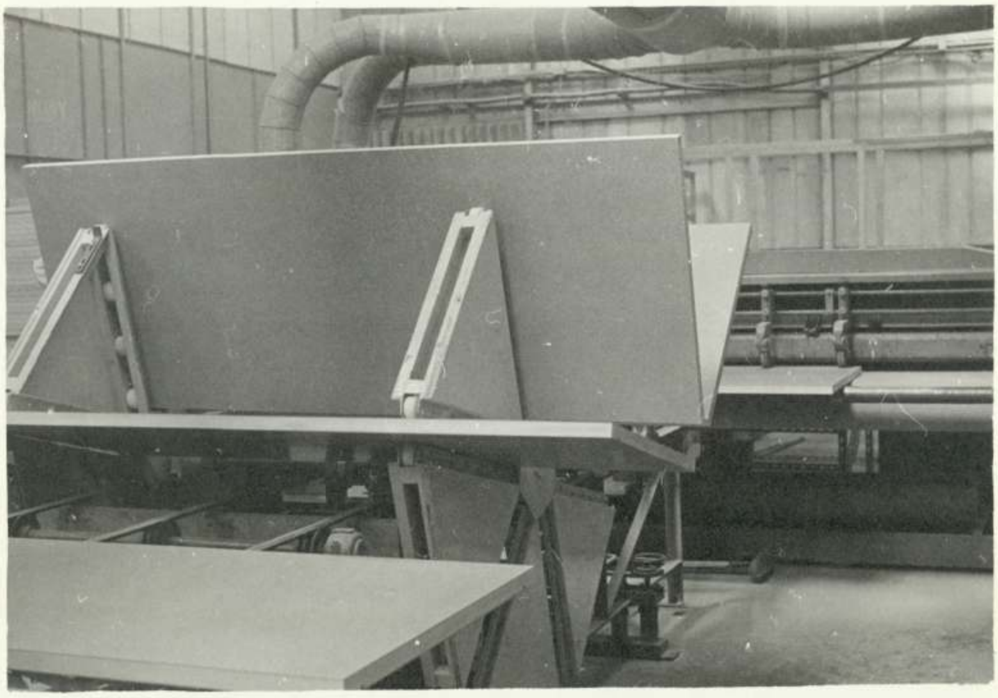

Fig. 4.4

Door being turned over for surface sanding

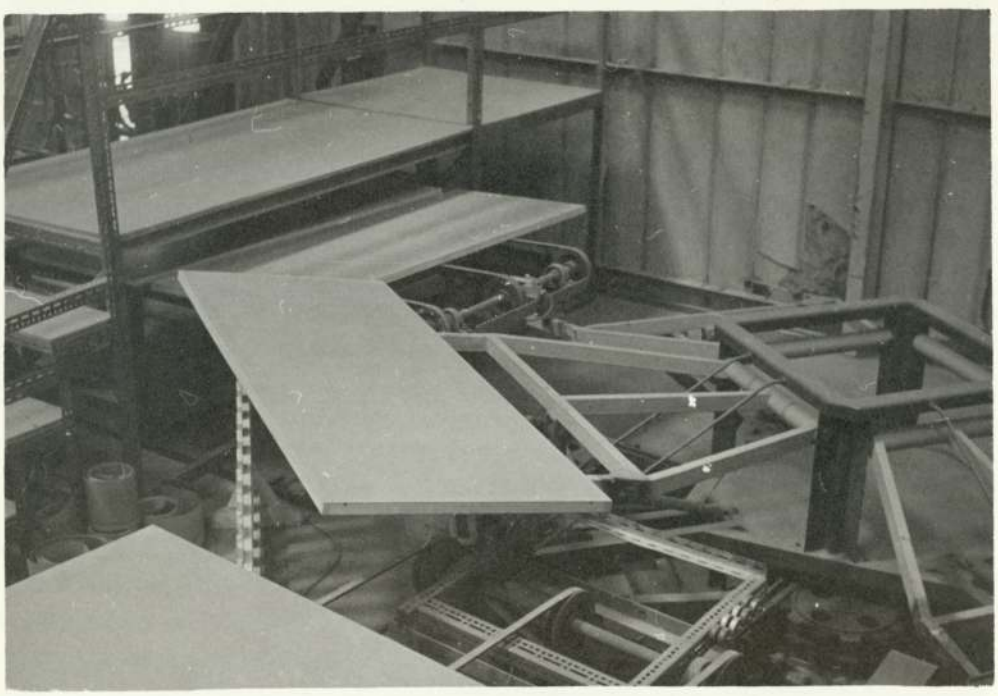

Fig. 4.5

Door being fed onto adjacent track

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PART 5 CURRENT PRODUCTION OF TIMBER FRAMED HOUSING

CURRENT PRODUCTION OF TIMBER FRAMED HOUSING

5.1 Systems Available

There are many systems of timber framed houses available to Local Authorities and the private developer. The systems for the private sector have been omitted since the project concentrates on Local Authority housing. The systems used by Local Authorities are listed in Table 5.1. This list includes all the major firms making timber frames. A few smaller companies have been included with Local Authority figures.

In the majority of cases the firm sponsoring the system also produces the actual frame. In other cases the sponsor sub-lets the production to a joinery manufacturer. In the current list (1) of Designers and Manufacturers for Timber Framed Houses over seventy firms are listed in either design and or manufacture in Great Britain. Sixty firms appear on the list as manufacturers of two storey houses, however, only twenty three are listed in "Housing Statistics".(2) Many of the systems listed as timber framed, are in practice, Rational Traditional, having load bearing walls of brick or concrete. Less than twenty five systems are truly timber-framed.

5.2 Firms producing Timber Framed Houses

As stated in part 3 of the project, a questionnaire was sent to all companies making and erecting timber framed houses for Local Authorities. Out of the twenty four companies listed in Table 5.1 a total of eighteen completed the questionnaire. The production of these companies represented a total of seventy two per cent of all timber houses built.

5.3 Field Work

In addition to producing timber framed houses three companies produced a system under the classification of Rational Traditional. Seven out of eighteen produced more than one system.

All produced two storey houses and fourteen produced single storey houses as well. Four firms produced three or four storey buildings in addition to the above.

Seven of the firms produced houses for the private sector in addition to local authority work. One company was exporting five per cent of its houses and one other company was negotiating for similar work in Europe.

Type of Frame

Only one company designed solely on the 'balloon frame' method. One other company supplied and erected both platform and balloon frames, in addition to this work they made balloon framed panels for another company to erect.

5.4 Production Details

Since Industrialised Housing figures are relatively new in the Ministry of Housing and Local Government Statistics there are no reliable figures for the production of timber framed houses prior to 1965. Eight of the companies replying to the questionnaire were producing houses in 1965 and three firms have produced houses for more than five years.

The systems were classified as 'open' or 'closed', depending on whether the system was capable of being used with other modular components. A closed system is one where the system is specifically designed for the sponsor and can not be used with other components.

Nine firms produced an 'open' system, six produced 'closed' systems, one produced both systems and two were non committal.

The size of contract undertaken by the eighteen companies varied widely from a minimum of one to a maximum of 'no limit'. Fig. 5.1 shows the range of contracts undertaken, showing the minimum and maximum together with the economic minimum. All but four firms were willing to accept contracts for twenty houses. Twelve firms were able to produce houses economically for contracts of fifty. Eight firms considered their economic minimum to be less than twenty five houses.

Thirteen firms were able to accept contracts exceeding five hundred dwellings, seven of these firms had no limit to the contract size. These figures show the limit of work undertaken by timber frame producers. The figures in Fig. 5.1 do not however, indicate the current amount of work undertaken by the firms contributing to the project. These figures indicate the production policy only.

All but one company stated that orders determined production. The exception stated that factory facilities were the prime criteria. Six firms stated that factory facilities were the second criteria to production, five stated that site erection problems were second in significance and three stated that storage was the second criterion in production. All firms stated that production could be increased; the increase ranged from twenty five per cent to six hundred per cent, indicating that the industry if running somewhere between fifty and one hundred per cent below potential.

Seven of the firms stated that production was affected by factors other than factory facilities, storage of components, site erection and orders. The factors given are as follows:- Finance, materials, labour, capital outlay, work load on design staff, and the number of systems to compete against.

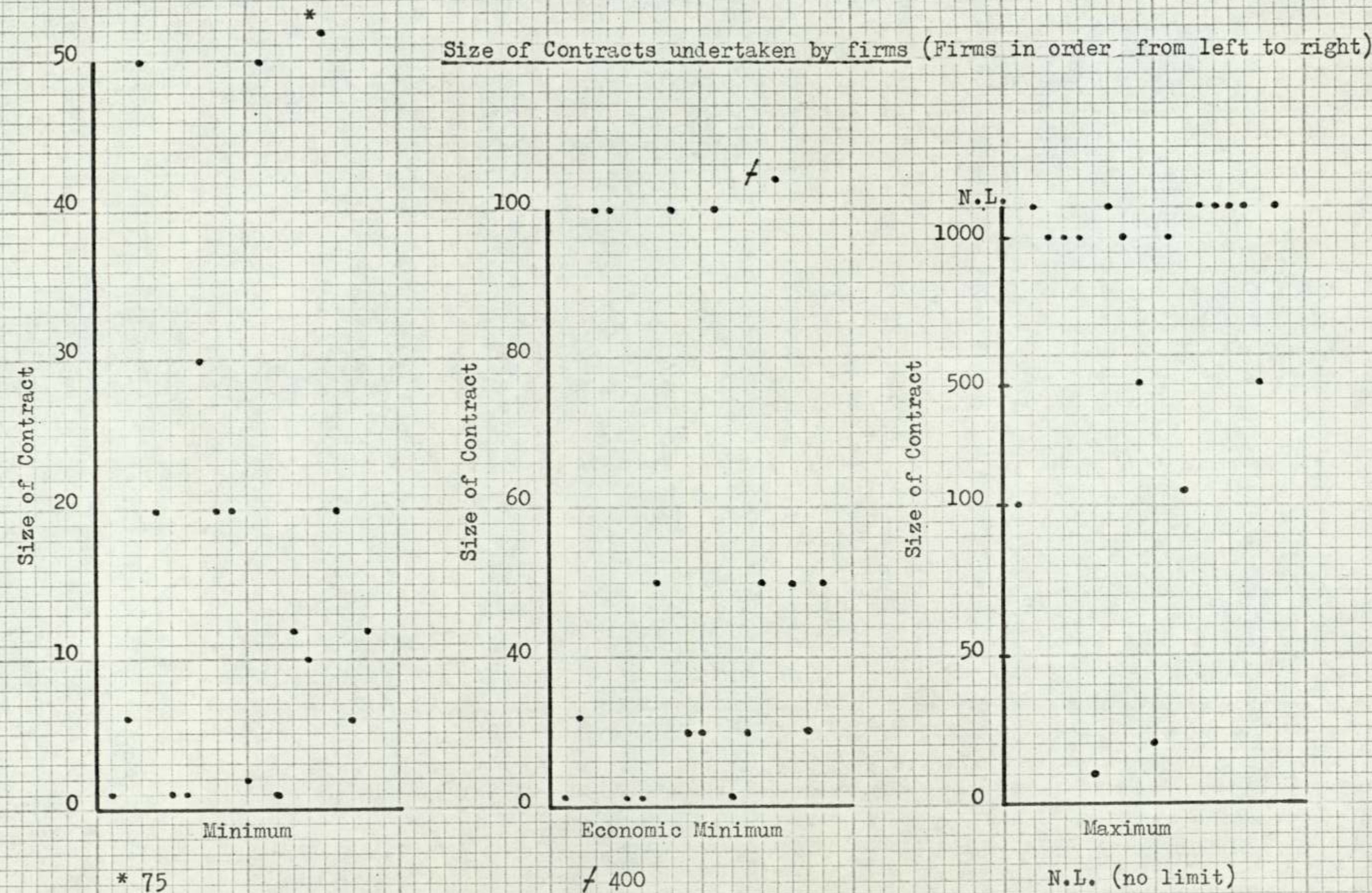

Size of Contracts undertaken by firms (Firms in order from left to right)
Size of Contract
50
40
30
20
10
0
Minimum
* 75
100
80
60
40
Economic Minimum
/ 400
N.L.
1000
500
100
Maximum
N.L. (no limit)

Figure 5:1

The manhours spent in production are shown in Fig. 5.2 the percentage reduction for batch increase is also shown. A detailed study on manhours and the effect of large batches is discussed in Chapter 6. The number of hours per unit varied from two hundred to forty for an average figure. These figures do not show how much work is completed in the factory but the majority of firms confined their activities to panel manufacture without external cladding. Six firms hung doors and fixed window frames into their panels, one since withdrawing the window fixing due to damage. One firm produced complete box units for the bathroom suite. Two fixed all insulation plus tiling battens. Two made complete floor units and only one fixed electrical harnesses before the panels left the factory. No firm attempted to carry out all the stages of prefabrication mentioned. Three firms had withdrawn stages of prefabrication due to the high percentage of damage. The items withdrawn were window fixing, moisture barrier and insulation material. The largest panel produced varied from 8'x7'6" to 30'x7' 6" and panel weight from 140 lb to ten hundredweights.

Nine firms, making panels of maximum length 14' to 30', used some form of cranage on site. Nine operated without site cranage, of these three were making panels between 16' and 20' long.

The source of timber for making the frames was rather significant. Fifteen out of eighteen used Canadian Lumber Standard, eight of these also used Scandinavian. Three used C.L.S. Scandinavian and Russian. Three remaining companies used Scandinavian, one using Scandinavian and Russian. No company was using home grown timber.

Factory Plant

With the ever increasing demand for new ideas in industry and better equipped production lines, there is a tendency to assume that manufacturers have installed fully automatic production lines. This is not the case. Many manufacturers are producing houses economically with the basic machines i.e. crosscut and panel saw. The amount and type of plant used in the companies assisting with the project are shown in Table 5.2. The choice between using a panel saw or router should be considered on the details of window fixing. Where windows can be fixed without having to set back the plywood sheathing around the opening, the router can save a great deal of time and waste in eliminating pre-cut panels. Only two firms were using this method of ply cutting. Eleven companies used some form of automatic nailing gun and from Table 5.2 it can be seen that such tools were not limited to the large company. The economic production using this equipment ranged from three units to four hundred.

Seven firms were producing panels up to 17' long without using cranage or fork lift trucks. Total mechanisation i.e. automatic flow lines were not being used, although three firms were using semi-automatic production lines and were considering further automation.

Nine firms carried out 'other work' i.e. box making, seven of which, were capable of dealing with housing contracts of 1000 units or more. In some cases, plant items such as fork lift trucks were being used on 'other work' as well as panel production. In one case the utilization of plant on panel production was only thirty per cent.

5.5 Transportation and Areas of Distribution

Seven firms had no limit to distance for delivery, but were operating a normal delivery between one hundred and two hundred miles. Four were operating within a fifty mile radius and one was site based in manufacture. The geographical areas for work are shown in Fig. 5.3. This map clearly shows the overlapping of areas and the problems of gaining orders on a competitive basis. Four firms had a policy of concentrating their activities within certain areas, these are shown in colour in Fig. 5.3. Arrows indicate the fields of activity for each firm, dots indicate the production centres.

Transportation Costs

The cost of transporting houses to site varied with the amount of factory work undertaken. Where window frames and door frames are fixed, the number of panels which can be loaded on a trailer is reduced. Where panels can be stacked flat the cost per house was as low as £5.6. Six firms were able to transport units up to a distance of fifty miles at a cost not exceeding £10 per unit. Where panels were insulated and prepared for tile hanging together with door and window frames the cost per unit was as high as forty pounds, Table 5.3. The cost trend is shown in Fig. 5.4, this graph takes into consideration the amount of factory work undertaken as listed in Table 5.3. Transportation costs are considered in a further chapter with comparison with site production and site handling.

From the information above it can be seen that there is a lack of data on the production and erection of timber framed houses. Firms have started producing systems without considering market demand, economies of production and the problem of batch variety.

Only one company produced units on site, which offered the facility of quick production variation to suit site requirements. Cost comparison for this production method is shown in Part 6.

Twenty four companies are competing for a market of approximately 8000 local authority houses per annum. This has the effect of limiting the type of production unit of any one company, unless the work load for private enterprise permits a high output production unit. The current local authority demand is too low and too varied to show production savings of any magnitude. Manufacturers cannot afford to specialise and therefore tender for all types of work in spite of high production and transportation costs. The export market has not yet provided enough work to be of any consequence in production methods.

The 'Balloon' type frame is not widely used and will probably diminish in quantity in favour of the platform method of construction.

While nine firms stated that their system was an 'open' system, it is doubtful whether such systems could in fact be successfully sold as a series of panel parts. In fact, some firms experience difficulty in interchanging panels within their own systems. Modular co-ordination was not evident and metrication tended to be based on equivalent linear units.

The economic criteria varied from firm to firm, with the exception that orders were all important.

Manhours for production of units varied too widely for the amount of factory work undertaken. Learning or improvement curves were often unheard of and therefore reduction of manhours for batch production was difficult to establish without very detailed study. However, from the manhours given by firms for various batch sizes it was possible to show general improvement curves. These depended on the complexity of panel construction and therefore led to a more detailed study recorded in part 6 below.

The amount of factory work was not as high as might be suggested by industrial correspondents. There were many practical reasons for this; mainly damage in handling and transportation. Some ideas had been withdrawn because they were uneconomic. Panel lengths were decided without much logic, many panels exceeded twenty feet in length thereby incurring cranage costs in order to off-set simple jointing costs on site. In many cases the panels which were crane handled were only sheathed. Further prefabrication, such as vapour barriers, insulation, water barriers and tiling battens could well have been fixed so that economies could be gained from handling methods.

The general tendency in panel manufacture is that of simple hand nailing. This is likely to continue where complexity of panels is low or where site demand is below twenty units per week. Where site demand is between twenty and fifty units a week there is need to examine production techniques. This is discussed more fully in Part 6. Transportation and areas for working will depend largely on the policy of each individual company, but hauling units long distances may prove uneconomical. This will lead to more and more site orientated production as opposed to factory orientated production.

5.6 Speed of Production and Erection

One of the prime features of the timber framed house is its fast erection. This is becoming increasingly important as the demand for housing continues to rise, and the supply fails annually to meet the demand.

In a recent survey (3) it was found that the national average for house building had been reduced from 2000 manhours to 1110 manhours over a period of fifteen to twenty years. The present average content for a local authority, traditional house, is 1200 manhours.

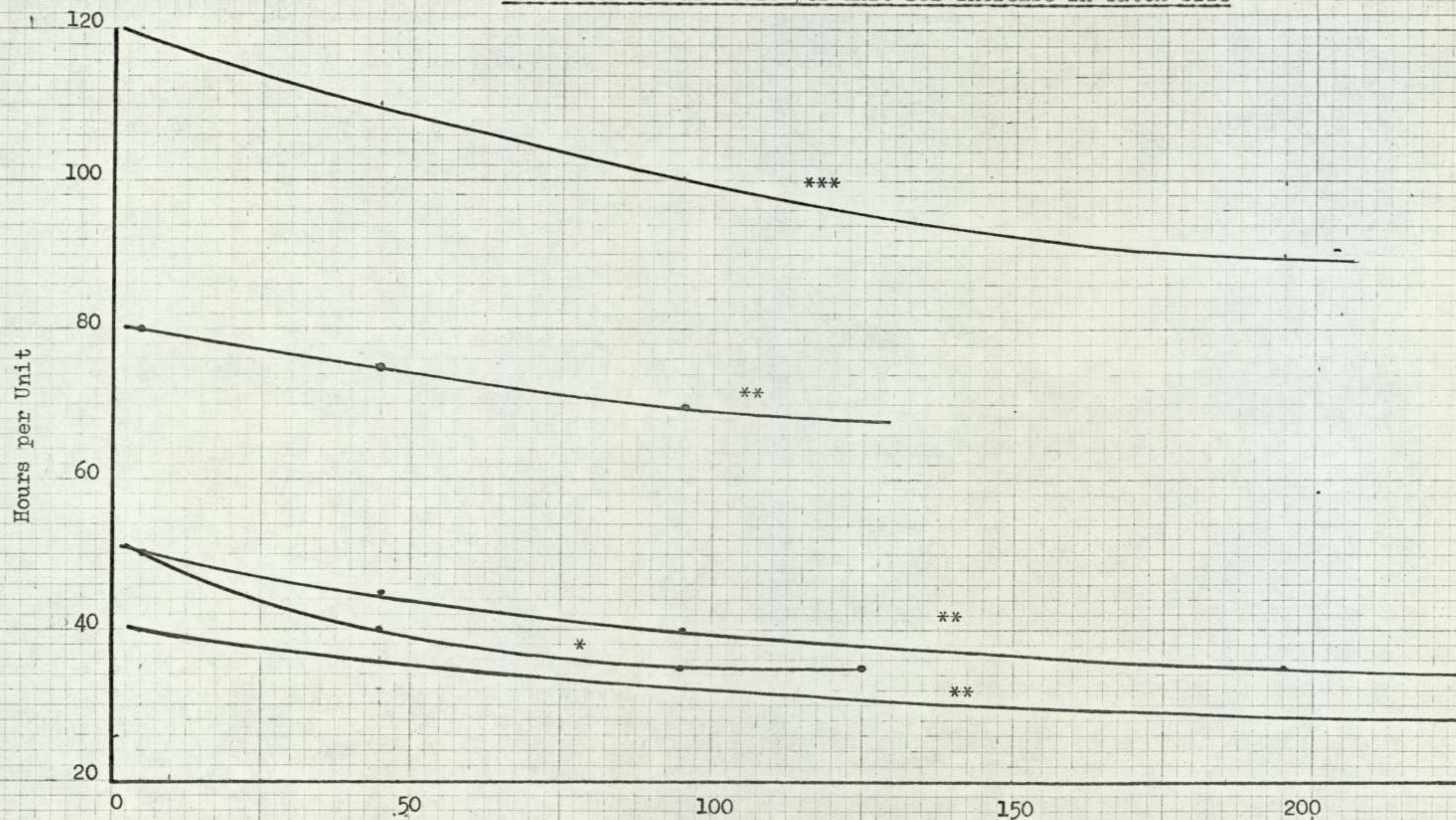
By comparison Tables 5.4 and 5.5 show the manhour content for timber framed housing and rational traditional housing. Timber framed housing varied in content from 594 manhours to 893 manhours with an average content of 775 manhours. Rational traditional housing varied from 727 manhours to 1177 manhours with an average of 981 manhours.

Rational traditional housing, which contains in many cases, timber infill panels, shows a saving of eighteen per cent in manhour content, over local authority traditional. Timber framed housing shows a saving of thirty five per cent in manhour content compared with local traditional and a twenty one per cent saving over rational traditional housing. With more thought given to such items as plaster jointing and claddings the manhour content can be reduced even further. However, it can be seen that the advantage of time saving cannot be overlooked by local authorities when choosing a system of housing.

5.7 Costs

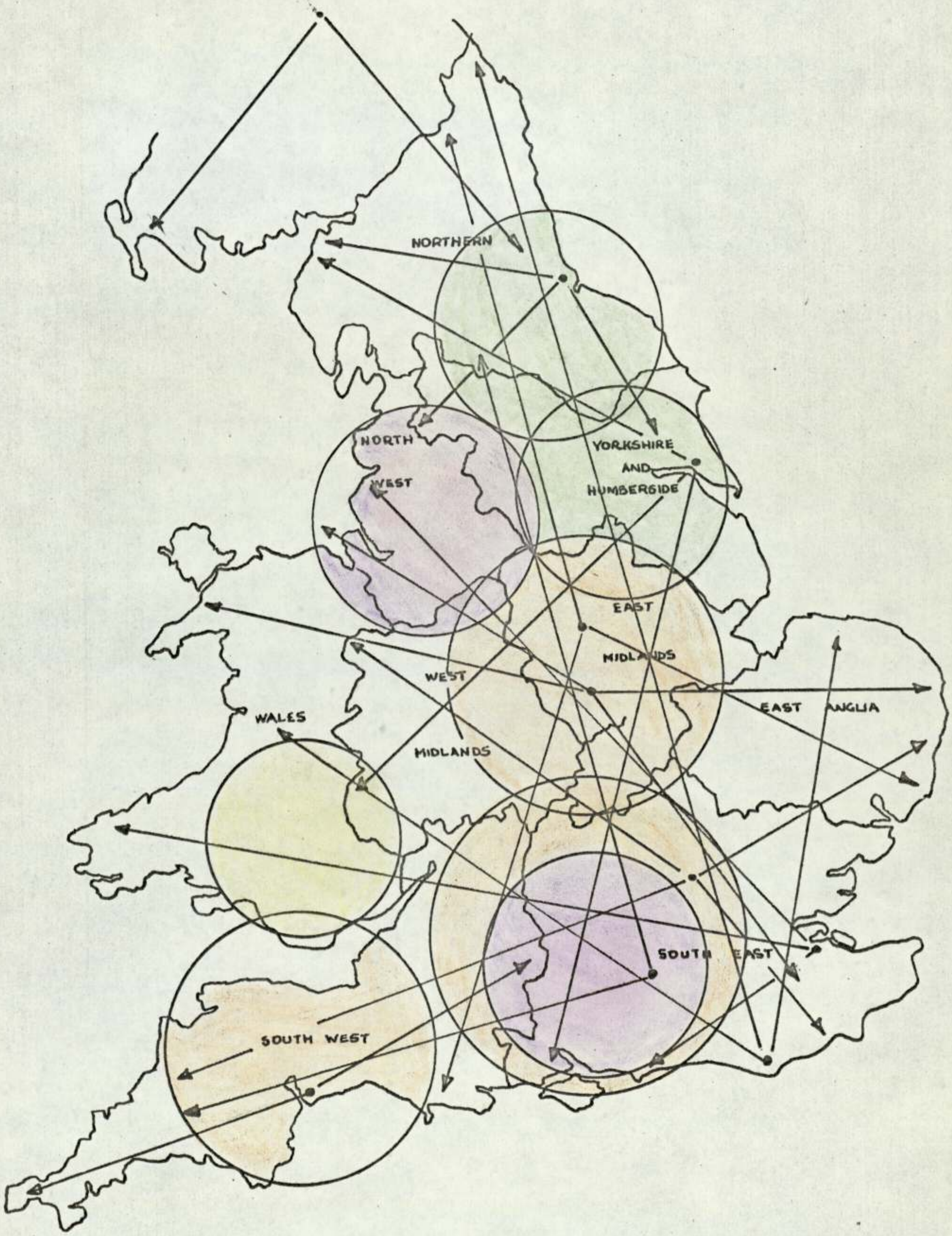
Since 1964 the cost (per sq.ft.) of traditional housing for local authorities has been lower than most industrialised methods. This was mainly due to the fact that Parker Morris standards, which were not mandatory until 1969, were being used in many industrialised systems. This has given a false picture for a period of five years. However, since Parker Morris standard became mandatory in 1969 the pendulum has swung the other way and for the first time housing costs are comparable. Fig. 5.5 shows the rising cost of housing over the period stated and also shows the cost increase for traditional when brought up to the same standards. The question of cost was not raised in the general questionnaire, partly because unreliable data might have been offered and partly because the time factor was all important i.e. the data in the questionnaire was collated prior to the cost effect of Parker Morris Standards. However, the companies who offered facilities for detailed study also offered costs for their work year by year. These costs, which were highly competitive, give an accurate cost trend for timber framed housing and are plotted on Fig. 5.5 for comparison with other methods. In this graph it can be seen that timber framed housing is cheaper than other forms of construction.

Reduction of Man Hours per unit for increase in batch size



* Stud and panel only
** Ditto with window frames
*** Ditto ditto with door hangings

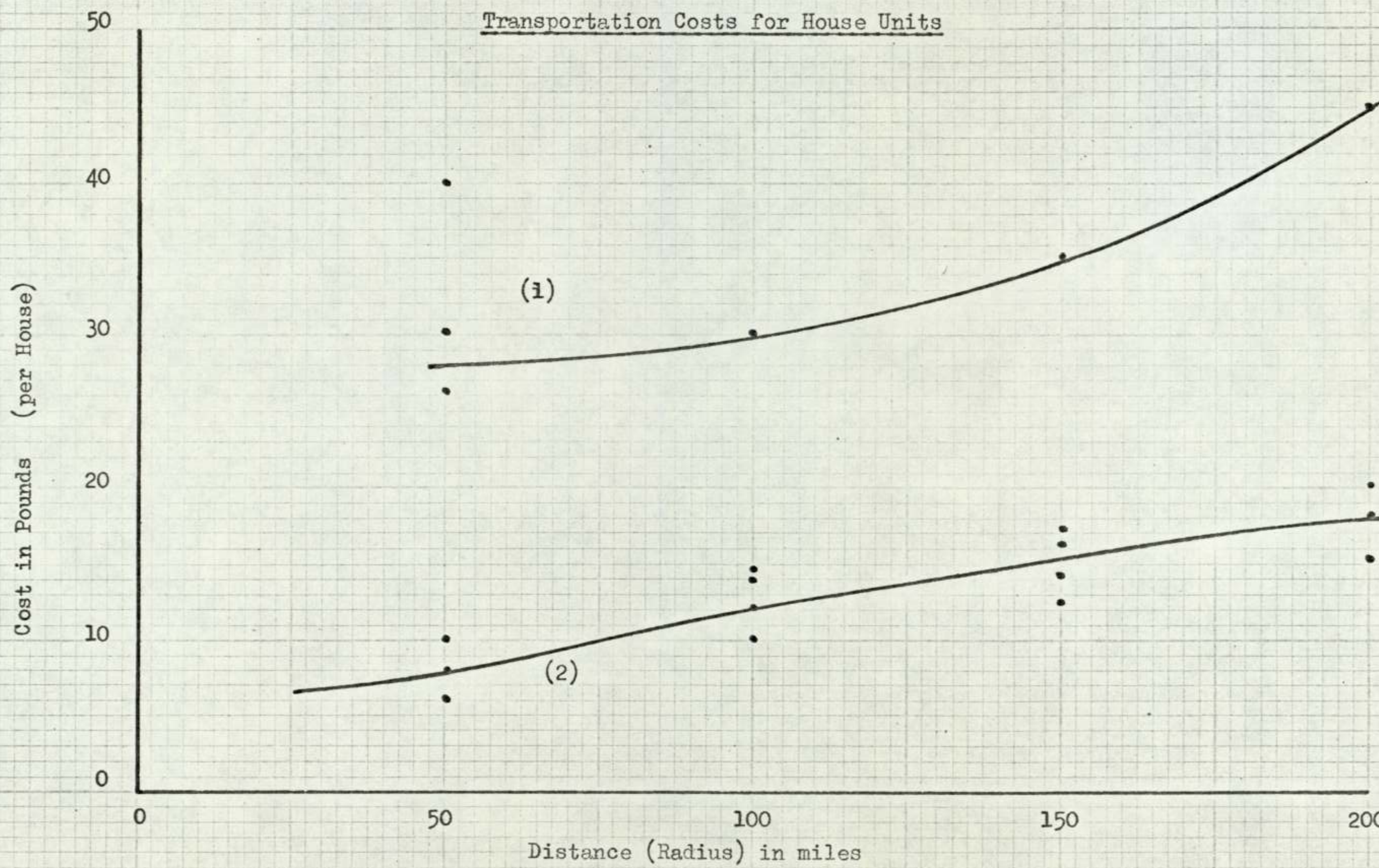
Fig. 5:2



Range of Distribution
(Timber Framed Houses)

Fig. 5: 3

Transportation Costs for House Units

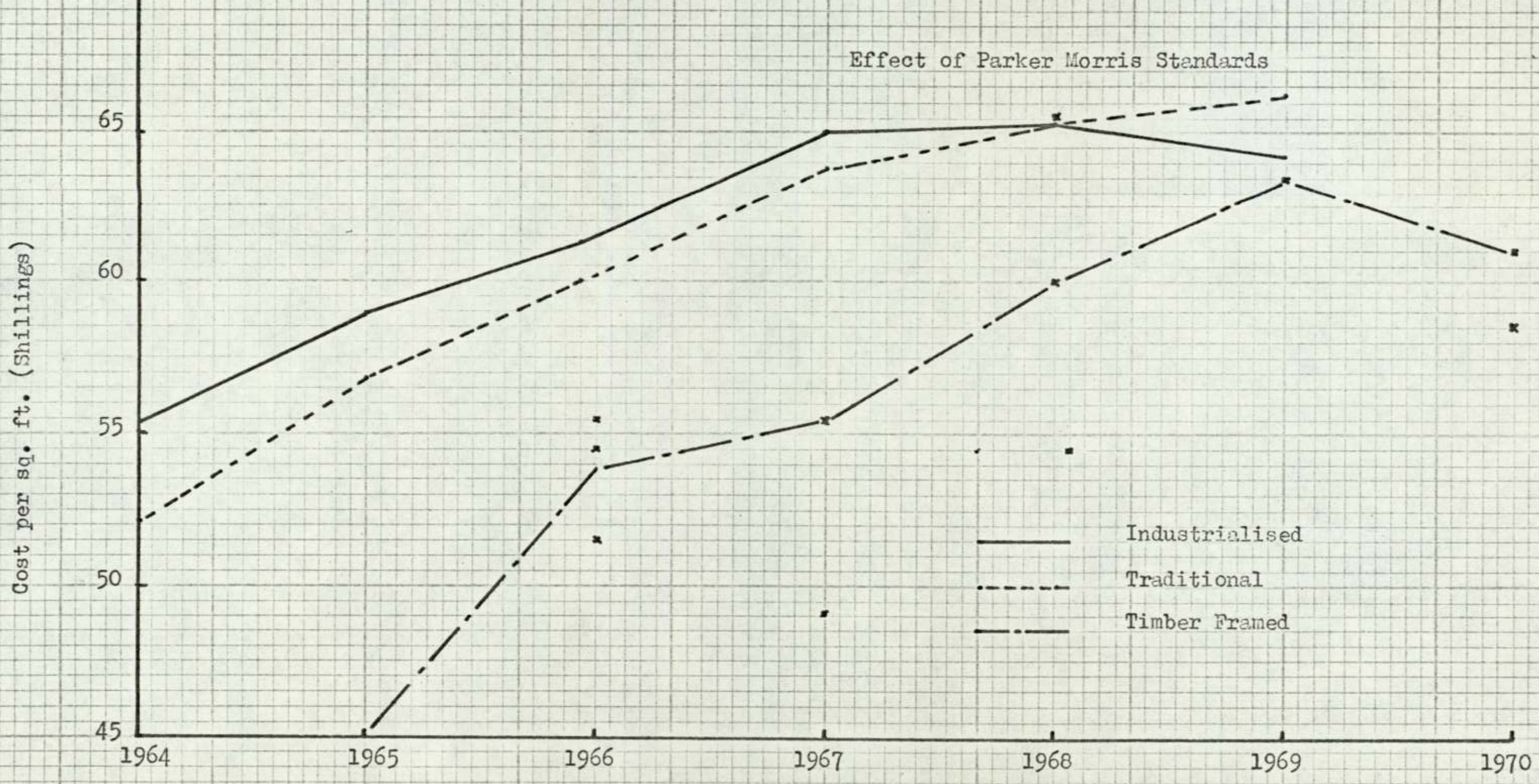


(1) Panels including doors, windows, insulation and battens.
(2) Panels with insulation only

Fig. 5:4

(Source: Table 5:3)

Comparative Cost of Housing - Industrialised and Traditional
(excluding cost of land, site works and garages)



(Source: 1. Housing Stats.)
2. Appendix

Fig. 5.5

Details of Timber Framed Housing

(Houses Completed)

(Five year period) (Ministry of Housing Stats.)

Firms	System	1965	1966	1967	1968	1969
Calders Ltd.,	Calder Homes	297	21	207	14	-
Canadian Timber Frame (Sys)	C.T.F.	-	-	8	122	45
George Calverley Ind. Bldgs	C.M.	-	6	33	176	272
Engineered Homes (Gt.Brit)	Engineered Homes	-	106	245	264	128
Guildway Ltd.,	Guildway	25	129	404	384	420
Vic Hallam	Mark 1.2.3	1002	1107	248	602	512
J.McLean & Sons	Mactrad	-	141	531	798	537
Medway Building Ltd.,	Medway	-	-	154	100	52
Midland Housing Consortium	M.H.C.	153	106	770	855	1033
James Miller & Partners	-	-	49	565	502	510
Minox Structures Ltd.,	Minox	-	-	126	73	261
Modern Building Wales Ltd.,	M.B.W.	-	-	-	11	14
Purpose Built Ltd.,	Purpose Blt	-	40	379	440	402
Quikbild Homes Ltd.,	Quikbild	20	168	213	442	385
F.J. Reeves	Reeves frame	-	21	48	42	50
James Riley & Partners	Frame form	-	-	39	189	405
W.J. Simms, Sons & Cook Ltd.	Simms C-DA	309	787	601	60	34
Spooner (Hull) Ltd.,	Caspon Urban	606	392	528	805	612
TRADA Timber Research and Development Ass.	Trada	-	40	91	5	-
Wates Ltd.,	Low Rise	-	8	30	245	688
Weir Housing Corporation	Weir Timber	-	267	100	104	462
William Old Ltd.,	Low Rise Resiform	-	-	-	20	54
Yorkshire Homes	Yorkshire	-	-	22	166	180
C.M. Yuill Ltd.,	C.M. Yuill	-	-	12	135	33
Local Authorities	-	-	-	214	509	880
Unit Construction Co, Ltd.,	Unit 66	-	113	562	772	461
	Total	2412	3501	6130	7835	8430

Table 5:1

Plant and Equipment used in the production of timber framed houses

Plant / Firm	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cross cut	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Panel Saw	*	*	*	*	*	*		*	*		*		*	*	*	*		*
Router							*					*						
Nailing Machine		*		*	*											*		
Nailing Guns		*		*	*			*		*	*	*		*	*	*	*	
Fork Lift	*	*			*			*			*			*	*			
Overhead Crane				*	*							*		*		*		*
Hydraulic Jig				*	*													
Fourcutter													*				*	
Stapling Jig									*									
Skill Saw							*											
Portable drills												*						
Spindle													*					
Door Hanging Machine		*																
Economic Production	1	24	100	100	1	1	50	100	20	20	100	3	20	50	400	50	20	50
Max. Production	100	N.L.	1000	1000	1000	10	N.L.	1000	500	20	1000	150	N.L.	N.L.	N.L.	N.L.	500	N.L.

Table 5:2

Transportation Costs for Timber Houses (based on 3 bed 5 person house)
in Pounds per Unit

Radius	Firm	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0 - 49 miles		-	-	-	10	-	-	10	10	-	30	26	40	5.6	-	-	-	6	8
50 - 99 miles		50	-	-	12	-	-	14	15	-	-	30	30	6.3	-	-	-	12	10
100 - 199 "		-	-	-	14	-	-	-	17	-	-	35	-	7	-	-	-	16	12
200 +		-	-	-	18	-	-	-	20	-	-	45	-	10	-	-	-	20	15
Normal Radius	mls	100			150			100	U.K.		30	600	100	200				150	U.K.
Amount of Prefabric.																			
Stud & panel only								✓						✓					
Ditto with insul.		✓			✓													✓	✓
Ditto with wnd. & dr.									✓		✓								
Ditto with tiling																			
battens & doors												✓	✓						

Table 5:3

Manhour Content for the Production
and Erection of Timber Framed Housing

Elements	Site	1	2	3	4	5	6	7	8
Sub-structure	S	120	125	72	100	120	145	128	160
	F	-	-	-	-	-	-	-	-
Wall Structure	S	103	77	143	164	23	139	100	62
	F	40	34	40	78	100	114	100	110
First Floor	S	9	2	10	24	22	6	20	6
	F	-	6	-	3	18	6	-	30
Roof Structure	S	11	22	16	28	15	19	20	18
	F	2	-	-	11	30	12	18	-
Roof Finishes	S	22	16	20	25	35	15	30	24
	F	-	-	-	-	-	-	-	-
Windows and Ext. Door Frames	S	2	9	12	5	11	6	10	8
	F	4	20	-	-	-	-	17	-
Rainwater Disposal	S	4	3	6	5	20	4	6	5
	F	-	-	-	-	-	-	-	-
Joinery 1st Fix	S	4	5	10	3	5	4	8	8
	F	-	-	10	-	17	4	12	-
Services	S	54	51	75	128	85	109	79	63
	F	-	14	-	-	-	-	20	-
Joinery 2nd Fix	S	38	54	50	64	150	42	30	101
	F	-	27	25	-	84	30	18	69
Wall and ceiling Finishes	S	88	80	95	94	32	64	98	77
	F	-	-	-	-	-	-	-	-
Ground floor Finish	S	22	11	15	24	36	14	12	14
	F	-	-	-	-	-	-	-	-
Glazing	S	2	8	6	4	6	8	4	7
	F	-	-	-	-	-	-	-	-
Int. and Ext. Decoration	S	47	41	75	88	110	48	90	120
	F	-	-	-	-	-	-	-	-
Scaffolding	S	8	6	11	8	15	10	8	11
	F	-	-	-	-	-	-	-	-
Miscellaneous	S	14	15	21	-	-	16	-	-
	F	-	-	-	-	-	-	-	-
TOTAL		594	626	746	856	844	815	828	893

Average Manhour Content = 775

S = Site Work F = Factory

Table 5.4

Manhour Content for the Production and Erection
of Rational Traditional Housing

Elements	Site	1	2	3	4	5	6	7	8
Sub-structure	S	120	120	120	120	120	120	120	120
	F	-	-	-	-	-	-	-	-
Wall-structure	S	295	118	259	161	215	217	364	302
	F	45	5	40	37	56	-	3	10
First Floor	S	21	8	10	35	45	41	17	44
	F	-	3	22	40	-	-	-	-
Roof Structure	S	24	30	27	13	100	50	45	61
	F	30	10	19	40	-	-	-	-
Roof Finishes	S	20	24	30	20	25	21	25	20
	F	-	-	-	-	-	-	-	-
Windows and Ext Door Frames	S	6	15	-	16	30	28	49	7
	F	-	-	-	-	-	-	-	-
Joinery 1st Fix	S	4	3	7	9	20	25	26	6
	F	-	-	-	-	-	-	-	-
Services	S	147	90	122	-	-	155	118	114
	F	-	-	-	108	97	-	-	-
Joinery 2nd Fix	S	32	43	86	40	80	80	58	110
	F	15	12	39	14	-	-	-	-
Wall and ceiling Finishes	S	52	136	31	45	70	127	206	94
	F	-	-	-	-	-	-	-	-
Ground Floor Finish	S	14	23	30	17	10	33	14	23
	F	-	-	-	-	-	-	-	-
Glazing	S	5	5	5	5	5	5	5	5
	F	-	-	-	-	-	-	-	-
Int. and Ext. Decoration	S	64	70	96	138	40	125	105	105
	F	-	-	-	-	-	-	-	-
Scaffolding	S	10	10	10	10	10	10	10	10
	F	-	-	-	-	-	-	-	-
Miscellaneous	S	-	-	-	-	100	78	-	-
	F	-	-	-	-	-	-	-	-
TOTAL		909	727	977	872	1027	1119	1177	1037

Average Manhour Content = 981

S = Site Work F = Factory

Table 5.5

REFERENCES

(1) - Timber Frame Houses. Designers and Manufacturers.
The Timber Trade Federation, October, 1969

(2) - Housing Statistics (Great Britain)
No. 17 April, 1970. H.M.S.O.

(3) - W.S. Forbes A Survey of Progress in House Building
(Building Technology and Management) April 1969 Vol VII
No. 4

PART 6 PRODUCTION ECONOMICS

PRODUCTION METHODS

A detailed and illustrated account of production methods used in the firms considered, precedes the data on production economics. This detailed account will assist in evaluating the various methods and production technology in common use.

6.1 Production Methods in Firm 'A'

Assembly Area

The assembly area consists of a pre-cast concrete portal building 34' wide and 165' long (in 11 bays). The building is an extension to the existing joinery workshop (Fig. 6.1). The total area of 5,600 sq.ft. is allocated to maching, storage of cut materials and assembly of panel units. The benches for assembly of panels are 8' 0" x 8' 0" (Fig. 6.2) allowing room for the largest panels to be made and at the same time capable of utilisation for joinery work. The arrangement of benches down one side of the work-shop leaves room for stacking of finished panels and the movement of fork lift trucks. Access to and from the assembly area is provided by sliding doors at either end of the workshop.

Material Storage

Ply and Canadian Lumber Standard (C.L.S.) are stored in the open yard prior to machining (Fig. 6.3). The finished units are also stored in open areas prior to transportation to site (Fig. 6.4). After the materials are cut to size they are stored alongside the benches and in racks adjacent to the benches.

Machining

On entering the storage yard end of the workshop the C.L.S. is crosscut by an automatic cross cut (Fig. 6.5) and the ply cut to size on a vertical frame panel saw (Fig. 6.6). The machines are manned by sawyers and labourers in a labour ratio 1:1 for each machine.

Method of Assembly

The benches have fixed stops to nail against when nailing the studs. These stops are left off one side of the benches to facilitate removal of the panels when complete. Simple plywood nailing jigs or templates have to be sorted for the various panel types (Fig. 6.7).

Studs are nailed by hand using 4" twisted nails (galvanised), the sheathing ply is stapled to the studs by air operated stapling guns. (Fig. 6.8). Lintols are made integral with the studs, 8" x 2" members separated by ply strips. Window frames are fixed into the panels prior to ply fixing, this allows the vertical plastic D.P.C. to be fixed with the sheathing. Guide lines, for stapling to studs are measured and lined in with straight and pencil.

Transportation

Transport to site is undertaken by prime mover and trailer unit (each 30 feet long and 8 feet wide). Each trailer unit is capable of carrying six complete frames (Fig. 6.9). The joinery, staircases, casings, doors, etc; can be carried by normal lorries (24'-0" long). Each load of joinery consists of six house sets, one set per house. (Fig. 6.10).

Loading panels on to the large trailers is carried out by a fork lift truck assisted by one labourer, this on average takes three hours per full load (six houses). Fig. 6.11, 6.12 show loading taking place.

Fig. 6.1
General view of work area for panel assembly

Fig. 6.2
Benches for panel assembly spaced to accommodate long 'balloon' type panels

Fig. 6.3

Storage of plywood and large panels

Fig. 6.4

Panels and timber in open storage

Fig. 6.5
Panel studs being cut on an automatic cross cut

Fig. 6.6
Plywood sheathing being cut to size
on a vertical panel saw

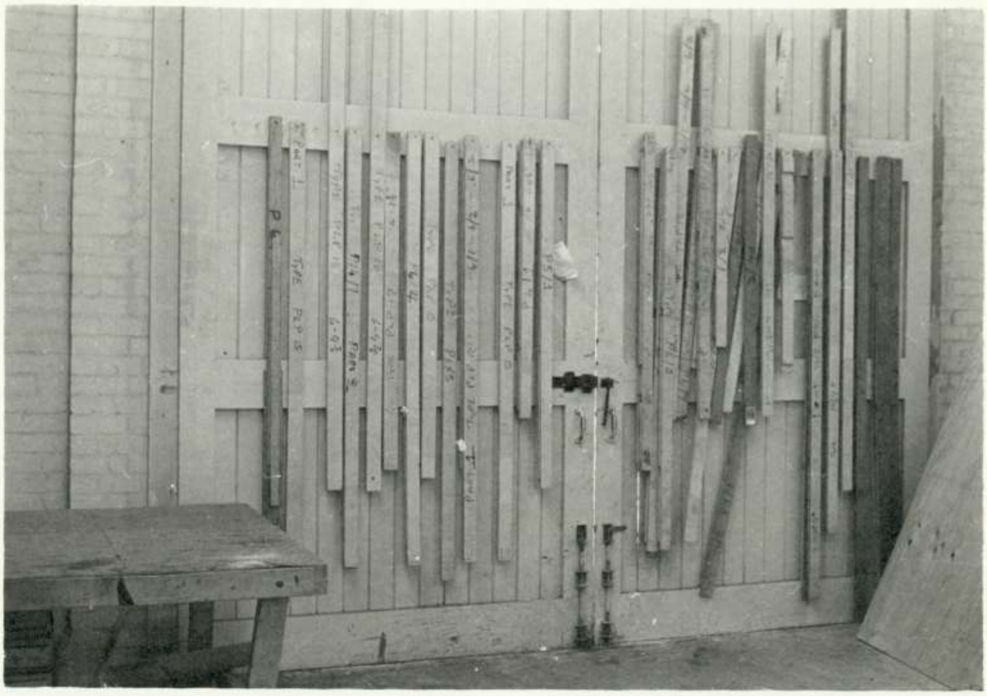


Fig. 6.7

Templates for panels hung on sliding doors

Fig. 6.8

Sheathing being fixed to 'Balloon' type frames using stapling guns

Fig. 6.9
Prime mover and trailer loaded with house panels

Fig. 6.10
Joinery sets being loaded to flat base lorry

Fig. 6.11

General view of storage area showing
plywood affected by water

Fig. 6.12

Trailer unit being loaded by fork lift truck

6.2 Production Methods in Firm 'B'

This company does not isolate machines for timber framed housing production, but utilizes all plant and machinery for diverse operations. This factor is overcome for price content by costing out each machine including floor space, general running costs, overheads and labour on an hourly rate. From work time-sheets a direct cost of machining can be allocated per house.

The company uses 'timborised' timber which is kiln dried prior to resaw, planing and cross cutting. Waste is kept to a minimum by returning all offcuts to the finger jointing machine which is used extensively for jointing studding for panel manufacture.

Assembly Area

The assembly area consists of a steel framed single storey building which is part of the general joinery department (Fig. 6.13). The actual area allocated to storage of material and for assembly and assembly of panels is 18,000 sq.ft. Almost 50% of this area is allocated to a nailing machine which has a twin assembly track (Fig. 6.14), which allows sub-assembly prior to ply fixing. Completed panels (excluding window and door inserts) are lifted onto a trolley by means of a hydraulic jib crane. (Fig. 6.15) prior to moving into storage.

In the rest of the assembly area the assembly of panels, wall, roof and floor panels, is manual. (Fig. 6.16). This is the normal procedure when the batch number of panels is too small to allow economic use of the nailing machine.

Material Storage

Ply sheathing and studding are delivered to the assembly area by fork lift truck and positioned by the assembly line by hand and fork lift truck. One labourer controls all the internal stacking and loading of materials.

Method of Assembly

In this factory there are no benches for the assembly of panels. Where nailing is used the machine has its own jig tables for moving the panels for various operations (roller mounted tracks). These jig tables are at the correct height for assembly. On this machine the panels are first of all sub-assembled, rolled a stage further for sheathing with ply, (temporarily stapled) moved across to the nailing track which feeds through the machine and then finally stapled in the areas over which the machine cannot nail (i.e. around window frames). The panels are then crane lifted onto trolleys and transported to the storage areas.

The nailing machine track will carry panels up to 25'0" long but at this length some difficulty is experienced in cranage onto the trolleys. Twelve men are involved in panel production on this machine:- two on sub-assembly, two on stud fixing and main assembly, two on panel fixing prior to machine nailing, two preparing for machine and completing stapling, two on loading trolleys (with aid of crane) and two men helping with various operations to fulfill machine loading programme. Where the batch size does not justify using this machine a small gang assemble units by hand. These panels are generally floor and roofing units (Fig. 6.17) but also include some wall panels. Where panels are hand assembled the work is carried out at floor level and never reaches a comfortable height for working till six or more wall panels have been completed (four in the case of floor units). Bottom panels were being used as the jig for the remainder of the panels in any one batch. Panels did not include window or door inserts, these are fixed on site.

Doors, however, were hung in the factory prior to delivery and the operations for cutting and boring holes for the furniture were completed in the factory.

Apart from the nailing machine, lay-out metal jigs were not used for panel assembly.

Transportation

Transportation to site was by prime mover and trailer unit (38'0" x 8'0"). Two trailers were used to carry six complete houses (this includes all wall, floor and gable end panels). A further two trailers carry fifteen sets of joinery (including staircases).

Prior to loading the panels have to be sorted from the stacking area and loaded by fork lift truck (Fig. 6.18). The time for loading six complete houses is one hour.

Fig. 6.13

General view of production shop for semi flow line production

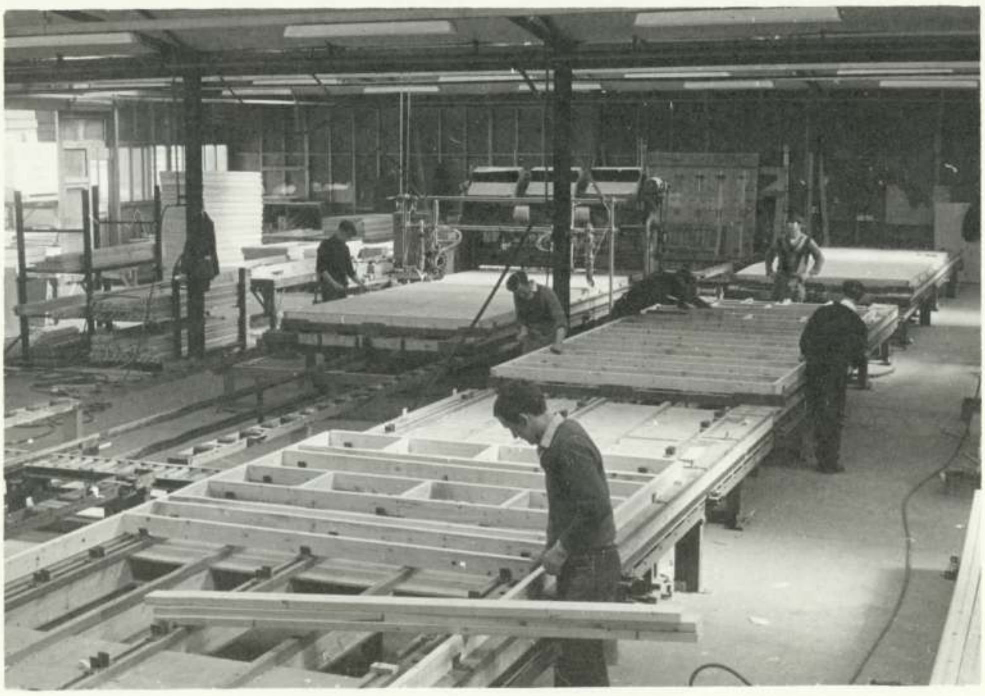


Fig. 6.14

Assembly line for automatic nailing machine

Fig. 6.15

Large panels being lifted from automatic track to trailer unit

Fig. 6.16

Assembly of floor units

Fig. 6.17

Roof trusses being assembled on jig frame

Fig. 6.18

Fork lift truck moving small panels to storage

6.3 Production Methods in Firm 'C'

Assembly Area

The assembly area in this instance was site based. A temporary factory, consisting of purpose made portal frame units with scaffold tube purlins and rails, was erected and sheeted with galvanised sheeting. (Fig. 6.19). The factory was 78' long and 40' wide, set on a concrete base. An automatic crosscut was installed for cutting studs, ply cutting and trimming were effectively carried out by a router.

Benches were made with slatted tops to accommodate the templates for the various panel sizes. (Fig. 6.20). Four benches were used solely for panel production and one further bench used for sundry work such as cutting packings and insulation materials.

These benches were placed along one side of the factory leaving ample room for materials to be positioned near the benches (Fig. 6.21).

Material Storage

Ply and C.L.S. were stored in a compound next to the site factory. Hand trolleys were used for bringing the materials into the factory. After cross-cutting, the C.L.S. was stacked adjacent to the benches ready for assembly. The ply was stored at both ends of the factory (Fig. 6.22).

Method of Assembly

Two carpenters worked at each bench, making panels in batches as required for erection. Both studs and ply sheathing were hand nailed. Window units and door units were not fixed in the factory, therefore ply sheathing could be applied without first cutting to size. Openings and edges were trimmed out with a router.

On completion, the panels were carried out through the adjacent door openings and stacked on a concrete hardstanding ready for site transportation (Fig. 6.23).

Transportation

A tractor and two trailers were used for taking panels to the exact site location (Fig. 6.24). All loading and off-loading was carried out by manual labour. Joinery is delivered separately to the site by sub-contractors.

6.4 Production Methods in Firm 'D'

Assembly Area

Similar to firms 'A' and 'B' the assembly area consists of a portal frame type building allowing room for movement of materials and finished panels (Fig. 6.25). Half the area is used for storage of units and assembly of prototype room units. The rest of the production area is set out with individual benches on which panels can be assembled, these benches are also utilised for other work.

Material Storage

Studs for panel assembly are stored alongside each bench in batch lots (Fig. 6.26). Ply is not used as a sheathing material so the storage space is greatly reduced.

Method of Assembly

Each bench is manned by one carpenter, who can get assistance from labourers when panels require moving. The first panel of every batch is used as the template for the rest of the panels (Fig. 6.27). Panels are normally made in batches of twenty and put into open storage (Fig. 6.28).

Unlike the normal method of sheathing with ply these panels are covered with felt, stapled onto the studs. Where necessary, window frames and door frames are fixed into the panels prior to felting.

Two other areas are set aside for assembly of floor units and roof trusses. The floor units consist of 2"x9" joists framed into

4'-0" x 15'-6" sections. Chipboard is resin bonded to the joists before the sections leave the assembly area. (Fig.6.29). The finished floor sections are stacked in open storage awaiting transportation to site (Fig. 6.30).

The roof trusses are assembled on special jig benches (Fig. 6.31) and (Fig. 6.32.) and impregnated in a purpose built tank (Fig. 6.33) prior to stacking.

Transportation

This operation is completed by using large trailer vehicles as in the other companies. The exception is found in the loading which takes place by hand. At present machine loading is hampered by stacking methods (Fig. 6.34), where panels are stacked vertically.

Fig. 6.19
General view of production area in site factory

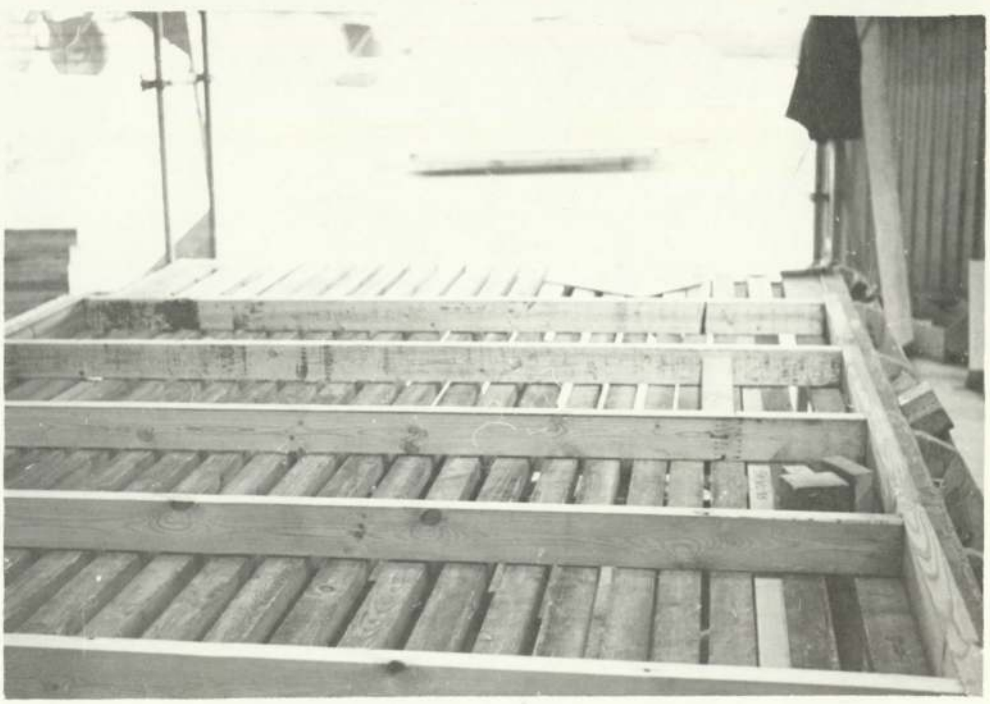


Fig. 6.20

Slatted benches accommodate templates for
the various types of panels

Fig. 6.21

Production of panels restricted to one side of factory

Fig. 6.22

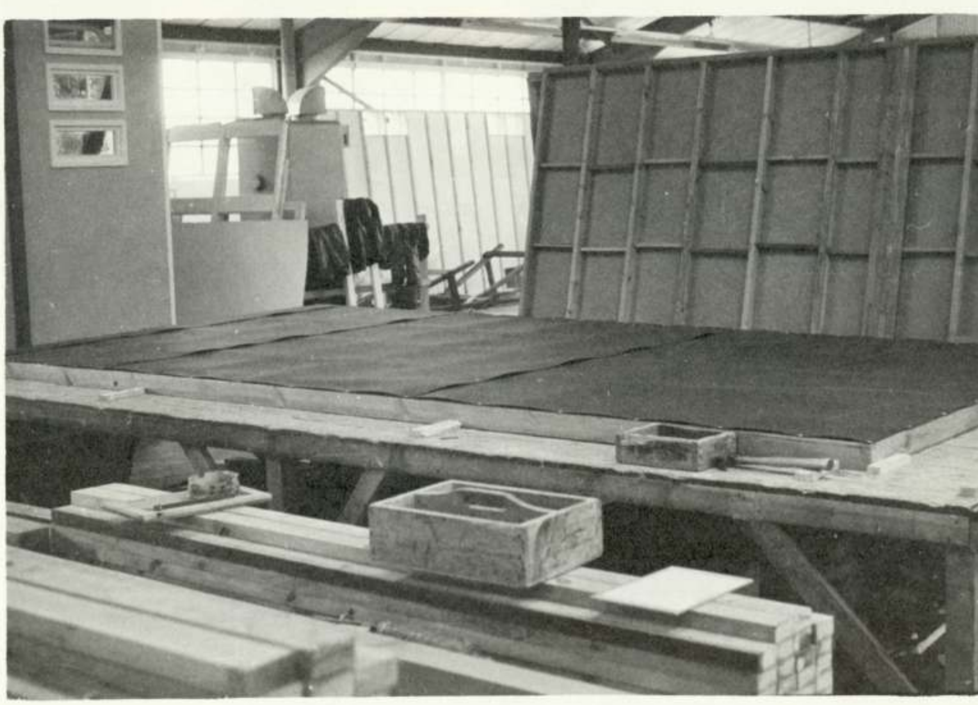
Material cutting, sorting and stacking in site factory

Fig. 6.23
Tractor and trailer used for site transportation

Fig. 6.24

Panels stacked alongside slab for erection

Production area for panels in Firm 'D'
Fig. 6.25



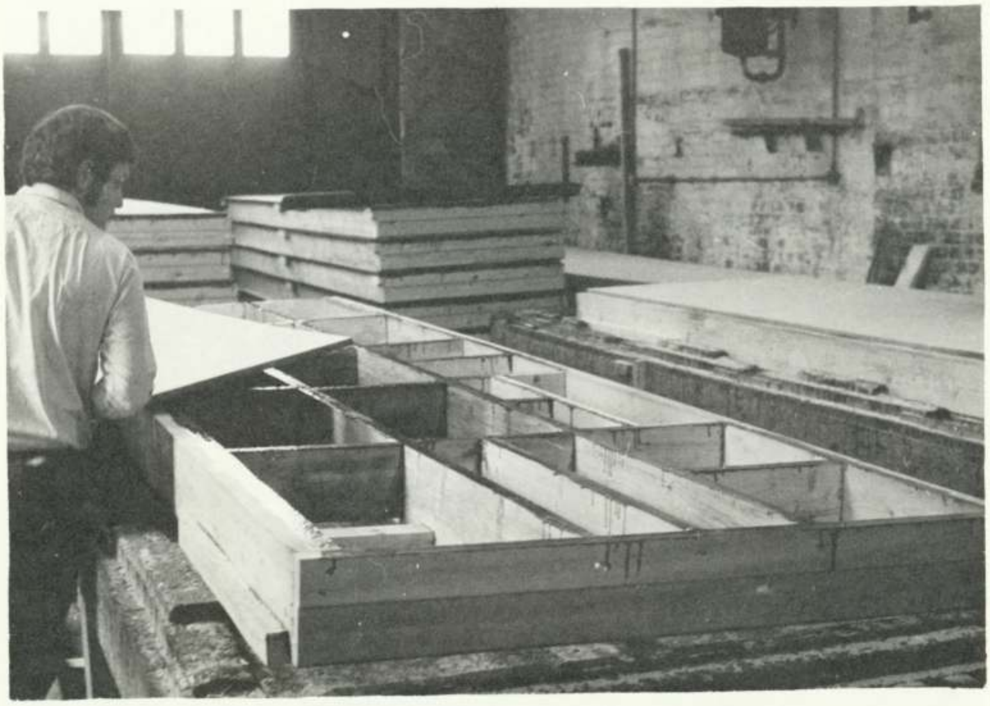
Material stored at bench in batch lots
Fig. 6.26

Bottom panel being used as template for
a set of panels

Fig. 6.27

Panels stacked in open storage

Fig. 6.28

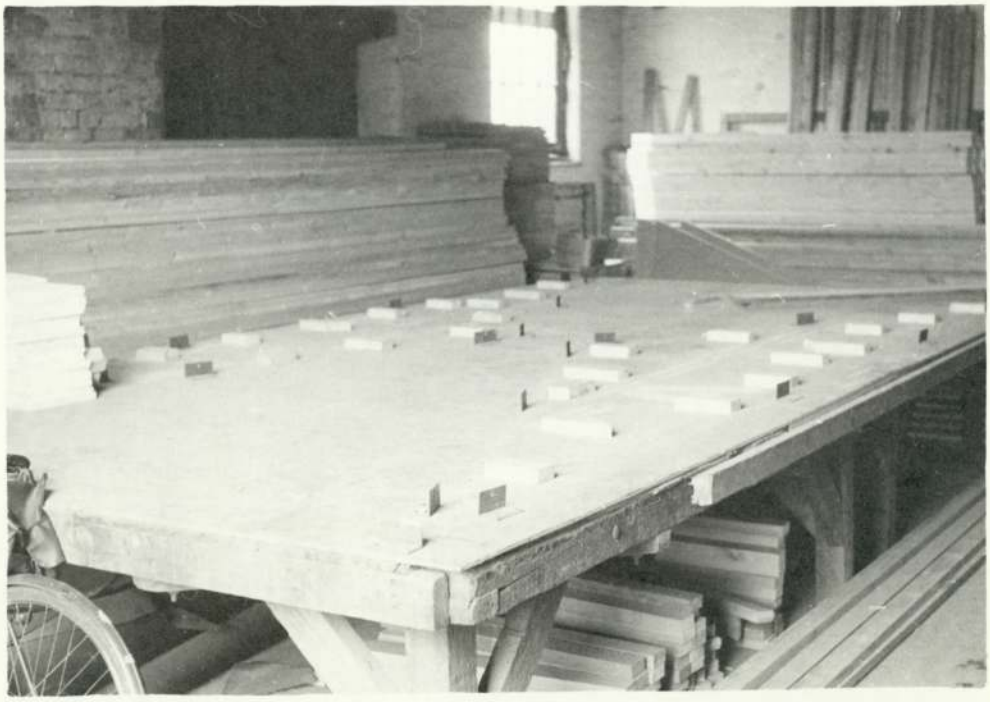


Production of floor units showing deck
in process of being glued

Fig. 6.29

Storage of floor units prior to
transportation (in block lots)

Fig. 6.30



Simple bench jig for roof trusses
Fig. 6.31

Completed roof truss on bench jig
Fig. 6.32

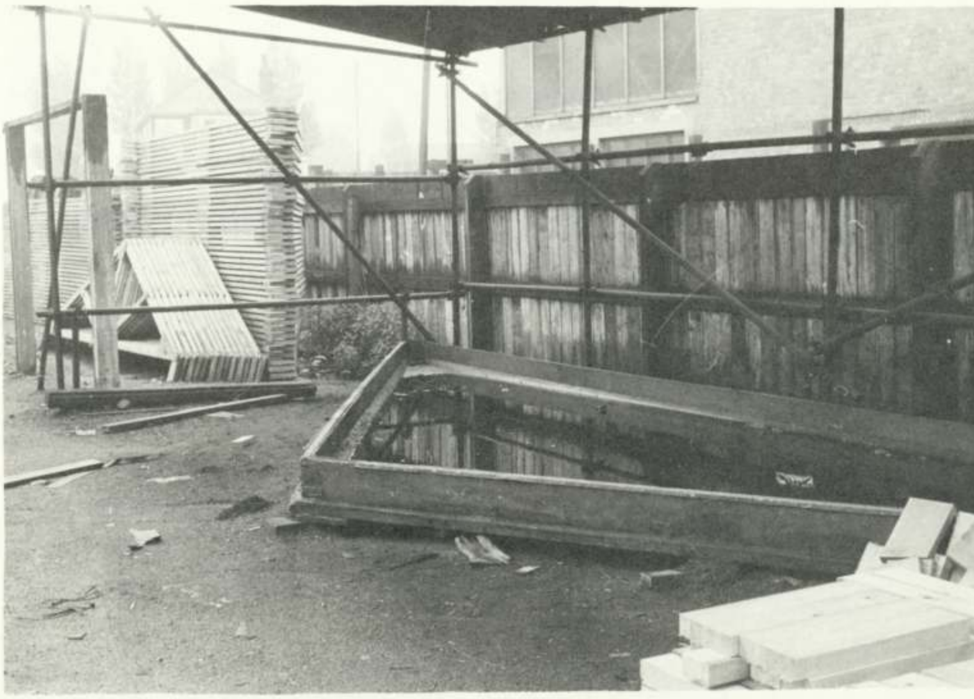


Fig. 6.33

Purpose made dipping tank for roof trusses

Fig. 6.34

General view of loading area

6.5 Production Costs

Each factory set up was costed for fixed and variable production costs. Details of the individual cost data are shown in Appendix 5.

The studies were made on firms 'A', 'B', 'C' and 'E'. The methods of production were sufficiently different to warrant a detailed study of each firm. The methods of Firm 'D' were not directly comparable with the general trend in timber framed housing and therefore their costs were not included.

Calculations for each factory set up are shown below giving fixed costs per week for all costs incurred prior to production. In addition to the fixed cost (A), the variable cost (x), is shown. The variable costs are shown for both basic labour and for labour including oncosts and incentive payments. The latter is shown in a tabulated form (Table 6.1).

Using the formula * $C = \frac{A + Bx}{Q}$ the production cost per unit for each method is shown and plotted in Fig. 6.35 and 6.36. Since all the firms considered were working on incentive based production, the comparison of costs in Fig. 6.35 is the most realistic for the timber trade to consider.

* C = Cost per unit of production

A = Constant for fixed costs

B = Quantity of units

Q = Total quantity per week

This shows clearly that site production is more economic than any other form of production. The only limitation to site production is the number of units produced per week, which is normally between twelve and twenty units. Since most sites can be adequately served by such a production flow and in most instances a site factory would only serve one site, this method of production must not be overlooked.

The only strong challenge to hand production on site is the method shown for Firm 'E', where the production line is fully automatic, with the exception of sheathing. This innovation, in the timber framed panel field, known as "The Hurn Numerical Control Panel Manufacturing System" is capable of producing 10,000 ft. run of panel per week. The system consists of an assembly point, fully mounted with automatic nailing and drilling equipment, pneumatic jigs and multi-position sill assembly unit. Gravity rollers feed string members and receive finished panels. Material for assembly is stored in bins adjacent to the assembly point and both placed and selected according to lights on the bins. The sawyer feeds the bins as the master control panel dictates, thus keeping the supply of cut material to a minimum.

The whole system is controlled by an Airmec A.E.I. Autoset N410 control unit. Into this unit a production tape is fitted, punched with data for the production of a complete house or set of panels. The assembly operator controls the master unit from a control panel, simply pressing a 'Go' button each time a stud has been fitted. On pressing this button the master unit instructs the sawyer on lengths of timber to be selected for cross cutting, automatically sets the saw and saw stops, as well as showing the sawyer where to place the cut pieces. All operations are carried out simultaneously which results in drastically cutting down the 'lead time' of operations.

The cost of production by this automatic system is shown on Fig. 6.35 and it can be seen to be an economical production method where demand exceeds fifteen units per week.

However, the cost of basic production is not the only criterion for choosing production methods. The method of production will determine the potential rate of production and the ideal place for production i.e. site or factory orientated. The former involves storage costs and the latter transportation costs.

Fixed and Variable Costs for Production

Firm 'A'

Fixed Costs

	£	s	d
Rates	400	-	-
Insurance	300	-	-
Canteen facilities	75	-	-
Staff Wages	2000	-	-
Office overheads	3000	-	-
Cost of factory (per annum)	420	-	-
Plant and machinery	1148	-	-
	£7343	-	-

Fixed Cost (A) per week - £147

Variable Costs (based on 10 houses per week)

	£	s	d
Lighting, heating and power	500	-	-
Loading	1000	-	-
Saw sharpening	50	-	-
Setting out	200	-	-
Cleaning workshop	100	-	-
Plant repairs	1100	-	-
Labour (based on 40 hr. week) 8/- hour	8000	-	-
	£10950	-	-

Units 10 x 50 = 500 per annum

Variable Cost (x) per unit - £22

Production Cost (Firm 'A')

Cost per unit of production = $\frac{A + B x}{\text{Total Quantity}}$

Where A = Constant (fixed cost per week)

B = Quantity

X = Cost per unit (variable)

Production Cost per Unit					
Prod.per Week	A	B	BX	A+Bx	Cost per Unit (£)
2	147	2	44	191	95.5
4	147	4	88	235	59.0
6	147	6	132	279	46.5
8	147	8	176	323	40.5
10	147	10	220	367	36.7
12	147	12	264	411	34.2
14	147	14	308	455	32.5
16	147	16	352	499	31.2
18	147	18	396	543	30.0
20	147	20	440	587	29.4

Production Cost for Firm 'B'

Fixed Costs

Rates	)	
Insurance	)	
Canteen facilities	)	
Staff Wages	)	per week £271.20
Office Overheads	)	
Cost of Factory	)	
Plant & Machinery	)	

Variable Cost (based on 30 units)

Handling and cutting materials	per unit	£13. 4. 0.
Nett labour making	per unit	4. 6. 0.
		£17. 10. 0.

x = £17.5

Production Costs					
Prod. per Week	A	B	Bx	A+ Bx	Cost per Unit (£)
2	271.2	2	35	306.2	153.0
4	271.2	4	70	341.2	85.4
6	271.2	6	105	376.2	62.6
8	271.2	8	140	411.2	51.3
10	271.2	10	175	446.2	44.6
12	271.2	12	210	481.2	40.0
14	271.2	14	245	526.2	37.6
16	271.2	16	280	561.2	35.0
,18	271.2	18	315	596.2	33.0
20	271.2	20	350	631.2	31.5
25	271.2	25	438	666.2	26.6
30	271.2	30	525	701.2	23.4

Production Costs (Firm 'C') Site Factory

Fixed Costs	£	s	d
Rates	200	-	-
Insurance	150	-	-
Staff	2000	-	-
Site Office overheads	150	-	-
Offloading timber	1214	-	-
Factory set up	2857	-	-
Total	£6751	-	-
Factory cost per week	£131		

Variable Costs	£	s	d
Lighting and Power	50	-	-
Plant repairs	25	-	-
Factory repairs and alterations	257	-	-
Nett labour cost for making frames	6750	-	-
	£7082	-	-

Units produced (equivalent 5p 3 bed) = 365

(x) Variable Cost per unit £19.4

Production Cost per Unit

Prod. per Week	A	B	BX	A+ Bx	Cost per Unit (£)
2	131	2	38.8	169.8	84.9
4	131	4	77.6	208.6	52.2
6	131	6	116.4	247.4	41.2
8	131	8	155.2	286.2	35.8
10	131	10	194,0	325.0	32.5
12	131	12	232.8	363.8	30.2
14	131	14	271.6	402.6	28.6
16	131	16	310.4	441.4	27.6
18	131	18	349.2	480.2	26.6
20	131	20	388.0	519.0	25.8

Production Costs for House Units

(including labour oncosts and bonus)

Firm 'A'

Constant ('A') = £147 per week

x (including labour oncost and bonus)

		£	s	d
Variables	=	2950	-	-
Basic Labour	=	8000	-	-
Bonus 20%	=	1600	-	-
Oncosts 33⅓% (£8000)	=	2666	-	-
		15216	-	-

Units per annum based 20% increased - 500 + 100 = 600 units

'x' Cost per unit = £25.4

Firm 'B'

Constant (A) = £271.2 per week

x (including labour oncost and bonus

	£	s	s
Handling and cutting mat. per unit	13	4	4
Basic labour (based on 30 units per week)	4	5	6
Bonus 20%		19	6
Oncost $33\frac{1}{3}$ labour	1	8	6
	19	17	10

Cost per unit £19.9

Firm 'C'

Constant (A) = £131

x (including labour oncost and bonus)

		£	s	d
Variable cost	=	332	-	-
Nett man hours	16937 x 8/-	6750	-	-
Bonus 20%	=	1350	-	-
Oncost 33⅓%	=	2250	-	-
		10682	-	-

Units produced $\frac{16937}{38}$ = 447

Cost per unit = £23.8

Production Costs for Timber Framed Houses
(incl. labour on cost and bonus)

Prod. per Week B	Firm 'A' A = £147			Firm 'B' A = £271.2			Firm 'C' A = £131		
	Bx	A+ Bx	Cost per Unit (£)	Bx	A+ Bx	Cost per Unit (£)	Bx	A+ Bx	Cost per Unit (£)
2	50.8	197.8	98.5	40	311.2	155.0	47.6	178.6	89.3
4	101.6	248.6	62.0	80	351.2	88.0	95.2	226.2	56.5
6	152.4	299.4	50.0	120	391.2	65.0	142.8	273.8	45.6
8	203.2	350.2	43.8	160	431.2	54.0	190.4	321.4	40.0
10	254.0	401.0	40.1	200	471.2	47.1	238.0	369.0	36.9
12	304.8	451.8	37.6	240	511.2	42.5	285.6	416.2	34.7
14	355.6	502.6	35.8	280	551.2	39.4	333.2	464.4	33.0
16	406.4	553.4	34.6	320	591.2	37.0	380.8	511.6	32.0
18	457.2	604.2	33.6	360	631.2	35.0	428.4	559.8	31.0
20	508.0	655.0	32.8	400	671.2	33.68	476.0	607.0	30.4
25	635.0	782.0	31.2	500	771.2	30.8	595.0	726.2	29.0
30	-	-	-	600	871.2	29.0	-	-	-
35	-	-	-	700	971.2	27.8	-	-	-

Table 6.1

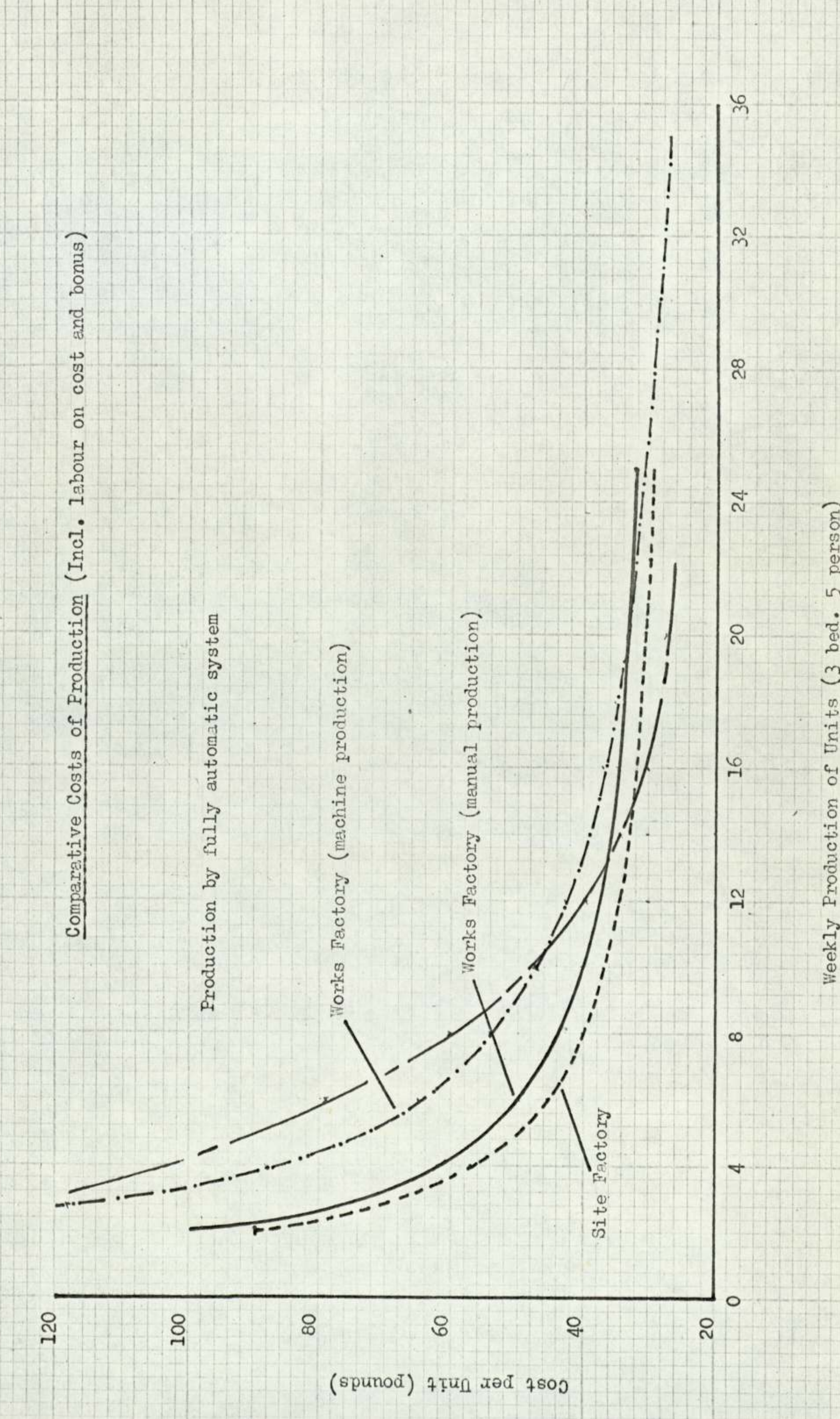

Comparative Costs of Production (Incl. labour on cost and bonus)
Production by fully automatic system
Works Factory (machine production)
Works Factory (manual production)
Site Factory
Cost per Unit (pounds)
120
100
80
60
40
20
0
4
8
12
16
20
24
28
32
36
Weekly Production of Units (3 bed. 5 person)

Fig. 6.35

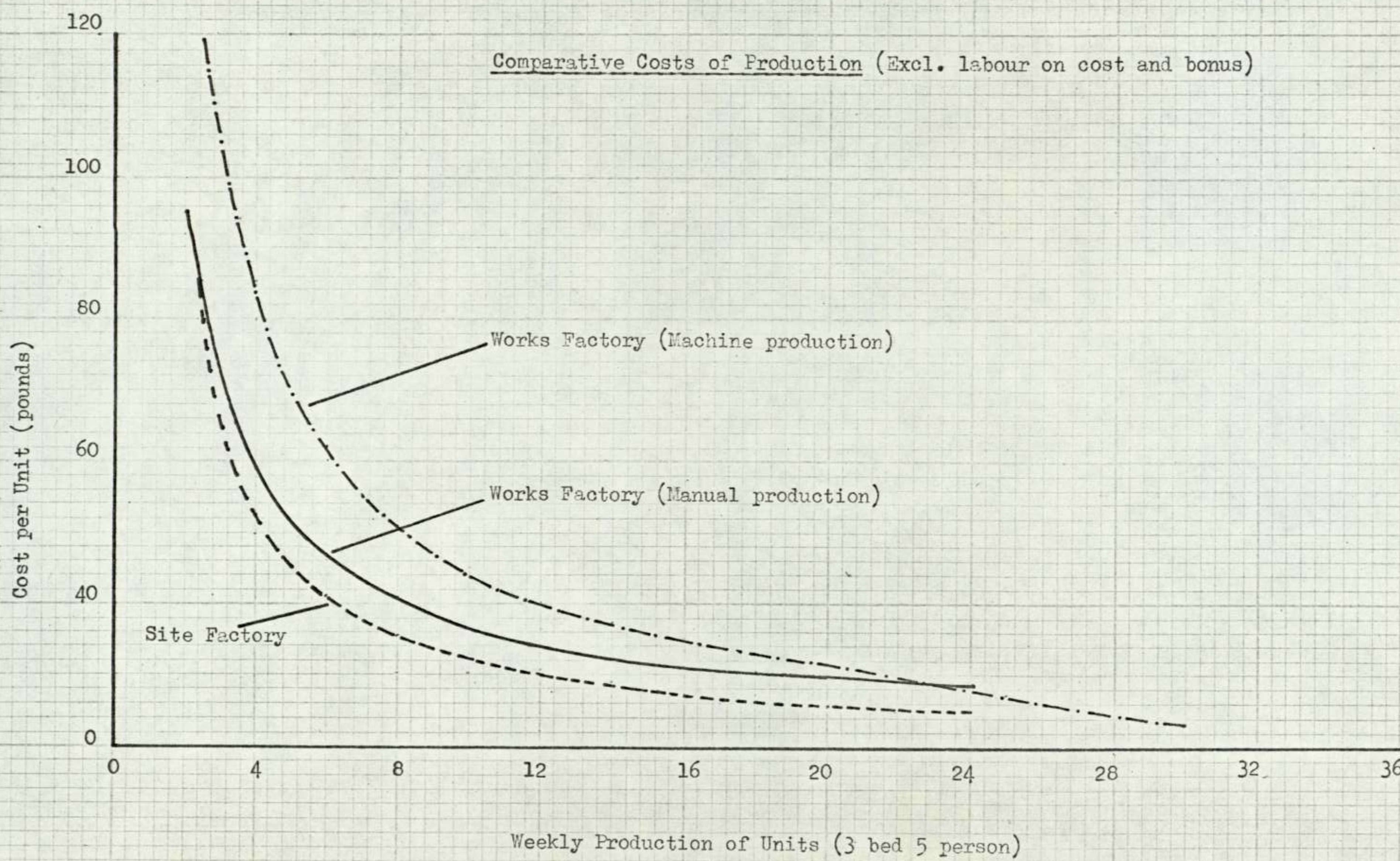

Comparative Costs of Production (Excl. labour on cost and bonus)
Works Factory (Machine production)
Works Factory (Manual production)
Site Factory
Cost per Unit (pounds)
120
100
80
60
40
0
0
4
8
12
16
20
24
28
32
36
Weekly Production of Units (3 bed 5 person)

Fig. 6.36

6.6 Storage and Transportation Costs

In addition to the cost of production, costs for storage and transportation must be considered. When the production exceeds the current site demand beyond that which is necessary to ensure continuity on site, the cost of storage may offset any gain achieved by increased production. The cost is not only that tied up in land rent but the real cost of capital tie up and interest on the capital.

Firm 'A' kept a maximum of twenty houses in stock, which were in stock an average of one month before moving to site.

Firm 'B' held a very large stock of houses at a time. Each house was in stock an average of three months. The main reason for stock holding was very high output of the semi-automatic production line. The output was always in excess of site demand.

Firm 'C' had no storage costs at all, since the site factory produced units for the programmes rate of erection.

In the case of Firm 'A' the nett cost due to interest on capital holding is as follows:

20 units @ £200 (capital value)			=	£40000
Interest on capital 10%			=	£400 p.a.
Charge per month	=	$\frac{400}{12}$	=	£34
20 units cost £34	=	£1.7 per unit		

In the case of Firm 'B'

1 unit @ £200

Interest on capital @ 10%	=	£20
Nett storage cost for three months	=	£5 per unit

This differential must be considered when choosing a system of production. The cost of storage, incurred by increased production, must be less than the differential of average production costs shown in Fig. 6.41. The first criterion for choosing the most economic production method is that of current demand which will keep storage cost to a minimum.

The second criterion for choosing a production system is complexity of panel construction. Where the system has been designed for cranage, or where the amount of factory work on panel prohibits manhandling, the cost of storage and transportation will rise accordingly. The complexity will also determine whether site factories can be used.

Transportation

The cost of transportation shown in Fig. 5.5 indicates that complex panel construction increases transportation costs threefold. A dwelling of average size costs twenty to thirty pounds more to transport, depending on distance to site, than a simpler form of sheathed panel.

Firm 'A' produced panels with window and door inserts but excluding any other form of work. The cost per unit for an average distance of fifty miles was £12.0.

Firm 'B' produced simple sheathed panels without inserts and the cost per unit was £7.

Firm 'C' produced panels on site thereby eliminating the main transport cost. However, some cost was incurred by site transport. A tractor and trailer was used to transport panels from the site factory to the place of erection. The cost of this transport is reduced by the fact that for fifty per cent of the time on site it is used for moving other materials. The cost per unit was £4.5. On the average cost for a fifty mile delivery, Firm 'C' saved approximately £5 per dwelling on transport.

The total saving for transport and storage on site 'C' was £7.5 compared with Firm 'B' and £9.2 against Firm 'A'. An average of £8 per unit must be considered when establishing the break-even point of the various methods of production Fig. 6.36. Site production of panels, where complexity is kept to a minimum, is the most economic method of panel production. However, this is only applicable when the number of units produced per week is below twenty five, and where contracts exceed 200 units.

Further economies, in factory costs, can be achieved for a site factory set up by using air houses (Fig. 6.42 and 43). This type of factory has not been fully exploited and initial costs over a ten year period are less than half of the kwik form type factory.

Where the number of units produced exceeds twenty per week and where site factories are not practical i.e. supply only firms, the fully automatic plant should be considered.

Assuming stock holding to be nil, since units can be produced in any order without difficulty or increase in cost, and transportation to be £10 per unit, the cost per unit becomes economic at thirty units per week (Fig. 6.35). However, where contracts are gained for over two hundred units, the setting up of individual site factories should be considered. (Fig. 6.37).

Where companies are both suppliers of panels to other contractors, and main contractors themselves, the fully automatic system will prove most economical. The flow of work can be quickly changed from one design of panels to another without affecting the improvement curve in production. This is because panel assembly requires no re-thinking time, this is done by the control panel.

The cost of storage and transportation have been stated but the alternative to storage, namely production to delivery demand, requires further amplification. Where production is reduced to delivery rate the cost of reduced production cannot easily be offset by deployment of labour and plant. Where this is the case the total cost for producing at optimum rate will be divisible by production of delivery rate. This means that costs, for producing at a production rate of 0.6 can be as high as sixty seven per cent greater than when producing at optimum rate. Calculations based on the tabulated data in Table 6.1 show the effect of producing at reduced rates.

<u>Example</u> (Firm 'A') <u>Table 6.1</u>

$$\text{Production Rate} = \frac{\text{Rate of Demand}}{\text{Rate of Optimum Production}}$$

Optimum Production = 25 units per week x 50 weeks
= 1,250 units.

Rate of Demand = 750 (assuming 0.6 production rate)

Total Cost of Optimum Production = 1250 x £31.2
= £39,000

Cost of producing at rate of demand (assuming inability to deploy labour and plant) = $\frac{39000}{750}$ = £52 per unit

Percentage increase per unit = $\frac{(52.0 - 31.2)}{31.2}$ = 67%

Production Rate of 0.7 = 875 units per annum

Production Rate of 0.8 = 1000 units per annum

Production Rate of 0.9 = 1125 units per annum

Percentage increase per unit	Increase %
Production Rate 0.7	43
" " 0.8	25
" " 0.9	11

Calculations for Firm 'B', where the optimum production is fifty units per week, and Firm 'C' show this increase to be constant. The figures are plotted on the graph in Fig. 6.38.

Where production rate is kept to the optimum the cost of storage can be calculated. Fig. 6.39 shows the percentage of total quantity which, when multiplied by total delivery period gives the number of units/weeks storage.

Example

Order 400 units

Optimum production - 25 units per week

Delivery Rate   15 units per week

Total Delivery Period - $\frac{400}{15}$ = 27 weeks

Delivery Rate = 0.6

From Fig. 6.40   0.6 rate = 20%

Total storage = 20% x 400 x 27 weeks

= 80 x 27 weeks = 2160 units/weeks

Cost per week say £2

Total storage cost = £4320

Cost per unit of order = £10.8

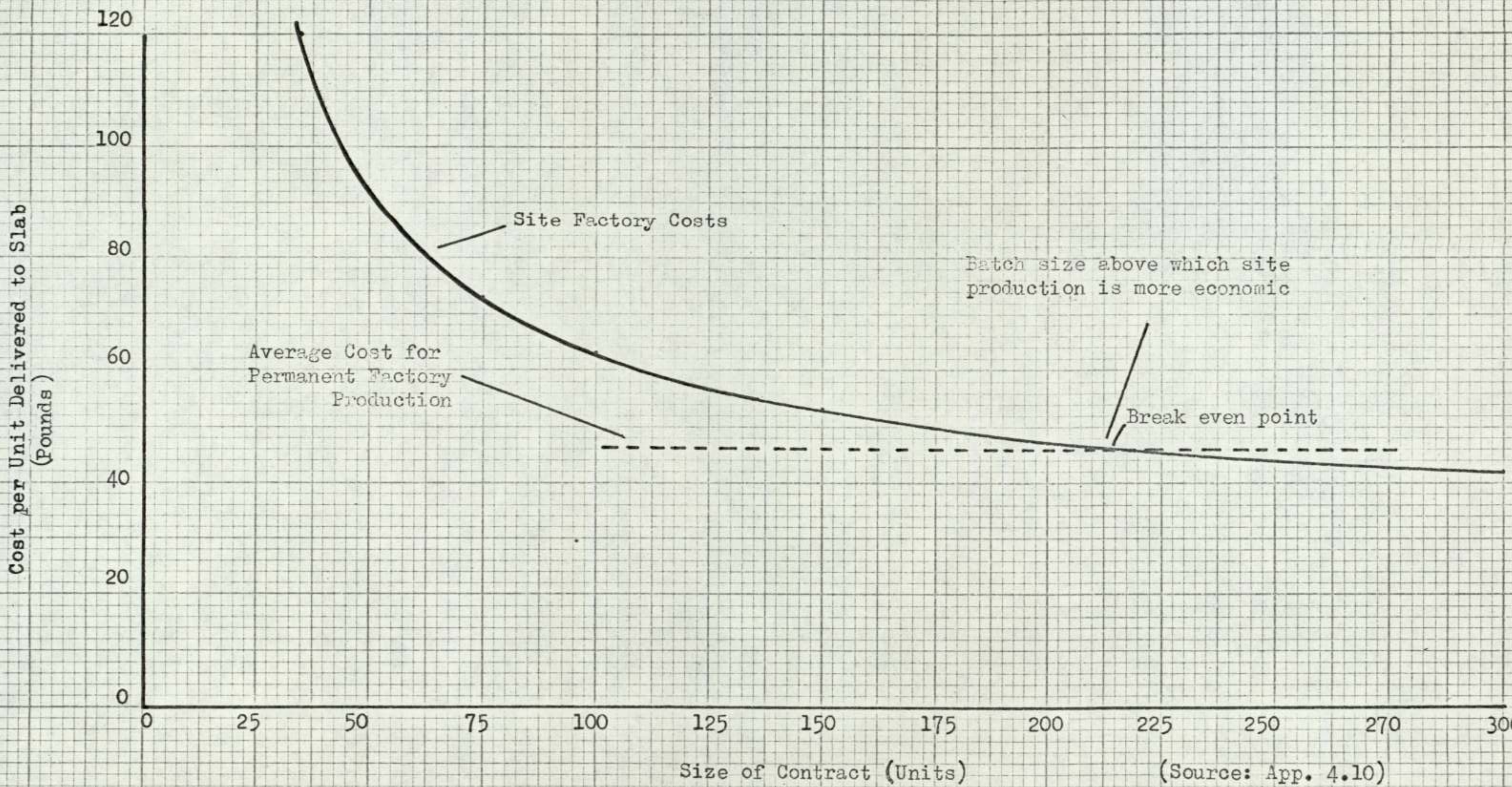
Therefore storage cost for various delivery rates are:

Where order = 400 Optimum production 25 units per week

Delivery Rate	Storage (Unit Weeks)	Total Cost	Cost Per Unit	* Percentage Increase on Optimum & oncost
1.0	Nil	Nil	Nil	Nil
0.9	354	708	1.77	5.7
0.8	800	1600	4.00	12.8
0.7	1354	2708	6.90	22.1
0.6	2160	4320	10.80	34.7

* Based on £31.2

Comparison of Costs for Site Factory and Permanent Factory Production



(Source: App. 4.10)

Fig. 6.37

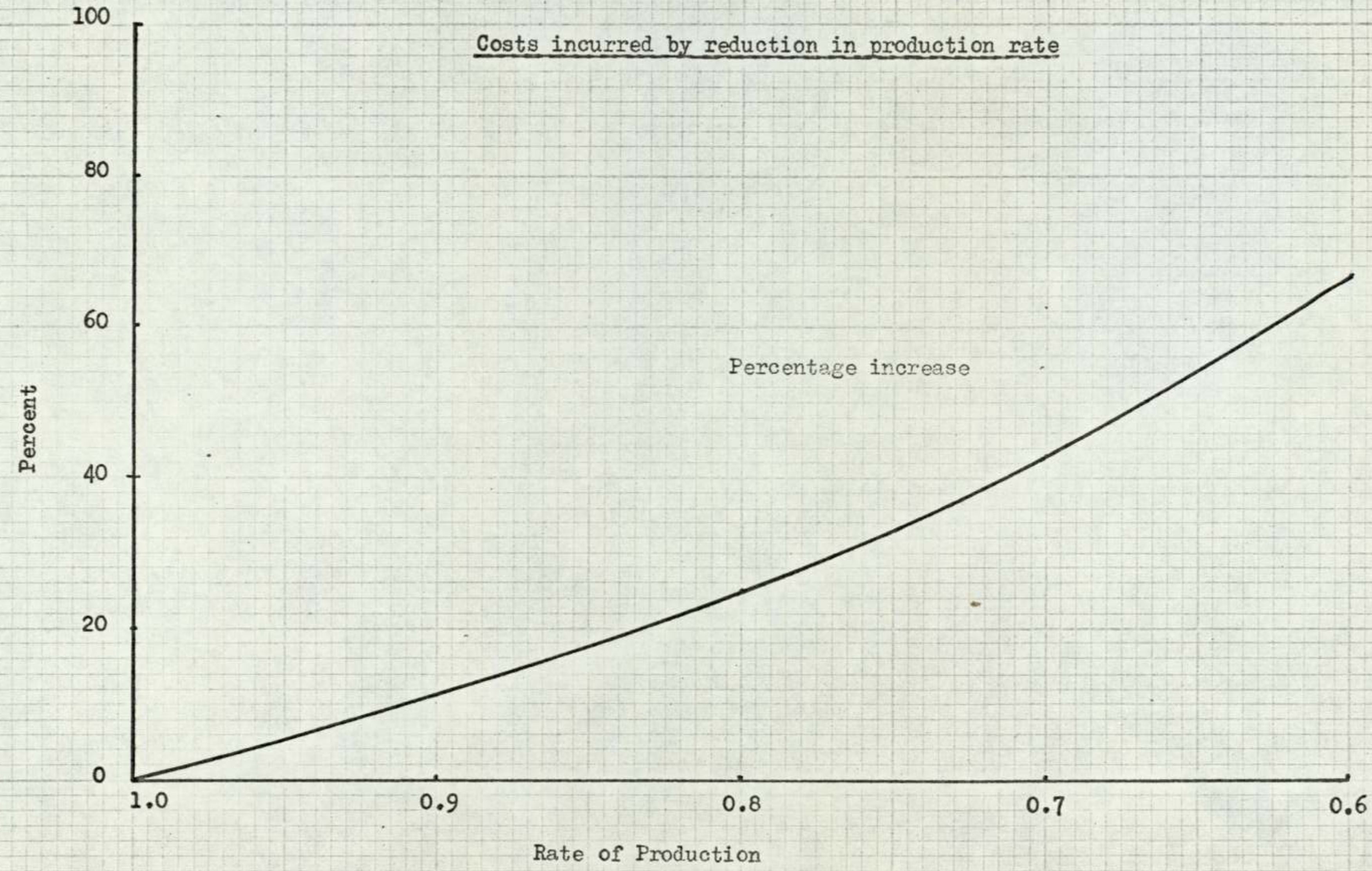

Costs incurred by reduction in production rate
Percentage increase
Percent
100
80
60
40
20
0
1.0
0.9
0.8
0.7
0.6
Rate of Production

Fig. 6:38

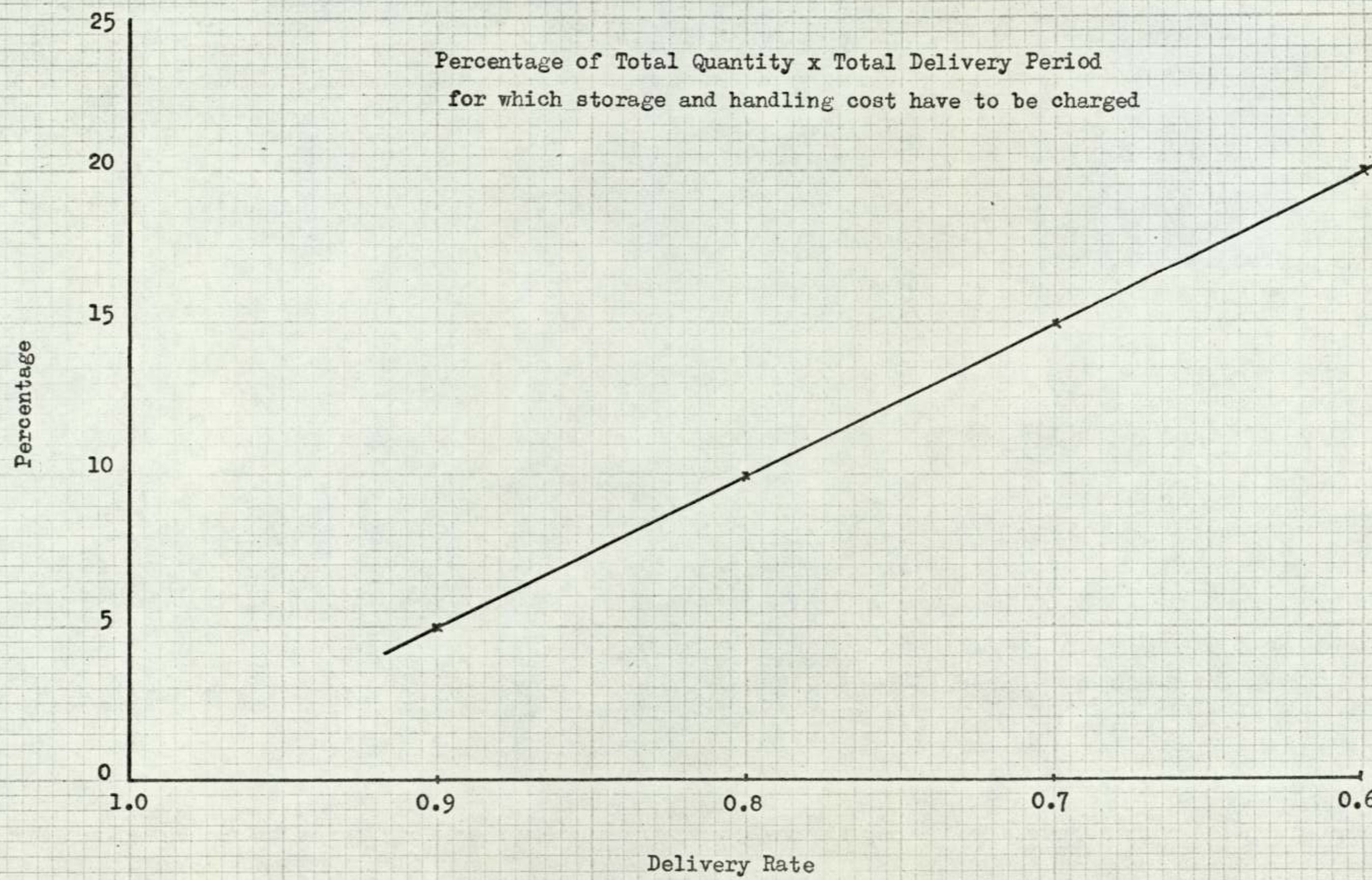

Percentage of Total Quantity x Total Delivery Period
for which storage and handling cost have to be charged
Percentage
25
20
15
10
5
0
1.0
0.9
0.8
0.7
0.6
Delivery Rate

Fig. 6:39

Increased costs due to reduced production may be greatly reduced by deploying labour. This does not affect the cost of plant and costs based on practical deployment of labour as shown in Table 6.1.

From these figures the actual increase can be calculated (as below) when labour is deployed to balance reduced production.

Production Rate	Actual Cost Per Unit	Increase on Optimum	Percentage Increase
1.0	31.2	Nil	Nil
0.9	31.9	0.7	2.24
0.8	32.8	1.6	5.10
0.7	33.6	2.4	7.7
0.6	35.0	3.8	12.2

From these figures a second cost curve can be plotted. This now shows the effect of mobility of labour on production costs. (Fig. 6.41). In some factories, where joinery is the main aspect of work, labour can easily be placed on the production of joinery. This pre-supposes that the labour for producing timber panels is skilled.

For a delivery rate of 0.6 the production rate should be reduced to 0.85 where labour cannot be deployed and to 0.735 where labour can be deployed. For other rates of delivery the cost of storage must be plotted separately. (Fig. 6.40).

However, there are instances where panels have been kept in storage longer than anticipated and therefore incurred a much higher cost per unit than shown by the graphical solution.

6.7 Production of Sheathed Panels

In addition to normal production of studded panels the method of sheathing i.e. machine nailed or hand nailed must be considered.

Data from Firms 'A', 'B' and 'C' was analysed over a number of months. Firms 'A' and 'C' hand nailed all ply sheathing, the former using stapling guns. Firm 'B' used a nailing machine in conjunction with a semi-automatic production track.

From Fig. 6.41 it can be seen that the average cost for hand nailing panels, for an average 3 bedroom/5 person house, is £15. This cost was the same, within a few shillings per unit, for both firms using hand nailing methods. The break-even point for machine nailing against the average hand nailing is twenty units per week.

The average cost for machine nailed panels, over a considerable production period was £12.5 per unit. This is achieved by producing twenty five units per week. The break-even point for hand nailing (on site) against the average machine nailing cost is nineteen units per week. Where the work was carried out in a factory with stapling guns, the break-even point is fourteen units per week. In the latter case the data was for unmixed batches.

From this data it can be seen that machine nailing of sheathing is only economical for a production rate of over twenty four units per week. Below this rate of production the stapling gun is the most economical, with hand nailing, although not as economical, still a better proposition.

The Hurn Numerical Control System produces at such a fast rate that the labour force for sheathing the panels may prove to be too large for normal production units. When producing at a normal rate of 2000 foot run of panel per day it requires eight men to cope with sheathing. When considering this method of production this factor must be considered, since a large sheathing gang cannot be easily deployed if demand falls.

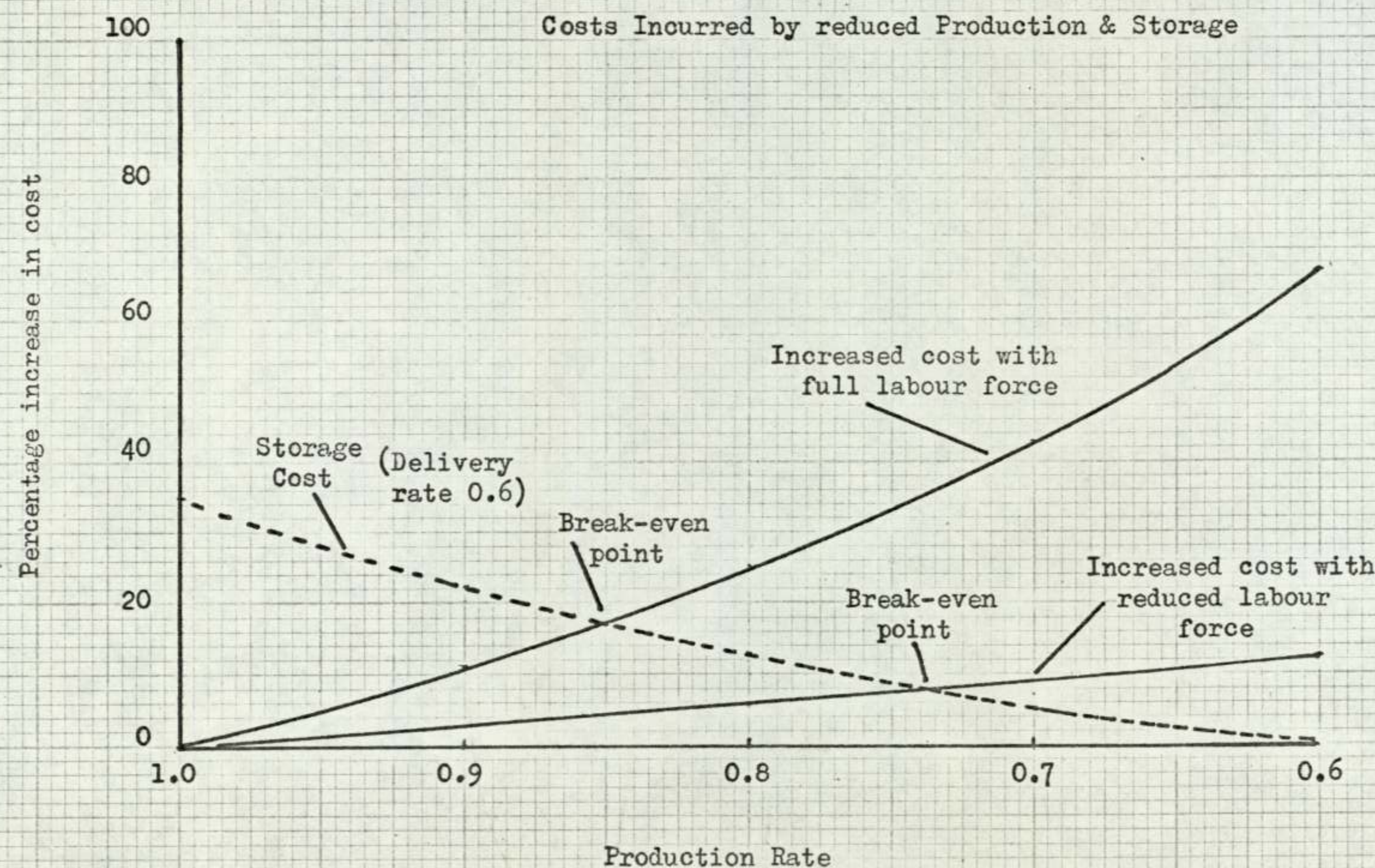

Costs Incurred by reduced Production & Storage
Percentage increase in cost
100
80
60
40
20
0
1.0
0.9
0.8
0.7
0.6
Production Rate
Storage Cost
(Delivery rate 0.6)
Break-even point
Increased cost with full labour force
Break-even point
Increased cost with reduced labour force

Fig. 6:40

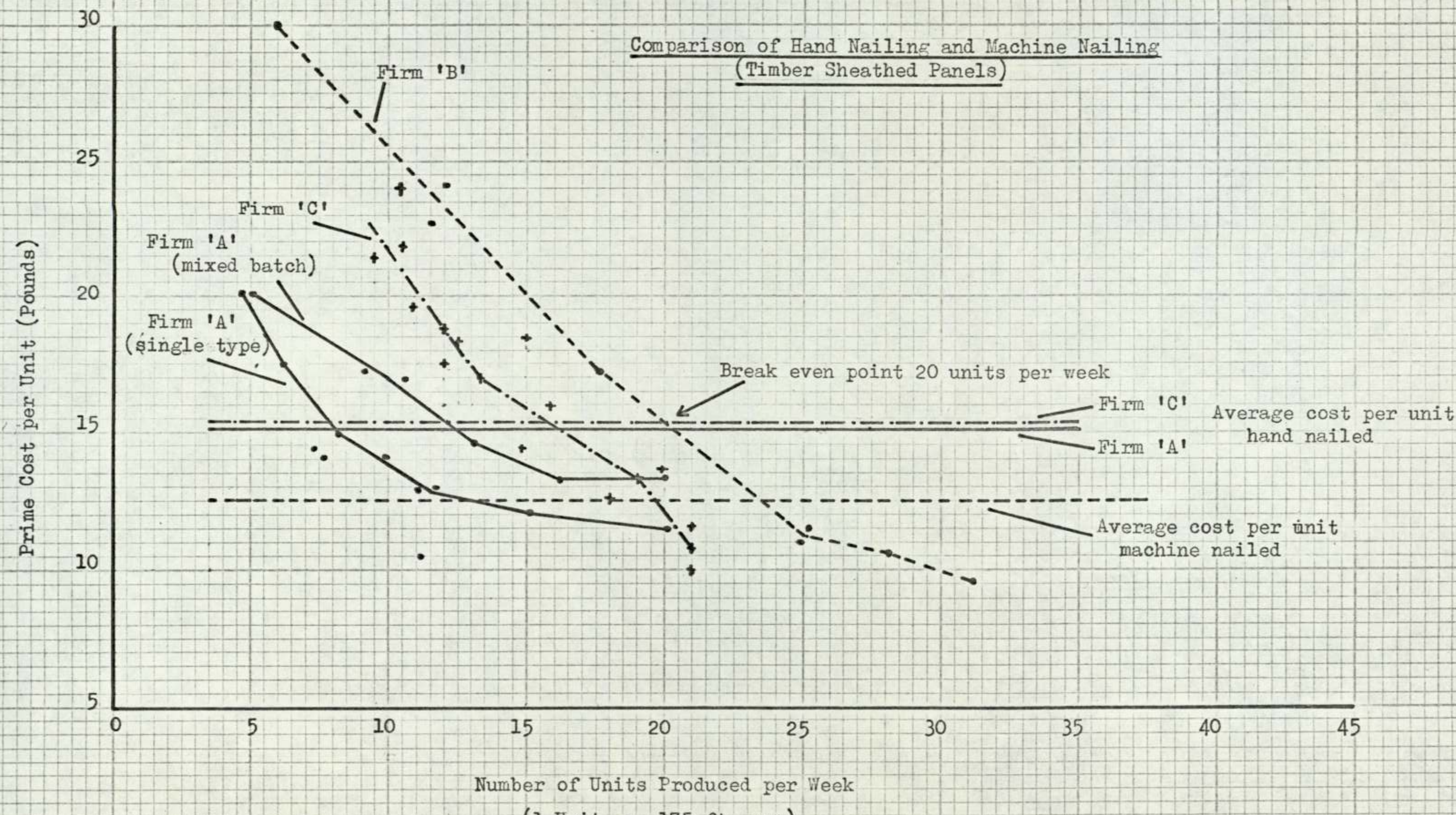

Comparison of Hand Nailing and Machine Nailing
(Timber Sheathed Panels)
Firm 'B'
Firm 'C'
Firm 'A'
(mixed batch)
Firm 'A'
(single type)
Break even point 20 units per week
Firm 'C'
Firm 'A'
Average cost per unit
hand nailed
Average cost per unit
machine nailed
Prime Cost per Unit (Pounds)
30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
Number of Units Produced per Week
(1 Unit = 175 ft. run)

Fig. 6.41

Fig. 6.42
General view of Air House showing passage entrance for fork lift trucks

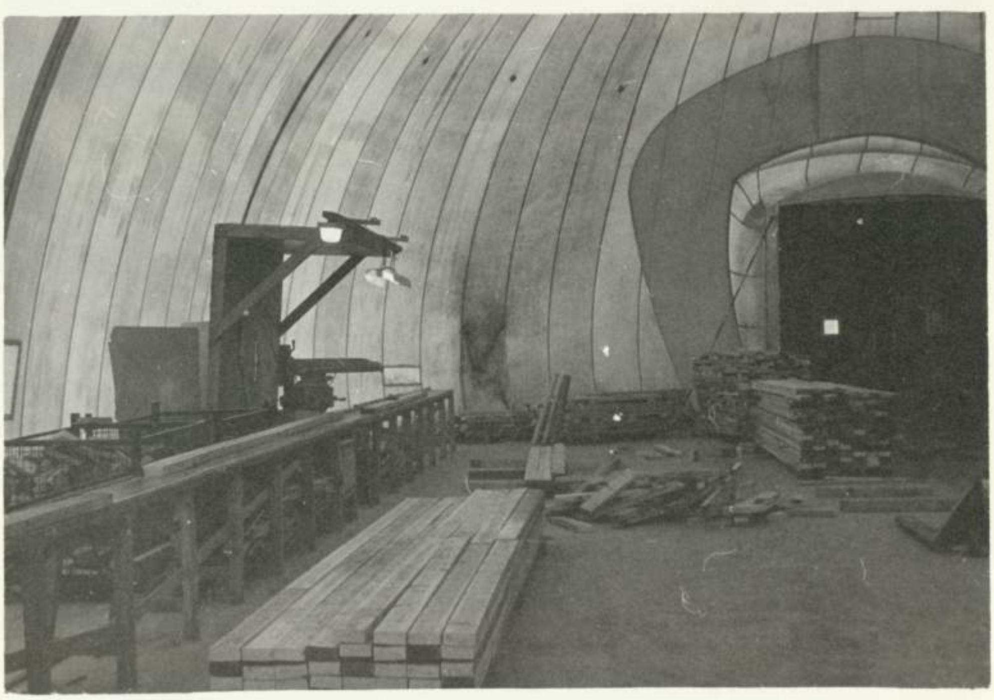


Fig. 6.43

Internal view of Air House showing cross cutting machine and cut studding

6.8 Improvement Curves

The improvement curve or learning curve in production has been something of a mystery to most manufacturers and in consequence little has been done to approach the subject systematically.

The data below shows that there are various factors which affect improvement curves, some of which are hard to define and measure. The first factor is simply batch size or continuity of work. Fig. 6.44 to 6.47 all show that continuity of work on similar panel frames will give improvement in time. However, a second factor, namely complexity, determines the amount of learning time and Fig. 6.45 shows the effect of improvement on simple 'balloon frame' panels. When compared with relatively complex panels, which included windows and door frames (Fig. 6.44) it can be seen that the shape of learning curve is fundamentally different. The main reason for the greatly reduced improvement curve in Fig. 6.45 is monotony. The panels were too simple to motivate the men to further productivity. There is sufficient evidence to show that a certain amount of complexity, which increases cycle time, has the effect of giving satisfaction to workers and therefore becomes a motivator to higher production(1). This is a factor which must be considered when establishing the amount of work which any one man can handle effectively.

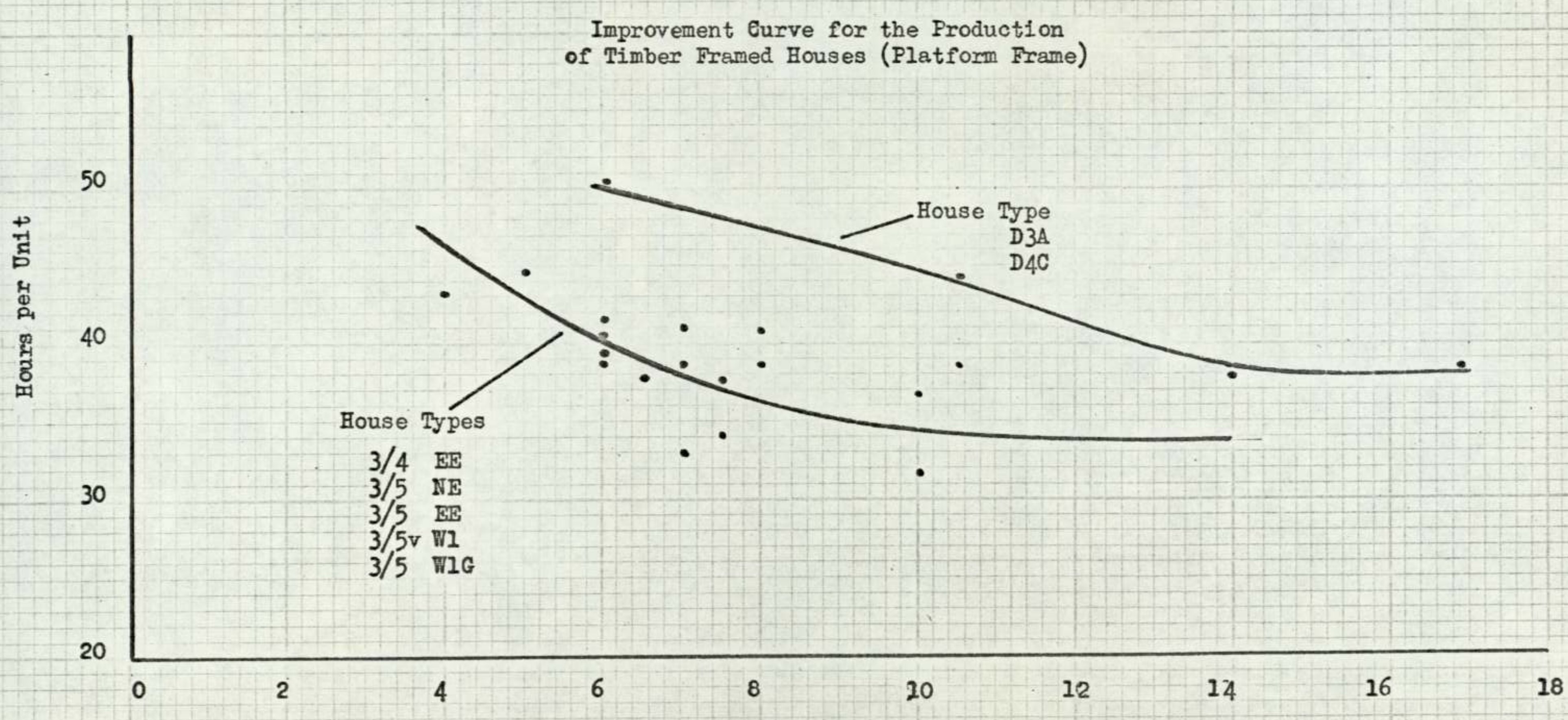
A further factor is satisfaction, men working on repetitive production either seek satisfaction through variety mentioned above or by earnings. With the former, higher productivity will result, but with the latter productivity may become stabilised. The reasons for this are varied and the effects difficult to measure. From discussions with the men it was evident, that on achieving a certain level of earnings, they were content to ease up on production. In some cases this was calculated to stabilise bonus agreements.

All production units but one were operating bonus systems based on production and there is no doubt that bonus is the prime motivator for improvement. Fig. 6.46 shows the situation where panels were being made without a productivity based bonus scheme. With the introduction of a proper bonus scheme the manhours were reduced twenty five percent. However, very little further improvement was achieved since the learning period had expired prior to the bonus system being introduced.

Absenteeism of one or more members of a team has a short term effect on improvement, and problems arising from lack of communication, delivery of materials, change of schedules can affect the flow of the curve. However, such high spots can be ignored when considering improvement curves over a reasonable batch size.

The worst problem in establishing improvement curves for panel production is production variation; this is where a firm will change its production to suit site requirements. This often happens where three or more sites are being supplied from one central factory. This problem does not arise in the erection stage and in the section below mathematical models are discussed in determining the percentage of improvement.

The factory improvement varied from thirteen percent for simple panel construction to twenty percent for complex panel construction. Large batch numbers in Fig. 6.47 show a saving of fifty percent on small batches.



Improvement Curve for the Production
of Timber Framed Houses (Platform Frame)
Hours per Unit
50
40
30
20
0
2
4
6
8
10
12
14
16
18
House Type
D3A
D4C
House Types
3/4 EE
3/5 NE
3/5 EE
3/5v W1
3/5 W1G
Weekly Production of Houses (Units)

Fig. 6.44

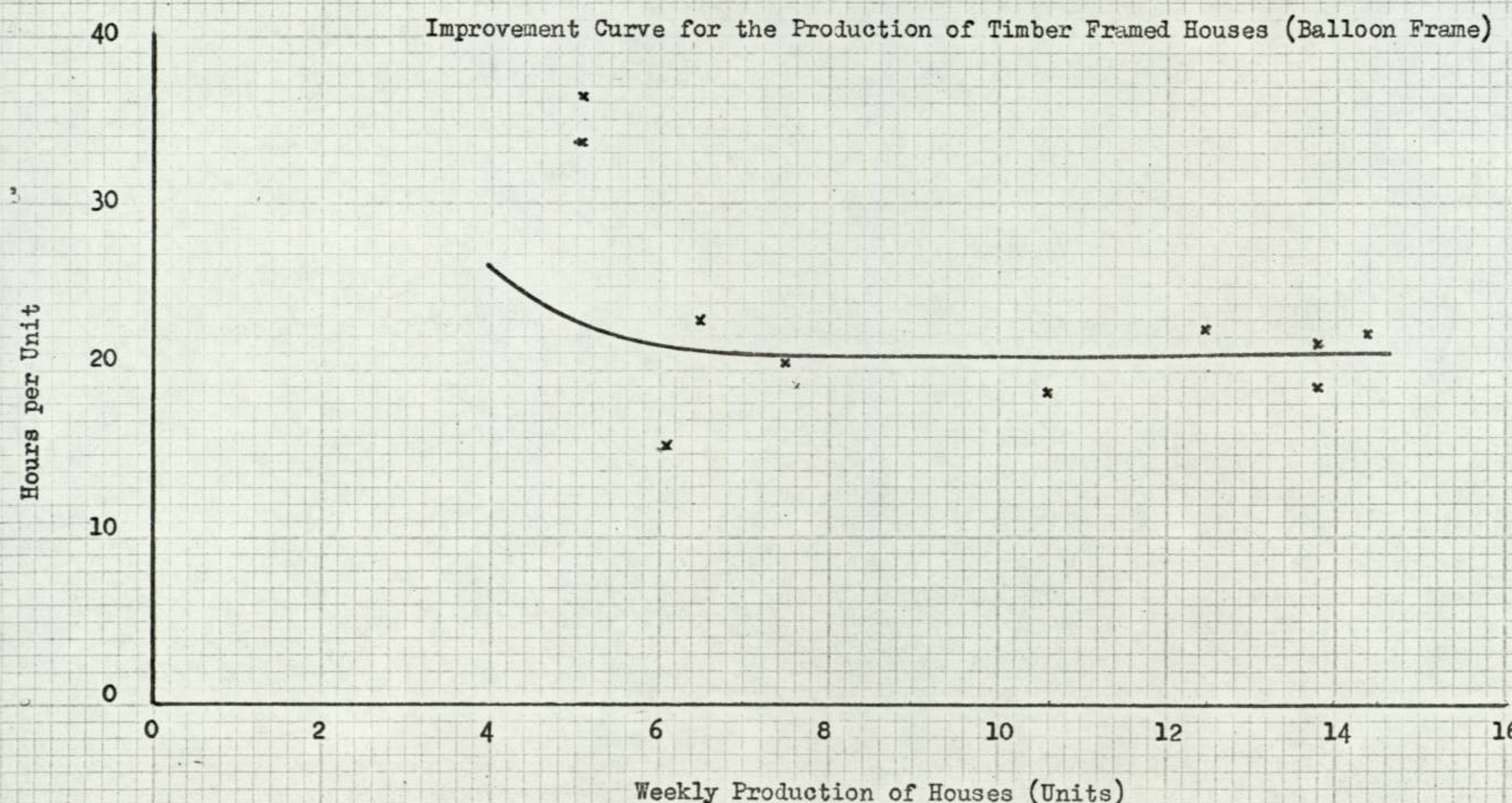

Improvement Curve for the Production of Timber Framed Houses (Balloon Frame)
Hours per Unit
40
30
20
10
0
0
2
4
6
8
10
12
14
16
Weekly Production of Houses (Units)

Fig. 6.45

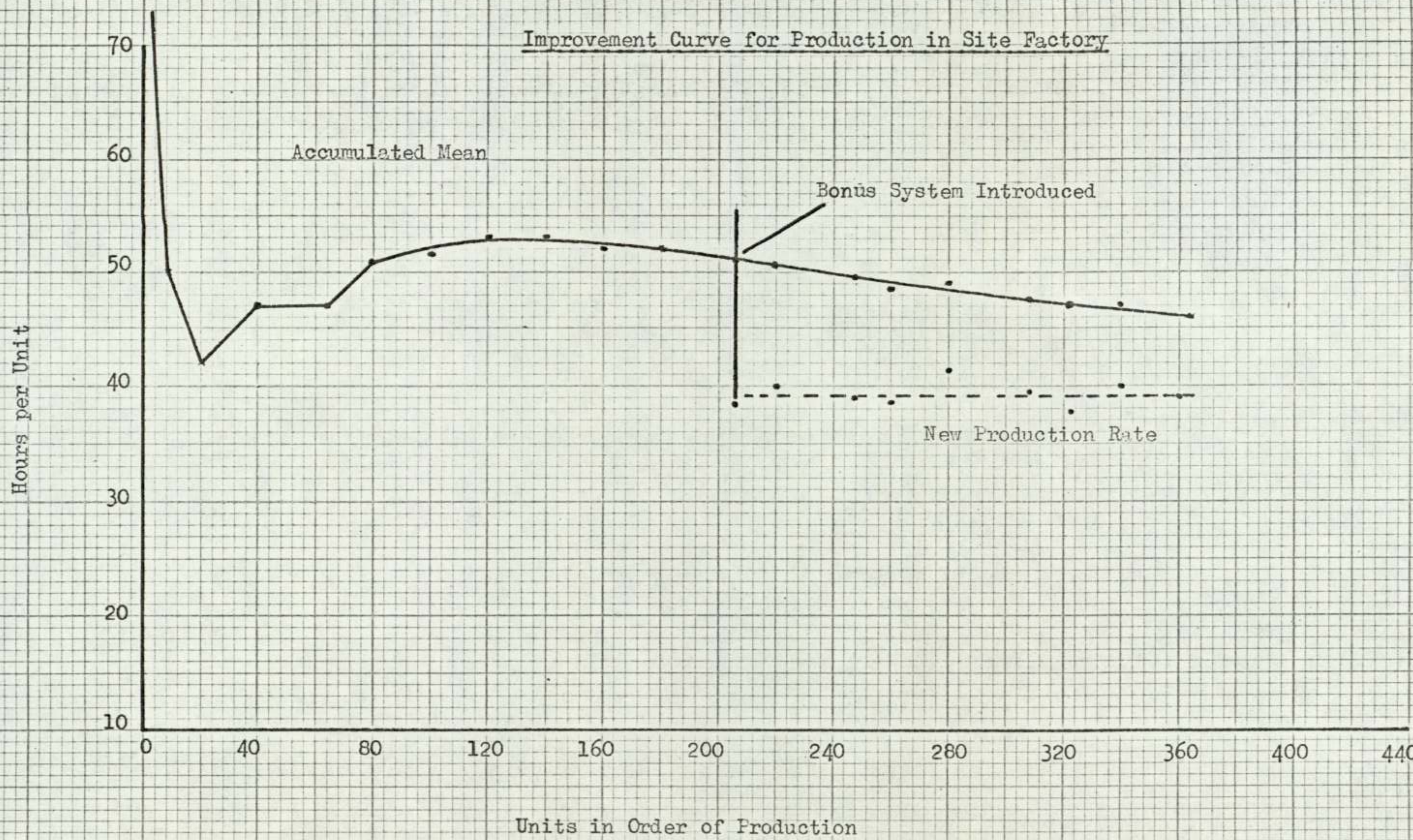

Improvement Curve for Production in Site Factory
Accumulated Mean
Bonus System Introduced
New Production Rate
Hours per Unit
70
60
50
40
30
20
10
0
40
80
120
160
200
240
280
320
360
400
440
Units in Order of Production

Fig. 6.46

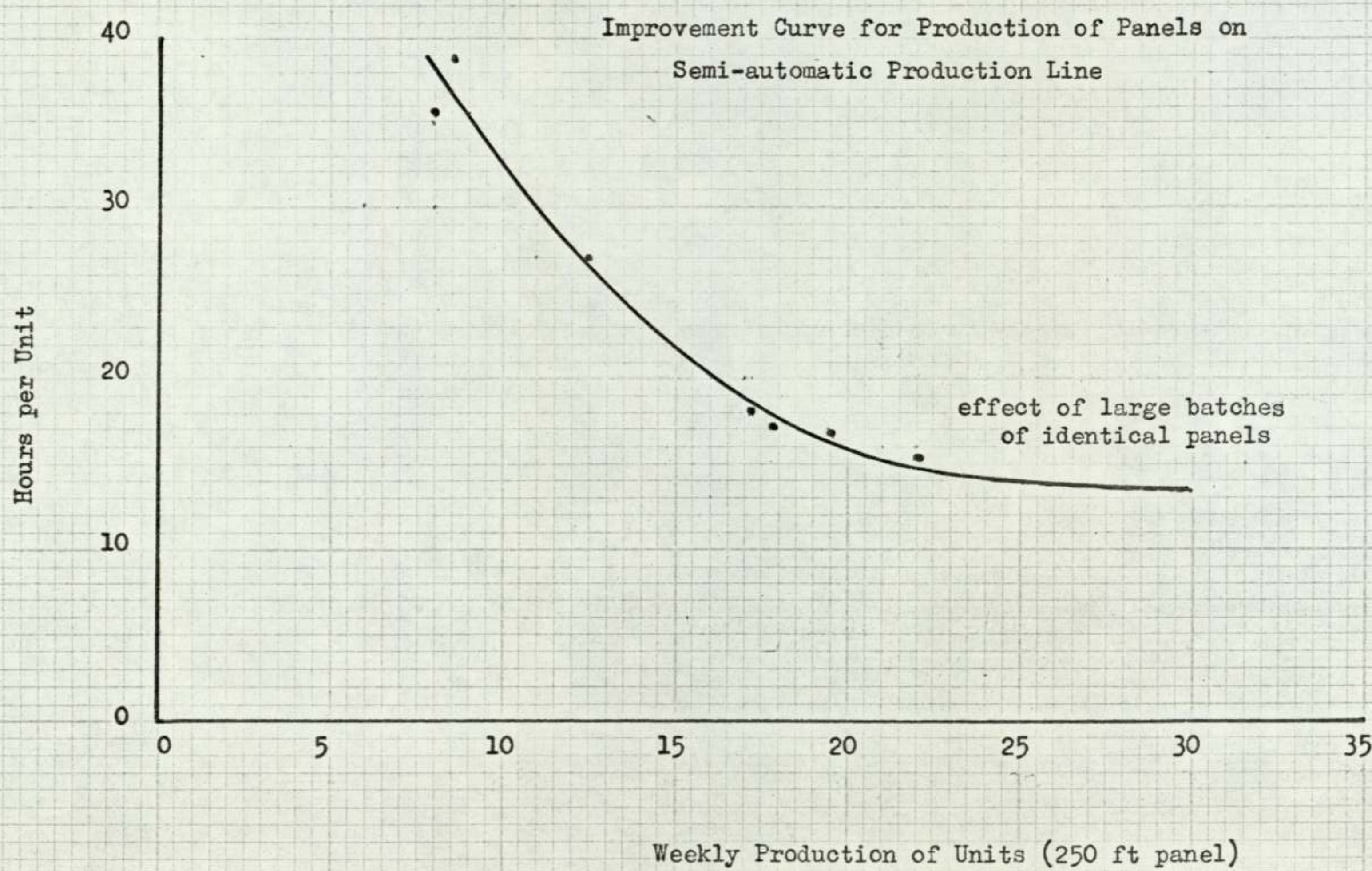


Fig. 6:47

(Source Appendix 3)

REFERENCE

(1) - Batch Size, Cycle Time and Setting Time as Determinants of Productivity in Skilled Maching Work.
A.B. Hill and J.M.B. Thickett
Management Centre, University of Bradford.

PART 7 ERECTION ECONOMICS

7.1 INTRODUCTION

The studies on the erection economics of timber framed houses lasted for a period of two years and for this reason were concentrated on sites belonging to firms 'A' and 'B'. This allowed time to set up an accurate data collection system and establish working agreements with the companies, concerning the availability of company records. Firms 'C' and 'D' are also considered but to a lesser degree since methods were, for most operations, identical. Firm 'E' built a pair of houses as proto-type for examining erection methods and materials. Details of these experiments are also considered.

Since detailed studies were undertaken in firms 'A' and 'B' the results are preceded by a detailed erection procedure. The detailed procedure will assist in evolving the most economic erection solution. Whilst the method of construction was similar the erection methods were different. Firm 'A' erected the frame manually, Firm 'B' used cranage. Firm 'C' erected manually, Firms 'D' and 'E' used cranage.

The method of erection is only one of the considerations in the minds of the contractors. Other problems are:-

Improvement curves and bonusing	(7.5)
Planning repetitive work	(7.6)
Budgeting for preliminary costs	(7.7)
Type and cost of plant	(7.8)
Type and cost of scaffolding	(7.9)

Each of these problems has been studied and where possible compared with traditional housing to show where adjustments have to be made. Photographs illustrate typical site erection and general progress of work. Cost data and graphs show break-even points for the various methods of working.

7.2 Detail of Site Erection for Houses in Firm 'A'

On this particular contract the contractor responsible for roads, paths and slabs was the main contractor. They handed over the slabs to Firm 'A' for house erection, then accepted the completed house back to complete paving before handing over to the Local Authority. Therefore Firm 'A' were in fact nominated sub-contractors although they controlled all the sub-contractors and suppliers for the housing project, and were responsible for all the planning.

Slab Preparation

The slabs were handed over complete with 'live' services, the electricity being sealed off in a service box (Fig. 7.1). No bolts were used for sole plate fixing so the main contractor had only size and levels of slabs to deal with. Many of the slabs were of incorrect size and required attention. Levels were often incorrect, mainly low, and because the sole plate was 'gun fixed' the panels required excessive packing and in consequence a thicker floor screed to bring the floor finish to the bottom of the timber frames. The main contractor agreed to pay the extra screed thickness required and on this basis many of the slabs were regarded as acceptable.

The number of slabs required before erection could economically proceed was estimated as fifty with a continuous production of ten slabs per week throughout the contract. This production was not being achieved mainly because the weather constantly hampered the contractor and partly because the ground conditions were very poor and temporary roads were not being used. Some slabs were completed out of the planned sequence because of site conditions, this however presented problems to the erection contractor who was trying to adhere to a tight programme regarding sequence of blocks. Changing a sequence of block erection often involved another house type. The slabs were cast directly on to the hardcore, no brickwork was involved below D.P.C. level. This proved to be a speedier method of slab production. The plinth was painted with R.I.W. bituminous paint which left a very acceptable finish below D.P.C. level.

Erection of Superstructure

When the slabs had been accepted the sole plate was fixed to the slab with cartridge fixings, the plate was fixed in line but not levelled since cartridge fixings require a solid backing. Some levelling had to be carried out by the erection gang who packed the ground floor panels off the sole plate prior to nailing with 5" wire nails. The erection gang consisted of four carpenters, who erected complete house units without plant assistance (with the exception of panels being lifted on to the first floor decking). The panels are designed so that four men can erect them, the largest panel being 12'-1" long by 7'-8½ high.

The first floor wall panels overhang the ground floor wall panels (Fig. 7.2). The floors are not made up into units (which would require cranage) but consist of 2"x7" C.L.S. packaged in house lots (Fig. 7.3), together with pre-cut sheets of ¾" ply decking transported direct from the timber importer. All notching and boring is carried out on site. Noggins are used to prevent floor decking springing at the joints, the latter are packaged in house lots, however, these noggins were being used for various jobs and in consequence there was a high wastage rate. Some other method of joint support is considered in the conclusions.

The roof trusses were of the gang nailed type seated on a top perimeter plate, the gable end trusses were fully sheathed (peak panels) and the party wall trusses were cladded with asbestolux both sides as a fire check. The party wall trusses were cladded on site (insitu) the panels having been pre-cut off site and delivered for fixing. The weight of these trusses (when cladded) prevented man-handling into position, hence the reason for insitu work. Wind bracing (4"x 1") was fixed to the underside of the trusses and anti-racking was achieved by fixing 5/16" ply sheet from gable end trusses to first roof truss (Fig. 7.4). On the completion of roof truss fixing, scaffold brackets were hung over the wall panels to form a scaffold from which the part 1 fascia board (there are two parts to the fascia and soffit detail Fig. 7.5) and guttering were fixed. The roofing tiles were also fixed at this stage. Since all windows and door inserts are fixed during panel manufacture the only operation prior to brickwork is the fixing of the moisture barrier, this is stapled to the panel sheathing (Fig. 7.6).

The scaffolding for the brickwork was the 'kwik stage' type, which had to remain in position until the vertical tiling had been completed. This often meant that scaffolding was tied up for long periods during bad weather because of the long time involved in facing the houses. The outer stores were completed along with the outer skin of brickwork. Glazing was carried out in two stages, stage one; the outer sliding leaf to all inserts (this site was completely double glazed), stage two; complete the units by adding the inner sliding leaf. Stage one glazing was carried out as soon as the roof was completed to allow internal working.

On the completion of the vertical tile cladding the soffit and fascia (part 2) was fixed, sealing off the eaves. The external doors complete the weather seal of the superstructure, (these doors have double glazed units, which were sometimes damaged during construction).

Sequence of Internal Work

The plumbing carcassing, gas carcassing, heating carcassing (ducting part i) and electrical carcassing all commence as soon as soon as the building is watertight. This is followed by screeds to ground floor slab and granolithic base to heater unit. At this stage, in theory, the heater unit should have been connected up and commissioned for drying out the structure prior to the fixing of insulation and internal moisture barrier. In practice however, the heating was not commissioned until insulation, moisture barrier and plasterboarding were all complete. The only drying out possible at this stage is the jointing to dry linings and decoration. On the completion of screeds the walls were insulated and covered with polythene, after which, the plasterboard was fixed. Party walls receive two layers of $\frac{3}{4}$" thick plasterboard planking (giving a total of 3" plaster on studs) this is to give increased sound and fire insulation. The stairs were then fixed. Paramount partitioning and internal door casing were fixed together with asbestos to heater and drying cupboards. False floors and ceilings to cupboards and framing to trunking was then completed. The electrical second fixing was completed as soon as the plasterboarding had been fixed to allow the electrical metered supply to be connected. The heating was switched on at this stage to assist the drying out of taping operations. The taping operations consist of (a) Taping, (b) Plaster joint 7" wide, (c) Plaster joints 10" wide, (d) Plaster joint 12" wide. During these operations the flooring ply was covered with plaster slurry which involved an extra operation of sanding floors.

On the completion of taping the plasterboard joints, the sink units, cupboard floors and window trims were fitted, followed by plumbing second fix. Heating grills and joinery second fix were then completed, followed by wall tiling and making good to plasterboard.

Internal and external decorations were then completed leaving the following operations prior to handover.

1. Plumber and Electrical Testing

2. Second phase glazing

3. Floor tiling (thermoplastics)

4. Sanding timber floors (work created by plastering without protection)

5. Snagging by finishing foreman.

External Works

Roadworks were not completed at an early stage to give good access to site and this caused some difficulty on site. In consequence the main contractor had considerable work to do prior to handing over the properties to the Local Authority. This included roads, public and private footpaths and soil to gardens.

A detailed breakdown of operations is shown in Table 7.1. This gives the main stages of work together with dependent operations. This breakdown was used for planning the work on site.

SHOLVER II - OLDHAM

C.M. HOUSING

The following is a major six stage breakdown for C.M. Housing on the above project showing items that must be 100% completed before the major stage operation can commence.

MAJOR STAGE	DEPENDANT OPERATIONS
1. ERECTION	Oversite slab and outhouse slabs Live services Drainage 100% Oversite slab cleaned off Ground around block levelled off Remedial work to slab where necessary.
2. ROOF TILING	Erection 100% Roof Trusses Scaffold brackets Fascia Part 1 Guttering complete & S.V.P.
3. PLASTERBOARDING	Roof tiling Glazing Part 1 & fixed glazing to doors External doors Floor screeding and Grano Carcassing all trades (plumbing, heating, elect) Insulation and Polythene * Bwk. cladding and Ext stores complete * Main scaffold erected * Vertical tile cladding * Soffitt and fascia part 2 * Note During fine weather brickwork, scaffold, tile cladding Soffit & Fascia Part 2 are not dependent operations, but are of course desirable.

Table 7.1

C.M. Housing - Continued

MAJOR STAGE	DEPENDANT OPERATIONS
4. TAPING	Plasterboarding Paramount & Internal casings Staircases and complete plasterboard Asbestos to heater & drying cupboards False floor and ceilings Framing to trunking Electrician Heater installation & meters.
5. DECORATIONS	Taping Joiner 2nd fix Sink units, cupboard floors & trims Kitchen units Plumber 2nd fix Heating complete Wall tiling Patching
6. CLEAN OUT	Internal and external decorations 2nd phase glass Floor tiling Joiner final fix Plumber and electrician test out Sand timber floors Snagging by Finishing Foreman

Table 7.1 (Continued)

Site slab with box terminals for
electrical connections

Fig. 7.1

Timber frame complete showing overhang
of upper storey

Fig. 7.2

Floor joists bundled in house lots

Fig. 7.3

Roof trusses fixed and supported by
wind bracing

Fig. 7.4

Details of eaves and window inserts
using two part facia and soffit

Fig. 7.5

Moisture barrier being fixed prior
to vertical tiling

Fig. 7.6

7.3 Details of Site Erection for Houses in Firm 'B'

Slab Preparation

The slabs were handed over to the housing contractor as shown in Fig. 7.7 with the electricity, gas and water services supplied to the units but not connected to the mains. Holding down bolts were set in the slab at predetermined positions to secure the perimeter plate. These bolts were often incorrectly positioned or out of line and had to be cut out and corrected. Many of the slabs had to receive attention before being acceptable for correct size.

The ideal number of slabs to be ready before erection could economically proceed was estimated at forty with a continual production of nine slabs per week throughout the contract. This production was not being achieved with the consequence that erection was being re-scheduled to meet the delay.

Access around the slabs for cranage and general handling of panels was very poor, continuous bad weather had caused boggy site conditions and plant soon formed deep ruts everywhere.

Erection of Superstructure

On the acceptance of the slabs the first operation was the fixing of the perimeter sole plate. This was bolted to the slab after being packed and levelled. The operation is carried out by a separate gang of two men thus allowing the erection gang to stay on superstructure.

The team working on superstructure consisted of three carpenters and the crane driver. The crane was a 22 R.B. with a 50'-0" jib and track mounted to overcome the bad site conditions. (Fig. 7.8). Cranage is required to lift the floor units and heavy wall panels, in some cases the latter units were 23'-0" long by 8'-0" high. Special slings and hooks were designed for lifting and all lifting holes were pre-bored in the factory. Some holes, however, required boring on site where units were bolted together and where corresponding holes had been omitted.

The complete ground floor panels were erected and tied in with first floor beams and floor units, before being coach screwed to the sole plate. The second storey panels and gable units were then erected and tied together by a perimeter plate, the latter being a wall plate for the seating of roof trusses. Some delays were being encountered with the crane not being able to travel over spoil heaps and having to wait for these heaps to be levelled out. On the completion of fixing the roof trusses a specially designed scaffold (which sits on the site slab) is erected (Fig. 7.9). This scaffold is bolted through the wall panels for stability. From this scaffolding the roof was fully braced and bargeboards, soffit and guttering were fixed. This operation was normally carried out by a gang of two men, followed by the fixing of window and door inserts together with a felt moisture barrier to the lower storey. The roofing, in some cases built-up felt roofing, in other cases single lap tiling, was completed to make the building water-tight (Fig. 7.10).

The scaffolding was then lowered to the first floor level to accommodate the carpenters for fixing plastic faced 'Tedlar' boarding. The boarding can be completed with the exception of the bottom board and areas where scaffold brackets are bolted to the panels.

After the Tedlar boarding had been completed (Fig. 7.11) the scaffolding was cleared away to allow the outer skin of brickwork to be built. On completion of brickwork the bottom board of Tedlar was fixed to complete the structure. The stores (Fig. 7.12) were built at the same time as the outer skin of brickwork. There was no vertical D.P.C. to openings, this was provided by means of a hardwood cavity strip which has a vertical water groove. Glazing was carried out after the completion of the roof coverings.

Sequence of internal work

The plumbing first fix was completed as soon as the shell had been erected. That involved fixing the plastic soil pipe, rain water pipe, hot cold pipe runs to ceilings and gas pipes. In some cases ducting to heater units was also fixed. This was followed by the first fix of electrical work which consists of wiring in prepared harnesses being laid in the floor joists (which were notched) and the cable unfolded to the various lighting and socket positions. At this stage a gang of two carpenters fixed the necessary noggins and bored additional holes to accommodate the wiring. On the completion of the first fix plumbing and electrical work the loose flooring panels were replaced. The flooring panels consist of 8'-0" x 4'-0" x $\frac{1}{2}$" ply sheeting nailed to seven inch joists, springing of cross joints is prevented by a 2" x $\frac{1}{2}$" hardwood noggin which is notched into the top of the joists. The asphalt flooring to ground floor was then completed, after which plasterboard to ceilings and the external walls was applied. Party walls receive two layers of plasterboard for sound reduction. The insulation to walls consisted of glass wool on bituminous paper, fixed between studs and covered with a polythene vapour barrier prior to plasterboard fixing. Internal partitions were fixed after the boarding of external walls and ceiling and cladded with plaster-boarding.

Internal casings, stairs and balustrades were then fixed, after which the joints to the dry linings were completed.

Jointing to dry linings consists of four operations:-

(a) Taping, (b) Boxing 7" wide,

(c) Boxing 10" wide, (d) Boxing 12" wide.

Problems arose in cold weather due to waiting time between each operation of plaster jointing.

Second fix plumbing followed the plastering and consists of fixing bath, wash-hand basin and toilet on the first floor (all pipes were formed at the factory). Cold water storage and chlorifier to cylinder cupboard, wash-hand basin and toilet to downstairs cloaks and kitchen unit (which was fixed after floor tiling). Electrical work and second fix joinery were then completed, followed by white glaze tiling and decoration (internal and external). The final operation prior to cleaning up was the laying of thermoplastic tiles to the ground floor areas.

External Works

These consist of public and private footpaths, soil to gardens and tree planting, the road works were completed at an early stage to give access to the site. Final connections and testing of services are carried out as the units are handed over to the Local Authority.

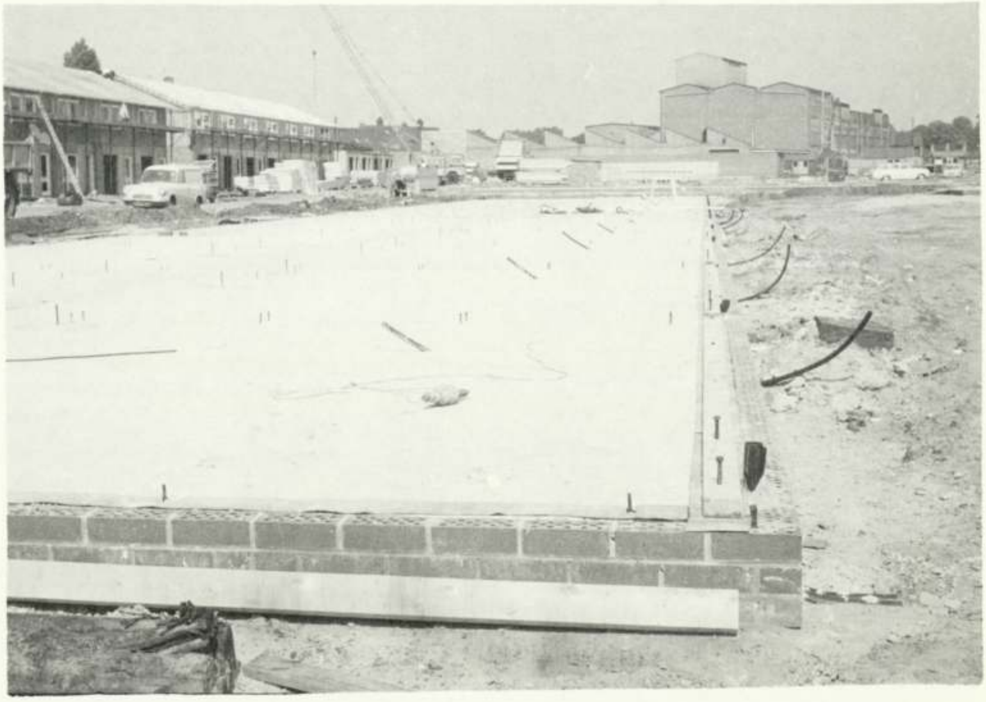


Fig. 7.7

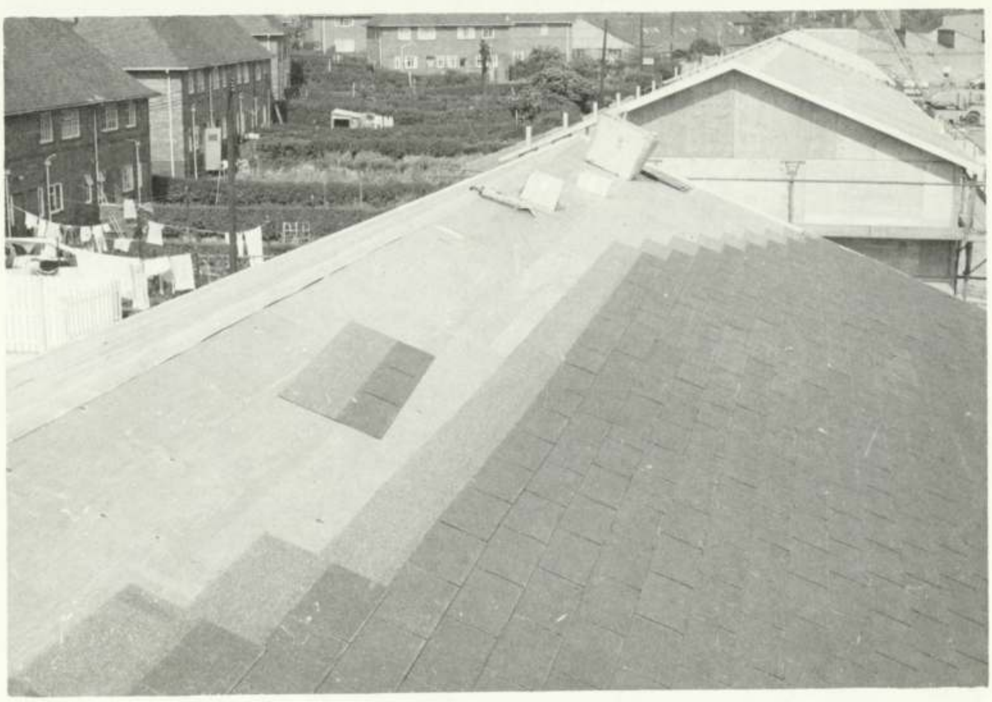
Finished slab with sole plate in position

Fig. 7.8

Crawler type crane for poor ground conditions

Specialist scaffolding bolted to gable end
for cladding operations

Fig. 7.9



Felt shingles being stapled to roof deck

Fig. 7.10

Fig. 7.11

Plastic covered cladding being fixed after roof completion

Fig. 7.12

External buildings and outer brick skin being erected after completion of cladding

7.4 Erection Methods

From the questionnaire data it was found that nine firms erected frames by mechanical means and nine erected manually. Some of the firms who erected manually were erecting panels up to 20' long. From detailed studies on various sites it was evident that no matter which method was used there was a considerable improvement curve on the erection time.

The type of construction used on the sites visited was platform frame. This is likely to be the only type of frame construction to be used within a few years, as discussed in part 5.

In most cases manual erection could have been used, often panels, which were crane erected, were simple sheathed panels without inserts or finishings. This stresses the need to design correctly for the erection method to be used. In all cases, where cranage was employed it was not utilised to the full amount. Since loads to be lifted are relatively small, seldom exceeding 1 ton, the type of lifting equipment must be selected to give economy. Heavy crawler type cranes were being used when much lighter equipment would have sufficed.

In some cases fork lift trucks assisted manual handling by lifting first floor panels onto the completed first floor. Other than this assistance the manual erection varied only in gang size or erection sequence.

With mechanical handling there were some difficulties which could be eliminated by better design. The first problem is one of slinging, although holes had been provided they were often in the wrong places or created as obstruction to the fixing of the panels. Slinging to some units i.e. apex panels, often involved erectors climbing to release the slings (Fig. 7.13). Panels were often lifted without concern for damage due to the abnormal lifting stresses (Fig. 7.14). Ground conditions could have been improved prior to using cranage. This could be achieved simply be levelling around the slabs, with a drott or similar machine, prior to erection. Fig. 7.15 and Fig. 7.16 show two different sites where cranage was to be used for erection. On the former site, the actual time for erection was greatly increased by the site conditions which restricted crane movement. There was no evidence to show that operations were linked to the availability of mechanical aids. Apart from using the crane to lift stairs and large internal partitions into the shell prior to completing erection, the crane was not used. Baths and other heavy units together with plasterboard were all man-handled into the houses.

The advantages to be gained from mechanical handling are not, with the present common trend in design, as advantageous as might be supposed. The erection time per unit, taking a centre three bedroomed unit as average, is reduced from forty man hours to approximately twenty five man hours.

Fig. 7.17 and Fig. 7.18 show the accumulated mean time for crane assisted erection. This shows both the improvement curve, which is discussed later, and the effect of erection over a reasonable period of time. This graph together with the information in Table 7.2 show that the average time for contracts of over fifty dwellings is twenty five hours per unit. The average varied very little from site to site, the highest being twenty eight hours per unit, the lowest twenty two hours per unit. The reason for this high figure, in relation to some published figures, is due to practical problems such as weather, site conditions and planning. These problems are discussed later with the effect on improvement curves. It can be said that the saving in time with mechanical erection is fifteen hours per unit. This only affects the programme of work, it does not necessarily mean a direct saving in cost. Fig. 7.19 shows the cost comparison for both methods of erection per thousand square feet of floor area. This shows that costs per thousand square feet are almost identical for sites of more than two hundred dwellings. The cost was twenty five pounds per thousand square feet.

Manual erection is more economic for contracts up to a hundred units. The main reason for this is the design and amount of factory work on panels. Cranage costs are high, utilization is very low where panels are basically designed for manual erection. Designers have been content to evolve a system of timber frame which is easy to prefabricate and transport but which fails to achieve economies in erection. There was no obvious advantage to be seen from the reduced time in mechanical erection. This was balanced out in manual erection by using two or more gangs, bringing total erection per week up to approximately ten per week.

Fig. 7.13
Crane erection of timber frames

Fig. 7.14

Panels twisting under stress of lifting

Typical site conditions on sloping site

Fig. 7.15

Typical site conditions on level site

Fig. 7.16

Time Consumption in the Serial Erection of House Shells

(crane assisted)

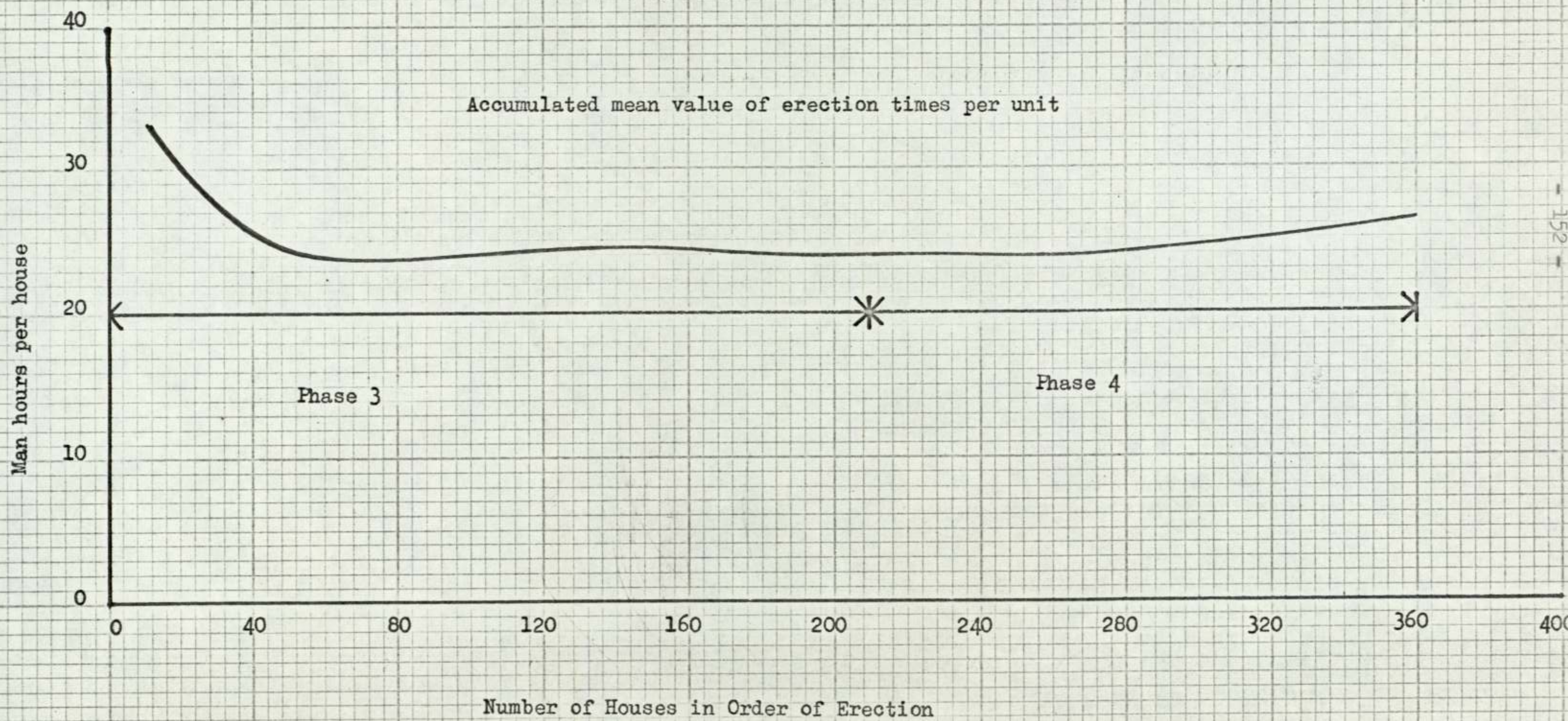


Fig. 7.17

Improvement Curve for Erection of Timber Shells (site L 1+2)
(crane assisted)

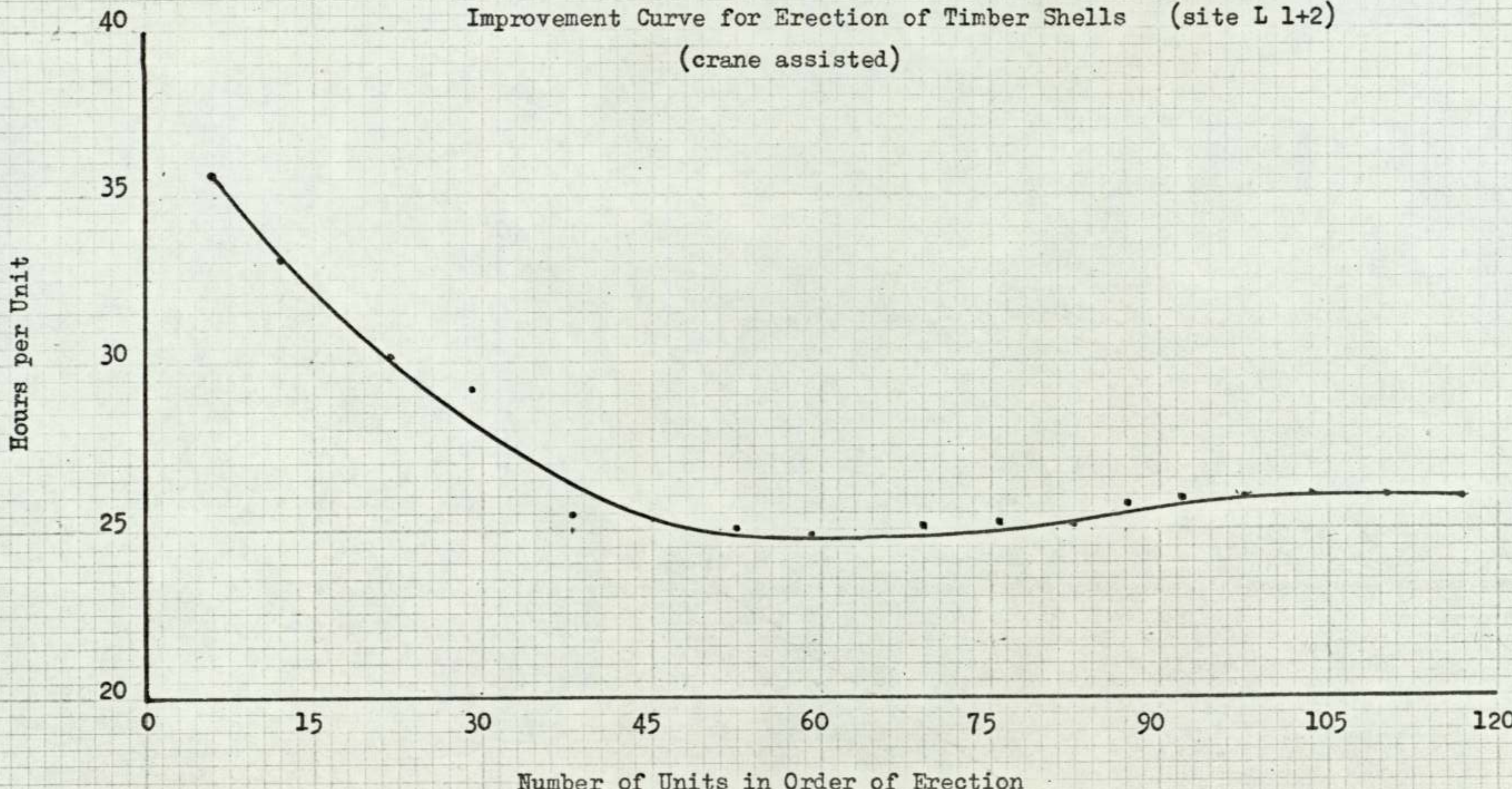


Fig. 7:18

Comparison of Erection Costs for Timber Shells

(manual and crane assisted)

Site	No. of Units	Av. Erect. Time (Hrs)	Total Man Hours	Prime Lab Cost/Hour	Total Prime Labour	Cranage Cost	Total Cost	Total Floor Area (sq.ft.)	Cost per 1000 sq.ft. Fl.Area
1- O	410	38.6	15803	0.5	7902	-	7902	342000	23.2
2 - D	81	43	3483	0.5	1742	-	1742	73101	24.0
3 - K	24	46	1104	0.5	552	-	552	18593	30.6
4 - B	100	42	4200	0.5	2100	-	2100	92070	22.8
5 - J.3	209	24	5005	0.5	2503	1312	3815	194000	19.7
6 - J.4	138	26.2	4104	0.5	2052	1476	3528	128200	27.6
7 - J.5	196	28.2	+ 5485	0.5	2743	* 1567	4310	194320	22.2
8 L ½	≠ 352	≠ 14.6	5148	0.5	2574	4211	6785	287540	23.6
9 R133	444	22.6	+ 10070	0.5	5035	* 4446	9481	420340	22.4

* Excludes Driver

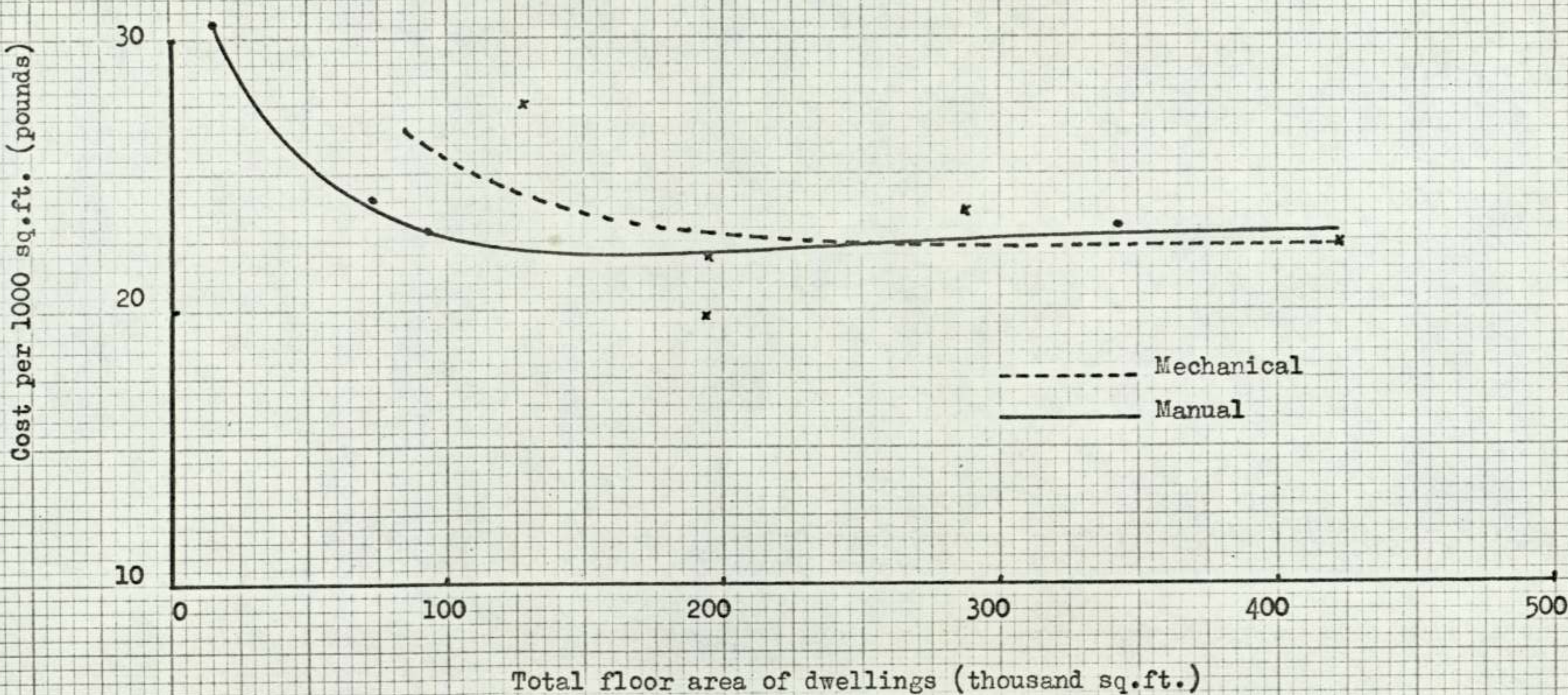
\+ Includes hours for driver

≠ Includes 235 flats

≠ Low figure by reason of flats. Average house unit 26 hours

Table 7:2

Cost Comparison for Mechanical and Manual Erection



Average dwelling - 920 sq.ft.

Fig. 7:19

7.5 Improvement Curves

As stated in Part 6 the effect of learning or improvement in repetitive work has not been fully examined in the construction industry. Data published on the effect of repetitive work has been limited during the last decade in the United Kingdom. This has created problems, especially in the rapidly expanding field of prefabricated buildings. Most of the work studied has been in the field of traditional dwellings (1), therefore the effect of repetitive work in prefabrication is not clearly a comparable case. The effect of repetition on the cost, output and productivity of building production has for some time been the subject of special study by the Committee on Housing, Building and Planning of the United Nations Economic Commission for Europe (ECE). In their publication (2), the ECE have offered solutions for learning curves, based on information received from eleven countries. The report states that although the influence of external conditions will affect the shape, the general pattern of curves is very similar. This could perhaps be qualified by stating that the exact shape of the curve will depend on the nature of the operation, i.e. simple or complex. There are two phases in the process of improvement of labour productivity in building, namely, an operation-learning phase and a routine-acquiring phase. The former relates to the worker gaining sufficient knowledge of the work to be performed and the latter to familiarity with the task which enables small changes in work method and organisation.

The factors which affect the shape of the curve towards the end of a series have been discussed in Part 6 and are equally applicable to erection work. The effect of complex operations on learning curves has been shown in Fig. 6.44 and 6.45 and can be seen in Fig. 7.20,21. Figs. 7.20 and 7.21 show the shape of a curve where the operations were complex. This effect of complexity also occurred where a large number of three-storey flats were erected. Fig. 7.18. Figs. 7.22 to 7.26 show typical learning curves for simple operations.

Calculation of Improvement Curve

Some mathematical models are collated by the ECE in their publication and merits of these are discussed below in the light of the data collected for timber framed housing.

The formula offered to the ECE by the United Kingdom is as follows:-

$$m^1 = \frac{te - ti}{te} \cdot 100$$

where m^1 = measure of improvement

te = average time for early series

ti = improved average for the remainder

Exp. (using data Fig. 7.20)

te = 15.5 (taking early series as 20 houses)

ti = 12.5

$$m^1 = \frac{15.5 - 12.5}{15.5} \cdot 100 = 19.3\%$$

The problem with this formula is the determination of the end point of the early series. If, for example, one chose the end point of the early series in Fig. 7.20 to be forty houses, te would be 13.5 hours. In that case the improvement would be:

$$\frac{13.5 - 12.5}{13.5} \cdot 100 = 7.4\%$$

So the simplicity of the model, as an advantage, is outweighed by the fact that the percentage improvement is governed by the uncertain position of the end point of the early series.

The second mathematic model to be considered is one offered by Hungary. In this model every time the number of units is doubled the time (i.e. time above basic time) is halved.

$$H = \frac{X \log 2}{\log (T_1 - T_b) - \log (Tx - Tb)}$$

X = Any number of units

Tb = Basic (Ultimate) time

Tl = Initial time

Tx = Time for number of units (x) considered

Exp. (Fig. 7.20) Consider 20 units

x = 20

Tb = 11.5

Tl = 19

Tx = 15.7

$$H = \frac{20 \log 2}{\log (19 - 11.5) - \log (15.7 - 11.5)}$$

$$H = \frac{20 \times .3010}{\log 7.5 - \log 4.2} = \frac{6.02}{0.2519} = 24.8$$

H = 24.8 say 25 units

Therefore at 25 units from unit 0 the time is reduced from 7.5 hours above basic to 3.5 hours above basic, approximately half. Since this model depends on knowing the ultimate operational time it is of little value to planners and estimators who have not yet collected accurate data for each operation.

The third consideration is Wright's law (published in 1936). Wright, an American, studied the accumulated mean values of time for repetitive work in the aircraft industry. This resulted in his well known 80 per cent rule, saying that the accumulated mean value of operational times will be reduced to 80 percent when doubling the number of identical operations i.e.

$$* \frac{t2x}{tx} = 0.80$$

* tx = Time for x number of units

t2x = Time for 2 times x number of units

According to experience gained in Finland and Sweden, Wright's law is valid also in the building industry. The percentage decrease depends to a great extent on the complexity of the operation in question but is generally lower in building than in the manufacturing industries.

Table 7.3 indicates the saving of time on various operations studied. It can be seen, that for timber framed housing, the reduction in time, when doubling the number of identical operations, varies from 86.5 percent to 95.5 percent. The average reduction is 87.5 percent.

Thus $\frac{t2x}{tx} = 0.87.5$

Wright's law would appear to be a suitable model with the modification that the 80 percent rule is changed to 87.5 percent. This shows a 12.5 percent improvement when doubling the number of operations.

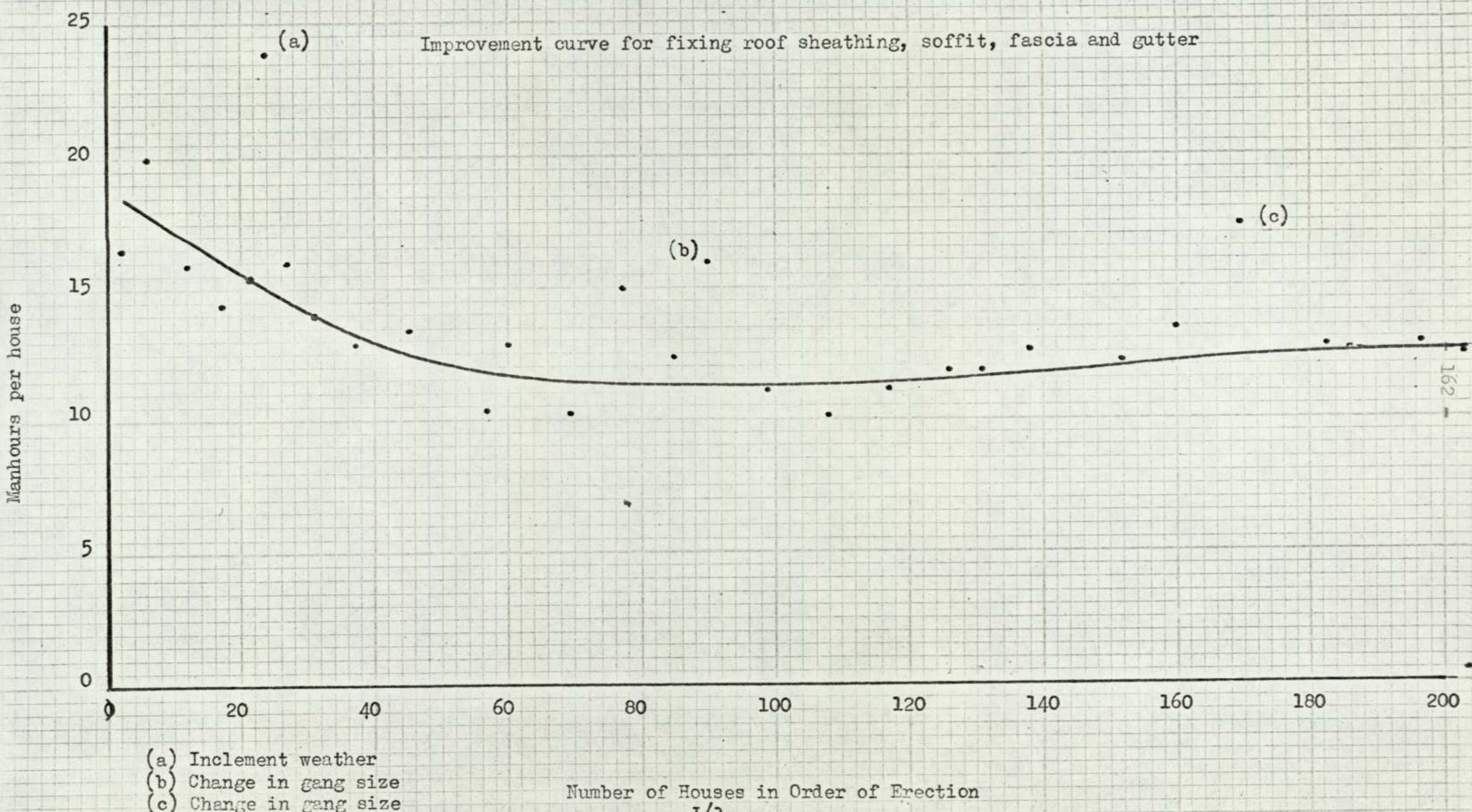
Table 7.3 shows also that the ultimate basic time T_b is achieved between forty and a hundred units, depending on complexity of operations. The amount of time involved in an operation has a separate effect on the learning curve as opposed to complexity. Some complex operations have a short duration time and therefore the routine acquiring time is lower. Fig. 7.27 shows the improvement slope for various operations. The greater the duration time, the steeper the slope and the greater the number of units to reach ultimate basic time. For operations with an initial time duration of between twenty five and forty hours, the time slope is ten degrees plus or minus one degree. Operations of sixty hours duration have a time slope of fifteen degrees. The majority of operations, which have duration times of twenty hours or less have a line slope of five degrees, plus or minus one degree. The average decrease in time, initial to ultimate basic, is forty two percent.

Allowance must be made for the slowing down effect towards the end of all serial runs. This tendency was evident on all operations. The reasons are varied and perhaps mainly psychological. Men see the end of a series coming and, unless there is similar work ahead, reduce their pace of working. From the graphs showing improvement curves it can be seen that the increase in time above ultimate basic time is between ten and twenty five percent. This factor must be considered in the planning stages. Improvement for work of timber framed housing can be based on an overall forty two percent reduction or twelve and a half percent reduction for the doubling of the number of units. The increase in time when approaching the end of a series run can be calculated, depending on the nature of the operation, to be between ten and twenty five percent. This gives clearer guide lines for bonusing and costing.

Improvement in Time for Repetitive Work

Fig. No.	Operation	Nature of Operation c= complex s= simple	Total Number of Units	Initial Time (T1)	Basic Time (Tb)	No. of units to reach Tb	Percentage Decrease in Time	$\frac{t\ 2x}{\%t\ x}$
7:20	Roof Sheathing	c	209	19	11.5	80	39.4	89.0
7:21	Plasterboard and Insulation	c	209	60	32	100	46.5	89.0
7:22	External Cladding	s	200	28	17	60	39.4	93.0
7.:23	Plasterboard and nail spotting	c	196	38	19	100	50.0	86.5
7:24	Erection of Shell	s	196	44	25	40	43.0	95.5
7:25	Erection of Shell	c	209	34	20	80	41.0	91.0
7:26	Erection of Shell	c	668	53	41	200	22.6	89.0
App. 8:26	Roof Tiling	s	120	11.4	7.0	60	38.6	87.5
App. 8:26 1st Fix	Joinery & 1st Fix	s	120	14.3	8.3	80	42.0	87.0

Table 7:3


Improvement curve for fixing roof sheathing, soffit, fascia and gutter
Manhours per house
0
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180
200
(a)
(b)
(c)
(a) Inclement weather
(b) Change in gang size
(c) Change in gang size
Number of Houses in Order of Erection

J/3

Fig. 7.20

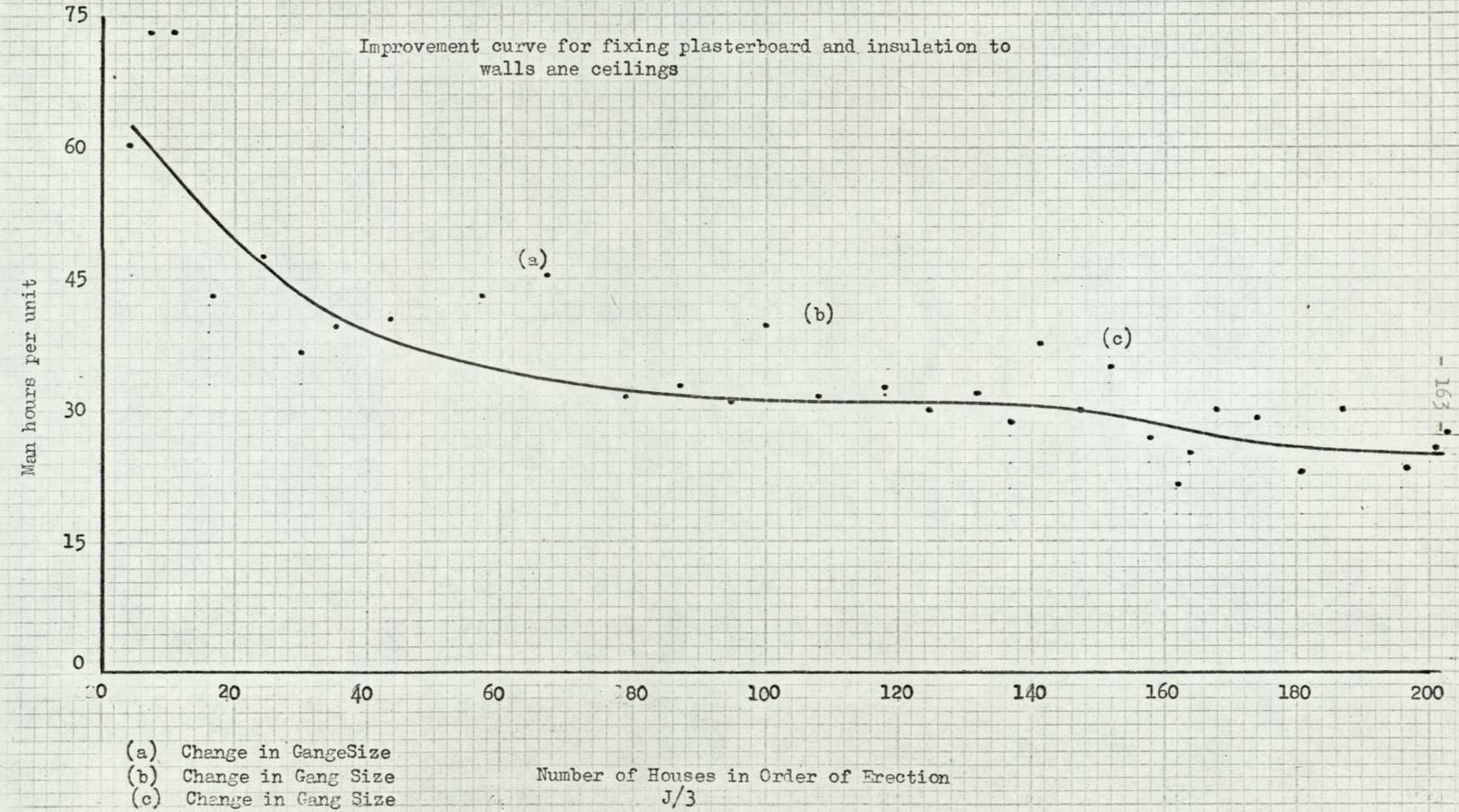
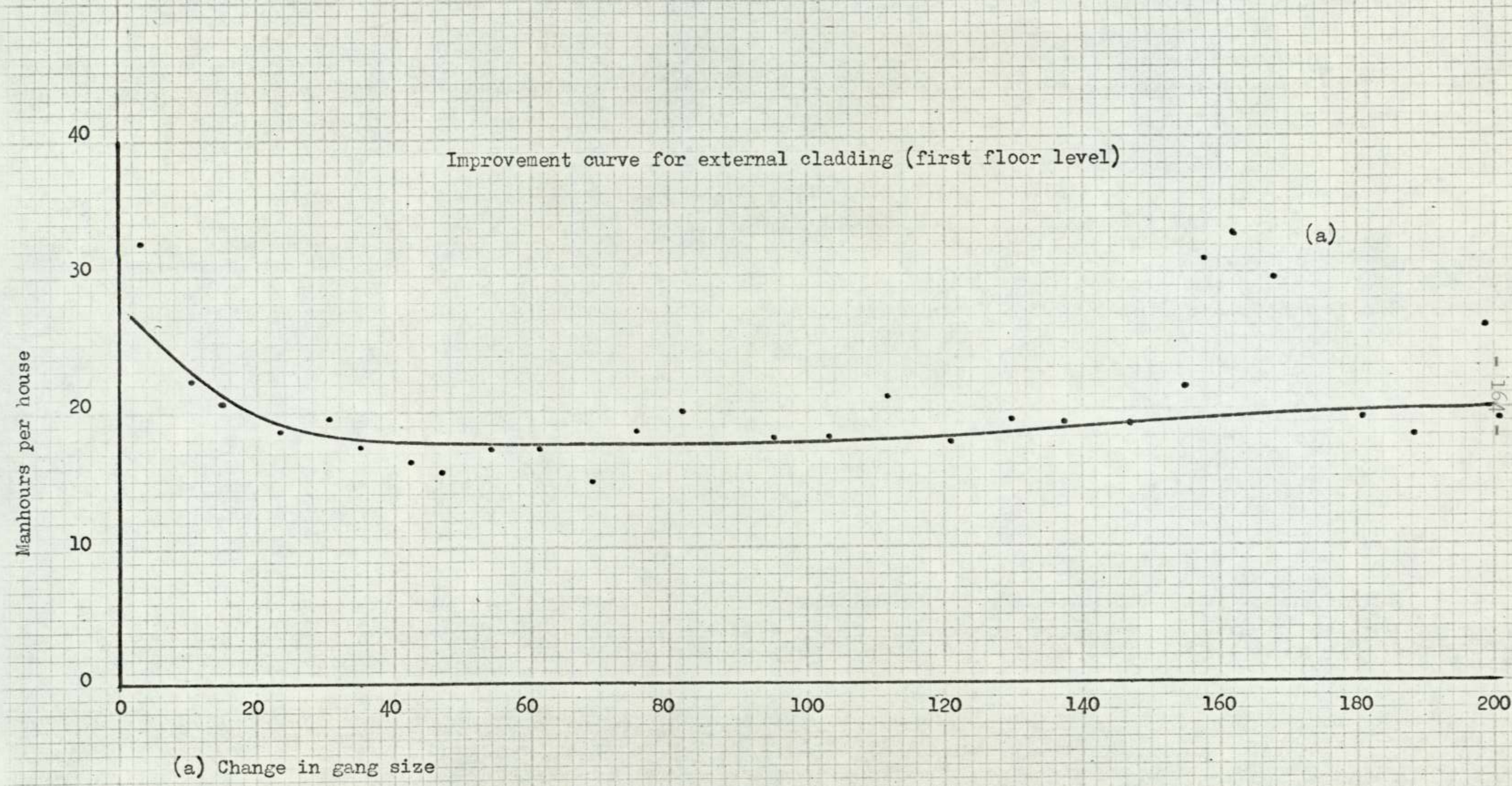

Improvement curve for fixing plasterboard and insulation to
walls ane ceilings
75
60
45
30
15
0
Man hours per unit
0
20
40
60
80
100
120
140
160
180
200
(a)
(b)
(c)
(a) Change in GangeSize
(b) Change in Gang Size
(c) Change in Gang Size
Number of Houses in Order of Erection
J/3

Fig. 7.21


Improvement curve for external cladding (first floor level)
(a)
Manhours per house
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
(a) Change in gang size
Number of Houses in Order of Erection

J/3

Fig. 7.22

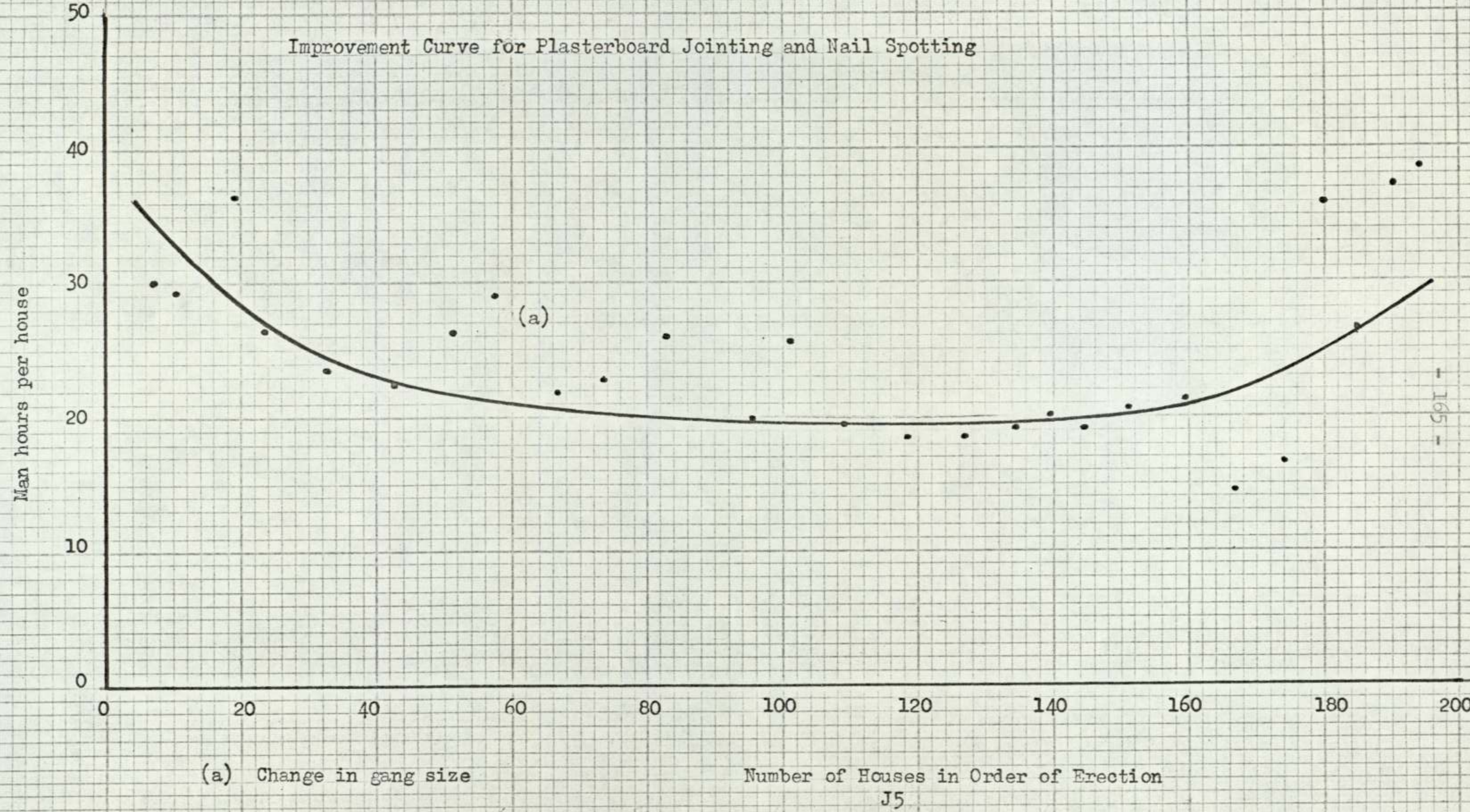

Improvement Curve for Plasterboard Jointing and Nail Spotting
Man hours per house
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
(a)
(a) Change in gang size
Number of Houses in Order of Erection
J5

Fig. 7.23

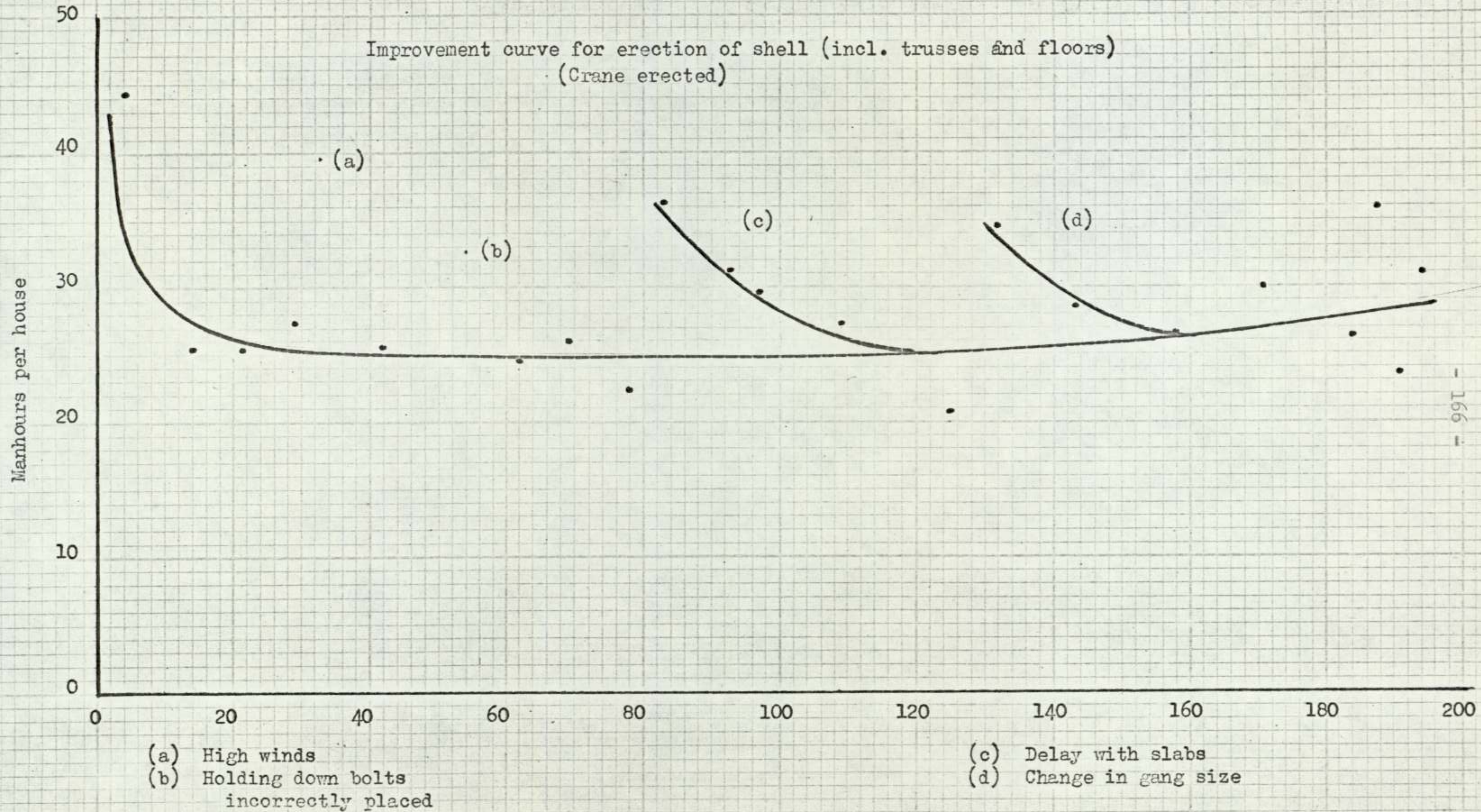
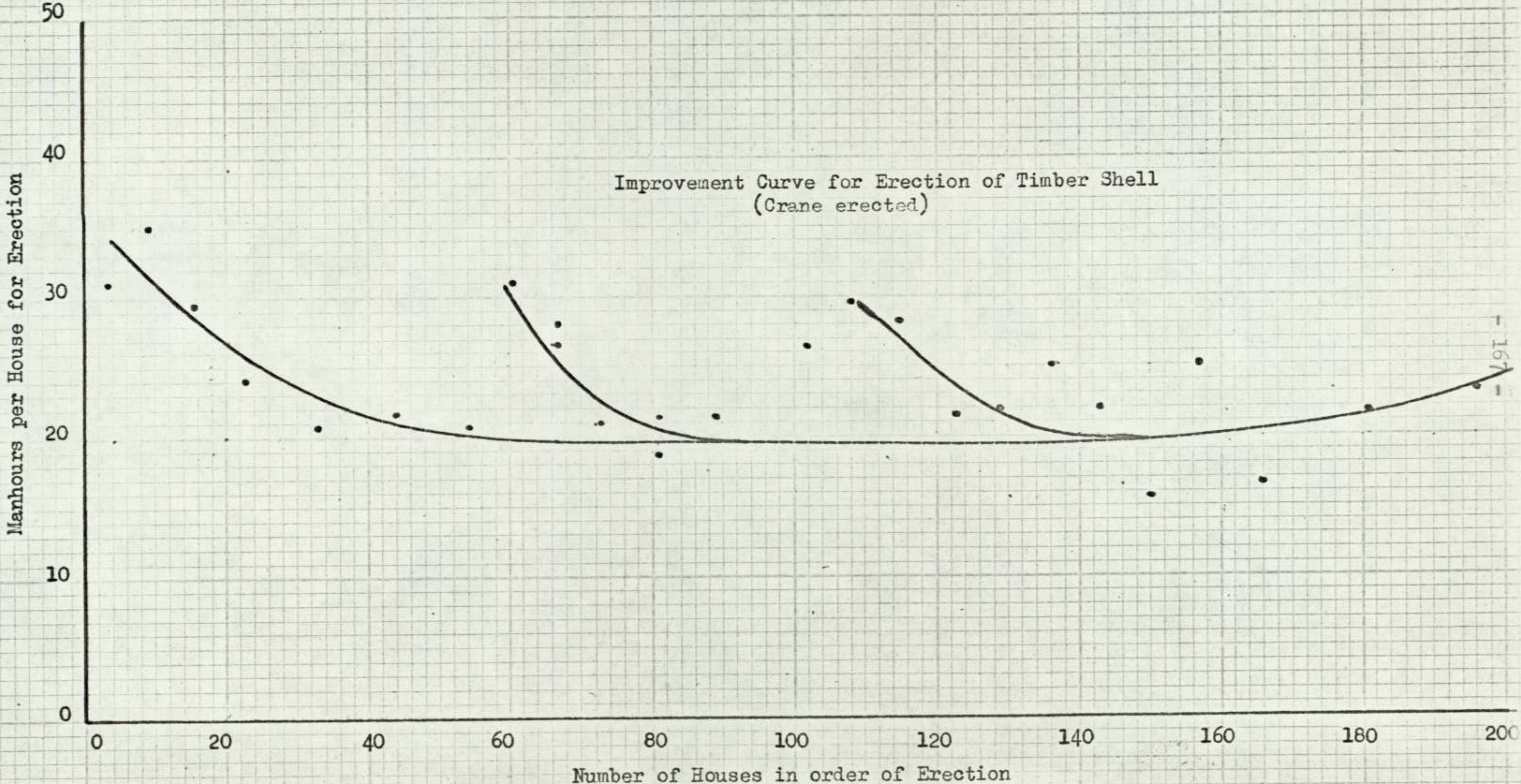

Improvement curve for erection of shell (incl. trusses and floors)
(Crane erected)
Manhours per house
Number of houses in order of erection
(a)
(b)
(c)
(d)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160
180
200
(a) High winds
(b) Holding down bolts incorrectly placed
(c) Delay with slabs
(d) Change in gang size

Fig. 7.24 J/5



Improvement Curve for Erection of Timber Shell
(Crane erected)
Manhours per House for Erection
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160
180
200
Number of Houses in order of Erection

Fig. 7.25

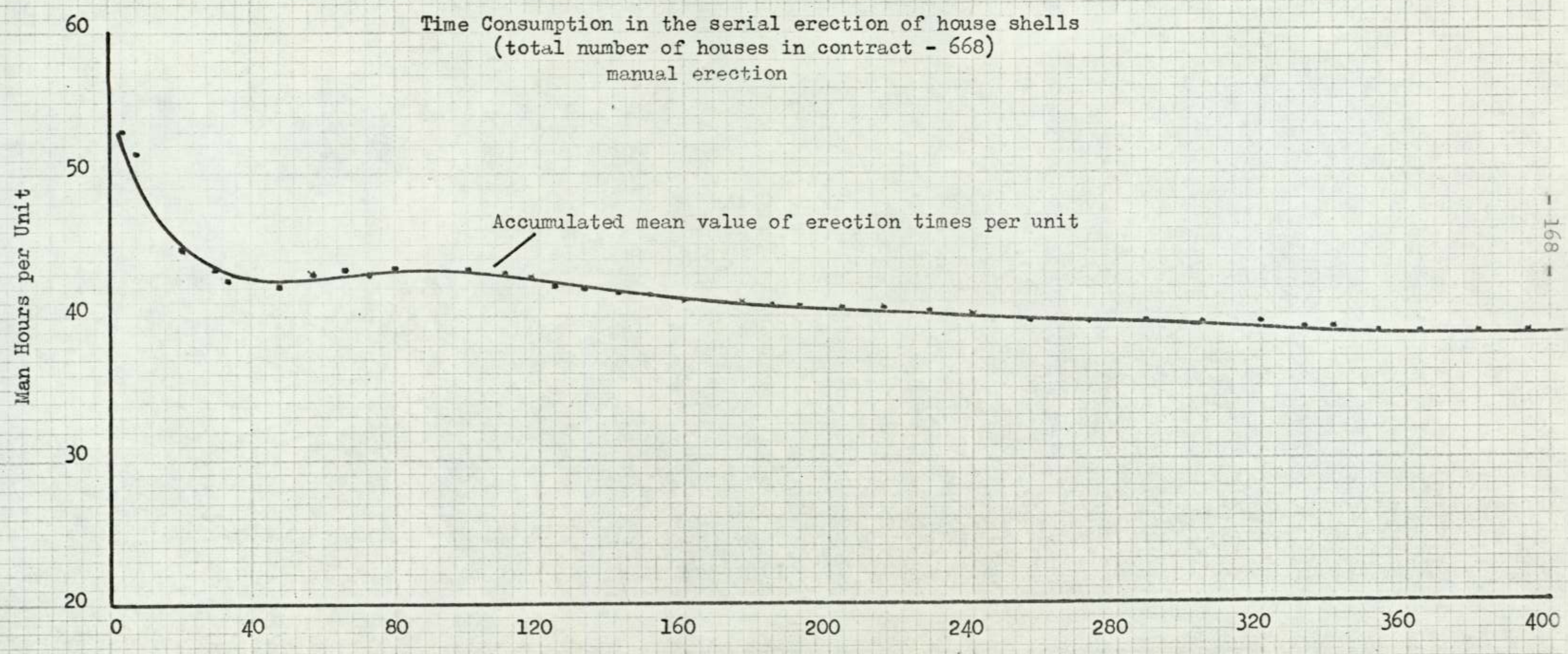

Time Consumption in the serial erection of house shells
(total number of houses in contract - 668)
manual erection
Accumulated mean value of erection times per unit
Man Hours per Unit
60
50
40
30
20
0
40
80
120
160
200
240
280
320
360
400
Number of Units in Order of Erection

Fig. 7.26

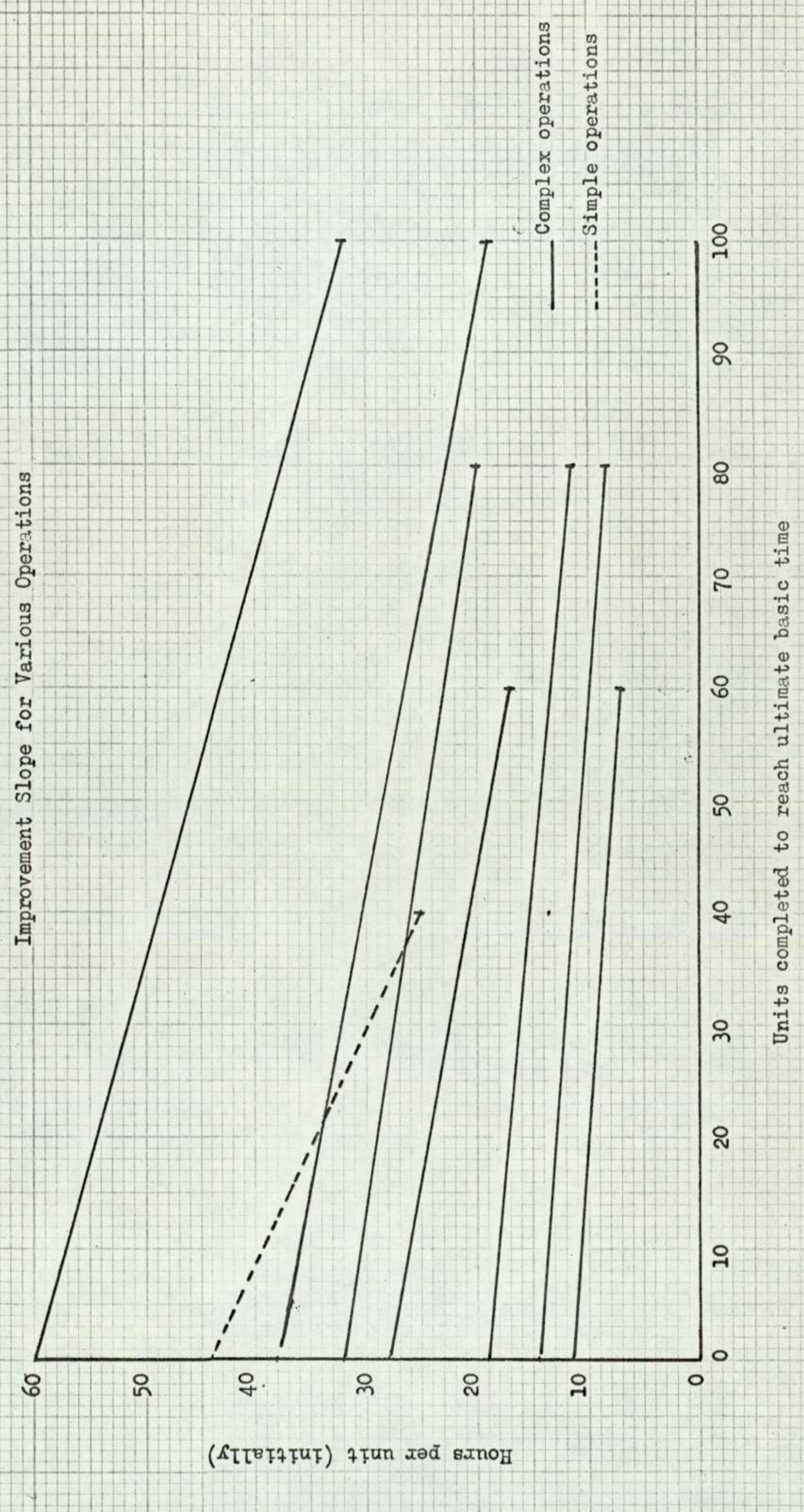

Improvement Slope for Various Operations
Complex operations
Simple operations
Hours per unit (initially)
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Units completed to reach ultimate basic time

Fig. 7:27

7.6 Planning for Repetitive Work

It may seem obvious that where construction processes are highly repetitive the methods of planning such processes must be equally advanced. However, the majority of the sites on which timber framed housing was being erected, were planned on traditional methods; i.e. bar charts. It was evident that this traditional method of planning was totally outmoded for the work in hand and progress was well behind schedule on sites using this method. This was not due to lack of planning expertise on the traditional methods, for there were personnel well able to deal with the normal planning problems, who were trying to vary bar chart methods to suit the effects of repetition. It was evident that the favourable effects of repetition were being partly or entirely lost.

The most suitable method of organising repetitive work, which allows for variation in speed of operations as well as gang balancing, is the method known as flow-line planning, or, better known in this country as line of balance. The process is one where the work is divided into a number of operations linked together by a common production rate. This is based on the same principle of a factory production line but, whereas in the factory the product moves and the men stand still, in this case the men move and the houses stand still. Each trade or operation has to be estimated separately regarding gang size and speed of working. From this an inclined line representing time and work load can be plotted. (Fig. 7.28). Each operation is plotted with a time buffer between each operation to allow for discrepancies and varying speeds of work. The programme for the complete contract will be seen as Fig. 7.29, the progress is shown with shaded areas.

As an experiment, two sites in the research project were monitored on the line of balance method after being originally programmed by traditional methods. The most striking factor that emerged in this experiment was the unscientific methods of estimating operation speeds. Many rules of thumb were being used which threw site progress out completely and demanded constant updating. One such rule of thumb was the number of slabs to be completed prior to commencement of erection. The general rule in the trade is stated to be fifty slabs. Erection has always been assumed to be economic at ten dwellings per week. These and many other rules have become the yardstick for planners dealing with timber framed housing. Very few firms kept data for each operation and since little is known about the improvement factor, the progress on most sites is well behind schedule. On the sites monitored the slab rule caused a delay in erection of five weeks. This was due to factory production being tied up with site programming, which is normal procedure. The frames were produced on schedule but completion of slabs would have allowed erection to have commenced at a much earlier date. No time allowance had been considered for slab correction, prior to erection, and this added to the delay. With line of balance these factors could have been overcome; buffer times could have been allowed for errors in slabs. Fig. 7.30 shows the main activities on site 1. and a list of typical problems which were encountered.

One company using a modified form of the line of balance method had not considered the problem of the improvement curve. In consequence the early series of houses were behind schedule and uneconomic methods were being employed to bring the contract back to schedule. The effect of learning must be considered in repetitive work and the general pattern is shown in Fig. 7.31. The other factor which must be considered is the decrease in production at the end of the series, this is also shown in Fig. 7.31. Both are factors which cannot be overcome by incentive methods and time must be allowed for them in the contract period. Buffer times must be adequate to compensate for likely problems. Consideration must be given to overlapping operations where such operations run in parallel. This is better than being too precise with gang sizing, although it may involve changing the sequence of certain operations at a given point in the progress. This can be achieved in timber framed housing where some operations are independent of other operations.

Varying house types are not a problem to this type of planning, providing that improvement is considered, since there is little difference in manhours for the various types of house built. This factor is overcome by taking mean values from previous contracts. The effect of adverse weather conditions on planning and productivity has long been a point for discussion but substantial data is not available for the actual loss of manhours on industrialised housing. In an investigation by Building Research Station (3) it was stated that manhours lost can be divided into five categories.

1. Bad weather time, cold and wet conditions.
2. Decreased productivity due to bad weather.
3. Time spent on damage caused by weather.
4. Lost time when men are stood off or do not report for work in bad weather.
5. Reduced working week in winter months.

The total bad weather time was an average of 24 hours per house. Reduced productivity on average of 13 hours per house. Repair work one hour per house. Lost time 25 hours per house and reduced working 34 hours. This made tht total average loss 97 hours per house. This represents between five and eight percent of all time spent on building traditional houses. The figure is much lower for timber frame houses since the weather tightness of a house can be achieved in less than four days. Therefore although designers could consider excluding every wet operation, the effect on planning, in respect of adverse weather condition, would be minimal.

The main task of the planners, in this specific field, is to estimate accurately the man hour content and practical gang size for each operation. The sequence of operations including learning time must then be considered, allowing buffer times to iron out problems. Caution must be used when the programme falls behind schedule, since increasing gang sizes without considering the cost effect, or the effect on other operations can result in decreased productivity. This is caused by upsetting the sequence or rhythm of other gangs and the secret of any repetitive process is rhythm.

Network analysis is a technique that is worthy of mention, for although network analysis as a planning technique is more suitable to 'one off' jobs, it can be used to great advantage in the construction of a line of balance programme. The single house or unit should be broken down into suitable operations and a network drawn to establish the logic of the work. This will prevent problems arising from a lack of logic in the line of balance, which, depending on the speed of execution, may delay the contract severely. This was seen in the monitoring on site 1. (Fig. 7.30).

In conclusion, planners will find that the line of balance method will be more economic tool if work study is applied to the erection sequence. On completing a multiple activity chart for all operations on a contract it was found that blocks of six dwellings allowed for the most economic site work. By making all activities a maximum of five days, each unit could be completed in forty six working days with a handover rate of six dwellings every ten days. Man power utilisation was between eighty one and ninety two percent. This however, involves the designers working with the planning team, a situation seldom found. Such techniques will enable planners to see problems arising before trying to solve them by the line of balance method.

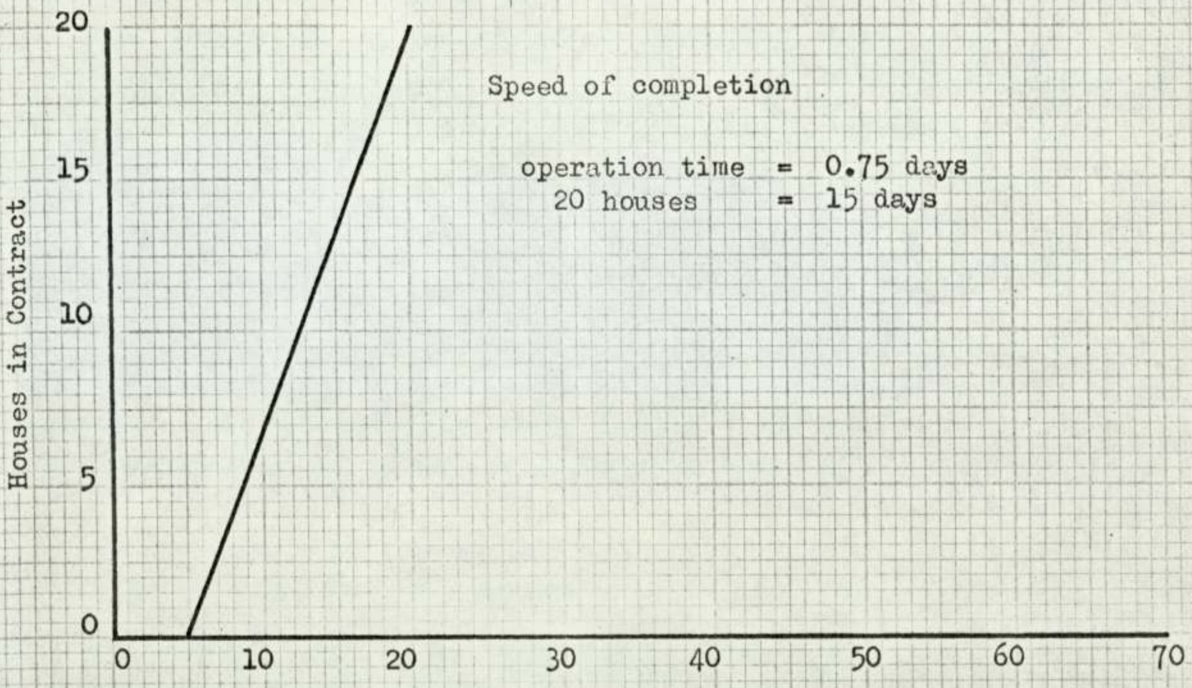


Fig. 7:28

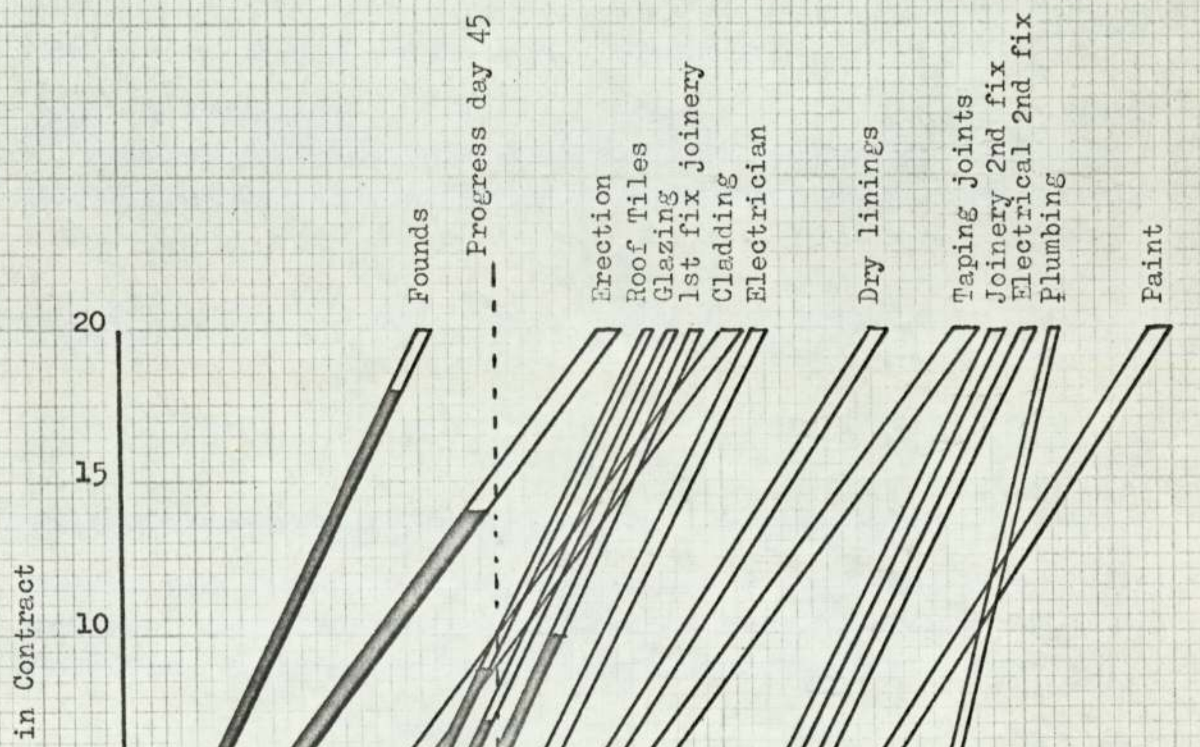


Fig. 7:29

Line of Balance for Progress on Site I
(First 50 units)

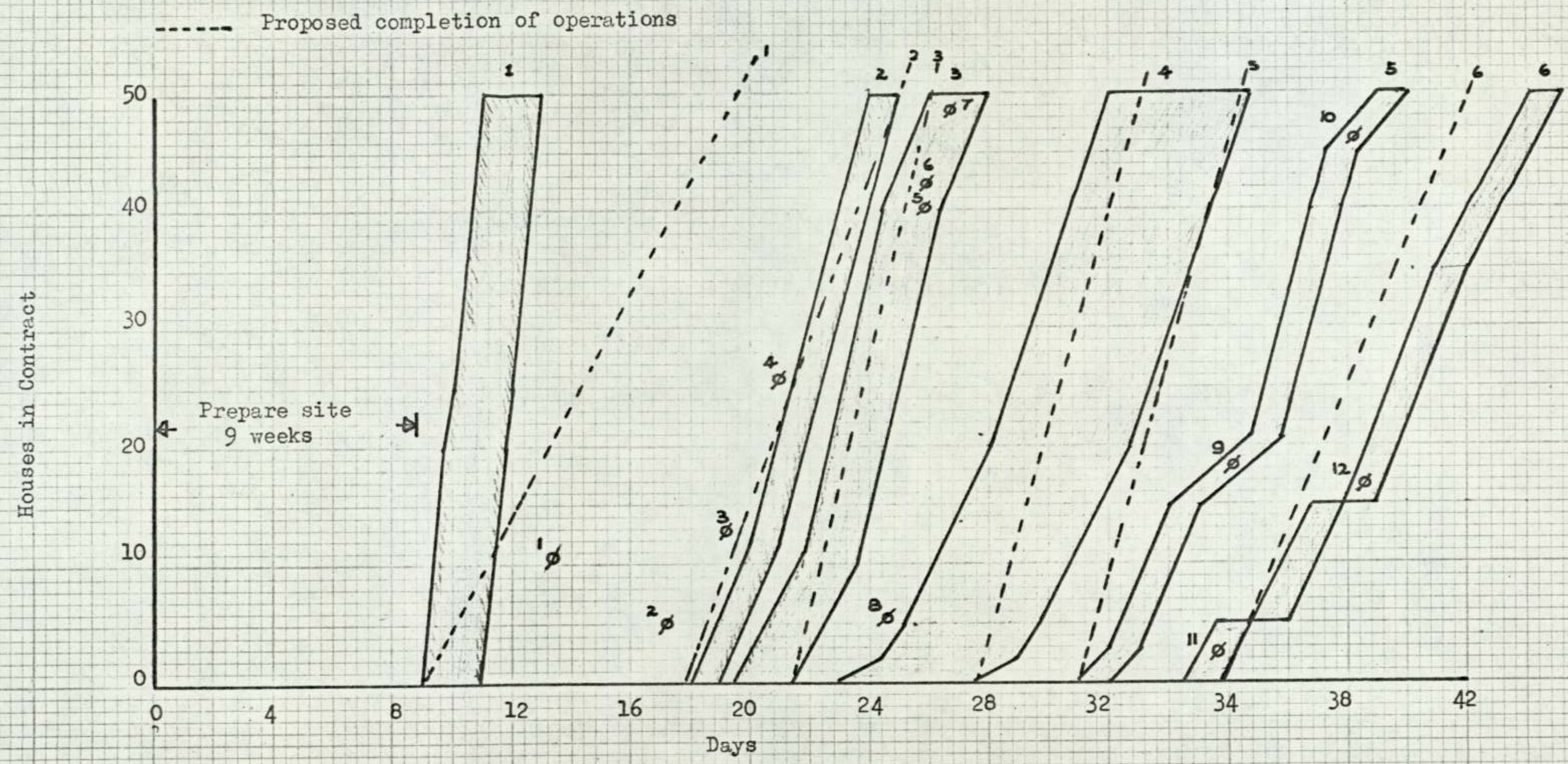


Fig. 7:30

Line of Balance Site 1

Key to Operations

1. Bases (10 working days)
2. Erection of shell including roof (5 working days)
3. Cladding and glazing (9 working days)
4. Internal wall and ceiling finishes (23 working days)
5. All 2nd fix work (5 working days)
6. Floor tiling and painting (6 working days)

Key to Problems

1Ø 50 slab rule causes six week delay
2Ø Remedial work could have been completed earlier
3Ø Fork lift out of action (off loading by hand)
4Ø 10 day delay in roof shingle delivery
5Ø Vandalism on glazing
6Ø Poor quality cladding (time lost in sorting)
7Ø Sub-standard gutter units
8Ø Plasterboarding gang too small
9Ø Kitchen furniture problems
10Ø Plaster patching delay completion
11Ø Extra incurred to pull finishes back to schedule
12Ø Furniture wrong handed

Further delays occured as the contract proceeded. The main delay was caused by delivery of panels in the wrong sequence. Other problems which developed and are worthy of note are:

1. Shortage of scaffolding for cladding
2. Modification to layout of plumbing
3. Short term operations catching up with other operations, leading to reduction in gang size and inefficient working

Corrections necessary for line of balance method

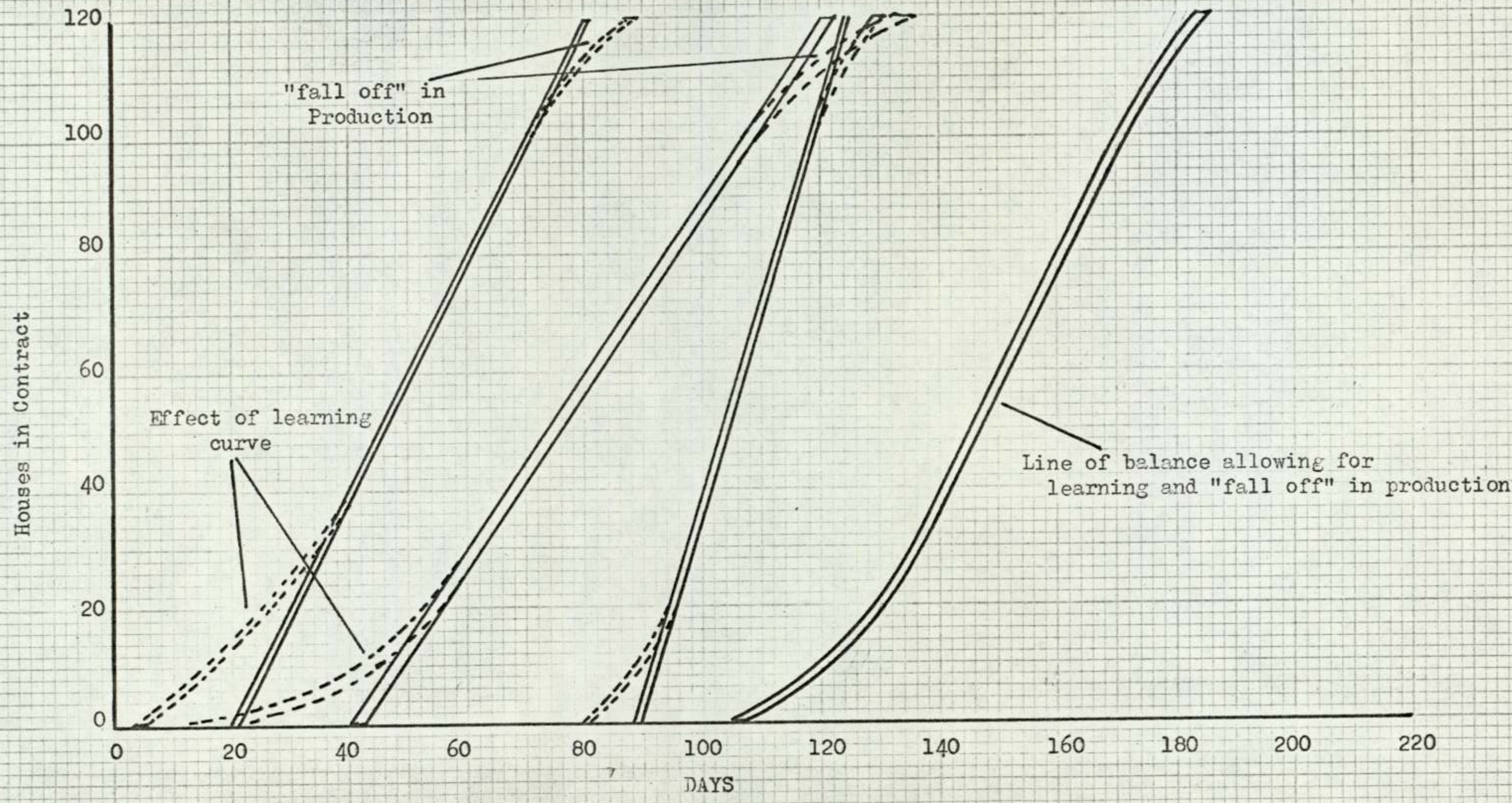


Fig. 7:31

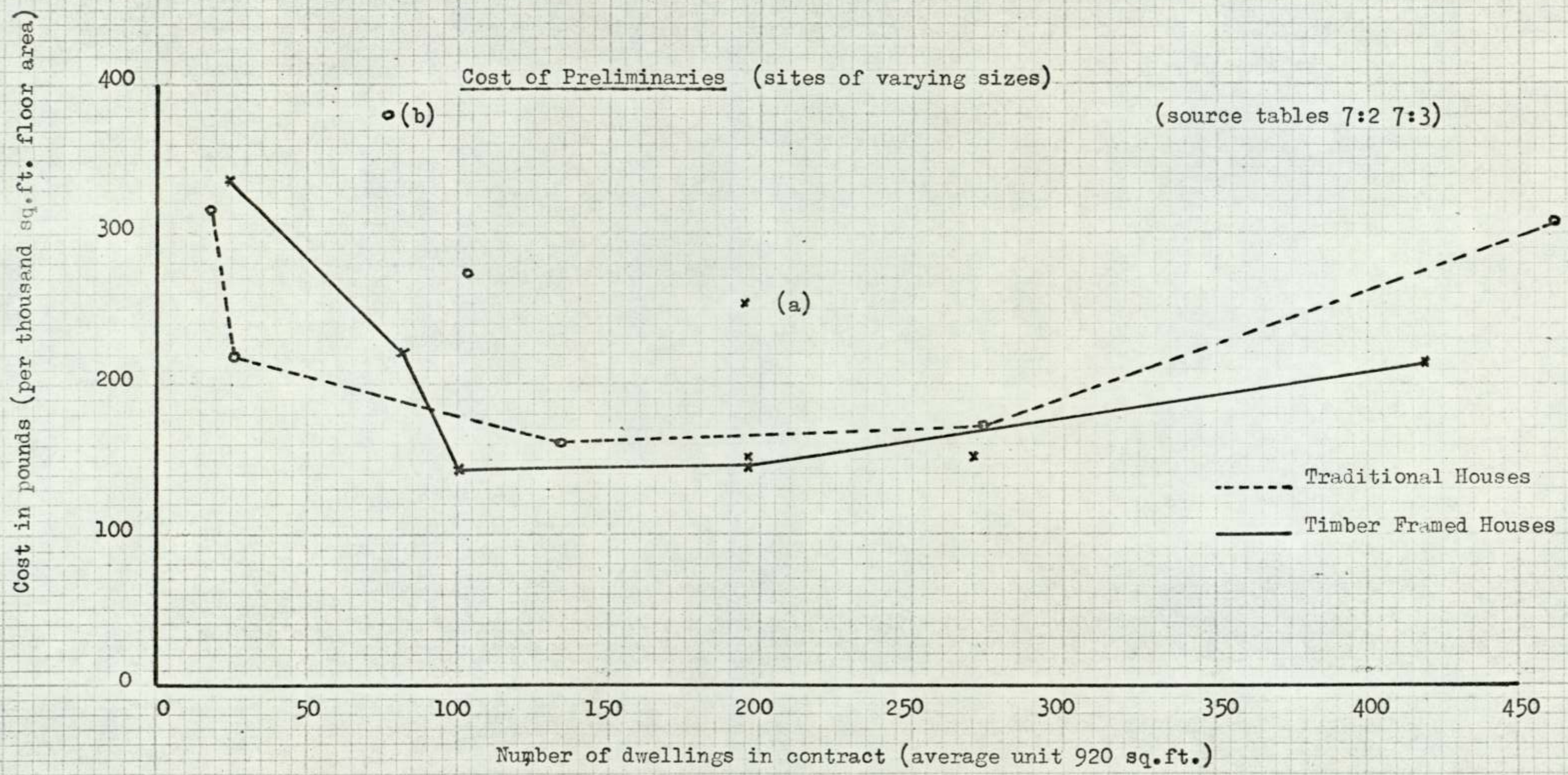
7.7 Budgeting for Preliminary Costs

The preliminary costs involved with industrialised building, especially timber framed construction are assumed to be much lower than those incurred by traditional building. This assumption is based on the fact that a fast dry construction, which is relatively simple to erect, would require less supervision and plant.

Data gathered from fifteen sites, seven of which were of traditional construction, shows that the reduction of preliminary costs is not as great as was expected. The graph in Fig. 7.32 shows the cost of preliminaries per thousand square feet of floor area for sites of varying size. From this graph the following factors are seen.

1. That the overall reduction of preliminary cost for contracts of ninety dwellings to three hundred dwellings is approximately twenty pounds per dwelling. This is a reduction of less than twelve percent. For contracts over three hundred dwellings and up to five hundred dwellings the average reduction is approximately nineteen percent.
2. That the most economic contract size lies in the range of one hundred dwellings to three hundred dwellings. The lowest expenditure being in the one to two hundred range.
3. The break-even point for costs incurred on traditional and timber framed housing is the ninety dwelling mark. Beyond this timber framed housing incurs lower costs.

The factors above are based on the following major preliminary items: (a) Site staff, (b) Office accommodation and hutting, (c) Plant (excluding scaffolding and mixing plant), (d) Small tools, (e) Transport, (f) Travelling fares and subsistance, (g) Site services, (h) Non-productive overtime, (j) Labour on scaffolding, (k) Sundry items i.e. clean roads, miscellaneous site work.



(a) Very high subsistance figure incl.

(b) Excessive supervision

Fig. 7:32

7.8 Plant - Type and Costs

The amount of plant used on timber framed housing is greatly reduced compared with that used on traditional housing and the cost effect is very noticeable. The main reason for the reduction is the simplicity of working, which, as with all prefabricated buildings dictates the amount of plant to very fine limits. All operations have their own particular requirements and few require the attendance of dumpers and such like plant for long periods of time. The other reason for low plant costs to main contractors is that most sub-contractors will provide plant for their own use to achieve economies on long runs of similar operations.

In addition to the main piece of plant such as cranage and tractor-trailer units some firms were using fork lift trucks for offloading and positioning materials. The tractor trailer unit was more commonly used than dumpers because of the nature of the materials moved around site. This led to greater economy in site transportation since much more can be loaded on the trailer unit than a dumper can carry. Portable circular saws were being used, by four out of eighteen companies, for dealing with alterations and daywork items. Other than these main items of plant the amount of plant on site was limited to small tools which were of a specialist nature. These specialist items included bolt runners, masonry nailing guns, sanding machines, taping and jointing machines and spraying equipment. These items were used by specialist gangs and were not kept on site for general use. Fig. 7.33 shows the cost effect of minimising the plant kept on site for general use. With the larger sites of timber framed houses, the cost of plant per thousand square feet of dwelling is very much lower than that for traditionally built houses. This should not, however, give rise to complacency because it was evident on some sites that costs could have been reduced even further by more specialisation or contra charging to sub-contractors.

Plant Costs for sites of varying sizes

Fig. 7:33

7.9 Type and Cost of Scaffolding

The nature of construction in timber framed housing demands a complete change of thought towards the type of scaffolding used for erection. The majority of sites are using traditional type scaffolding, which, apart from being costly, creates problems for the fixing of claddings. This occurs because some form of scaffolding is necessary for eaves and first floor wall cladding, often prior to ground floor cladding. The various types of scaffolding used on timber framed housing are shown in Figs. 7.34 - 7.39. The most successful type is shown in Figs. 7.36 and 37 where the scaffold can be quickly erected for roofing and cladding. Height adjustment is achieved simply by lifting the cantilever brackets. Brickwork to lower level is completed from a single lift of 'H' frames. Fig. 7.38 shows the use of hanging brackets for roof finishes, the disadvantage of this type of scaffold is that it cannot be used for the first floor claddings. Therefore, a two or three lift scaffold is also necessary for cladding.

Scaffolding should be designed for the use of all external work only where such work can be programmed to follow on a flow line basis. However, since upper claddings are often of a nature which allows for rapid fixing i.e. tile hanging or shiplap boarding it is better to use a scaffold similar to that in Fig. 7.36. This allows the verges and first floor claddings to be completed with a minimum cost of specialist scaffolding. Pre-painted eaves and verge boards reduce the time for scaffolding to stay in position. This is discussed further in the next section on design considerations.

The capital cost of having special scaffolding made for this type of construction is more than offset by the saving in hiring charges for normal scaffolding. The hiring charges were checked on four sites and these varied from fifty two pounds to eighty seven pounds per unit built. This represents seventeen to thirty percent of the total preliminary cost per unit (assuming that scaffold hire is to be included in preliminaries).

The labour costs per unit for the erection and dismantling of special scaffolding in Fig. 7.36 were less than half of the cost of those for traditional scaffolding. This is a great incentive to consider new types of scaffolding for this work.

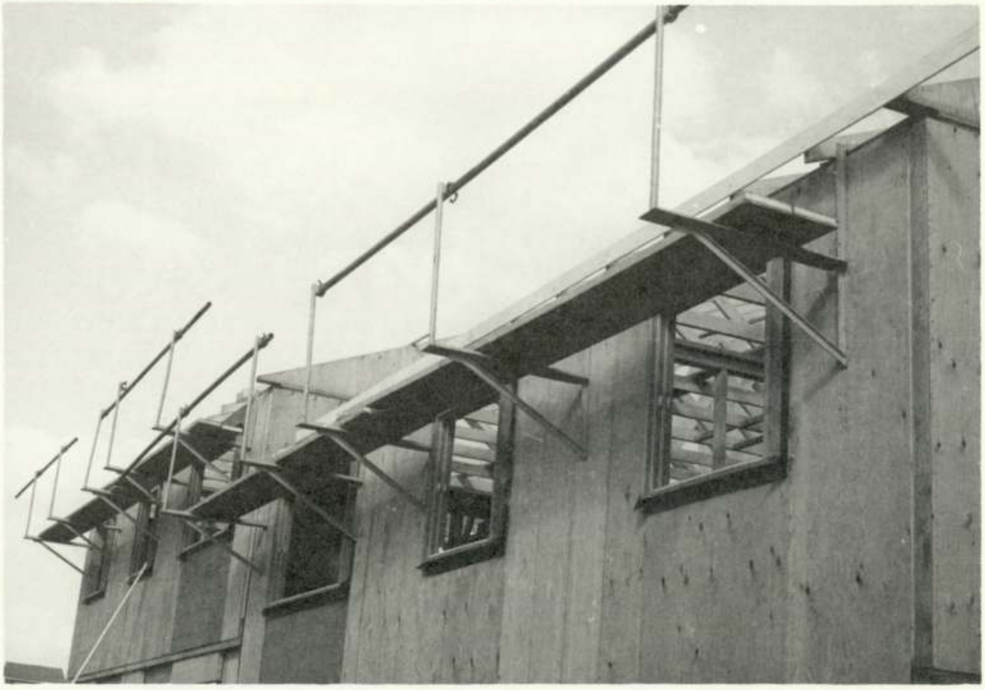


Fig. 7.34

Scaffold brackets hooked over wall enabling roof work to be completed

Fig. 7.35

Typical scaffolding used on timber framed housing

Fig. 7.36

Purpose designed scaffolding for timber framed housing

Fig. 7.37

Close view of purpose designed scaffolding showing base plates and method of height adjustment

Fig. 7.38
Independent scaffolding with extension brackets (Kwik-stage type)

Fig. 7.39

Improvised scaffold brackets for fixing soffit to overhanging floor

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PART 8 MATERIALS

8.1 MATERIALS USED IN PANEL PRODUCTION

The most common softwoods used for panel production are Western Hemlock (C.L.S.) and Scandinavian. The former tends to be less accurate in cross sectional dimensions but this has not proved to be a great disadvantage. There has been some incidence of fungal attack in C.L.S. during the time the timber is stored in packaged lots. One of the largest importers has a policy of breaking open the packages on arrival from Canada to prevent the fungi developing.

There is an increasing trend to preserve the timber against insect and fungal attack. This trend is possibly to allay the fears of local authorities rather than being a necessary step for this type of construction. Panels are usually sheathed with 6mm thick fir ply. However, there are trends in developing the use of oil tempered hardboard and other fibre boards,[1] for this purpose. Tests, using the new material have shown excellent results.

The amount of waste in panel production has caused manufacturers to take a fresh look at methods of selection. This is probably justified with sheathing materials where wastage is as high as thirty percent. Cutting sizes must be selected to suit standard sheets. The optimum reduction in waste can be achieved under factory conditions where better control can be exercised and offcuts have wider alternative uses. The consideration of reducing waste on studding must take into account the overall value of studding involved. The waste factor on studding is in the region of five percent, this represents approximately fifty shillings per house for a three bedroomed house. Any reduction on this is a minimal saving, therefore finger jointing techniques and time spent on selection are suspect when looking for real economies in material usage.

8.2 Materials in Floors and Roofs

Materials for ground floor screeds are usually of the traditional type i.e. sand cement screeds. This is rather archaic for industrialised building, which prides itself on dry construction. A better method of dealing with the ground floor is an asphalt screed which gives the additional barrier against dampness as well as providing rapid continuity for floor finishes. Upper floors are, almost without exception, constructed of $\frac{1}{2}$" or $\frac{3}{4}$ ply decking on timber joists which provides an excellent floor in minimum time and cost.

The roof structure varies with design, and falls into three categories (1) Pitched, (2) Mono pitch, (3) Flat. Each have their own merits from a design point of view, but tend to follow a similar pattern in usage of materials. This is normally some form of trussed rafter, or deck, in the case of flat roofs. The coverings to the roofs, especially in the case of pitched roofs give rise to some further investigation. Most clients specify roofs with concrete tiles, an operation carried out by sub-contractors, which is often behind schedule. An interesting innovation, carried out on two of the sites visited, eliminated the sub-contractors completely by using felt tiles. These were fixed onto ply sheathing by joiners using stapling guns. It resulted in a pleasant rigid finish which could be completed as fast as the shells were being made available.

8.3 Materials used in cladding

The general trend was to build a half brick facing wall to first floor level, ostensibly to reduce maintenance caused by damage. The upper area, first floor to roof level, usually tile hung in concrete tiles. Alternatives to tile hanging are shiplap boarding, some of which is plastic coated, stucco rendering, aluminium boarding and other sheet materials such as pre-finished plywood panels. While the first floor level claddings are dry and fixed without delay to other trades, the lower area, usually brickwork requires further consideration. On one site the skin of brickwork had to be taken down because of poor workmanship on several blocks. This added greatly to the time required for completion. Even with additives to assist in continuing production in winter the process is foreign to an industrialised based concept of building.

The answer is probably to be found in the use of plastic or glass fibre based panels. These have been used on other industrialised buildings i.e. school clinics. Such panels have been used on a private development in the north of England in order to reduce costs. The panels used were "TEXALITE" (2), basically a polyurethane foam enclosed in glass fibre with an asbestolux backing and an aggregate face. The standard 2" panel weighs 3lb per sq.ft. and is claimed to have a thermal efficiency equal to three 11" cavity walls.

The panels can be manufactured to any size, shape and colour. The material is being manufactured by the building division of Dunlop and Ranken Ltd., of Leeds.

This type of panel would greatly increase the speed of cladding the building in all weathers and provide an indestructible, maintenance free wall.

8.4 Internal Finishes

The most costly item of internal finishes is that of taping and boxing the joints of walls and ceilings. In the winter months this operation cannot be properly executed without providing heat to assist drying out or alternatively allowing plasterers to occupy fifteen to twenty dwellings at one time to allow for natural drying out of the various stages. Both solutions are costly.

One method of reducing the time spent on ceilings is to apply a plastic finish to the complete area. There appears to be no easy solution to the taping and boxing of walls if the wall finish is to continue looking exactly like a plastered wall. Simple taping to joints and nail spotting are sufficient if the walls are to be papered. Alternatively, there is a need for the development of a faster drying material used for boxing and nail spotting. One company plastered the walls in the normal way, this brings the wet trade back into industrialised building but the time spend per unit was no greater than the taping and boxing.

Protection to the first floor is necessary during the plastering stage. This could be low grade polythene sheeting which should be placed on completion of internal boarding. The sanding of plywood decking to make it presentable cost thirty shillings per unit (labour cost) on one large site.

8.5 Protective and Decorative Treatments

The protection and decoration of components can be either factory or site orientated. This depends on the following considerations:

(a) Quality obtainable in factory or on site.

(b) Economies to be gained by factory control

(c) Extent to which treatment is necessary before leaving factory.

(d) Effect of pre-treatment on the sequence of erection.

(e) The effect of site and factory jointing techniques on decoration.

(f) Cost of protecting finishes against damage by finishing trades.

Generally, site finishes are more expensive than factory finishes and a better finish is obtained by factory methods. However, experience has shown, for normal paint finishes, that the last undercoat and final coat should be left for completion on site. Window frames and door frames are usually marked by other sub-contractors and require an extra coat on site thus eliminating any advantages gained by factory finishes. Decorative panels are best completed in the factory and protected with low grade ply or other sheet material on site. This allows the factory to apply the finish on material with a controlled moisture content and achieve a better quality finish.

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PART 9 DESIGN FACTORS

DESIGN FACTORS

9.1 Introduction

The subject of design in timber framed housing is one which lies foremost in the aims of this research. The data collected on production and erection techniques has been used below to show where designers should channel their efforts if they are to design an economical dwelling for local authority requirements. The main problem facing the designers is one of demand, yet if they wait for the tide of demand to rise before they make a move to change basic illogical designs, the problem will increase. The ideal situation is to produce a dwelling, at a low cost, that will please every client with regard to aesthetics and standards. This of course is Utopia and is not easily obtained.

Another problem facing the designers is one of prefabrication and of how much work should be factory orientated. Some even consider that total factory production, i.e. box units, should be achieved. However, this is not the answer for the many local authorities, who have the sovereignty of any customer. Local authorities require flexibility in site layout, with as many as five or six different house types, the complete antithesis of flow line production. One company who have designed a system incorporating box units, i.e. complete factory production which can be erected, ready for occupation at the rate of four per day, have been faced with decreasing orders from the local authorities. This clearly indicates that complete factory production of units, which of necessity limits the variety of house types, also draws orders from a limited market.

The designer must look at other ways of obtaining orders with flexibility in mind but with methods of obtaining optimum production runs.

9.2 Design Consideration in Production

Systems

As stated above the complete factory unit has not received the response that designers had hoped for and therefore a different approach has been necessary. This approach has been to design units for production which are purpose made for the particular system and which cannot be used with other systems. Such systems are known as "Closed" systems. The opposite approach has been to produce modular units that can be used in a series of systems and are known as "Open" systems. It has been stated that closed systems are likely to become obsolete, but since designers are always developing new ideas, the closed system is every likely to be changed from series to series before the market has plunged for the "all providing" open system. Designers must consider the potential market they wish to capture, if this includes consortia housing, then open systems are a must. If however, the market excludes consortia then the most economic closed system is the answer for any one company. It is far better to design for economy and simplicity of erection than to boast of a design which is reputed to embrace all components but has no market. Some companies are producing wall units for open systems, with claddings, doors and window fixed and completely glazed. However, units of this nature are intended to capture the open consortia market and must not be allowed to distract the designer who is concerned with a complete system for his own company.

Designers could however, design a system of units of modular sizes, which would fit into an endless number of designs. These would not need to comply with other open systems and therefore would be a closed system with a wide variety of types. This would provide the local authority planners with enough variation to satisfy environmental and aesthetic conditions. At the same time, by coding methods, the production could be simplified and storage eliminated. The Hurn Numerical control system has the advantage over other methods of production when such a system is being designed. It allows for endless house types to be produced, panel by panel as required, without affecting the improvement curve obtained by batch production.

Component Design

Much work is still required on the design of panels and other components. Where standard components are available, the panels into which they fit should be designed to receive them without impairing the speed of assembly. In far too many instances panels are of odd sizes, varying in length from each other by as little as + or - ½". This leads to confusion and error when sheathing is fixed, for some ply panels only vary ¼" in size. Short of measuring panels as they leave the storage bin (they are sometimes in the wrong bin) there is no way of assuring that the correct ply sheet is used. Where the studs determine the overall size accurately, it means a slight delay while the correct ply is sorted. There is no rationalisation in panel lengths, the height is fixed by storey height of the building or first floor level, therefore the only factor that remains to be examined is panel length. There is no difficulty in making panels to the nearest full inch or twenty five millimetre mark but designers continue to ignore this factor. The maximum length of panel made depends upon the method of erection, assuming the factory can cope with long panels. As stated in the section dealing with erection, the sites using cranage were not achieving anything like maximum utilisation of cranes. Most panels which are crane erected, with the exception of large floor units, could have been erected manually. Therefore the designer must design for a higher utilisation factor from such plant by increasing the factory work on panels. This could mean fixing all inserts, insulation, electrical harnesses, felting and tile battens. With a little more thought even claddings of the plastic type, with granite finish could be fixed on ground floor panels. There have been some problems with the fixing of the tile battens in the factory. This has been due to non-alignment on site and has only been rectified by stripping the battens off completely. This reflects the accuracy to which panels are made and on the adjustment that is available on site, at the sole plate level. Much more detail is required at working drawing stage and even using full size models to iron out the erection problems.

Alternatively, designers must abandon the idea of the factory made house, where an ever increasing amount of site work is transferred to the factory. There is no evidence to show that factory based work is more economical, in fact, with overheads incurred by factory manufacture, many operations are more costly. In addition to this, components are subject to a much higher cost if damage occurs, together with higher transportation costs, which do not offset the cost differential when work is completed on site. The bare panels necessary to achieve shelter at an early stage are all that is necessary, cranage can be eliminated completely.

In conclusion, the extent to which components are to be prefabricated in the factory will depend on the following factors:-

(a) The relative cost of factory work compared with the same standard achieved on site.

(b) The cost of handling, transportation, storage and protection

(c) The effect on erection and subsequent trade finishes.

(d) The size and nature of the site.

(e) The rate of production required.

(f) The type of labour available, i.e. can the work be done by semi-skilled workers.

9.3 Design Consideration in Erection

These studies have been limited to two storey local authority dwellings, a few three storey dwellings were being erected on two sites but these were an exception. With this in mind there should be no confusion with the consideration for high rise timber frame dwellings.

Methods of Construction

The most common type of construction used in this country is platform frame. This has proved more popular than the modified frame and independent frames, which are variations of the platform frame, the difference being that upper storey panels are supported directly on the lower panels without positioning the flooring. The balloon frame is not as popular as designers expected even though it is reputed to have the shortest erection time for two storey houses [2]. If this trend continues, the balloon frame may well disappear in favour of the platform frame, since the latter can easily be erected with a gang of three or four men.

The actual sequence of erection requires little research providing there are no obvious mistakes in the design. It was found that the men on site would acquire the best method of erection during their improvement time, irrespective of being given detailed erection instruction. Various factors such as labour skills, nature of site and even gang size will affect the method of producing the highest bonus and thus affect the erection time. In considering methods of construction the designer is faced with the ever increasing problem of the lack of skilled men. The whole industry is having to face this change, namely that less tradesmen are capable of tackling complex problems. This stems basically from streaming in education at an early age, together with the greater opportunities that are available to school leavers. Hence the industry is having to take men of a much lower ability into the trades. Design for erection must therefore be simple, eliminating recesses, bays and other features which add to cost but which do not necessarily add to aesthetics.

External Finishes

The external leaf of brickwork, which is an excellent incombustible material and reduces maintenance costs, must be superseded by a dry construction of equal merit.

Vertical tiling has been causing concern through damage and excessive cost of repair (by nature of fixing). In addition it is a sub-contract element of work which has held work up on some sites. This work could well be superseded by other forms of cladding less likely to damage (from window cleaner's ladders etc) and equally free of maintenance cost. Plastic coated boarding and plastic pre-formed siding are but two suitable materials which can be fixed easily by semi-skilled labour.

More detailed thought is necessary on the verge and eaves finishes. Pre-formed ladder rafters including barge boards would save work on the gable-roof finish. Boxed eaves, in two parts, the top being fixed first to allow roofing and gutters to be completed, would speed up external finishes. The bottom part would be fixed by the cladding gang on completion of the first floor cladding.

Roof cladding could be finished in some form of durable sheeting material which would only require joint seaming insitu. This would greatly reduce time spent on making the building weather tight. The glazing operation is a relatively short one and needs no special consideration. The maintenance costs involved for sealed window units and sliding window units outweigh the cost saved in erection time.

Party walls need mentioning before discussing internal finishes. In general they are formed by studding covered with two layers of gyproc boarding, each side of the wall being 1½" thick, giving suitable sound insulation. In some cases however, the party wall consists of 9" brickwork built between the studding. This creates problems in speed of erection and is executed in the most uncomfortable manner by tradesmen having to work between the two erected party wall panels. If local authorities insist on having a denser fill to the cavity then perhaps designers would look at some other form of construction that would eliminate this wet and laborious operation. Where cranage is being used the cavity side of the party wall could be lined with stramit. On one site, the party walls were filled with concrete, insitu, after the erection of a complete block. This operation, using a gang of two men and a crane only took half an hour per dwelling to complete.

As stated above there was no advantage gained by present mechanical erection methods, mainly due to lightweight panels being used. In some cases manual erection was cheaper than crane erection. This is an indication that design needs further development or that erection methods need to completely revert to manual techniques.

Internal Finishes

In the case of services, namely electrical, sanitary and heating, there is a need for designers to visit sites to see at first hand the problems that are encountered by engineers. In most cases some modification is necessary and it is solved by the men on site together with the designer who pays a fleeting visit. If however, the designer spent more time in assessing the problems encountered and the effect on other trades, the end result would be more satisfactory. Electrical harnessing can be completed in the factory, either fixed to the panels or supplied in packages for house types and simply placed in position on completion of erection. Pre-boring holes for wires must be more accurate or left out altogether. On one site, where pre-boring was employed, two carpenters had to re-bore holes and move noggins for electricians. This cost an extra £4 per unit. For that price all the necessary holes and noggins could have been fixed on site without any factory assistance. Since industrialised building systems are designed to eliminate site cutting, fitting and wastage, more time should be spent on costing the design methods. In some cases plumbing stacks are pre-formed, in other instances complete "heart units", consisting of a metal angle frame supporting header tank, hot water cylinder and plumbing stacks, are lifted into the building prior to roofing.

Internal frames can be storey height with doors hung in the factory. Internal wall and ceiling finishes require further investigation. Some ceilings have a plastic coated finish which eliminates taping but wall finishes take up a vast amount of time in relation to the rest of the internal work. The taping and boxing of walls could be well superseded by some rapid drying grouting process.

Floor decking, which is usually supported on timber noggins at the joints, could be supported by a simple galvanised tee bar, of the same thickness as the decking; usually $\frac{3}{4}$" deep. This would eliminate waste on noggins, which are often pre-cut, and lost as well as reducing the labour cost for the floor deck.

These are but a sample of the many points that can be seen by observation on site, and are intended to stimulate designers into taking a 'fresh' look at their work.

In conclusion designers must exert most pressure on the items where savings are likely to be worthwhile. An example of this can be seen in the production of panels by manual methods in Firm 'A'. The panels for a typical 3 bedroom, 5 person house could be produced for a nett labour cost of fifteen pounds. A great deal of effort would be required to make a saving of 10% on that particular production line; and the saving would only be worth 0.00006% of the total cost to the local authority. The cost of making such a saving would probably be greater per annum than the saving itself. Each operation must be costed carefully and the costs and methods analysed. The areas that offer the greatest economies are the areas where work is undertaken by sub-contractors. In many cases, with a change in design, the cost can be improved. There is little or no incentive for a sub-contractor to reduce his own capital turnover by suggesting better methods to the main contractor.

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PART 10 CONCLUSIONS

10.1 Introduction

Timber framed housing has become an increasingly popular form of construction with respect to Local Authority housing. Ministry of Housing and Local Government Statistics show that for the five year period 1965 to 1969 the timber houses completed rose from approximately 2500 to 9000. This represents an increase from two percent to five percent of all housing built for local authorities in Great Britain. The number of orders for this type of structure continue to rise and some assistance is being offered by the government for the erection of proto-type houses for large authorities. The trends are of enough significance to cause national contractors to examine the system as a likely source of competition to other industrialised methods. The main reasons for this trend are as follows:-

(a) Total hours per dwelling are almost halved, this represents a saving of 600 man hours per dwelling.

(b) Rapid completion, due to the fast erection of the shell, which enables services and finishes to be completed under cover. The normal rate of completion is about nine weeks.

(c) Semi-skilled labour can cope with a greater part of the work requiring only a few tradesmen to control the work. The higher the factory content, the lower the skill required.

(d) The use of low cost plant, equipment and jigs. The frame can be made rapidly with the use of an automatic cross cut and stapling guns.

(e) Capital turn-over can be accelerated to twice or three times that of traditional work, without increase in labour.

(f) The degree of accuracy and finish that can be obtained with this type of construction, which eliminates almost all wet operations, is higher than that for other forms of construction.

The above list does not exhaust the advantages of this form of construction but in a measure shows that the economies to be gained are not minimal either for the producer or the client.

This research has set out to examine the production,erection and design of timber frame houses so that the advantages might be more economically obtained by the firms tendering for local authority work.

10.2 Production Methods

The most common production method is batch production. There are systems in use which tend towards flow line production but are by no means utilised to the extent which is envisaged by flow line techniques. It can be shown that the time saved in factory based work compared with similar site work is not totally due to mechanisation but to the sheltered, organised working conditions. Therefore it is a fallacy to conclude that mechanised flow lines will of necessity increase productivity. The orders that are available from local authorities, although increasing significantly year by year, do not warrant the use of flow line methods for timber frame housing. The only situation where such techniques are economic is one where companies produce both private and public dwellings or where a firm supplies panels, not houses, as components for other types of construction i.e. Rat-trad dwellings or consortia customers. The problem of continuity of work is the main reason for advocating batch production and further more for advocating the most economic batch production. For continuity is not only impeded by small orders i.e. less than 250 dwellings but also from the problem of house types within an order. It is commonplace to have four or five house types within one order, thus reducing a contract to a series of small batch orders. Large orders, with a minimum of house types, is but a dream in timber framed housing and while it is the bane of the production engineers life, it is a fact that needs to be allowed for in the production methods undertaken. One of the largest orders placed by a local authority in the last five years was a contract for nearly 700 dwellings. There were twelve different house types in the contract. The production methods, based on ten houses per week were undertaken economically by carpenters on simple benches, using simple jigs. The only mechanisation involved was cross cutting, panel saw and stapling guns. This method of production, whether carried out in the factory or on site, is the simplest way of meeting the demand for this type of housing and is likely to remain so for the next decade.

10.3 Design

The amount of work undertaken in the factory, as opposed to the site, is not as high in this country as in Canada and the United States. The main reason for this is the flexibility in design, together with site layout that is required by most planning authorities. This means that a very high capital outlay is necessary to accommodate plant and equipment to cope with the likely variation in demand. One company in the United Kingdom has attempted to overcome the problem by offering one house type only, completely factory built and transported to site in box sections. The factory content is approximately 300 man hours and the site work, including pavings approximately 40 man hours. This type of construction has long been suggested as the answer to production methods; however, orders have dropped as the demand for flexibility has risen.

The majority of systems have a factory content of 50 to 100 man hours, excluding window and door manufacture, and a site content of 500 to 800 man hours. This situation has been created by the comparative economies. The ideal situation, where more and more site work is transferred to the factory, has not been realised and probably never will be realised for large local authority contracts. Many stages, which have involved more factory work, such as roof sections and totally glazed units have been abandoned in favour of site work, usually because of cost.

The only acceptable design concept that will gain orders is one which is simple and adaptable in layout. It is better to offer a 'closed' system of components, which can be used to provide several house types, than to offer an all embracing 'open' system which test the resources of the company involved, rather than provide an ideal proposition to the client.

Designers must also consider the shortage of skilled labour in the Construction Industry. If highly mechanised production methods are uneconomical, because continuity of work is lacking, then design for manual work must be simpler. This has been brought about by the changing scene in education where school leavers, with the wherewithal to learn a skill and show initiative, are being chanelled into technician and technologist fields. Therefore simplicity of design is more than a pre-requisite for productivity, it is a necessity for the future labour force.

10.4 Production Costs

The cost figures in part 6 show clearly that the most economical method of production, up to twenty units per week, is the site factory. This has the limitation that each site must have a factory, unless two contracts are secured within a few miles of each other. However, the costs show that temporary factories, with a limited amount of plant, are capable of producing units more economically than any other type of factory and there is no difficulty in setting up such a factory. The air house factory is probably the most economical type of structure that could be used. Assuming a ten year life such a factory would cost less than £500 per annum, well below other forms of temporary buildings, giving large unobstructed areas.

The cost (excluding materials) of producing a complete set of panels on site for an average 3 bedroomed house is approximately £30. This cost covers the factory and plant cost, together with total labour cost, i.e. including oncosts and bonus. A permanent factory produces the same units by hand methods for approximately £32.8 and a semi flow line factory produces units for approximately £33.6 per unit. These figures are based on producing twenty units per week. The very high cost of automatic nailing machines prohibits such plant from competing with hand nailing until site demand reaches thirty units per week. Then and only then should such production methods be considered. The demand must be constant and rising to prevent storage, since storage costs, as discussed below, often cripple economic production. A further advantage of site factories is the valuable service provided for any adjustments necessary to the construction. This, together with production to suit exact site requirements makes the site technique the best solution.

Sheathing to panels can be done by hand, using hammer and nails, stapling guns, or alternatively, by automatic nailing machine. The break even point for hand nailing (with stapling gun) against automatic nailing is twenty units per week. Below this production rate hand nailing is cheaper. Site work, nailing with two inch nails, is more costly than stapling but still cheaper than machine nailing.

10.5 Storage Costs

Many firms are suffering losses created by storage costs because they adopt a policy of full production. This policy is based on the fact that highly capitalised factories must work at full rate to be economical. This policy is only acceptable when the production rate is being met by the rate of demand or delivery rate. However, before reducing the production rate to meet the forecast for demand, companies must accurately cost their storage. This is due to the fact that reduced production increases the cost by as much as sixty seven percent (this is for 0.6 production). The likely 'basic cost' of storage per unit week will vary from £1.5 to £5, depending on facilities offered. This is not the 'real cost' of storage per unit of each order. The cost of storage per unit of each order undertaken depends on the rate of delivery to site, where delivery is around sixty percent of production the storage cost rises from a basic £2 per unit to £10.8 per unit of order. It can be seen from Fig. 6.41 that the break-even point for such a delivery rate, to give lowest storage costs, is a production rate of 0.85. This is the point where increased production costs break even with storage costs. It is therefore essential that delivery rates be increased to match production if storage costs are to be kept to a nominal cost of £2 per unit. By reducing the production rate to 0.85 in the case stated, it was found that storage cost would be reduced from £10.8 per unit of order to £4.9 per unit of order.

In one case the cost of storage per unit order was £27, with approximately 400 units being stored for a period of six months.

10.6 Transportation Costs

The cost of transporting units, composed of simple framed panels, varies a great deal from the cost of transporting units which contain panels complete with door and window inserts. The difference is approximately three fold. For a fifty mile journey the cost of transporting a simple panelised house is approximately £8. whereas the cost of transporting more complex panels is £26 per unit. Taking a radius of a 150 miles as being the average long distance trip that most companies would have to make, the costs are £15 per unit (simple panels), £35 per unit for complex panels. To this extra cost must be added the extra cost in handling and storage, if the real costs are to be known. The extra cost of transporting the complex panels is not offset by time saved, since the erection time of the main frame is not so critical, and more important, the extra factory work can be completed more economically on site. Some companies had withdrawn factory work, mainly because of cost, and transferred it to site where overheads are low.

This again is where the site factory scores points, the transportation is greatly reduced. The transportation costs for site factories are not eliminated as some people have stated. There is a cost for transporting the panels from the factory to the erection area. This cost is usually approaching £4 per dwelling. The cost includes tractor and trailer transport with two labourers in attendance. By contra charging sub-contractors for site transport the cost per unit can be reduced by £2 per unit. It can be seen that site production makes a saving of at least £6 to £8 per unit on transport costs. The optimum transport cost is determined by production policy and must be considered in this context if economies in transportation are being sought.

10.7 Methods of Erection

There is no evidence to show that mechanical erection has any advantage over manual erection. In most cases, the panels, which were crane lifted, could have been fixed manually without much difficulty. Although cranage reduced the erection time by ten to fifteen man hours per unit the cost advantage was only marginal, as discussed below. The most important factor was that in several cases, total erection per week by cranage was no greater than the total for a manual gang. Although crane erection can achieve twelve to fifteen erections per week this is no distinct advantage, for it is easy to achieve such an output with two manual gangs, without increasing erection costs per unit.

Some sites employed fork lift trucks for 'off loading' and moving materials, these were economically used to lift first floor panels onto the platform deck to eliminate heavy lifting.

However, better design could make mechanical handling an economic proposition. If panels were designed to withstand damage when lifted, and allowed for simple slinging methods to be used then the erection time would be reduced. On one site friction grip type clamps were used to provide lifting eyes for the sling; this resulted in a panel falling out of the grips and being badly damaged. Heavier panels i.e. containing a greater amount of factory work would be the only type of panel which would justify cranage on a two storey type building.

10.8 Erection Costs

The average time for a crane erected dwelling is twenty five man hours. The average time for a manual erection is forty man hours. These times are the optimum times after the improvement curve has been achieved. The low utilisation of cranage together with bad site conditions often results in a lower output than the twenty five man hours per unit and therefore costs are extremely high. However, even when achieving such outputs the costs are only marginally lower than manual erection, and in some cases costs are higher. Where the number of units in a contract exceed 200 the cost of crane erection is less than five percent cheaper than manual erections. In some cases less than two percent cheaper. Below 100 units per contract the cost of cranage erection is higher than manual erection.

This shows that there is little to be gained by crane erection on contracts of less than 200 units. Over 200 units the cost saving of two to five percent may well be offset by a greater demand for scaffolding, necessary for roof work. Since scaffolding is often badly utilised, the increased erection speed may involve extra scaffold costs.

10.9 Operation Times and Improvement Curves

Every operation, when carried over a series of units, has a factor of improvement. The simpler the operation the smaller the improvement. The longer the operational time the greater the improvement. So both complexity and length of time spent on an operation, have an effect on improvement curves. It is possible to have simple operations which take a long time to complete, by the nature of the magnitude of the operation. Therefore operations, though simple to understand, may take such a period of time to complete that they offer a routine acquiring phase, resulting in improvement. With timber housing, when doubling the number of operations, the time is reduced from the original (100 percent) to between 86.5 percent and 95.5 percent.

The average reduction is from 100 percent to 87.5 percent. In real time this represents an overall saving of 12.5 percent of the operational time each time the number of operations is doubled. The overall average decrease in time on operations, from initial time to ultimate basic time is 42 percent.

A degree slope can be calculated for the improvement of various operations depending on complexity and duration time of operation.

For operations with an initial duration of between 25 and 40 hours, the time slope is 10 degrees (plus or minus one degree).

For operations of 60 hours duration the time slope is 15 degrees and where operations are less than 20 hours duration they have a time slope of 5 degrees. Operations over 20 hours duration reach the ultimate basic time by 80 to 100 units. Below 20 hours the ultimate is reached by 40 units.

This information allows costing departments to plot the line of slope for each operation and arrive at the likely ultimate time for each operation. This will enable them to negotiate staggered bonus systems to allow for the improvement curve.

10.10 Scaffolding Costs

The costs of hiring scaffolding for timber framed housing is having a crippling effect on the contractor. Conventional scaffolding is not ideally suited to this form of construction and steps must be taken to design and buy simple, purpose made scaffolding. This may have to be supplemented by conventional scaffolding until adequate stocks have been purchased. In some cases the scaffolding costs have amounted to thirty percent of the total preliminary costs for a site. This, when reduced to a cost figure, represents £52 to £87 per unit. Such costs must be reduced if contractors are to stay in the timber framed housing field.

10.11 Site Preliminaries

The cost of site preliminaries varies per unit on the size of contract. The optimum size of contract is 200 units and the most economic batch size between 100 units and 300 units. Above 300 units and below 100 units the costs per unit are approximately ten percent higher. Within the batch size of 100 to 300, the total preliminary cost (excluding scaffold hire) is approximately £150 per unit.

Such costs are higher than anticipated, for this type of construction requires a low plant premium, and is completed in approximately half the time of traditionally built houses. Yet the preliminary cost for the economic batch size is only twelve percent lower than traditionally built houses.

It may be concluded from the analysis in the thesis that Timber Framed Housing offers several advantages over traditional construction.

It has been shown, under conditions that are practical, that Timber Framed Housing is a cheaper form of construction offering benefits in greater productivity. This applies both in the public and private sectors of housing. Productivity is probably the overriding consideration in the housing programme and timber frame is one of the most attractive forms that achieves this important objective in meeting the housing needs of the country.

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