ST/ECE/HOU/14

ECONOMIC COMMISSION FOR EUROPE

EFFECT OF REPETITION ON BUILDING OPERATIONS AND PROCESSES ON SITE

Report of an enquiry undertaken by the Committee on Housing, Building and Planning

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PREFATORY NOTE

Measures and means to increase the output and improve the efficiency of the building industry have for a long time been the subject of special attention of the ECE Committee on Housing, Building and Planning. It was early found that strong efforts must be made to adopt as far as possible industrial principles of production throughout the building process. At the same time, it was recognized that building production showed many specific features which made it impossible to make use of the experiences gained in the manufacturing industries without careful adaptation. A problem which called for special study was the relationship between the length of series of identical products (buildings, sections of buildings, or building components) and the cost per unit, i.e. the effect of repetition on building production costs.

A first attempt to quantify the effect of repetition in building was made in an enquiry undertaken between 1960 and 1962. The results of this study, which exclusively dealt with the relationship between the size of series and unit costs in the manufacturing of building materials and components were published in 1963 [15].[1]

The next stage of the work, which ends with the publication of this report, has been devoted to a study of the effect of repetition on building operations and processes on site. The study was requested by the Committee on Housing, Building and Planning at its twenty-fourth session in June 1963 (see report, document E/ECE/HOU/105). An outline of the study and methods of work were discussed at a meeting of experts organized by the ECE in close collaboration with the International Council for Building Research, Studies and Documentation (CIB) in October 1963.[2] It was agreed that an enquiry should be undertaken which would draw on the data and information already available in participating countries. The Secretariat was therefore asked to prepare, on the basis of information to be submitted by Governments and any other relevant material, a provisional report for discussion at a meeting of experts in the autumn of 1964 (see document HOU.COST/1, para. 16 and annex II).

Pursuant to this decision, a draft report (HOU/BUILD/3 and Add.1) was prepared by the Secretariat with the invaluable assistance of two consultants, Mr. G. HIERHOLTZ

(1) The references in square brackets relate to the bibliography (annex III)

(2) A list of the experts who took part in this meeting will be found in annex I.

of the Centre Scientifique et Technique du Bâtiment (France) and Mr. G. SEBESTYÉN of the Institute for Building Economy and Organization (Hungary).[1] The report was examined by the Working Party on the Building Industry at its first session held in November 1964.[2] The Working Party accepted the draft report in principle and agreed that it should be completed as rapidly as possible for general circulation. Governments were invited to submit comments and other relevant material which could usefully be taken into account in the preparation of the final version of the report (see document HOU/121; HOU/BUILD/8, para. 5). The recommendation made by the Working Party was subsequently endorsed by the Committee on Housing, Building and Planning at its twenty-sixth session in May 1965 (see report, document E/ECE/HOU/111, para. 12).

Accordingly, the Secretariat, in collaboration with its two consultants, Mr. HIERHOLTZ and Mr. SEBESTYÉN has revised and completed the report in the light of the discussion at the first session of the Working Party and of comments and material received from Governments up to 1 June 1965. The final version of the report is now being published under the sole responsibility of the Secretariat.

Relevant material for the study has been received from twelve countries, namely, Bulgaria, Czechoslovakia, Finland, France, the Federal Republic of Germany, Hungary, the Netherlands, Norway, Poland, Sweden, the Ukrainian SSR and the United Kingdom. In addition to the participants listed in annexes I and II, mention should be made of the valuable contribution to the study made by Mr. W. TRIEBEL, Director of the Institute for Building Research, Hanover (Western Germany), Mr. A. FJØSNE and Mr. R. HUGSTED, Civil Engineers, the Norwegian Building Research Institute, Mr. M. JACOBSSON, Director of the National Swedish Council for Building Research and Mr. K. GÖRANSSON, Civil Engineer, AB Skånska Cementgjuteriet, Stockholm (Sweden).

The evidence presented in this report emerges partly from national studies already published and partly from other relevant information submitted by Governments. The lack of a common approach and of uniform concepts in the collection and presentation of data has prevented a more thorough analysis of the material. Extreme caution

(1) Mr. Sebestyén has since been appointed Vice-Minister of Construction.

(2) A list of participants in contained in annex II.

should be exercised therefore in any direct comparison of the results obtained in the various countries. It should be mentioned, moreover, that the main purpose of this study is not to provide a scientific analysis of the effect of repetition on building operations but rather to present in a logical form the information available in order to help Governments in their policy making. It will be the task of national building research institutes and their international organizations to go more deeply into the subject.

The report comprises six chapters and four annexes.

Chapter I introduces and summarizes the report and sets out certain conclusions which would appear valid at this stage, as well as recommendations for further research to be done in this field.

Chapter II presents and analyses the available evidence of the effect of repetition on operational times. The two main sections are devoted to a theoretical discussion of the problem and the results of field studies, respectively.

In chapter III follows a discussion on the effect of repetition on building costs, with particular reference to expenditures on the building site. As in the previous chapter, the two main sections are dealing with principal issues and results of practical field studies.

Chapter IV is devoted to a discussion of the conditions necessary to achieve favourable effects of repetitive work. It provides a rather comprehensive analysis of the different obstacles to efficient execution of work on the building site.

Chapter V deals with the problem of organizing building production in order to obtain the maximum benefit from the effect of repetition. Specific attention is paid to the "flow-line" method of organization, which has been found to be the most effective means of organizing highly repetitive work.

Chapter VI provides a brief review of problems which have been dealt with in some of the country reports but which, though related to the subject matter of the study, do not lie strictly within the scope of the enquiry.

Annexes I and II list the names and functions of those who participated in the two ECE meetings at which respectively the study was launched and the draft report examined. In annex III, the bibliography, are listed the published reports referred to in the study. Finally, annex IV provides a brief description of a method used in the Ukrainian SSR for the calculation of the economic effect of using flow-line methods in construction.

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(1) The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country or territory or of its authorities, or concerning the delimitation of the frontiers of any country or territory.

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CHAPTER I

INTRODUCTION, SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Background

One of the most serious problems facing Governments all over Europe today is the inability of the building industry to keep pace with the ever-growing demands for construction work of all kinds. In most countries available labour resources have been fully taken up and the possibilities of effecting mechanization and "everyday rationalization" of site work already largely utilized to raise the capacity of the building industry. At the same time, there is a continuous demand for industrial buildings and public works, necessary to allow for a further growth of the economy, combined with rising needs for housing and social service buildings such as schools, hospitals and assembly halls. Particular efforts are called for in the housing sector. The hard fact is that the present rate of dwelling construction in many countries is not much higher than what is necessary to prevent a deterioration of present housing standards. The production level must in some cases be raised, not by 10 or 20 per cent, but by 200 or 300 per cent, if an acceptable rate of improvement is to be achieved. In addition to these enormous requirements for new construction comes an ever-increasing need for maintenance of existing buildings, withdrawing from new production an increasing share of skilled labour force.

It is natural in such a situation that Governments look for radical measures and means which could help to increase substantially the output and productivity of the building industry. The generally accepted solution to this problem lies in a far-reaching application of industrial principles of production throughout the building process. Any industrial production is based on the manufacturing of identical products in long series and the application, as far as possible, of specialization and mechanization in the production process. The problem now arises how to apply these principles in the production of buildings. Must the whole buildings be produced in large series or rather the components from which they are assembled? How far should standardization be brought in order to result in optimum solutions from the economic as well as functional points of view and under different conditions in terms of weight, cost and size of building components, transport distances, and so on? Can any appreciable improvement of labour productivity be achieved by training in the case of building operations carried out on the site and, if so, what is the economic gain to be obtained therefrom?

The production of buildings - in particular in industrial forms - no doubt presents a number of technical, organizational, economic, aesthetic and social problems which are not common to any other product destined for mass consumption. At the same time, the need for a general increase in productivity and output is perhaps more urgent in the building industry than in many other branches of the economy. For this reason, the ECE Housing Committee(1) decided to start special investigations on an international level into the effect of repetition on costs and labour productivity in the building industry. The general aim of the studies was to find out how and to what extent industrial principles of mass production could usefully be applied in the building production process. The first stage of the work, which dealt with the relationship between the size of series and unit costs in the manufacturing of building materials and components, was completed and the results published in 1963. /15/ The second enquiry on the subject, the results of which are published in the present report, has been devoted to the effects of repetition on building site work.

Purpose of the study

The main purpose of the study as set out in the agreed outline, was to establish the influence on labour productivity and building costs of the scale of production and the degree of repetition of operations carried out on the building site. Particular attention was to be paid to the specific problems of maintaining continuity of work on the building site despite adverse influences of external conditions. It was hoped also that the study could provide some advice and guidance as to suitable methods of organization of the site work, with a view to avoiding or limiting the effect of adverse factors and thus exploiting to the maximum extent the increased efficiencies to be gained from repetition.

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(1) Later transformed into the Committee on Housing, Building and Planning.

The results of the study were to be used by Governments in elaborating technical and economic policies, with particular reference to the suitable scale of building operations and the creation of conditions necessary to improve the productivity of house construction. The results were also to serve contractors and building organizations in planning housebuilding projects and in estimating their cost. Finally, it was hoped that the study would provide useful information for devising suitable forms of remuneration of building labour in different phases of the building process.

Scope of the study

In the outline of the study, its scope was restricted to the following three broad aspects of the problem:

(a) the effect of repetition on operational times;

(b) the effect of repetition on the cost and productivity of building operations on site;

(c) the organizational problems which have to be solved in order to achieve the benefits of repetition.

In the collection, analysis and presentation of the data, separate consideration was to be given to three related fields in which the effect of repetition could be studied, namely:

(a) operations: the work of individual gangs on the building site;

(b) dwellings: the total amount of work of all gangs employed in the production of a dwelling;

(c) projects: the average amount of work required to produce a dwelling in repeated contracts.

Method of work

It was agreed that the enquiry should be based on the data already available in participating countries. Governments were invited to collect relevant material from such sources as research institutes, labour organizations, contractors, building organizations and public authorities. While recognizing that the comparability of data would be greatly improved if national information were collected according to a common plan and an agreed set of definitions, it was appreciated that such a procedure would lay too heavy a burden on participating Governments; it was accordingly agreed that the information should be communicated to the Secretariat in its original form, together with explanations as to the coverage, method of collection and analysis, statistical significance and so on.

On the basis of the information thus collected, the Secretariat was to prepare a preliminary report for examination by a group of experts. It was envisaged that, arising out of the enquiry, proposals might be elaborated for a more comprehensive study, based on the collection of fresh material according to a common method and an agreed set of definitions.

SUMMARY AND CONCLUSIONS

General

As was to be expected from the methods of work adopted, the contributions of countries to the study are uneven and incomplete. Nevertheless, except for the specific question of the effect on production cost of repeated contracts, all aspects of the study have been covered. One chapter of the report deals with the effect of repetition on operational time, mainly from the point of view of the effect of training on labour productivity. Another chapter contains the evidence received of the effect of repetition on building costs. The conditions necessary to achieve favourable effects of repetitive work and the organizational problems involved in its execution were found to call for specific attention and analysis. Two separate chapters have therefore been devoted to these aspects of the subject. A concluding chapter has been added to provide a brief discussion on certain other closely related problems.

In the socialist countries of eastern Europe the series of identical building operations are often of such magnitude that the specific problems connected with the running-in of production processes are of negligible significance. Furthermore, the specific way of organizing site work usually employed in these countries (the "flow-line" method, see chapter V), is based on a predetermined output, involving a large number of highly specialized simple building operations. These reasons may explain the lack of comprehensive data contributed to the study from some of those countries. The careful balancing of gangs of operatives working on the same flow-line is however likely in the future to call for the most accurate and penetrating knowledge of all factors affecting the labour productivity of different operations in these countries as well.

In western European countries, owing to the more limited length of the series of identical building operations normally prevailing, the problem of the influence of repetition on labour productivity and building costs is more serious and more difficult to solve. The crux of the matter is that the series of repetitions are often not large enough to allow for a stable operational time to be attained before completion of the work. This fact, together with the uncertainty about a number of external factors affecting operational time, explains the problems arising in all kinds of pre-planning of site work; the execution of building operations is often characterized by improvisation rather than organization. The principles of scientific management are, however, gaining ground and will result in more adequately planned processes. The report provides evidence of the possibility - through proper planning - of keeping gangs of workers on the same type of work for periods of up to a couple of years.

Despite the uneven nature of the information provided for the study, which has seriously limited the depth and quantitative analysis of the effect of repetition on building site work, certain general conclusions may be drawn.

As in the manufacturing industry, labour productivity and production costs in building depend on the technology used and the extent of routine attained by the operatives. Both factors are considerably and favourably affected as the scale of production and the degree of repetition increase. The larger the scale of production, the greater is the justification for additional investment in equipment and a higher degree of specialization of work. In building, however, the nature of the product imposes certain limits to the application of this rule. The fact that the workers and not the product have to be moved from one working area to another and that the working areas are only provisionally organized and adapted to production, prevents a more far-reaching specialization and mechanization of the work. The special problems of applying industrial principles of production in building should, however, not be exaggerated and should not be allowed to excuse the use of obsolete techniques and out-of-date methods of planning and organization.

The comparatively primitive circumstances under which site work has to be performed and the unfavourable influence of unforeseeable external disturbances render the problem of co-ordination and continuity of work more difficult to solve in building than in other production work. Indeed, in each specific case, the advantages of specialization must be very carefully weighed against the problems of co-ordination which, under unfavourable conditions, may lead to an extension of construction time and thus to an increase in indirect costs (labour on-costs, short-term financing, costs or rents for mechanical equipment, overheads, etc.).

Generally speaking, it would appear that the process of improving labour productivity through the repetition of a series of identical building operations does not differ from that observed in the manufacturing industries. The rate and degree of improvement depend largely on the nature of the building operation, the number of operatives engaged in its execution and the stimulation of the workers, e.g. through the remuneration system. The main difference as compared with manufacturing lies in the number of adverse factors influencing building work. It is not enough to ensure that building production allows for repetitive work in large series. It is of equal importance to ensure that the conditions necessary to achieve the favourable effects of repetition are fulfilled. From the evidence presented in this report, it is clear that building managers and supervisors - and sometimes also public authorities - grossly underestimate the importance of continuity of work. Breaks in time, a change in personnel, the removal of working teams from one task to another, and other measures aimed at utilizing available resources to the maximum extent, may well defeat their object. The key to maximum productivity in repetitive work is the opposite of improvisation, namely, thorough preplanning, careful organization and scrupulous maintenance of continuity of work.

Certain sectors of construction activity, in particular housing construction, are particularly well suited to the application of industrial principles of production. Governments would find it profitable to ensure, or promote ensuring, that these favourable possibilities of increasing the output and improving the efficiency of the building industry are utilized to the maximum extent. This can be done by the adoption of long-term financing and investment plans for residential construction and by other measures aimed at securing a continuous housing output.

Governments could further promote the development of industrialized building by ensuring or fostering the organization of demand for construction work of all kinds in such a way as to avoid unnecessary variations in the products and services required of the building materials and construction industries. The principal means of achieving this goal is the unification of building bye-laws and regulations and the adoption of national or international standards for functional requirements, qualities and dimensions of the building products.(1) Typification of designs based on scientific research into users' requirements should provide the basis for standardization and dimensional co-ordination in building.

It is recognized that demand, even if organized to an optimum degree, will remain diversified and geographically scattered. The series of identical building works to be carried out may therefore differ in length. It is of great importance for the achieving of maximum labour productivity that the methods and organization of building operations be adapted in each specific case to the size of the series. Governments are thus recommended to disseminate information about the methods of work and forms of organization that are most appropriate under different conditions.

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(1) See the recommendation adopted by the Committee on Housing, Building and Planning at its twenty-sixth session, in May 1965 (document E/ECE/HOU/111, annex I).

Effect of repetition on operational time

The basic effect of repetition on building operations and processes on site is the successive reduction of time required to execute identical operations carried out repeatedly and successively. The favourable influence of repetition on operational time is due to increased labour productivity achieved by training but also by successive improvements of work method and arrangements in the immediate environment of the actual operation, as well as a steadily improved attuning within the gang and between the gangs engaged on the operation.

For analytical and planning purposes, the gradual improvement of labour productivity attained by repetition is usually illustrated by means of improvement curves showing, in one way or the other, the relationship between the operational time and the number of operations completed. The general shape of improvement curves is well known: the operational time is always greatly reduced at the beginning of the work sequence, while the reduction in time required successively decreases.

It is of vital importance for the planning, execution and remuneration of repetitive work to be able to anticipate the rate and degree of improvement of labour productivity in the running-in process of different building operations. For this purpose, data on actual improvement achieved have been analysed by many research workers, with a view to finding a generally applicable formula or theoretical model which would enable repetitive work to be planned in a scientific way. Examples of such models are presented in chapter II. The American WRIGHT found that in the manufacturing industries, the improvement curve could be described by a logarithmic regression function or power formula, corresponding to the following rule: the accumulated mean value of operational times is reduced by 20 per cent, when doubling the number of identical operations. The Norwegian Building Research Institute has found that in the building industry, the improvement curve could best be described by means of an exponential function, which may be expressed in the following way: that part of operational time, which can be reduced by routine acquiring, will be reduced by half after constant numbers of repetitions. Other theoretical formulae for the calculation of the repetition effect are reported from Norway and from the United Kingdom.

The second main part of chapter II presents the observations submitted by different countries on the effect of repetition on operational time. The material is related, on the one hand, to the execution of specified individual building operations and, on the other, to the repetition of groups of operations required for the execution of functional building units, namely identical buildings, identical dwellings and identical storeys in multi-family buildings.

Improvement curves for the individual building operations, "assembling of formwork", "concreting", "dismantling of formwork" and "floorlaying" have been reproduced by way of example from the comprehensive studies undertaken in Western Germany in this field. Data on the increase of labour productivity in the repeated execution of wooden formwork has been received from Finland. The French contribution to the study contains information on the repetition effect on the time required for assembling formwork, erecting "tunnel shutterings" and prefabricated panels and for concreting. The assembly of heavy concrete elements, placing of formwork elements, handling of bolts for formwork, placing of light concrete insulation, fixing of wall measurements and assembling of framework for hoistways have been analysed by the Norwegian Building Research Institute. In a Swedish study of forty-four one-family houses, the entire work on the building site was divided into nearly 100 different operations, on each of which detailed records of actual time consumption were kept, together with information about breaks of different kinds, weather conditions and other factors having an influence on labour productivity. By way of example, the labour productivity achieved in the following three operations is reported: "sawing and erecting loadbearing structure", "setting up of combined kitchen and bathroom elements" and "making of roof trusses on site". From the United Kingdom, improvement curves relating to the erection of plasterboard partitions, electrical carcassing, and execution of the first stage of brickwork and floorboarding are reported.

Figures on total labour consumption for the erection of identical or similar buildings are quoted from studies undertaken in Finland, France, (twenty similar blocks containing 1,010 flats), Israel (two identical four-storey buildings), Poland (five identical multi-storey blocks of flats), Sweden (two groups of identical single-family houses), the Ukrainian SSR (six identical five-storey multi-family buildings) and the United Kingdom (pairs of identical single-family houses erected on five different sites).

The results of detailed calculations on the time required for the production of identical dwellings in series of different length are reported from Czechoslovakia. Information received from the Netherlands contains figures on the labour consumption in the construction of 240 identical flats built in three-storey blocks.

Information on the total labour requirements for the completion of identical storeys in multi-family buildings has been submitted by Finland (twenty identical storeys in five four-storey buildings and eighteen identical storeys in three six-storey point blocks), France (135 identical storeys in nine prefabricated point blocks and fifteen identical storeys in a slablike fifteen-storey building), Israel (four identical double storeys in a ten-storey building), Poland (eleven identical floors in a thirteen-storey block of flats), and Western Germany (fifteen identical storeys in a high-rise building and eight identical storeys in three different buildings).

Analyses of the effect of repetition on labour productivity on site are hampered by the influence of a large number of adverse factors and outside conditions affecting the execution of operations. Almost all work sequences studied in this report were found to have been more or less disturbed by bad weather conditions, breaks in time, changes in the composition of work gangs, and the like and many processes had suffered from lack of planning and management efforts. Despite these unfavourable influences, which are the subject of a more detailed treatment in chapter IV of the report, it would seem to be possible to draw some general conclusions on the basis of the material collected.

A successive improvement of labour productivity is achieved in all kinds of building operation, carried out consecutively and continuously in series, provided the capacity of the operative(s) is not predetermined or seriously affected by the output of machinery or equipment involved in the execution of the operation or by the capacity of other operatives whose work is closely linked to the operation in question.

In most of the improvement processes studied, one could observe two phases, namely: an operation-learning phase, during which the workers acquire sufficient knowledge of the task to be performed and when labour productivity increases rapidly; and, secondly, a routine-acquiring phase, during which a gradual improvement of labour productivity is attained through a growing familiarity with the job and through small changes in work method and organization. In most cases an approximately stable operational time is ultimately achieved.

In practice, it is often difficult to draw a distinct borderline between the operation-learning phase and the routine-acquiring phase. Nevertheless, their existence should be borne in mind when attempts are made to compare improvement curves obtained from different work gangs. If the members of a gang have worked for a long time together and if they are familiar with the work process in principle, this means that the gang has already passed part or the whole of the operation-learning phase. The improvement achieved by such a gang cannot easily be compared with that of a newly established gang carrying out an operation with which it is not familiar.

The exact shape of the improvement curve, i.e. the speed and degree of improvement at different stages, depends on the nature of the operation studied and the conditions under which it is performed. The improvement of labour productivity due to repetition is the combined result of better knowledge, better organization and better co-ordination of the operation. Simple operations, consisting of a limited number of part-operations and calling for a minimum number of instructions, normally show a rapid increase in labour productivity, and a stable operational time is achieved comparatively soon; the degree of improvement depends by and large on the precision called for in the execution of the work. As the complexity of a building operation increases, the rate of improvement is slower and a stable operational time takes longer to achieve. Another important factor influencing the improvement process is the degree of mechanization, i.e. if the operation calls mainly for physical strength rather than technique and training. In the former case, of course, there is a natural limit to improvement. The size of the work team has also a substantial bearing on the improvement process: the larger the team, the more the time and effort required for co-ordinating the work. In the extreme case of individuals carrying out their tasks independently, there is, of course, no co-ordination problem at all.

It is claimed in some of the reports submitted for this study, that the possible degree of improvement achievable by repetition is greater in non-traditional operations than in traditional ones. Such observations may be attributed to differences in the nature of the operations involved, as discussed in the previous paragraph, and to differences in the level of preplanning, organization and supervision of work.

Thus, for instance, the division of building operations between a few traditional crafts does not provide for a sufficiently high degree of specialization. A skilled bricklayer has to know how to execute a wide range of different kinds of brickwork and he is seldom left to improve his ability on one single type of work during a long period. If, however, a bricklayer specializes in only one type of brickwork, a substantial improvement of his capacity can be achieved as has been reported from some of the eastern European countries. Information received from the Netherlands seems to confirm that, provided sufficient specialization and proper organization are applied, a very considerable improvement in labour productivity can be attained by repetition, even if the work methods may be classified as traditional.

Furthermore, the notion "traditional" implies that the operation in question is more or less known to the operative and that the operation-learning phase of the improvement process during which most of the improvement in labour productivity is attained has already been passed. In the case of non-traditional operations, it is naturally difficult to know in advance how to organize the work in the most efficient way, and this may contribute to an exceptionally high labour consumption in the very first operation cycles.

In view of the great variety of individual building operations, it is not to be expected that one single mathematical formula or model of the improvement process could be applicable to every kind of operation. On the other hand, the entire group of activities and operations necessary to complete a building or part of a building could always be considered as a very complex over-all operation, similar to the complicated assembling operations studied in the manufacturing industries. The main difference would lie in the almost unlimited number of adverse factors and outside conditions affecting building work. It could be assumed, therefore, that the pattern of improvement in the building industry should be similar to that in the manufacturing industries but that the degree of improvement would be lower. Based on these assumptions, the expected decrease in the average mean value of operational times, for each doubling of the number of executions, should in the building industry, lie between zero and 20 per cent. which is valid in manufacturing. The actual percentage should depend on the efficiency of the organization of building operations in each individual case. This hypothesis seems to be confirmed by the results of studies contributed to the report. The percentage improvement of over-all time consumption observed at well-organized building sites varies between 8 and 13 per cent for each doubling of the number of executions.

Effect of repetition on building costs

To achieve improved labour productivity by repetition could be a target in itself. But the ultimate aim is, of course, to attain a favourable effect also on building costs. The economic aspects of repetitive site work are dealt with in chapter III of the report. Here again, there is a section devoted to a theoretical discussion of the problem, and another to the results of field studies.

The economic effect of repetition of site operations is due to a decrease in operational costs, on the one hand, and to indirect cost savings caused by the reduction of construction time (lower labour on-costs, costs for finance, machinery and equipment, etc.), on the other. The direct savings in operational costs depend, in turn, on the gradual decrease in operational time attained in repetitive work, on better organization and greater specialization of the work, as well as on the higher degree of mechanization which may be justified in serial production. When such rationalization involves investments, however, it is of extreme importance to predetermine the run size correctly. If the run size is over-estimated - i.e. because new requirements call for new technologies - a real loss may easily result instead of an economic gain.

An important factor influencing direct as well as indirect building costs is the type of remuneration system. If a purely hourly wage system is employed, the entire economic gain from improved efficiency will appear in terms of lower wage costs. On the other hand, as the earnings will not reflect the results of the work, the operatives will have no great inducement to improve their ability. The effect of repetition could therefore be expected to be comparatively small, and thus also the indirect savings emerging from the reduction of construction time. The advantages and disadvantages of a purely piece-rate system of remuneration are the reverse of those of the hourly wage system; small or no savings in direct wages, but substantial indirect savings due to the shortest possible construction time. In many countries a combination of the two systems has been found most economic and efficient, and several examples of such systems are provided in the report.

Data from Czechoslovakia, referring to the construction of type dwellings in 1959, illustrate a reduction of different cost components and total building costs when increasing the run size of identical dwellings. The savings, due to the effect of repetition on operational costs and to the acceleration of the production cycle, were calculated by a construction enterprise. The saving in total costs when increasing the run size from 250 to 2,250 was estimated at 9.4 per cent. From the Netherlands, it has been reported that a decrease of 20 per cent in total building costs is possible by increasing the series of identical dwellings from 72 to 432. In Finland, labour costs went down in one case by 14 per cent and in another by 18 per cent, when identical buildings were erected consecutively. In Western Germany, a reduction of 6 per cent in total building costs and of 16 per cent in costs of wall construction was observed in a study of 500 terrace houses erected in two phases.

The very few and scattered data that have been made available concerning the effect of repetition on building costs do not permit a proper analysis and evaluation of the different factors affecting cost savings in repetitive work. However, all information submitted on the subject, as well as hypotheses based on the effect of repetition on operational time, point clearly to the fact that substantial savings in building costs can be gained both directly and indirectly from the repetition of identical building operations in long work sequences. Available evidence seems to indicate that, in construction according to modern methods and techniques, implying a high degree of mechanization and specialization, indirect savings gained from a reduction of construction time predominate and are growing in importance. Operational costs do not decrease to the same extent as labour productivity because the wages of the workers are normally linked in some way or another to their output. Thus, in most cases, the repetition of identical operations has a favourable effect, not only on labour costs but also on wages.

Conditions necessary to achieve favourable effects of repetitive work

The basic condition for achieving favourable effects of repetition is continuity of work. The operations to be carried out have to be identical (operational continuity) and they have to be executed by the same operatives and, as far as possible, without breaks (executional continuity). When operations of a repetitive character are carried out in a factory, it is merely a matter of thorough preplanning, careful organization and observant control, to ensure that the work will run continuously and undisturbed by external influences. For operations on the building site, conditions are less simple and the problems relating to production less easy to foresee and tackle. Building operations are adversely affected by inclement weather, difficulties of access, delays in the delivery of building materials, special problems arising when work has to be carried out far above ground level, and so on. These external influences not only impede the efficiency of work, they also cause breaks in executional continuity and thus prevent the full effect of repetition being achieved. Real operational continuity is also difficult to attain, since certain building operations have to be adapted to differences in the nature and slope of the ground and other site conditions.

Many examples of the serious adverse influence of external disturbances and of breaks in continuity on repetitive site processes have been submitted and are reported in chapter IV. The results of breaks in operational continuity have been observed in Finland, France and the Netherlands. The effect of time breaks on labour productivity in repetitive work sequences has been reported by Finland, Sweden and the United Kingdom, and the effect of change of operatives by Sweden and the United Kingdom. The problem of sufficient work space for different gangs simultaneously carrying out tasks on the site has been highlighted in the Netherlands contribution. The influence of inclement weather has been studied in Finland and France. The so-called "end effect", i.e. the increase observed in operational time per unit when a series of operations is approaching its end, has been illustrated in several of the examples submitted.

The evidence presented in this report clearly shows that even comparatively small differences in the operations to be executed (operational discontinuity) as well as time breaks or changes in the personnel executing the work (executional discontinuity) seriously affect the improvement process. In fact, breaks in continuity can, under unfavourable conditions, almost completely neutralize the repetition effect. Breaks in continuity are most often caused by external influences, but can also arise from inadequate organization of the work or from the fact that the project does not lend itself to proper organization - for example, if the space available is insufficient for repetitive work.

Influence of external conditions on site work can hardly be avoided altogether. Their adverse implications, however, depend on the nature and duration of the operations. Wet building processes, such as bricklaying, concrete casting and plastering, are generally sensitive to weather conditions and, at the same time, take more time to execute than dry processes of the assembly type. The key to increased independence of such influences seems, therefore, to lie in a more extensive use of prefabricated components, jointed by dry methods on the building site. This does not mean, of course, that favourable results of repetition cannot be attained in wet building processes. Provided adequate measures are taken to ensure continuity of work, a high degree of improvement in the labour productivity of wet building operations can be achieved, even under winter conditions, as has been proved in many of the studies supplied for this report.

Inadequate organization of work on site is often due to insufficient knowledge of the organization method most suitable to repetitive work of a particular kind and duration, or to ignorance of the serious implications of breaks in continuity. In repetitive work, the traditional improvisation of site work must be replaced by thorough preplanning and organization of the work, based in each case on the length of the series to be produced as well as on other relevant characteristics of the project. For single projects, in particular those related to urban renewal, it may sometimes be difficult to organize the work in the best possible way, because the project does not allow for sufficient specialization. In the construction of new housing areas, however, it should be possible to take fully into account executional requirements in the design of buildings. This can be done either by a close collaboration between the designers (the town-planner as well as the architect) and the building organizations, or by the designers themselves acquiring sufficient knowledge of the production requirements.

The material provided for this study seems to indicate that building work is not seriously affected by the height above ground level at which it is executed, at least not in the case of buildings of less than twenty storeys. Some operations are rendered somewhat more difficult with the increasing height of the building but, provided the storeys are identical, productivity is still positively affected by repetition. Which of these two factors predominates will depend on the nature of the construction work and the efficiency of its organization.

The increase in operational time often observed at the end phase of repetitive work sequences seems in most cases to be due to modifications and additions of operations which are called for in the end phase, i.e. operational discontinuity. Sometimes, however, the end effect has been found to be due to lack of planning and management.

In summary, the following factors contribute to a maximum favourable effect of repetition on the building site:

(a) architectural and structural plans ensuring maximum identity of operations;

(b) adequate size of projects allowing for sufficient specialization as well as sufficient space for each of the work gangs involved;

(c) proper preplanning and organization of site works; and

(d) adequate day-to-day management and supervision of site work.

Planning and organization of repetitive work

In so-called "traditional" construction, particularly of single objects, knowledge of the work to be executed is generally limited while the number of factors influencing the production is large. Detailed preplanning and systematic organization of the work are therefore often out of the question. In many cases the site work is started even before all drawings and specifications are available. In such circumstances the efficiency of the building work will depend exclusively on the ability of the supervisory staff to improvise and on the workers' degree of flexibility and skill.

With increasing size of building projects and growing use of repetitive work processes, the need for up-to-date methods of planning, organization and supervision of site operations is more and more accentuated. This problem is dealt with in chapter V.

For several reasons, the optimum degree of specialization of work increases with the length of the series of identical operations to be performed. In the case of highly repetitive construction processes, it has been found most effective to organize the work according to principles very similar to those used in the mass production of consumer goods on belt lines. The building cannot, of course, be moved from one working station to another; instead, the operatives have to move between different working areas. Nevertheless, flow-line construction is based, like manufacturing processes, on the separation of the production process into specific and simple tasks which are carried out by specialized workers or teams of workers. Flow-line construction also, like belt-line production, works with a stable output which may be adjusted from time to time with the increasing ability of the workers.

Flow-line methods of construction are being used in all European countries but it is in the socialist countries of eastern Europe that they have been most thoroughly studied and widely applied. Indeed, the concentration of demand in these countries, the centralization of investment programmes and of architectural and structural designs, and the concentration of the construction industry have created particularly favourable conditions for the repetition of building operations. These conditions are being utilized to the utmost by standardization and typification of buildings, building components and technological processes, the specialization of building enterprises and the allocation of a constant or increasing amount of work to each enterprise.

A comprehensive theory of the flow-line method, including a terminology of more than 150 concepts and a series of formulae have been established in eastern Europe; some examples of the notions used are provided in chapter V of the present report. Constant attention and research are devoted to the perfecting of the method, inter alia, by the application of network planning and computer techniques.

Substantial savings in terms of labour consumption as well as building costs, due to the use of the flow-line method of construction are reported from Bulgaria, Czechoslovakia, France, Hungary, the Ukrainian SSR and Western Germany.

Irrespective of the size of the project and the degree of specialization applied, it is of extreme importance that the planning and organization of site work should be based on the best possible knowledge of the effect of repetition on different kinds of building operation.

In the case of small and medium-sized projects, a stable operational time is seldom achieved before completion of the construction works. This means that the work is carried out under the operation-learning and routine-acquiring phase of the improvement process and that a gliding productivity has to be expected throughout the work-period. It is particularly important therefore to allow for such an increase in the productivity to be attained by flexible organizational arrangements. The experience gained in Norway shows that it is not an insurmountable task to apply scientific planning of site processes even when the series are comparatively limited and therefore a considerable adjustment of construction time has to be made to take into account the extra time necessary for the running-in of different building operations [16].

In highly repetitive work processes, where an advanced degree of specialization can be applied, the running-in process is passed more quickly and has, on the whole, less influence on the planning of the work. Accordingly, execution of the work can be based on a stable production rate established from the ultimate or basic operational times of the different tasks involved. Since, however, for practical reasons, the different operations are normally linked together (chain work), it is most important that the different work gangs be properly balanced and synchronized so that one work gang does not impede another. For this reason it is equally important in the organization of flow-line processes to possess the greatest possible knowledge of the rate and scope of improvement that can be expected for different kinds of building operation.

Related problems

The material analysed in this report has shown clearly the difficulties of isolating the influence of any of the wide range of factors affecting building production. The effect of repetition on building operations is only one, and perhaps not the most important, of the consequences of introducing large series of identical building components or functional units in the building trade. Furthermore, the effect of repetition, even in its widest context, is often overshadowed by other important factors influencing building production. It has been noted that certain external conditions and other factors impede or prevent the drawing of reliable conclusions from data collected on building sites. In addition, building costs and labour productivity are substantially affected by the organization and mechanization of the work, the size of contracts and building enterprises, the technology used (size of building components, dry or wet processes, etc.) Some examples of such influences are provided in chapter VI. It is necessary, therefore, to view the effect of repetition on building operations in the wider context of measures and means aiming at the transfer of building from a handicraft business to a fully industrialized sector of the economy. The further success of the industrialization process will, to a large measure, depend on the objective and penetrating analysis of the relationship and interdependence of all the relevant factors influencing development. International exchange of experience in this field, which has already given some encouraging results, will probably prove even more important and useful in the future.

RECOMMENDATIONS FOR FURTHER STUDIES

The studies so far undertaken do not permit of recommendations to Governments on how best to organize a basis for building production. While it is realized that many Governments may have only limited possibilities of influencing the location of plant for the production of building materials and components, it is felt that a generally applicable knowledge of the problem would be valuable. But the optimum organization of the building production process, including the design, manufacture and transport of building materials and components and the construction work on the building site, depends on such a wide range of local conditions, prescriptions and so on, that an international enquiry or review of actual production patterns would seem less profitable. It might be found useful, therefore, to restrict a study in this field to a theoretical analysis of the interrelationship of the size, weight and value of building components, scale of production, transport costs, and consumption intensity. The aim of such an analysis would be to establish a generally applicable model, showing the quantitative relationships between the factors mentioned. This model could then be used in different countries, applying in each case the parameters valid in the country.

It would be useful also to investigate further the effect of repetition on different types of building operation in order to arrive at a scientific basis for the efficient planning of building work. It would also be useful to study the effect of repetition on the organization and cost of building design. Such studies are, however, more of a building research character and could most profitably be carried out under the aegis of the International Council for Building Research, Studies and Documentation (CIB). A special CIB working commission might be set up for this purpose.

CHAPTER II

EFFECT OF REPETITION ON OPERATIONAL TIME

INTRODUCTION

The basic effect of repetition on building operations and processes on site is the successive reduction of time required to execute identical operations carried out repeatedly and successively. The favourable influence of repetition on operational time is due to the increased productivity achieved by training but also by successive improvements of work method and arrangements in the immediate environment of the actual operation. The nature of this phenomenon is well known but experience concerning its intensity is still rather limited.

The purpose of this chapter is to review various theories on the nature of improvement processes in building, as proposed by different experts in this field and to present the practical results of field studies into the effect of repetition on separate building operations, groups of operations or the entire site work of a building project.

In most of the countries' contributions to this study, as well as in specialized literature on the subject, it is claimed that two principal phases of improvement are to be distinguished, namely:

(a) the operation-learning phase, i.e. the period during which the worker acquires sufficient "know-how" of the task to be performed; and

(b) the routine-acquiring phase, during which successive improvements of performance are achieved through growing familiarity with the job and through small changes in work method and organization.

It should be borne in mind that the two phases often overlap, the second beginning before the first is quite finished. It is therefore rather difficult to distinguish clearly between them. Some experts are of the opinion that the first phase itself is a combination of two distinct sub-phases, namely:

(a) the initial organization of the work, which may take some time, depending on the knowledge and ability of the job manager; and

(b) the real operation-learning phase, i.e. the period during which the workers are being taught how to carry out the new job.

The improvement of operational times achieved by repetition during the phases described, is usually illustrated by means of improvement curves showing the decrease in manhours and the number of operations completed. These curves may refer either to the unit time or to the average operational time of all finished operations, i.e. the accumulated mean value. The total time necessary for the production of all units or the speed of production may also be used. For obvious reasons, improvement curves showing the decrease in unit time when repeating a particular operation will have a steeper course than the one relating to the accumulated mean value of unit times. The physical unit of measurement may be over-all units of surface or volume (square metre of floor space, cubic metre of building volume, etc.), functional units (room, dwelling, storey, section of a building, complete building, etc.) or units of construction works (cubic metre of concrete, square metre of shuttering, etc.).

The general shape of improvement curves reported by different experts are very similar. Thus, the operational time is always greatly reduced at the beginning of the work sequence, while the reductions in time required successively decrease.

During the operation-learning period an uninterrupted and continuous decrease is seldom obtained. The curve flattens out before falling again. The reason for this is often that the operator makes some minor changes in his motion pattern, e.g. he employs more combined motions. Another reason could be fatigue caused by too great a concentration, both physical and mental.

The routine-acquiring period may occur either as a direct continuation of the operation-learning period, or every time a new work is started in the field in which the operator is trained and qualified. In the latter case, the pattern and the aim of the job are known to him. New features could be the design, part of the equipment or external conditions. In connexion with the starting of new work, additional time of an operative nature always occurs which more or less splits the first operation cycle. The operator, or work gang, must find the right rhythm and distribution of tasks. The operational time then falls as the operation is repeated; it will, however, fall more and more slowly. After some time the curve flattens out before a relatively constant operational time is obtained. By repeating a certain motion pattern the ability increases, and the motions of the body and the hands are reduced to a minimum for the operation concerned; the eye motions will also be reduced as ability and knowledge of the motion pattern increase. Furthermore some minor method improvements might be introduced, e.g. a knack, a change of the order of the part-operations or of a combination of motions.

THEORETICAL MODELS

The effect of repetition on operational time has for a long time been the subject of keen attention and study in the manufacturing industries. Despite the main differences between manufacturing and building, it is natural to try to make maximum use of the experience gained outside the building industry.

Power formula

One of the best known studies in this field was published in 1936 by the American, WRIGHT.(1) It deals with the processes of routine-acquiring in the serial production of aircraft. Wright studied the accumulated mean values. If the times per unit are denoted T_1, T_2, T_3, ... T_x, then the accumulated mean value t_x for the first x units will be:

$$t_x = \frac{T_1 + T_2 + T_3 \ldots + T_x}{x}$$

Wright found that a logarithmic regression function of the form $y = ax^b$ can be used as t_x can be represented as a function of t_1 and x_1, namely:

$$t_x = t_1 x^{-k} = \frac{t_1}{x^k}$$

In this formula -k is a parameter characterizing the improvement curve (the "elasticity" of the improvement). Wright determined k as 0.322. The equality:

$$2^{-0.322} = 0.80$$

results in Wright's well-known 80 per cent rule, saying that the accumulated mean value of operational times will be reduced to 80 per cent when doubling the number of identical operations (figure 1), i.e.

$$\frac{t_{2x}}{t_x} = 0.80$$

Obviously the total accumulated operational time (Y) can be expressed by the formula:

$$Y = a\,x^{b+1} = a\,x^{1-k}$$

because:

$$Y = x\,t_x = x\,t_1\,x^{-k} = t_1 x^{1-k}$$

---

(1) The presentation of Wright's theory follows mainly [1] (see bibliography).

From the equation $t_x = t_1 x^{-k}$ a simple function can be derived for the time per unit T_x which is sufficiently approximate for $x > 10$. This function reads:

$$T_x = T_1 \; /1-k/x^{-k} = \frac{T_1/1-k/}{x^k}$$

The time per unit T_x is in direct proportion to the accumulated mean value t_x, for

$$T_x = T_1 \; /1-k/x^{-k} = /1-k/T_1 x^{-k}$$

$$t_x = t_1 x^{-k}$$

$$T_1 = t_1$$

$$t_x = T_1 x^{-k}$$

which gives:

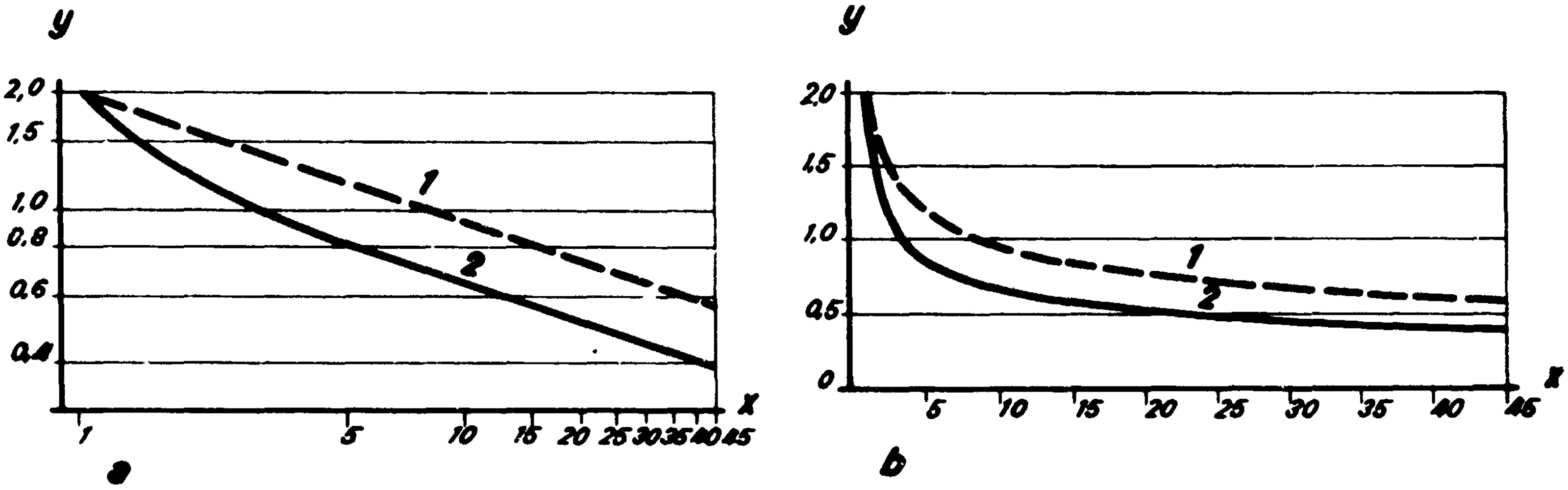
$$T_x = (1-k)t_x$$

According to experience gained in Finland and Sweden, Wright's law is valid in principle also in the building industry. The average mean value of time per unit always decreases by a certain constant percentage when the number of units is doubled. The percentage depends to a great extent on the character and difficulty of the operation in question, but is in general lower in building than in the manufacturing industries. The equivalent of Wright's 80 per cent has thus been found to be 87 to 93 per cent in building operations of a repetitive nature. The lower degree of improvement in building is to be expected, since the environment in which building is done changes from day to day and undoubtedly influences the process of routine-acquiring.

Although the coincidence between experience gained in manufacturing and in building is good, it has, according to information received from Finland, often been seen that in building the operational time decreases more rapidly immediately after the start than is assumed in Wright's theories. In most cases the reason is to be found in defective preliminary planning of the building site, involving an unnecessarily high consumption of labour at the beginning of the work sequences. It may be concluded that preliminary planning has a great effect on labour consumption.

Figure I

Time consumption in the serial assembly of aircraft according to WRIGHT (United States of America)



Source : [1].

a = Assembly of aircraft (log log scale).
b = Assembly of aircraft (linear scale).
x = Number of units.
y = Time.
1 = Accumulated mean value of operational times per unit.
2 = Operational time per unit.

Another version of a power (logarithmic) function has been proposed by the American STANFORD, namely:

$$y = a\ (x + B)^n$$

or with the symbols used above:

$$T_x = T_1\ (x + B)^n$$

This formula establishes the function not for the accumulated mean value but for the individual value of operational times per unit. According to STANFORD it can be assumed that:

$$n \approx -0.5$$

wherefrom:

$$y = \frac{a}{\sqrt{x + B}} \qquad \text{or } T_x = \frac{T_1}{\sqrt{x + B}}$$

If B = o, then

$$y = ax^{-o.5} \qquad \text{or } T_x = T_1\ x^{-o.5}$$

Taking into account that

$$2^{-o.5} = \frac{1}{\sqrt{2}} = 0{,}707$$

This rule would result in a 70.7 per cent reduction of individual operational time per unit when doubling the number of operations.

Exponential formulae

The Norwegian Building Research Institute has found that the routine-acquiring process can be described by means of an exponential function [2]. On the basis of field studies a formula has been established corresponding to the following rule: That part of operational time which can be reduced by routine-acquiring will be reduced by half after constant numbers of repetition. The formula proposed reads as follows:

$$T_x = T_b + \frac{T_1 - T_b}{2^{x/H}}$$

where H = "halving-parameter" which is a constant,

T_b = the ultimate (basic, ideal) operational time per unit, i.e. the extreme value of the function T_x when $x \to \infty$.

T_1 = the initial operational time per unit

If the initial and ultimate operational times together with one set of x/T_x values are known, the halving-parameter can be determined from the following function, which is referred to in the contribution received from Hungary. (see also figure 2):

$$H = \frac{x \log 2}{\log/T_1-T_b/ - \log/T_x-T_b/}$$

The Norwegian Building Research Institute [16] has also proposed a formula for the total operational time (Y):

$$Y = xt_x = T_b + He^{-\frac{T_o}{H}} \quad (1-e^{-\frac{T_b}{H}})$$

where T_o and H are parameters deciding the initial speed and time correction to be made.

The speed of the process at any time may be expressed as:

$$\frac{dY}{dT_b} = 1+e^{-\frac{T_o}{H}} \cdot e^{-\frac{T_b}{H}}$$

The total time correction ΔY may be expressed as:

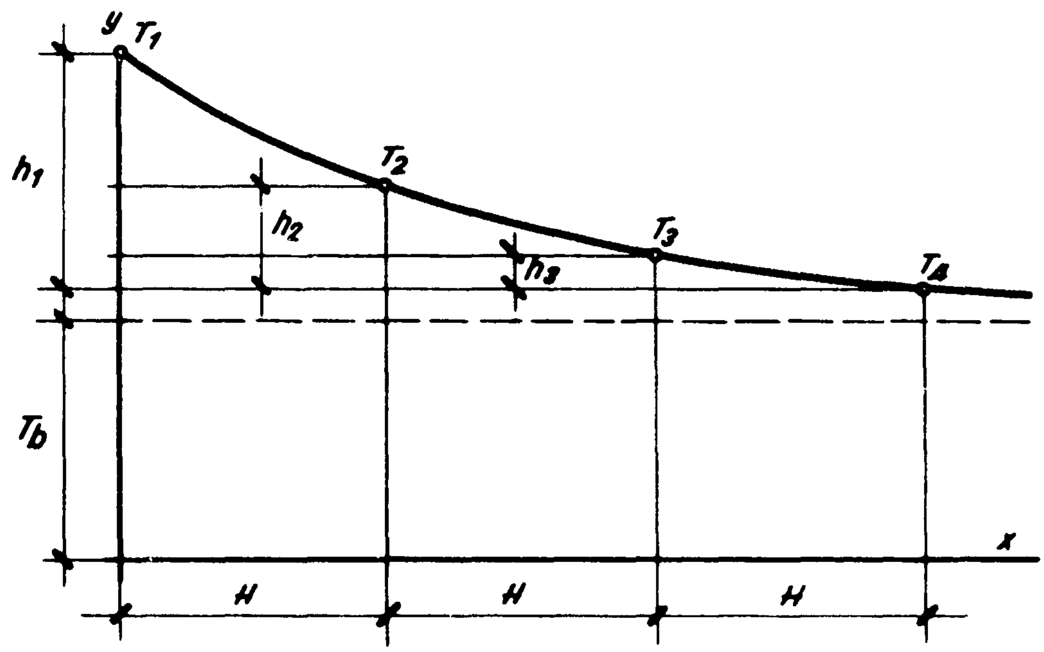
$$\Delta Y = He^{-\frac{T_o}{H}}$$

If $T_o = 0$, the total time correction is H and the initial speed of the process is one, meaning that the process starts with double time requirement compared with the basic time requirement - that is half speed. This explains why the parameter H is called the "halving-parameter".

In practical planning, the Norwegian experience has shown that the work on the first working unit will often start at half speed, i.e. at a unit time 100 per cent higher than the basic rate. This means $T_o = 0$ and a time correction for the gang time equal to H. The time correction thus always refers to a certain gang size and the total time correction in working hours is H multiplied by the number of men in the gang (provided the work starts at half speed).

Figure 2

Operational time per unit in relation to number of units (Hungary)



Source : Information received from the Government of Hungary.

x = Number of units.
y = Operational time per unit.
T_b = Basic (ultimate) time.
T_1 = Initial time.
H = Halving parameter.
$h_1 = 2h_2 = 4h_3$.

Other formulae

A somewhat different approach to the theoretical study of improvement processes is reported to be used in the United Kingdom. The notions "improved average" (t_i) and "measure of improvement" (m) are introduced where:

$$t_i = \frac{T_{p+1} + T_{p+2} + \dots + T_x}{x - p} \; ; \quad \text{and}$$

$$m = \frac{t_x - t_i}{t_i} .100$$

When calculating the improved average, the first "p" operations are not taken into account. It was found that m normally varies between 2 and 6 per cent.

An alternative measure of improvement (m') can be obtained by expressing the difference between the average time of the early series of operations carried out before the steady level of time consumption has been reached (t_e), and the improved average of the remainder (t_i) as a percentage of the average of the early series:

$$m' = \frac{t_e - t_i}{t_e} .100$$

Measured in this way, the time required for the operations, studied by the Building Research Station, improved on an average by 8 - 12 per cent; some non-traditional operations alone showing an improvement of about 33 per cent. The high rate of improvement is typical for non-traditional operations where new techniques are to be learned.

The model used in the United Kingdom, like the Norwegian formulae quoted above, is based on the assumption that the improvement can attain only a certain relative measure, independently of the number of operations. This may be correct although, for series occurring in practice, the same result can be obtained with the formulae used in Sweden and Finland, which do not exclude, theoretically, an unlimited process of improvement. The simplicity of the United Kingdom model can be regarded as an advantage; on the other hand, in practice, there may be some uncertainty concerning the end-point of the "early" series.

RESULTS OF FIELD STUDIES

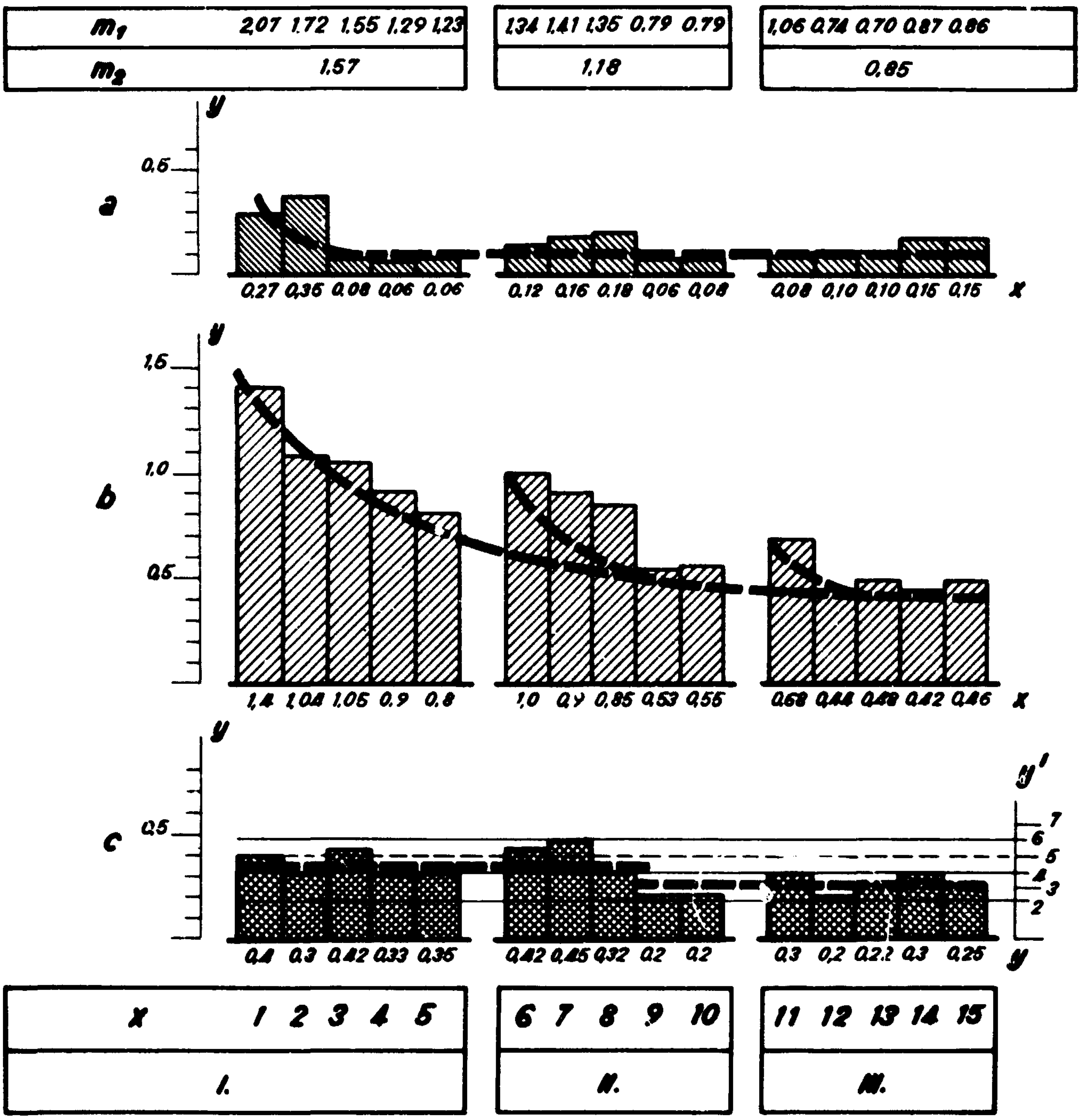
Systematic and comprehensive field studies into the effect of repetition on building operations on site have been carried out for a long time in Western Germany, in particular by the Building Research Institute in Hanover [3 - 6] and [18]. Interesting results of ad hoc studies in this field are reported also from Czechoslovakia, Finland, France, Israel, the Netherlands, Norway, Poland, Sweden, the Ukranian SSR and the United Kingdom. The information received concerns on the one hand the execution of specified individual building operations and, on the other, over-all figures on the time consumption of groups of activities and operations connected with the execution of identical buildings or buildings units - for instance, identical dwellings, houses, pairs of houses and storeys of buildings. Some countries have supplied more indirect evidence on the effect of repetition. Thus, for instance, comparisons of labour productivity have been made between objects organized in a traditional way and objects organized according to the flow-line method, or between building contracts of different sizes. Since the objects are not identical or even, in some cases, similar, the results of such comparisons are inevitably affected not only by repetition but by many other important factors and have therefore been presented separately in chapters V and VI.

Studies of individual building operations

The Building Research Institute in Hanover, Western Germany, has assisted in the organization of several building sites with a view to promoting a wider utilization of the repetition effect in building operations. In this connexion, detailed investigations have been undertaken into the degree of improvement possible, in terms of costs and time consumption, in different kinds of individual building operations. The results of such studies undertaken in the period 1950 to 1960 are presented in a comprehensive report [3], from which figure 3 is taken. The figure relates to the construction of in situ cast concrete floors. Improvement curves are reported for the three main operations, namely, assembling of formwork, concreting, and dismantling of the formwork. As can be seen, a substantial reduction in the time required was achieved in the operation assembling of formwork; the manhours per square metre of floor space decreased from 1.40 at the first execution to 1.04 in the second, i.e. by 25 per cent. The improvement achieved in the following executions of the work was 13 per cent and 11 per cent, respectively. The concreting operation shows a different pattern of improvement. In the first eight

Figure 3

Time consumption in the serial execution of dismantling formwork, assembling formwork and concreting (Western Germany)



Source : [3].

a = Dismantling the formwork.
b = Assembling the formwork.
c = Concreting.
x = Number of operations in order of construction.
y = Manhours per square metre of floors.
y' = Manhours per cubic metre of concrete.
I = Floors above the basement.
II = Floors above the first floor.
III = Floors above the second floor.
m_1 = Accumulated mean value of manhours per square metre.
m_2 = Over-all mean value of manhours per square metre.

sequences of this operation, the output was approximately stable, requiring about 5 manhours/m^2 of floor space. The mixing of the concrete was then re-organized, which resulted in a fall in labour consumption to 3 manhours/m^2. It is thus obvious that this operation was heavily dependent on the rather inflexible output of a machine and that the effect of repetition was a factor of relatively small importance to labour productivity. As to the dismantling of formwork, the effect of repetition was found to be something intermediary between the two other operations described. The conclusion was drawn that the possible improvement in labour productivity as a result of repetition is greater for complicated operations, such as assembling of formworks, than for simple operations (dismantling of formworks).

Another important conclusion drawn in the West German report was that the improvement possible is much smaller in traditional, well-known operations than in new operations which are not familiar to the workers. Thus, for instance, it was almost impossible to observe any improvement in bricklaying, whereas the time consumption was found to decrease quite substantially when repeating such operations as assembling of large panels. This, of course, is rather natural since in the former operation the operation-learning phase of the improvement process has to be passed by the worker before he is recognized as a skilled craftsman. It is interesting to note in this connexion, however, that in some countries considerable improvement of labour productivity in bricklaying has been achieved by strict specialization within the craft, i.e. one worker or one team of workers doing only one kind of brickwork.

An interesting example, illustrating the fact that repetition is only one of the factors affecting labour productivity, is supplied in the same report. The operation studied was floor-laying. The work was undertaken subsequently by two different building contractors employing different gangs of workers. In the first case the labour consumption decreased from 2.13 manhours/m^2 to 1.71 manhours/m^2. The workers of the second contractor at first needed considerably more man hours per square metre than the first gang. On the other hand the second gang, as time passed, was able to reduce its time consumption to 1.42 manhours/m^2. The effects of the different factors contributing to this result are almost impossible to separate.

Assembling of formwork, concreting and assembling of prefabricated building components (staircase units) have been subject to study also in Finland and France. The results generally confirm the Western German investigations, i.e. the improvement of labour productivity in concreting, as a result of repetition, is very slow, while there is a steep decrease in labour consumption in the assembling of prefabricated units.

Figures 4 and 5, taken from the Finish study, show the changes in time required for the execution of wooden formwork during the building of successive storeys. In the first case the accumulated mean value of the operational time exactly follows Wright's law. The average mean value was found to decrease to 87 per cent when the number of executions was doubled. In the second case the time required also decreased gradually, up to the eighth storey. Then, in the following storeys, an increase could be observed due probably to the "height effect" and "end effect" (see chapter IV).

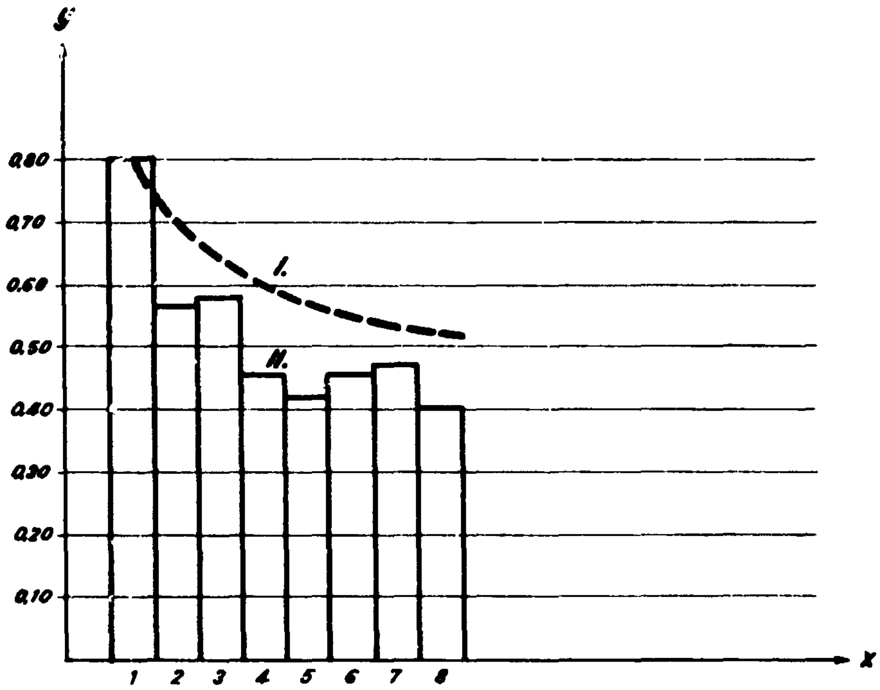
The results of a French study, which was undertaken by the Centre Scientifique et Technique du Bâtiment, were obtained from the observation of nine identical point blocks [7]. The buildings were erected by five different building contractors but the results coincide fairly well (figures 6, 7 and 8). Thus, the time required for assembling formwork and concreting was between 30 and 40 per cent higher at the first storey than at the sixth, while the corresponding difference for erecting prefabricated panels was around 125 per cent (figure 9).

Data has been obtained also from another French study regarding the man-day consumption for erecting "tunnel-shutterings" (steel formwork for the concreting, in one pour, of the walls and ceiling of one room). The monthly average for this operation, which was repeated 553 times, fell from 2.8 to 0.79 man-days per unit erected, a rather stable productivity being obtained from about the hundredth repetition. (figure 10).

The influence of repetition on the assembly of heavy concrete elements, placing of formwork elements, handling of bolts for formwork, placing of light concrete insulation, fixing of wall measurements, and assembling of framework for hoistways, has been studied by the Norwegian Building Research Institute [2]. All the improvement processes studied were found to fit into one and the same pattern, namely, "that part of the production time which could be reduced by training, was cut down by half after a constant number of repetitions". The individual improvement curves for the assembling of heavy concrete elements and the handling of bolts are shown in figures 11(a) and (b), respectively. It is of interest that the decrease of operational time is still noticeable after the handling of 22,000 bolts. Of particular interest, however, is the result of a detailed analysis of all the different operations studied. It was found that if the curves were harmonized by using the "halving parameter" as the scale for the abscissa and the operational time expressed as a percentage of the ultimate operational

Figure 4

Time consumption in the serial execution of wooden shuttering in an eight-storey building (Finland)

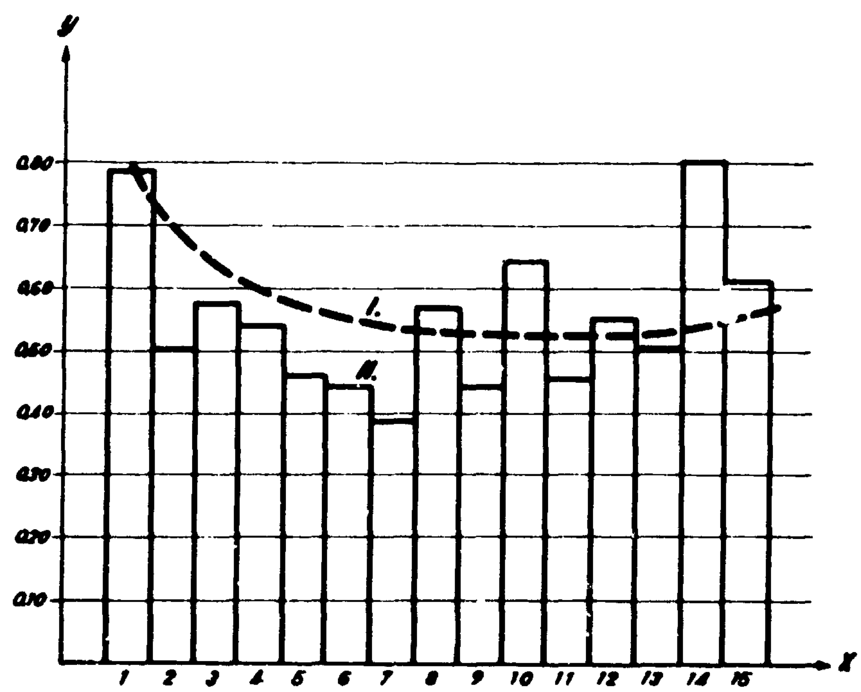


Source : Information received from the Government of Finland.

x = Storeys.
y = Manhours per square metre of shuttering.
I = Accumulated mean value of operational times per unit.
II = Operational time per unit.

Figure 5

Time consumption in the serial execution of wooden shuttering in a fifteen-storey building (Finland)

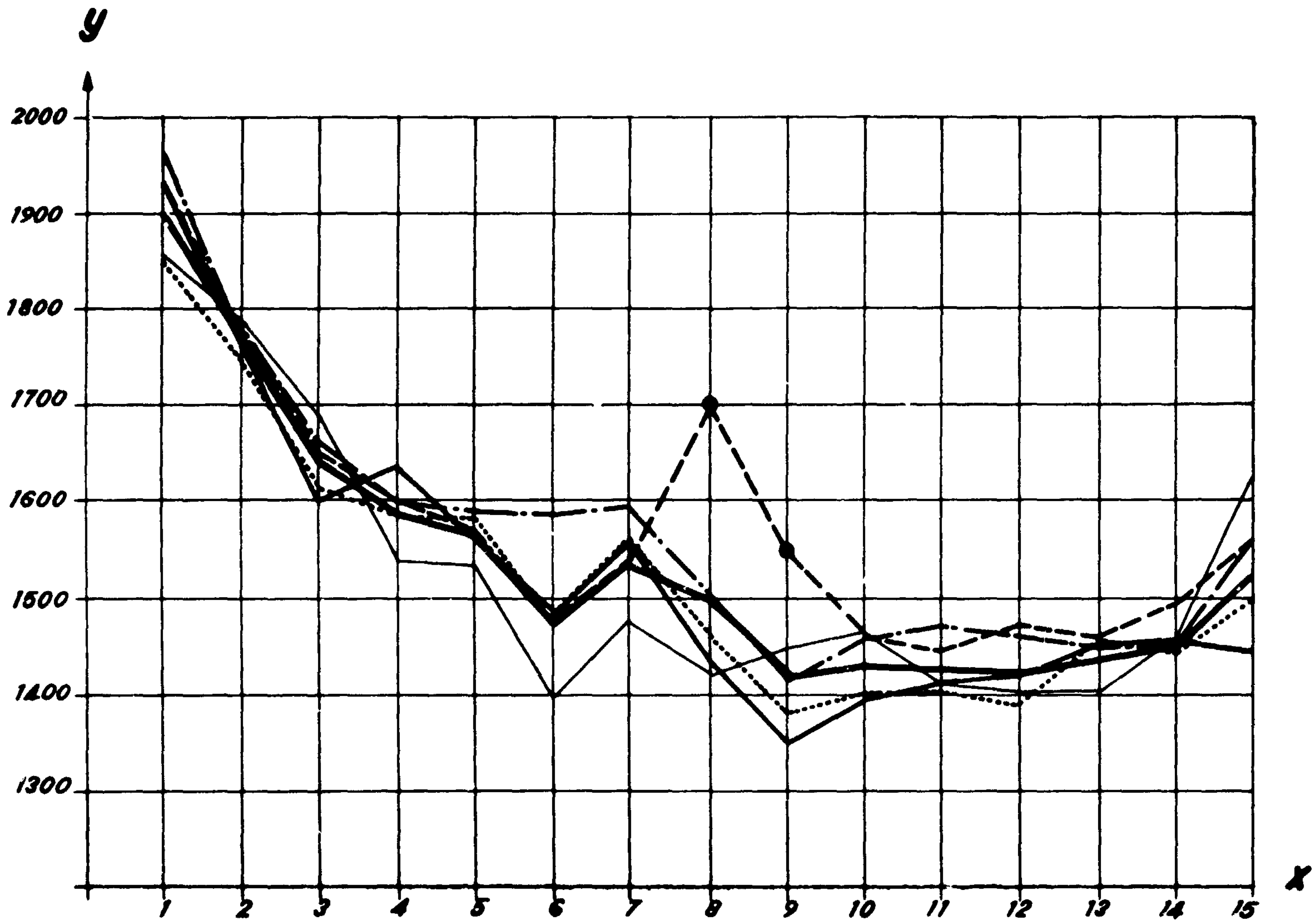


Source : Information received from the Government of Finland.

x = Storeys.
y = Manhours per square metre of shuttering.
I = Accumulated mean value of operational times per unit.
II = Operational time per unit.

Figure 6

Time consumption in the serial execution of assembling and dismantling formwork (France)



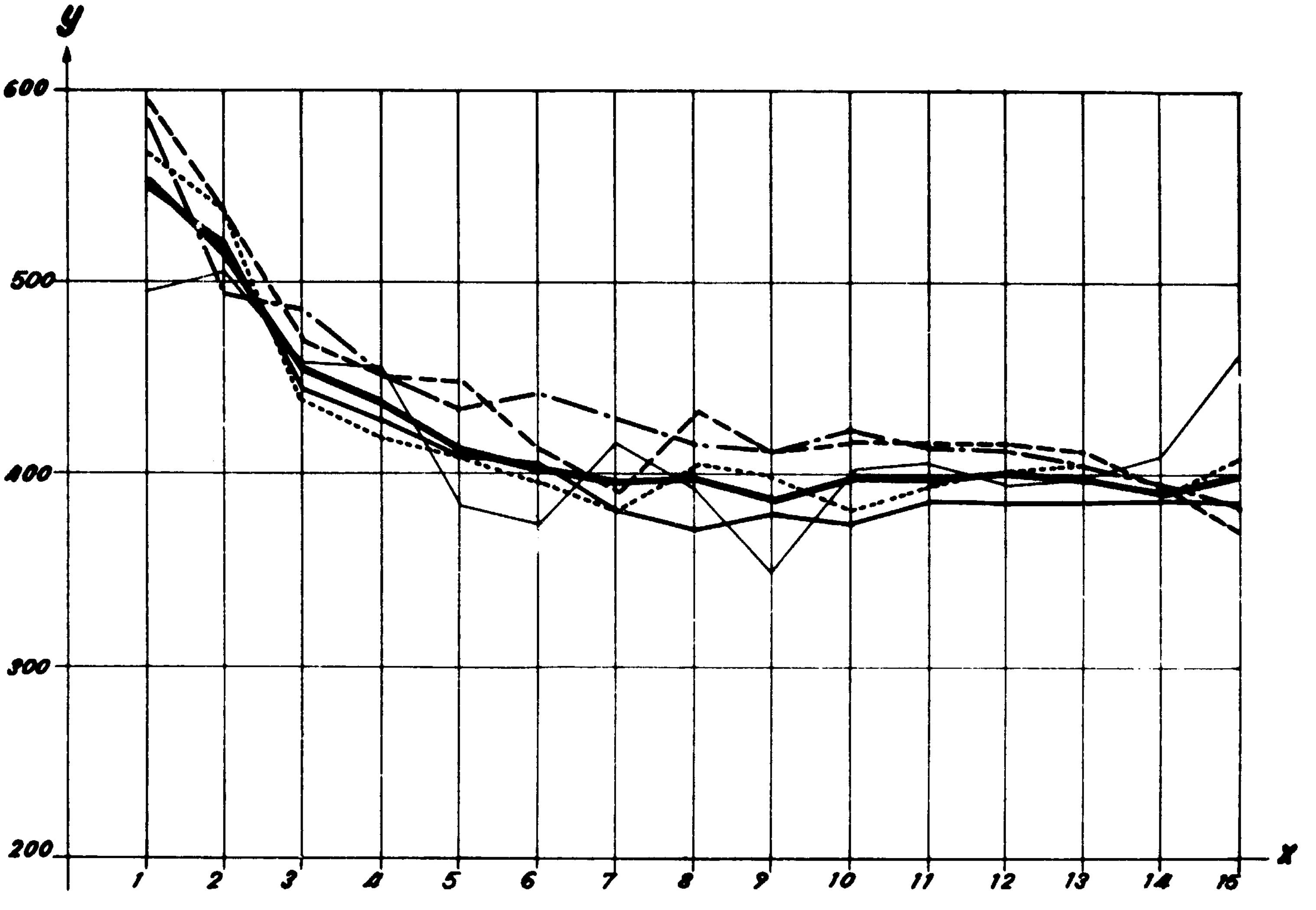
Source : [7].

Note : The five thin lines refer to results achieved by five different building firms. The thick line shows the average result.

x = Storeys.
y = Manhours per storey.

Figure 7

Time consumption in serial execution of concreting (France)



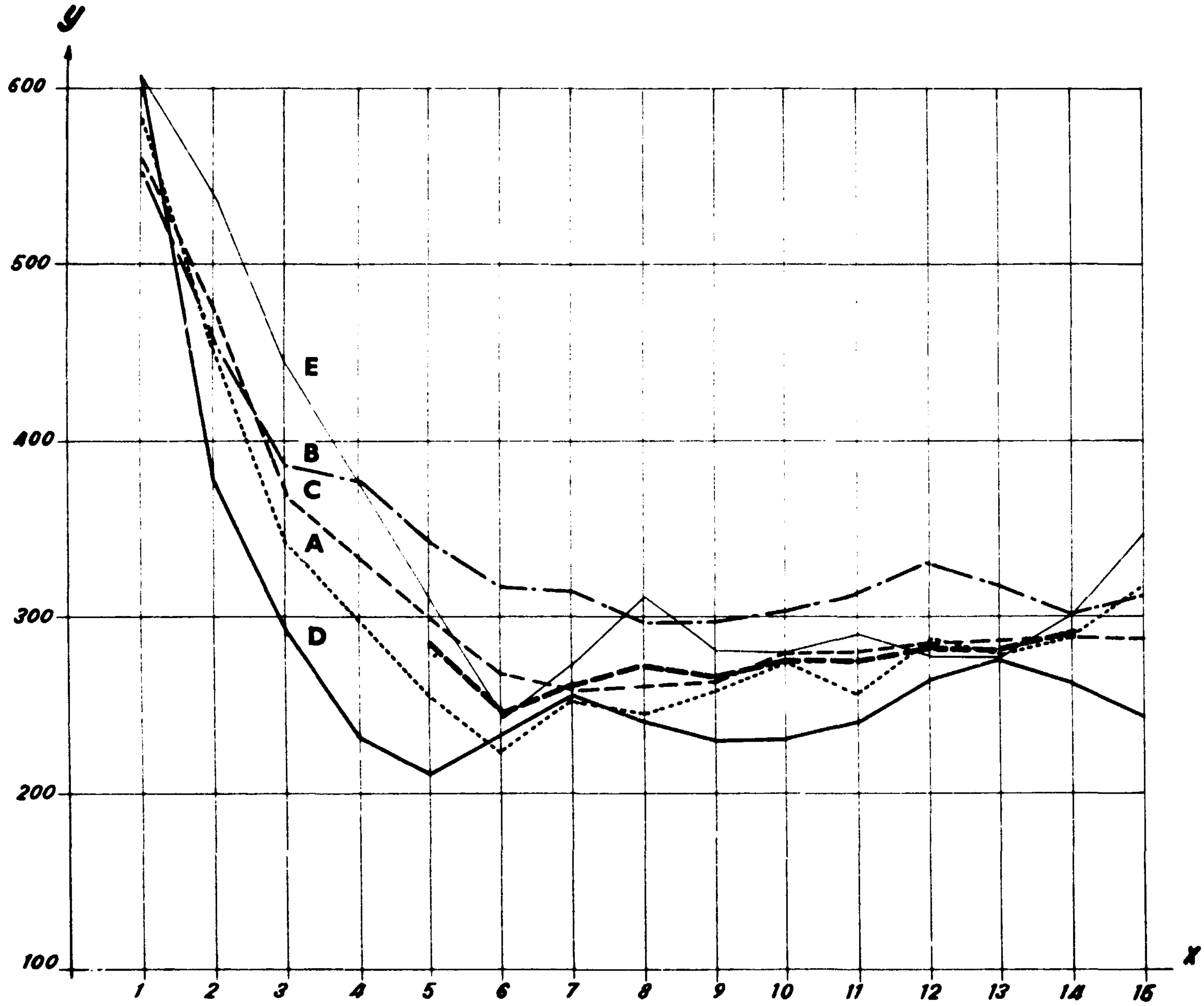
Source : [7].

Note : The five thin lines refer to results achieved by five different building firms. The thick line shows the average result.

x = Storeys.
y = Manhours per storey.

Figure 8

Time consumption in serial placing of panels (France)



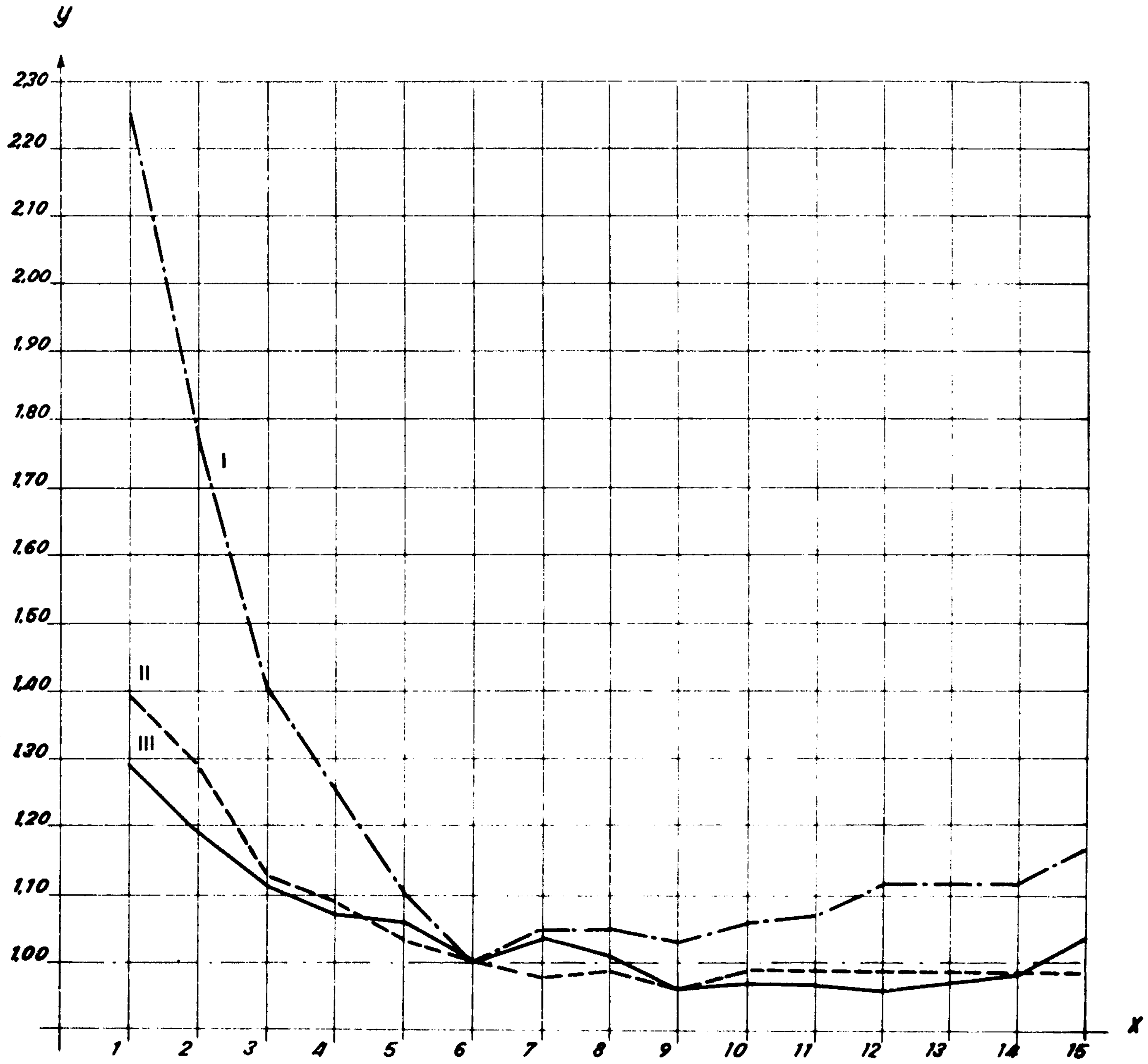
Source : [7].

Note : The five thin lines refer to results achieved by five different building firms (A, B, C, D, and E).
The thick line shows the average result of the firms A, C and E.

x = Storeys.
y = Manhours per storey.

Figure 9

Operational time expressed as a percentage of basic operational time in the serial execution of assembling and dismantling formwork, concreting and placing of panels (France)



Source : [7].

x = Storeys.

y = Operational time expressed as a percentage of basic operational time (actual time on the sixth floor).

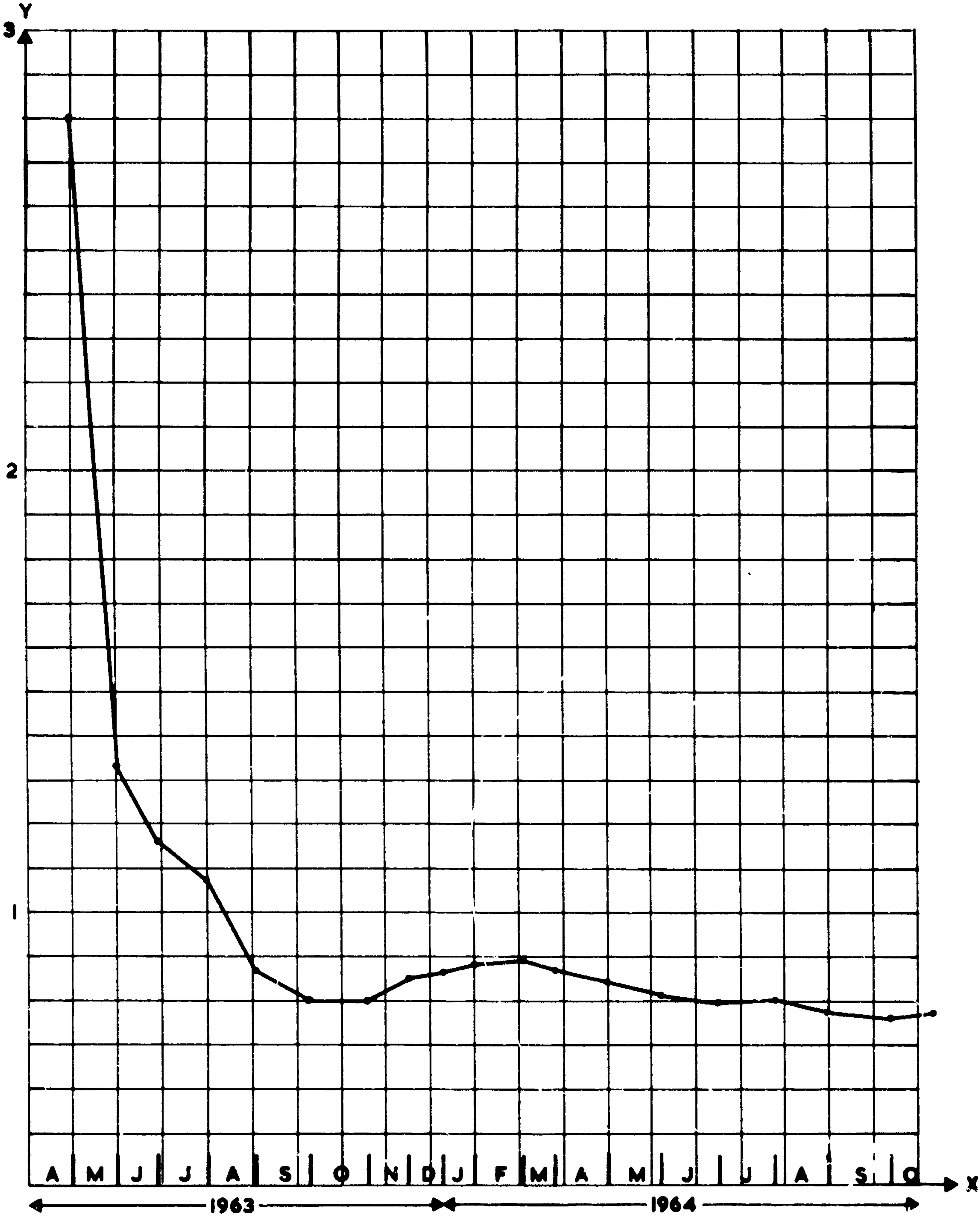
I = Assembling and dismantling formwork.

II = Concreting.

III = Placing of panels.

Figure 10

Time consumption in the serial erection of "tunnel formwork" (France)



Source : Information received from the Government of France.

x Number of months (calculated on the basis of working days).

y Mandays per erected unit.

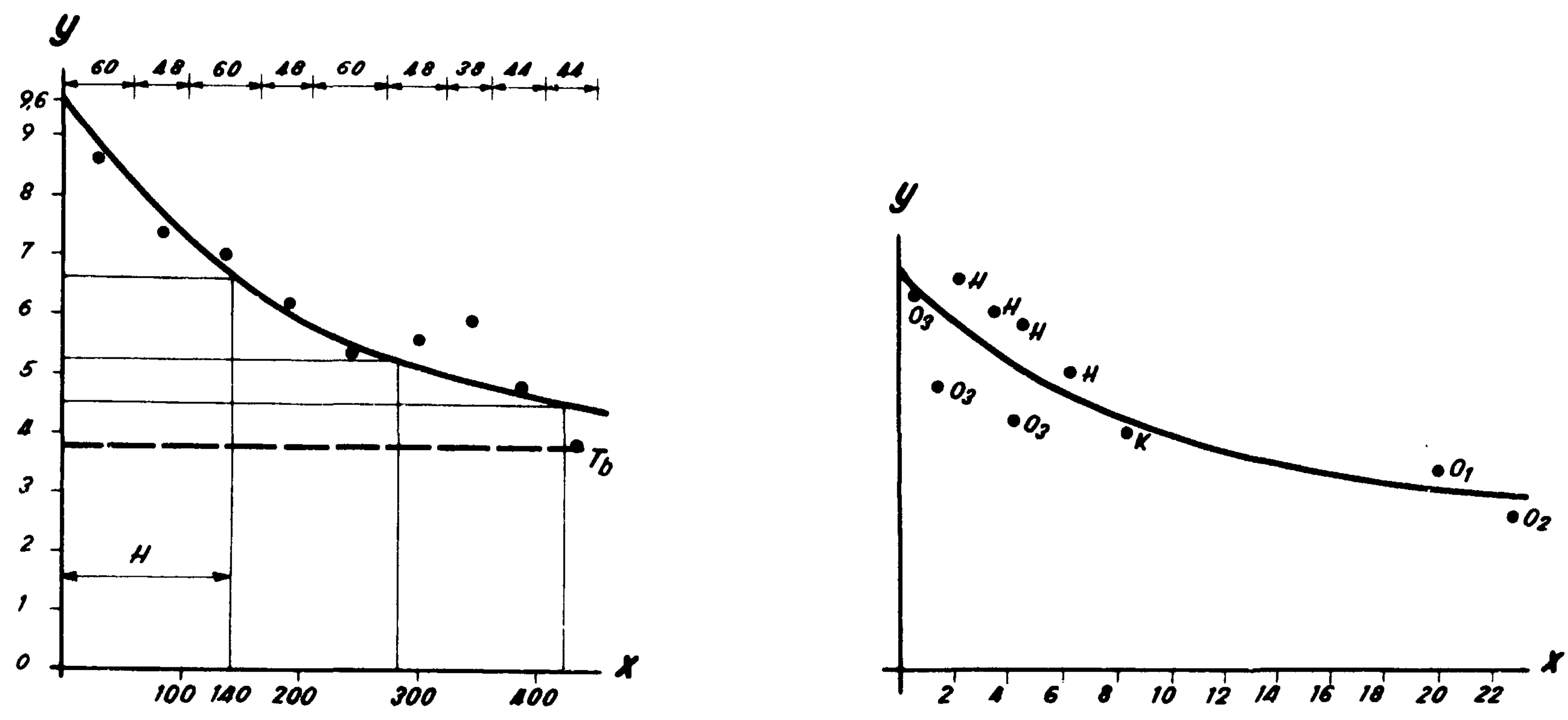
J, F, M, A, etc. January, February, March, April, etc.

Figure 11

Time consumption in the serial execution of building element assembly and handling of bolts (Norway)

a : Building element assembly.

b : Handling of bolts.



a b

Source : [2].

a x Number of assembled elements.
y Average manhours per element.
z Production series in the order they were assembled.
H Halving parameter.
T_b Basic (ultimate) operational time.

b x Thousands of bolts.
y Operational time per unit.

time on the Y axis all the curves had the same shape. By displacing the individual curves horizontally they fell into one single curve, the general improvement curve (see figure 12).

The report of a study on the effect of repetition on building operations undertaken by a Swedish contractor contains a lot of information on the improvement processes of individual building operations /1/. The subject of the study was a group of one-family houses including forty-four units of three different types. The fact that the houses were not quite identical was of little importance, partly because only a limited number of operations were affected by the differences and partly because productivity was expressed in manhours per unit of material and not per house. The entire work on the building site was divided into nearly 100 different operations and the study as a whole comprised about 30,000 observations. Detailed records of actual time spent on the different operations were kept, together with information about breaks of different kinds, weather conditions and other factors having an influence on labour productivity. It was found that almost all operations were disturbed at one point or another by different kinds of adverse factor impeding an efficient execution of the work (see chapter IV). Figures 13, 14 and 15, however, illustrate improvement curves which are not too gravely distorted by adverse factors. They show, on the one hand, the operational time per unit (a continuous line) and the calculated accumulated mean value of the operational times (a broken line). Figure 13 illustrates the labour productivity achieved in sawing and erecting the load-bearing structure. It should be noted that the fifth and the eighth executions were disturbed by rainy weather. Figure 14 refers to the setting up of combined kitchen and bathroom elements, including the chimney. It can be seen that the effect of routine-acquiring is quite considerable in this operation. The curve includes an element of operation-learning, since some of the personnel had not earlier participated in this kind of work. Figure 15 relates to the making of roof trusses on site. This kind of operation is much less complicated than the assembly operations studied by Wright in the aircraft industry, and the process of routine-acquiring is therefore more rapid and the time-per-unit curve becomes stabilized more quickly than is presumed in Wright's theories. Accordingly, the logarithmic function of the accumulated mean value is not a straight line in this case.

A study of different methods of house construction, carried out by the Building Research Station, United Kingdom, presents comprehensive information on actual manhours spent on different kinds of operations carried out consecutively in series [8]. The results are reported in table 1, where the figures relating to operations considered to be of a specifically non-traditional character are enclosed in a triangle. Similar two-storey semi-detached houses of traditional brick (type A) and three types of non-traditional construction (types B, C and D) were built on five sites in different parts of England by different contractors. Between twenty-five and sixty pairs of houses of two types or more were built on each site, there being not less than twelve identical pairs of one type on a site. In recording the building times in this study, a pair of houses rather than a single house was used as the basic unit, because each pair of houses formed a single structure. The measure of improvement used was the percentage increment of over-all average over the improved average achieved in the construction of the later pairs of houses (see "Other formulae" at the end of the section "Theoretical models," above).

Table 1

Influence of trade and house type on improvement

(United Kingdom)

(expressed as percentage increment of over-all average over improved average)

Trade	House type			
	Traditional	Non-traditional		
	A	B	C	D
Bricklaying	3	6	4	5
Roof tiling	5	6	3	-
Concreting to walls	-	-	-	10
Carpentry	6	5	11	16
Prefabricated partitions	-	15	13	25
Plumbing	6	8	4	14
Plastering	4	5	7	5
Electrical work	9	6	9	3
Painting	5	5	0	1

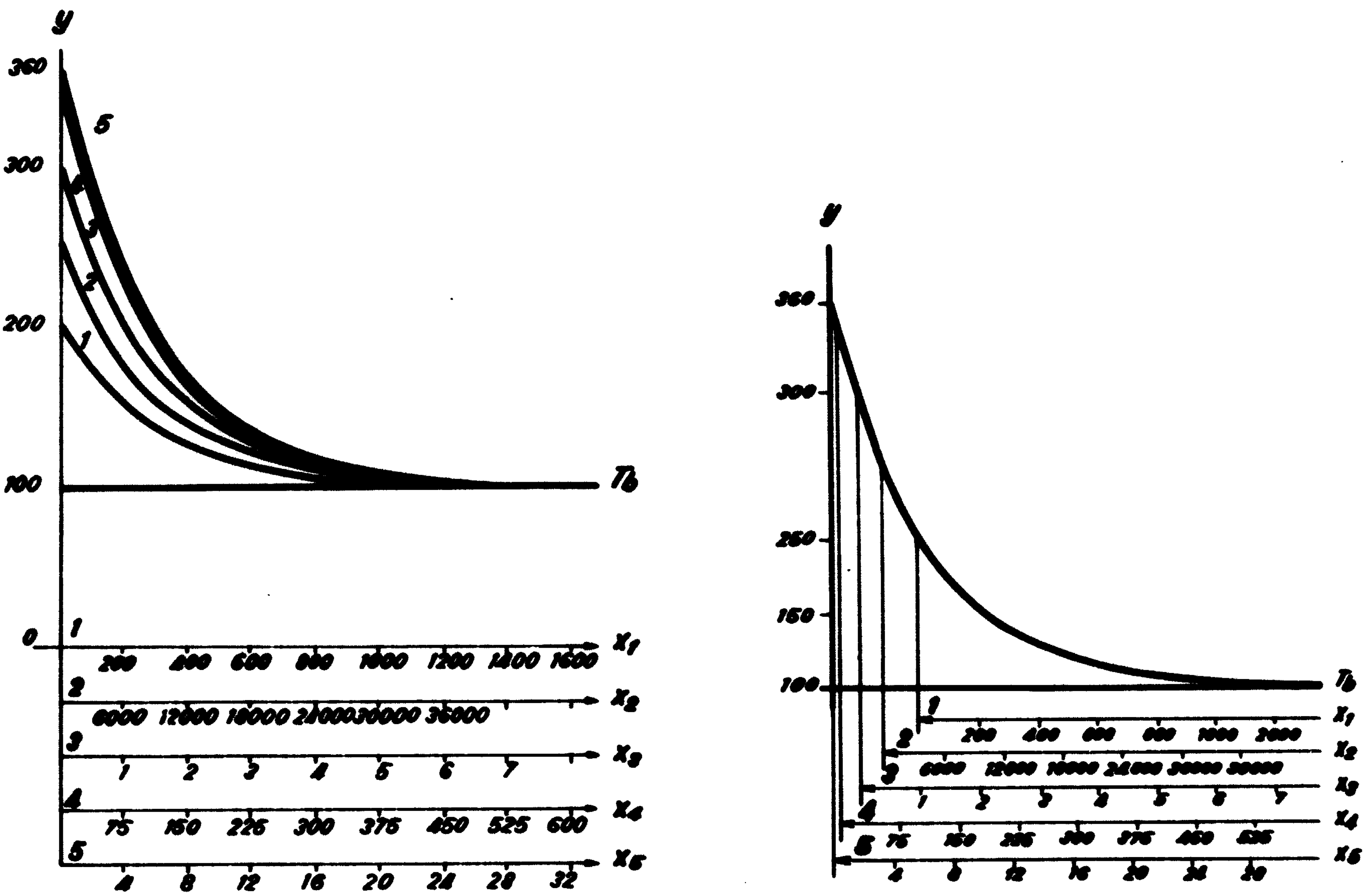
Source: [8].

Figure 12

Time consumption in the serial execution of formwork element assembly, handling of bolts, placing of light concrete insulation, fixing of wall measurements and assembling of framework for hoistways (Norway)

a : Improvement curves, original (see text).

b : Improvement curves, horizontally removed (see text).



a

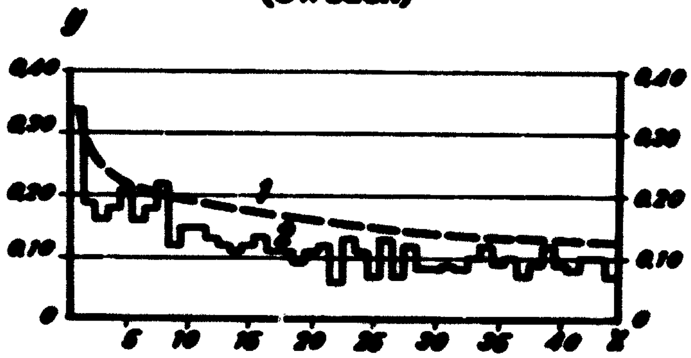
b

Source :[2].

- x_1 = **Placing of formwork elements (number of elements).**
- x_2 = **Handling of bolts (number of bolts).**
- x_3 = **Placing of light concrete insulation (number of storey sections).**
- x_4 = **Fixing of wall measurements (number of walls).**
- x_5 = **Assembling of framework for hoistways (number of units).**
- y = **Operational time per unit expressed as a percentage of basic (ultimate) operational time per unit.**
- T_b = **Basic (ultimate) operational time per unit.**

Figure 13

Time consumption in serial sawing and erecting of load-bearing structure (Sweden)



Source :[1].

x = House number.

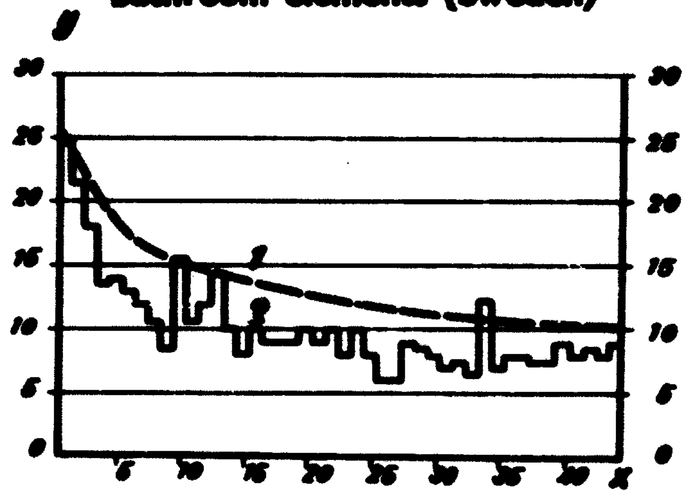
y = Manhours per square metre.

1 = Accumulated mean value of operational times per unit.

2 = Operational time per unit.

Figure 14

Time consumption in the serial setting up of combined kitchen and bathroom elements (Sweden)



Source :[1].

x = House number.

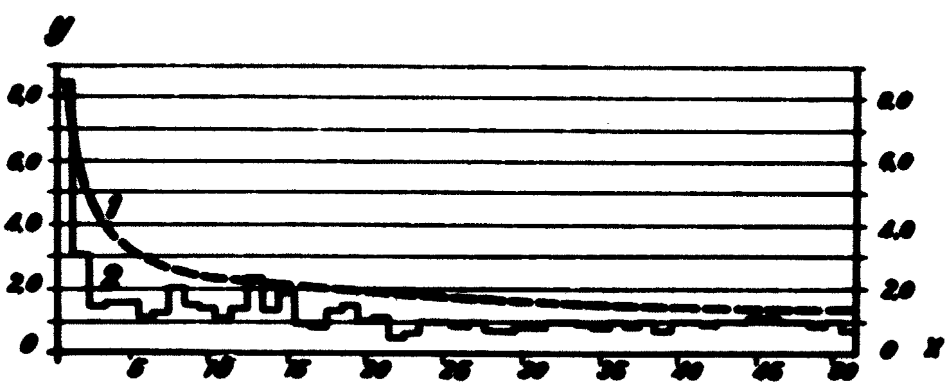
y = Manhours per house.

1 = Accumulated mean value of operational times per unit.

2 = Operational time per unit.

Figure 15

Time consumption in the serial making of roof trusses on site (Sweden)



Source :[1].

x = Number of times the work was restarted.

y = Manhours per unit.

1 = Accumulated mean value of operational times per unit.

2 = Operational time per unit.

Detailed records and improvement curves have been provided for several operations on different sites. Some of the work sequences have, however, been disturbed by different adverse factors. In this chapter, therefore, the more regular curves are presented, namely those on the erection of plasterboard partitions (figure 16), electrical carcassing (figure 17), first stage of brickwork (figure 18) and floor boarding (figure 19).

Identical Buildings

Data on total labour consumption were obtained in the Swedish study of forty-four one-family houses [1]. The over-all time consumption was studied separately and was not derived from a summation of the times required to execute the different operations. The total time recorded thus covered all time, including breaks caused by bad weather conditions and other adverse factors. The purpose of the study was to show what actually happened on the site and not what might have happened if the conditions had been ideal. In addition, however, the observations were so numerous and the duration of the study so long that occasional external influences could not appreciably affect the picture as a whole. The results of the study are shown in figure 20. It is interesting to note that, contrary to the experience gained from the study of most of the individual operations, the total number of manhours required to complete a house fell regularly according to the theories set by Wright, i.e. the accumulated mean value of the operational time decreased by a certain proportion after every doubling of the number of executions. The proportion was established at 10 per cent, which means that an equivalent of Wrights' 80 per cent rule, valid in manufacturing industries, should be a 90 per cent rule in the building industry. Further studies carried out by the same building contractor confirms this theory. Thus, another object observed showed an improvement of total time consumption corresponding to a 92 per cent rule.

The total number of manhours required to complete pairs of houses was recorded also in the United Kingdom study already referred to [7]. Figure 21 shows the improvement curves obtained from the study of the number of manhours required for the superstructure of pairs of identical, traditional houses erected on five different sites. Since the houses were of traditional design, the materials and operations were not new to the operatives, but even so in most cases a considerable reduction in the time consumption over the first few houses could be observed. In figure 22 a comparison is made between the improvement curves obtained for traditional and non-traditional houses erected on the same site. As can be seen, the decrease in manhours required is substantial over the first seven pairs of houses. The fall of the curve relating to the non-traditional houses is sharper than the other; nevertheless, it never falls below the curve of the traditional houses.

The over-all time consumption required to build identical multi-storey blocks of flats has been studied by the Polish Institute of Housing. The study referred to five buildings, each with five storeys, erected in the town of Poznan. The following time consumption was recorded:

Building	manhours/m^3
I	5.17
II	4.22
III	3.84
IV	4.02
V	3.42

The time consumption for the last building was thus only 66 per cent of that for the first building. Similar results have been obtained also from another study of three identical blocks of flats built in Poznan.

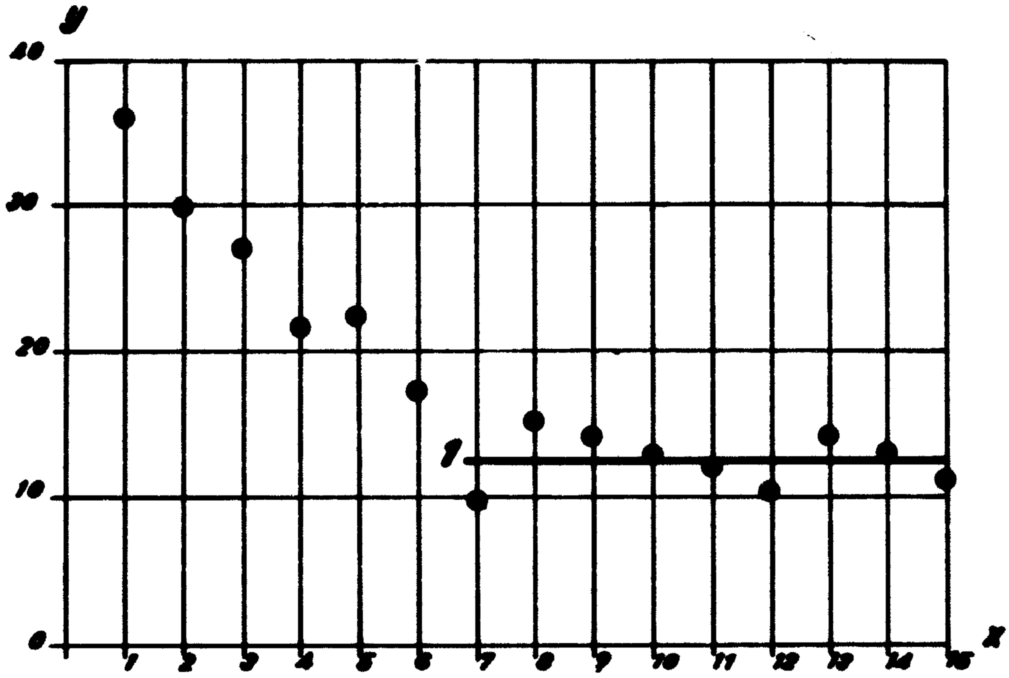
In Israel the total time required for the erection of two identical four-storey buildings, built successively, was recorded. In comparison with the first building the working hours for the second building amounted to 83 per cent for the structure, 98 per cent for finishing works and 83 per cent for the subcontracted work.

Observations on the construction of six identical buildings in the Darnitsk district in Kiev in the Ukrainian SSR, have shown only a slight increase in labour productivity. On the other hand, a considerable increase in the productivity of the tower-cranes was observed and the construction time was greatly reduced.

It has been reported from Finland that a clear effect of repetition has been observed when similar buildings are being erected by the same supervisors and the same organization, even when they are not erected on the same building site. Thus, for instance, in one contracting firm it has been possible to reduce the number of manhours per cubic metre of buildings from about 9 to about 4 in the course of the last five years (see figure 23). The decrease in time consumption is regarded as being due mainly to the gradual training of supervisors and operatives. Although construction technology and the degree of mechanization have developed during the period reviewed, these factors are not considered to have brought about such an appreciable improvement in labour productivity.

Figure 16

Time consumption in the serial erection of plaster board partitions (United Kingdom)

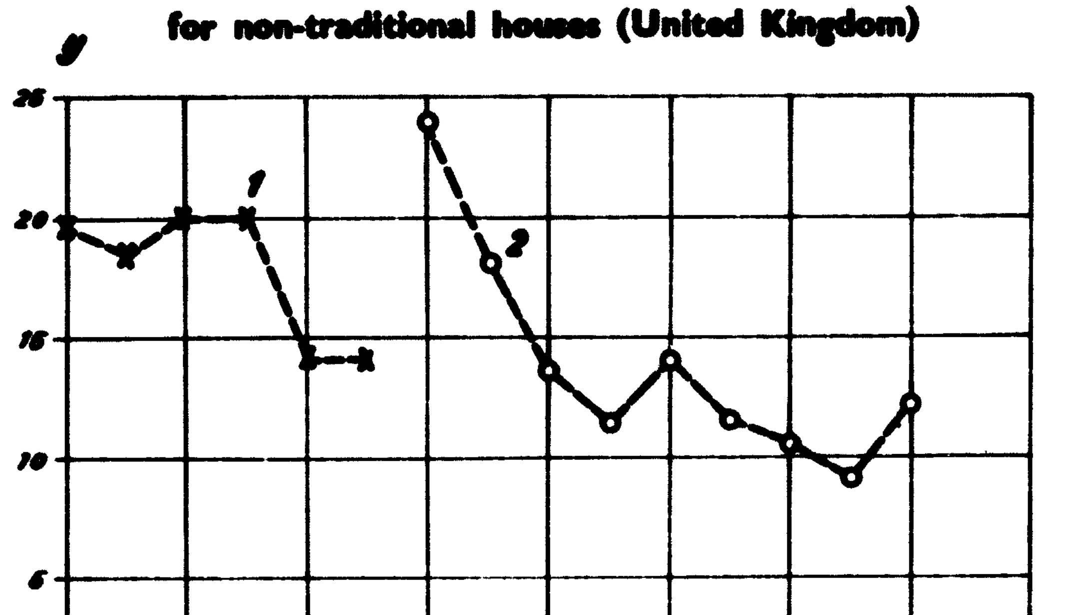


Source : Information received from the Government of the United Kingdom.

x = Pairs of houses in order of construction (type 3 houses on site D).
y = Manhours per pair of houses.
1 = Basic operational time per unit.

Figure 17

Time consumption in the serial execution of electrical carcassing for non-traditional houses (United Kingdom)

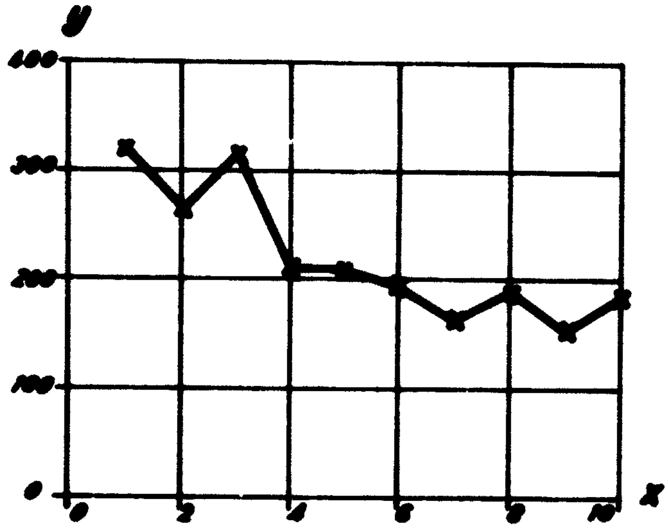


Source : Information received from the Government of the United Kingdom.

x = Blocks in order of construction.
y = Manhours per house.
1 = Gang 1.
2 = Gang 2.

Figure 18

Time consumption in the serial execution of brickwork operations (United Kingdom)



Source : Information received from the Government of the United Kingdom.

x = Pairs of houses in order of construction.

y = Manhours per pair of houses.

Figure 19

Time consumption in the serial execution of floor-boarding (United Kingdom)

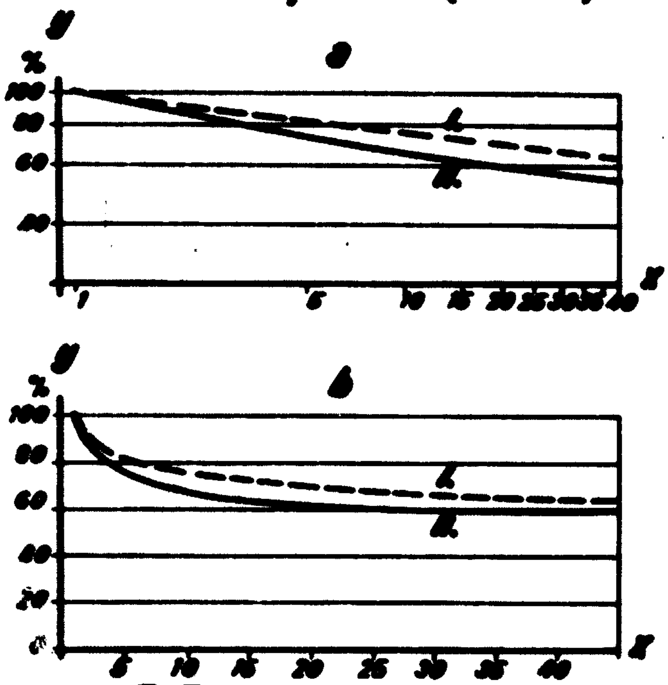
Source : Information received from the Government of the United Kingdom.

x = Pairs of houses in order of construction.

y = Manhours per house.

Figure 20

Total time consumption in the serial erection of one-family houses (Sweden)



Source : [1].

a = Total amount of work (log log scale).

b = Total amount of work (linear scale).

x = House number.

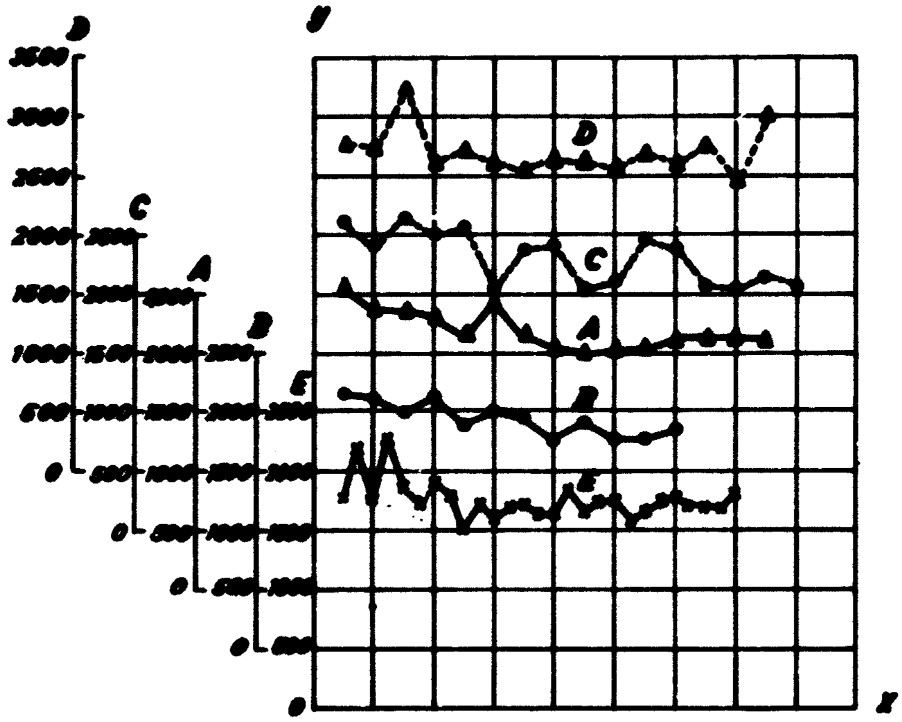
y = Time (percentage of initial operational time).

I = Accumulated mean value of operational times per unit.

II = Operational time per unit.

Figure 21

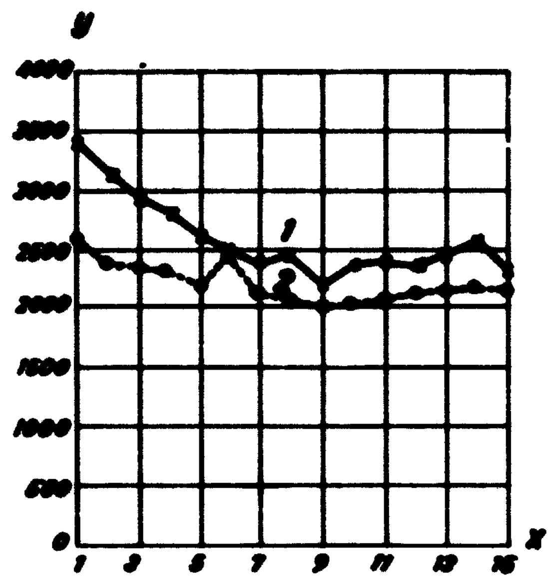
Total time consumption in the serial erection of pairs of one-family houses (United Kingdom)



Source : Information received from the Government of the United Kingdom.
x = Pairs of houses in order of construction.
y = Manhours per house for superstructure.
A, B, C, D and E = Sites.

Figure 22

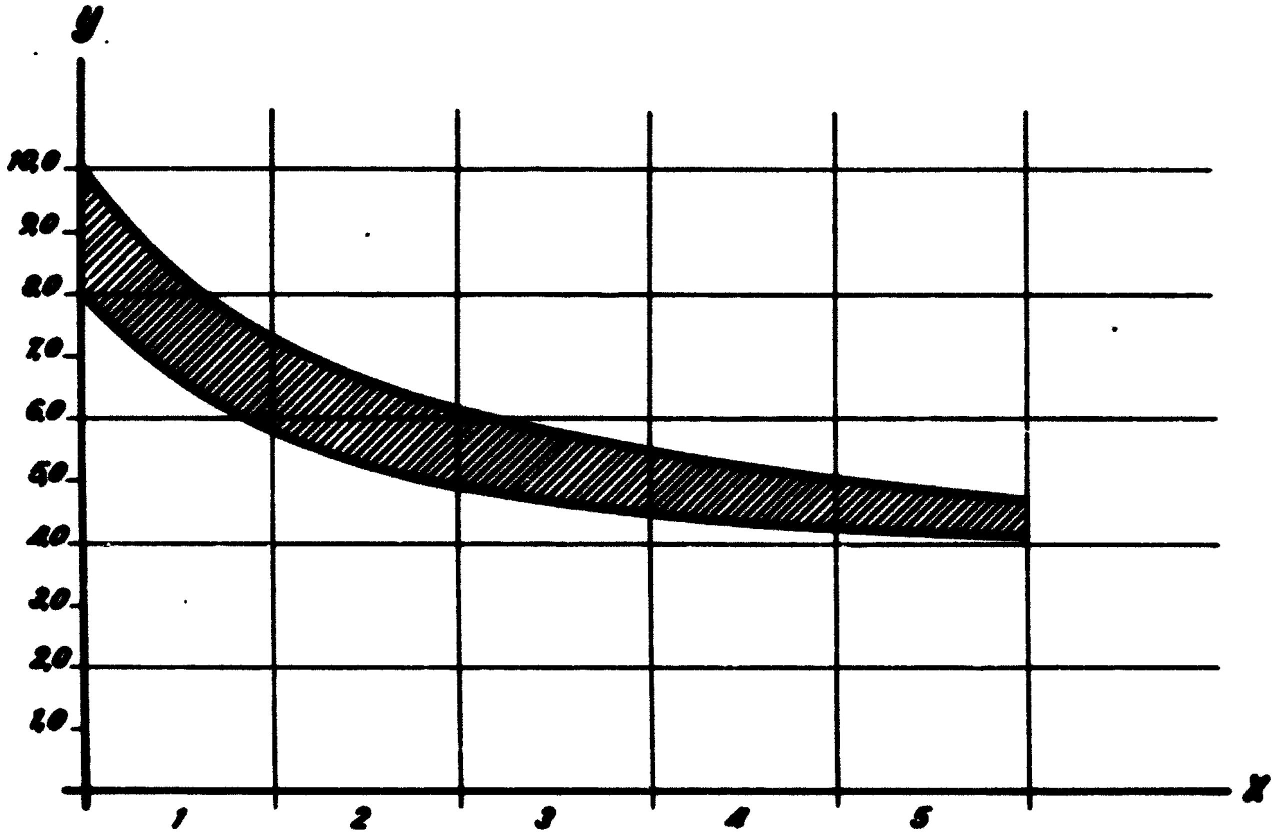
Total time consumption in the serial erection of pairs of houses of traditional and non-traditional type (United Kingdom)



Source : Information received from the Government of the United Kingdom.
x = Pairs of houses in order of construction.
y = Manhours per house for superstructure.
1 = Times for non-traditional houses on site A.
2 = Times for traditional houses on site A.

Figure 23

Manhours per cubic metre of buildings completed during a five-year period (Finland)



Source : Information received from the Government of Finland.

x = Time in years.
y = Manhours per cubic metre of building.

Finally, in France, a survey has been made of the time consumed for the building of twenty similar blocks containing altogether 1,010 flats and assembled from identical components. The successive times of erection for the different buildings, which were simultaneously constructed in two sequences by two groups of workers, clearly tend towards an appreciable reduction, as can be seen from figure 24. Some differences between the buildings, however, impeded any more spectacular saving. This will be discussed further in chapter IV.

In Czechoslovakia the Research Institute for Building Production in Prague has undertaken a detailed analysis of data on the time required for the production of brick-type multi-storey buildings (type structure G-57), erected in 1959. The time consumption for different series of identical dwellings was not derived from actual production but was calculated from actual figures obtained in the production of 375 dwellings. The results of these calculations are shown in table 2.

Table 2

Relationship between labour requirements and run size of dwellings (Czechoslovakia)

Item	Run size				
	125	250	375	500	750
Manhours per dwelling	870	650	595	540	500
Index[(a)]	146	110	100	91	84

Source: Information supplied by the Government of Czechoslovakia.

(a) Reference run size: 375 dwellings.

Data reported in the Dutch study [9] refer to the construction of 240 dwellings of one and the same type. The dwellings were identical portal frame flats built in three-storey blocks. The structural design of the flats was standard and traditional. The time required was 1,990 manhours for the first dwelling but only 732 for the last, the average number of manhours per flat in this series being 882. The improvement curve obtained in this study is shown in figure 25. In considering the results it should be borne in mind that the figure on manhour consumption relate to all activities on the construction site, both by the principal contractor and by the sub-contractors. As can be seen, the improvement in labour productivity at the end of the series is rather modest. Nevertheless, the conclusion was drawn that for this type of dwelling the minimum run size should have been at least 400 dwellings. Even if the labour consumption per dwelling is in no way affected by extending the length of the series, the extra time required for the running-in of the production process is spread over a larger number of dwellings, e.g. the accumulated mean value of manhours per dwelling will decrease further. According to the report of the study, series of at least 300 to 600 identical dwellings (depending on the construction method) should be organized if real benefits of serial production are to be achieved. Fixed, specialized and continuous assignment of tasks for all labourers have been found possible only if the building output amounts to at least one dwelling per workable day.

Identical storeys

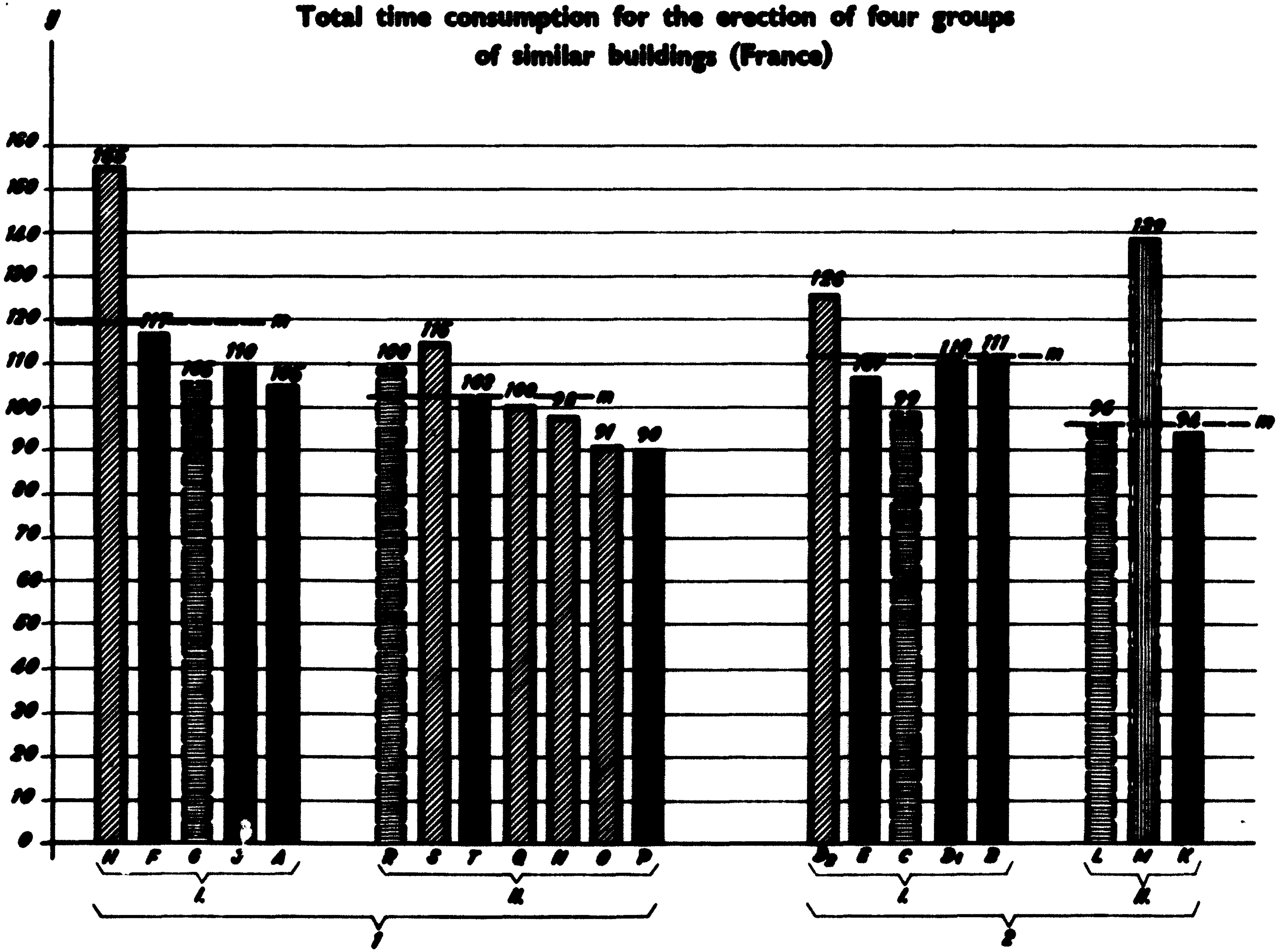
In a Finnish study, the labour input for carrying out the framework of 5 identical residential buildings was recorded. Each building had 4 storeys and two entrances both leading to eight flats. The loadbearing walls were cast in situ, while the external walls and floors were assembled from prefabricated concrete elements. The improvement in labour productivity was considerable, decreasing from 1,980 manhours for the first storey in the first building to 480 for the last storey in the last building. As can be seen from the improvement curve illustrated in figure 26, the labour consumption did not fall quite steadily. When moving from the last floor of one building to the first floor of the next, the manhours showed a slight increase. This is probably due to the fact that the storeys were not quite identical; the bottom floor of a building normally requires some more work than the others, even if the dwellings are by and large of the same type as in the other floors.

Similar results have been reported also in another Finnish study regarding the framework construction of three six-storey point blocks, each containing thirty flats. As in the previous case, the loadbearing walls were case in situ and the external walls and floors were constructed from prefabricated concrete elements. The number of manhours per storey went down from 1,800 for the first floor in the first building to 650 for the last storey in the last building (figure 27).

One set of curves, obtained from the French study already mentioned above [7], relates to the construction of nine identical, partly prefabricated point blocks, each consisting of fifteen identical storeys above ground floor (see figure 28). The pattern of improvement is generally the same in all the buildings observed, the maximum difference between the improvement curves being only 9 per cent. Time consumption falls steadily for the first few floors and is almost stable as from the sixth

Figure 24

Total time consumption for the erection of four groups of similar buildings (France)



Source : Information received from the Government of France.

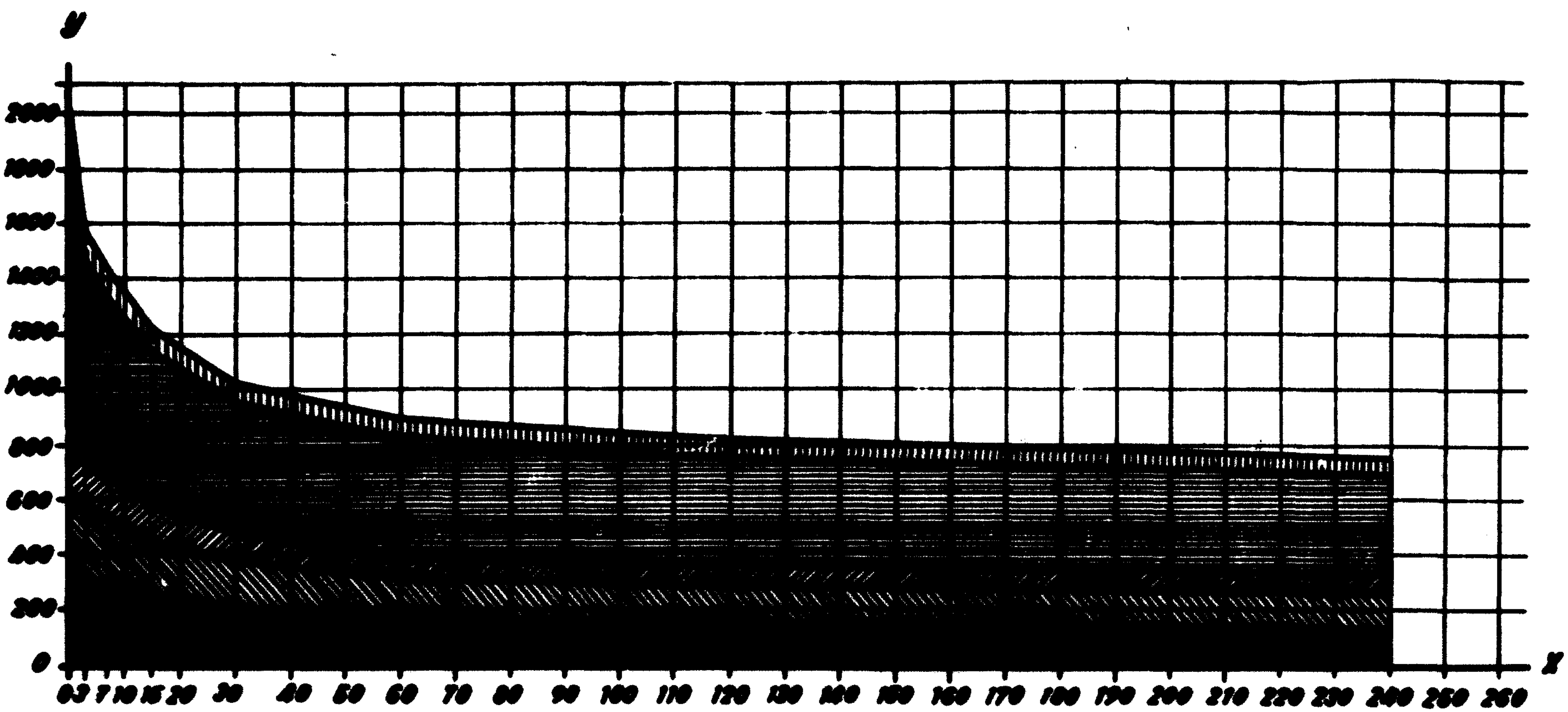
H, F, G . . . . L, M and K = Sign of the building, following the order of construction.

I = First group of buildings.
II = Second group of buildings.
1 = First group of gangs.
2 = Second group of gangs.
y = Manhours per room (rooms = living-room, bedroom, kitchen).
m = Average time per room within a group of buildings.

Note : Buildings G, R, C and L contain only one-room and two-room flats, whereas the other buildings contain three-, four- and five-room flats.
Buildings H, S, Q, N, O and D_2 are identical buildings.
Building M has only two storeys, the others have four.

Figure 25

Manhours per dwelling in the serial production of identical dwellings (Netherlands)

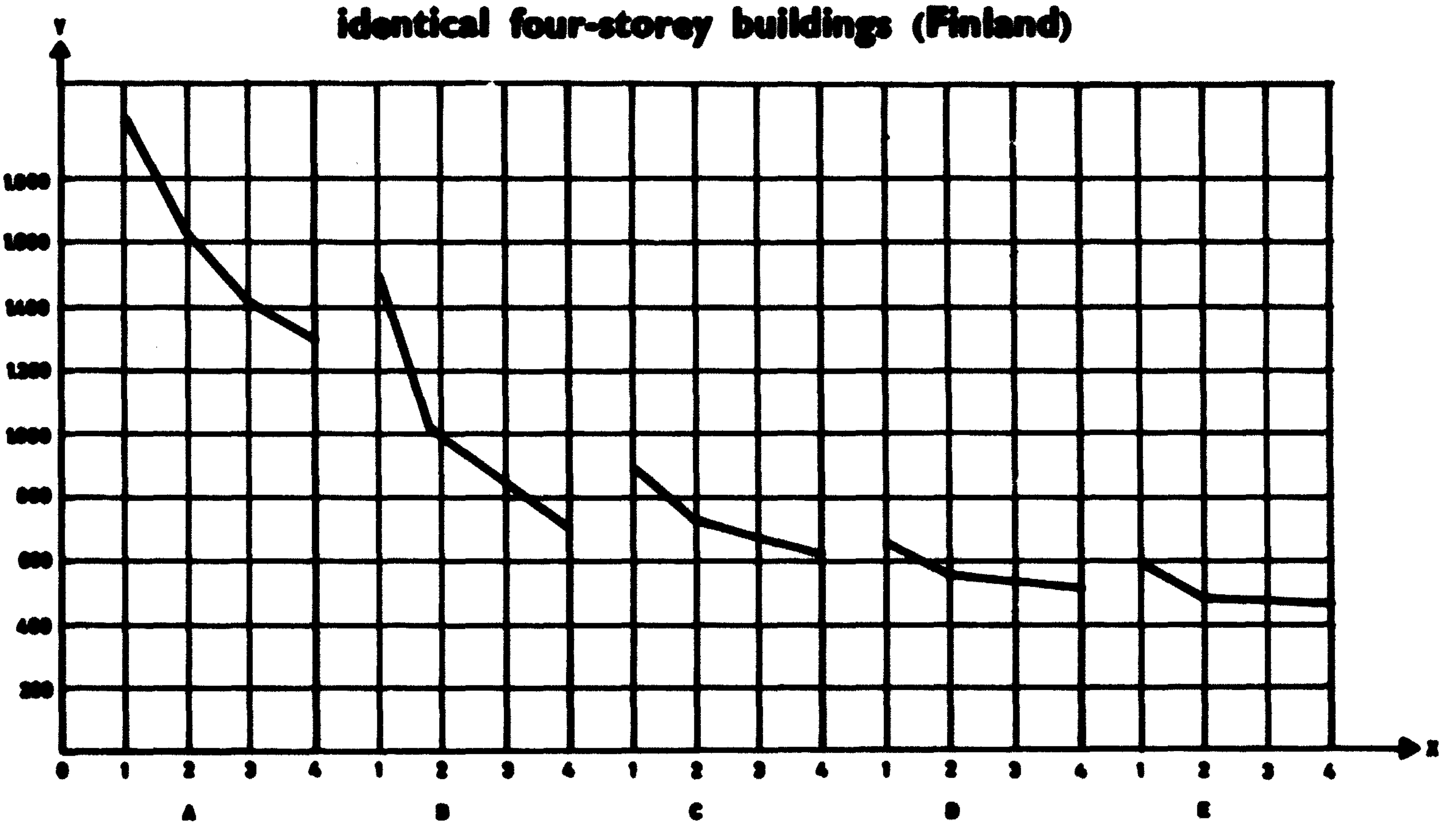


Source :[9].

x = Dwellings in order of construction.
y = Manhours per dwelling.

Figure 26

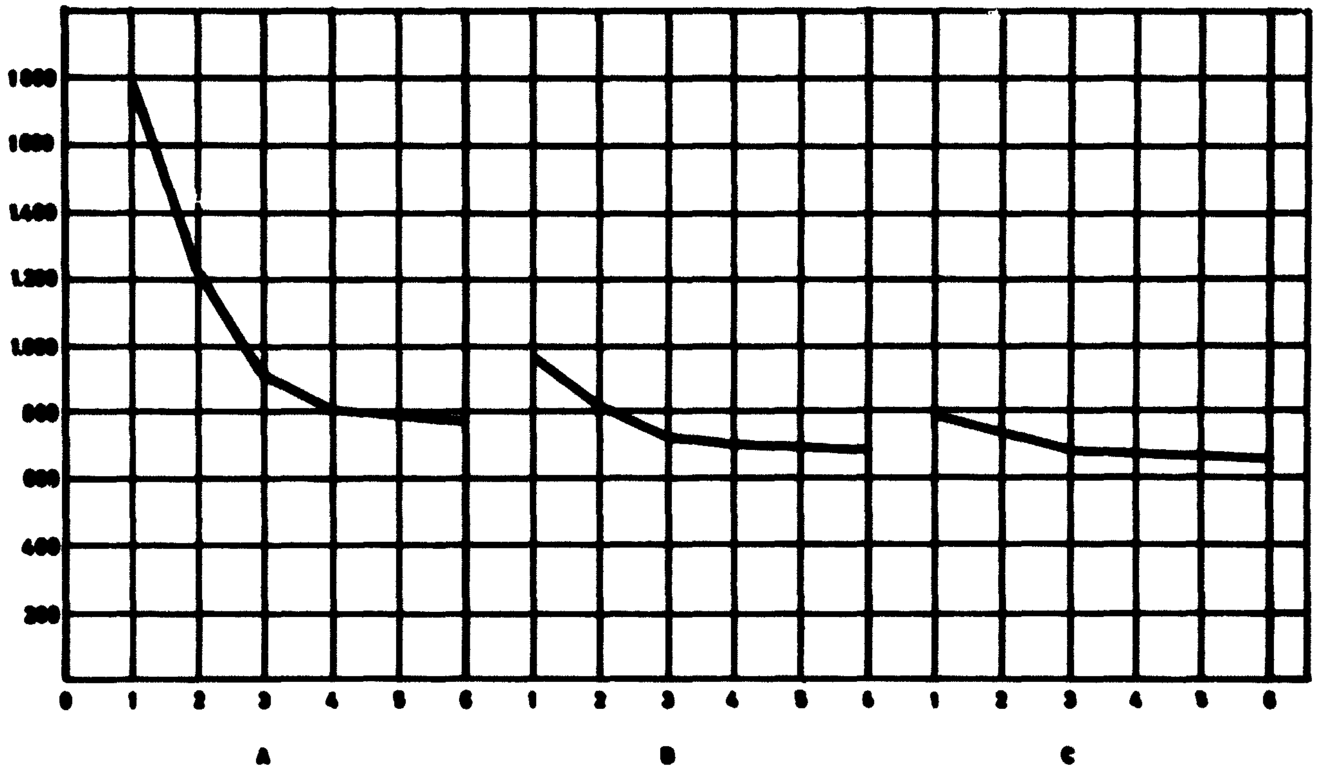
Time consumption per storey in the erection of five identical four-storey buildings (Finland)



Source : Information received from the Government of Finland.
x = Storey number.
y = Manhours.
A, B, C, D and E = First, second, third, fourth and fifth houses.

Figure 27

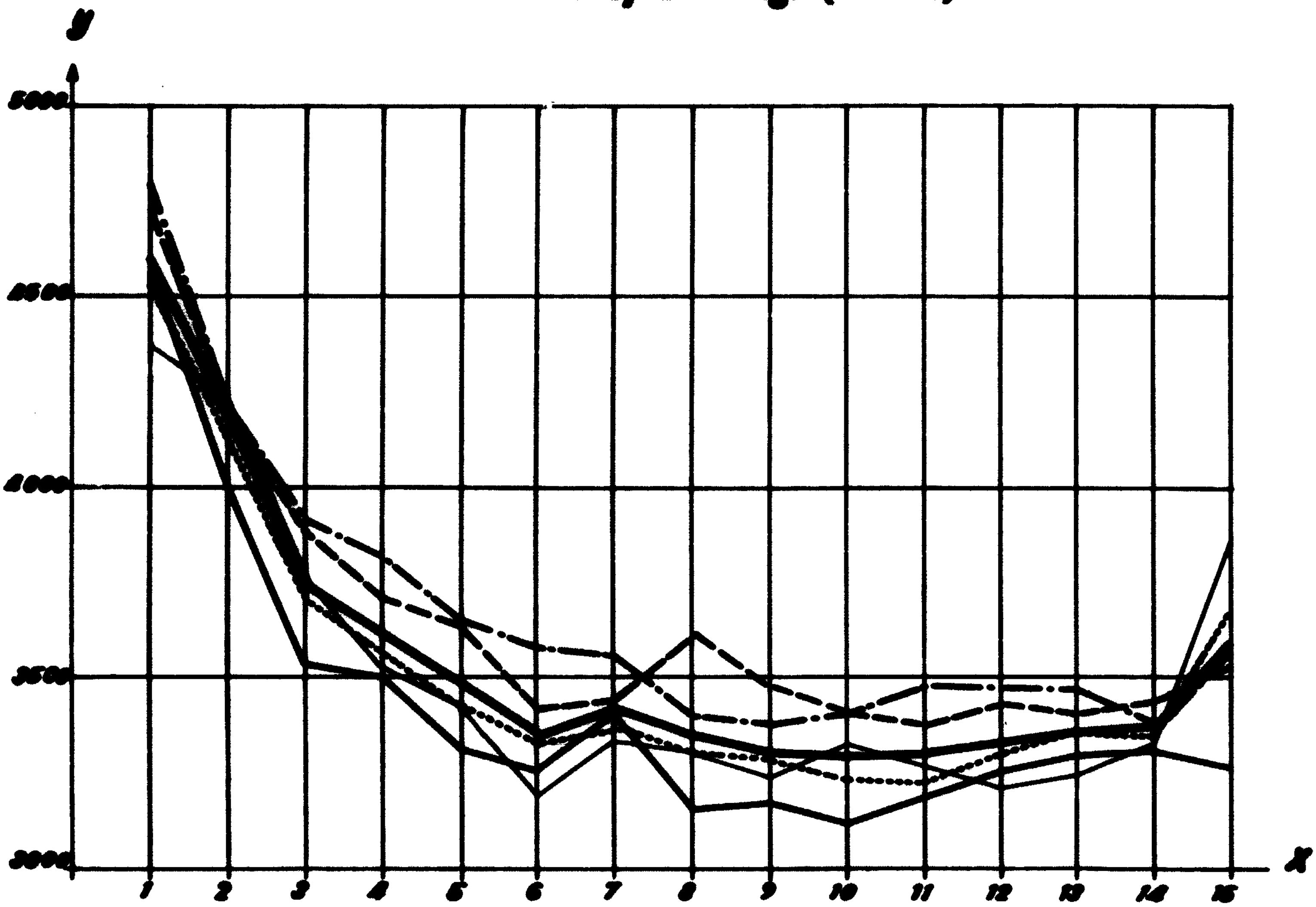
Time consumption per storey in the erection of three identical six-storey buildings (Finland)



Source : Information received from the Government of Finland.
x = Storey number.
y = Manhours.
A, B and C = First, second and third houses.

Figure 28

Total time consumption per storey in the erection of fifteen-storey buildings (France)



Source : [7].

Note : The five thin lines refer to results achieved by five different building firms.
The thick line shows the average result.

x = Storeys.
y = Manhours per storey.

storey. A slight increase in the manhours required was observed for the execution of the last few storeys. The difference between the arithmetic mean value of time consumption for the optimum sixth storey and the first, second, third, fourth and fifth storeys was 37 per cent, 24 per cent, 12 per cent, 8 per cent and 4.4 per cent, respectively. The total extra time required during the "running-in" period of construction was calculated at 6 per cent of the total number of manhours for construction of the buildings.

In another French study the time consumption was recorded from the construction of identical storeys in slablike, fifteen-storey buildings assembled from completely prefabricated large panels. The accumulated mean value of manhours required to complete a storey decreased in this case from 32,000, after the first floor, to 5,500 when the last floor had been completed (figure 29). It is interesting to note, however, that if the first storey is disregarded the time consumption per storey increases slightly with the height of the building. It would seem that in this particular case, where the storeys were very large, the effect of repetition was achieved already at the first storey and that further improvement in labour productivity was more than neutralized by the unfavourable influence of increasing height (particularly of wind on the large panels).

Two Western German examples of results of investigations into the effect of repetition of identical storeys in multi-family buildings are illustrated in figure 30. Figure 30(a) shows the consumption of manhours in the construction of walls, floors and staircase of a building erected at Berlin-Roseneck. The super-structure of the building consisted of fifteen storeys (plus two basement storeys), each floor comprising six dwellings. The walls were cast in situ. In the basement the construction of external walls called for 10 manhours/m^2; then the time consumption fell to 6 manhours/m^2 on the sixth floor and further to 3.5 manhours on the last floors. The time necessary for the construction of the internal walls was reduced from 7.5 to 2.8 manhours/m^2. Similar reductions could be observed for the floors and the staircase. The over-all manhours per square metre of living floor space was 10 in the basement and only 4 on the last floors. The increasing vertical transport distance had no adverse influence on the labour consumption, i.e. no "height effect" was observed. Similar results were achieved in the construction of eight storey residential buildings at Sprendlinger (figure 30(b)).

Observations on the time required for the construction of reinforced concrete frames on identical floors of a thirteen-storey block of flats have been made in Poznan, Poland. The results obtained, expressed in terms of manhours per cubic metre of concrete, are set out below in index form.

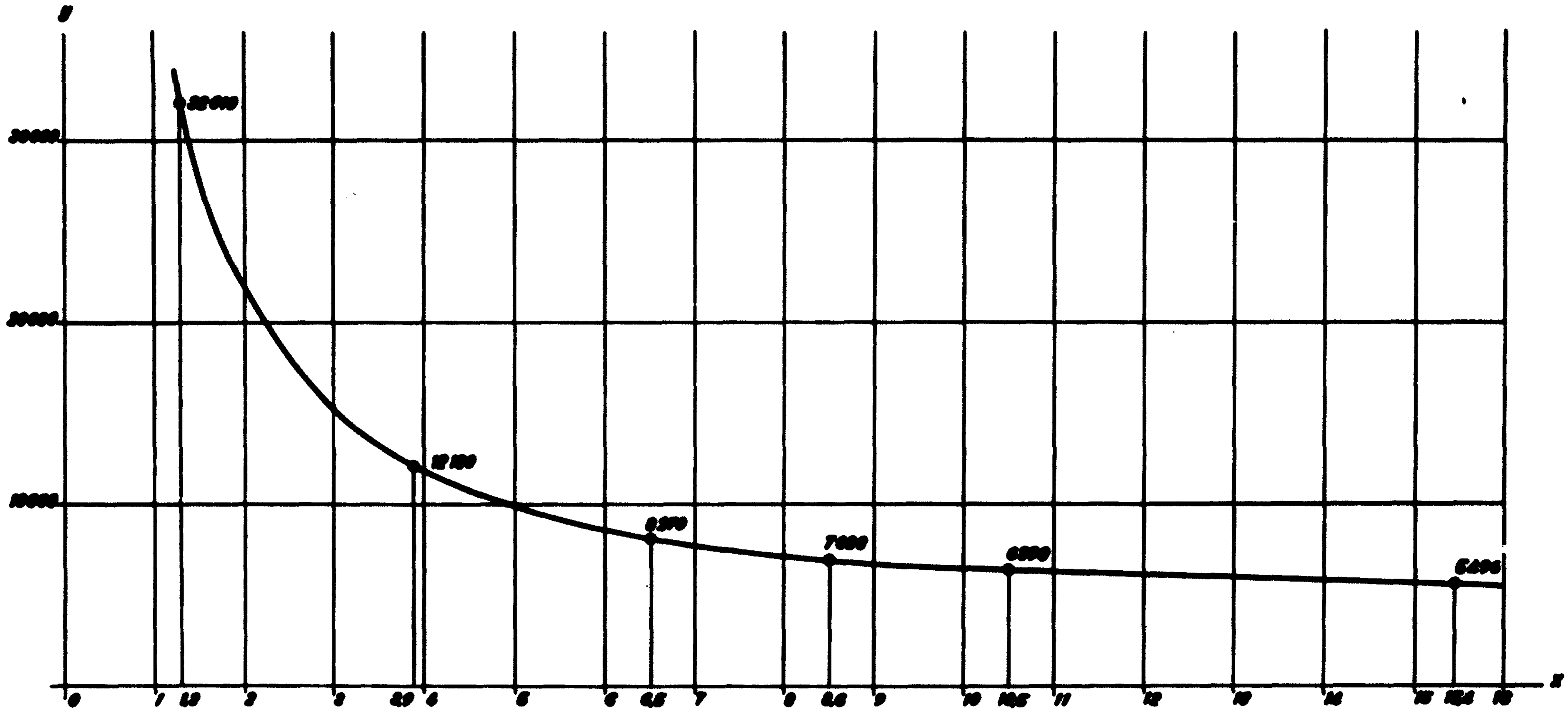
Floor no.	Total	Formwork	Concreting
1	100.0	100.0	100.0
2	94.0	96.1	86.8
3	71.6	72.9	63.1
4	88.0	84.6	76.4
5	97.0	88.7	84.2
6	75.2	73.2	71.5
7	88.2	82.2	64.9
8	63.3	50.7	68.0
9	73.5	60.2	63.1
10	62.3	52.7	66.2
11	107.3	-	-

The working hours required for the erection of a ten-storey building have been reported from Israel. The apartments in the building were of the split-level type with a common corridor for every two storeys. The actual working hours per pairs of storeys were:

	%
Storey 1 and 2 (Corridor 1)	100
Storey 3 and 4 (Corridor 2)	88
Storey 5 and 6 (Corridor 3)	84
Storey 7 and 8 (Corridor 4)	82

Figure 29

Accumulated mean value of manhours per storey in the erection of a sixteen-storey building (France)



Source : Information received from the Government of France.

Note : The non-integer x value denote the number of storeys constructed.

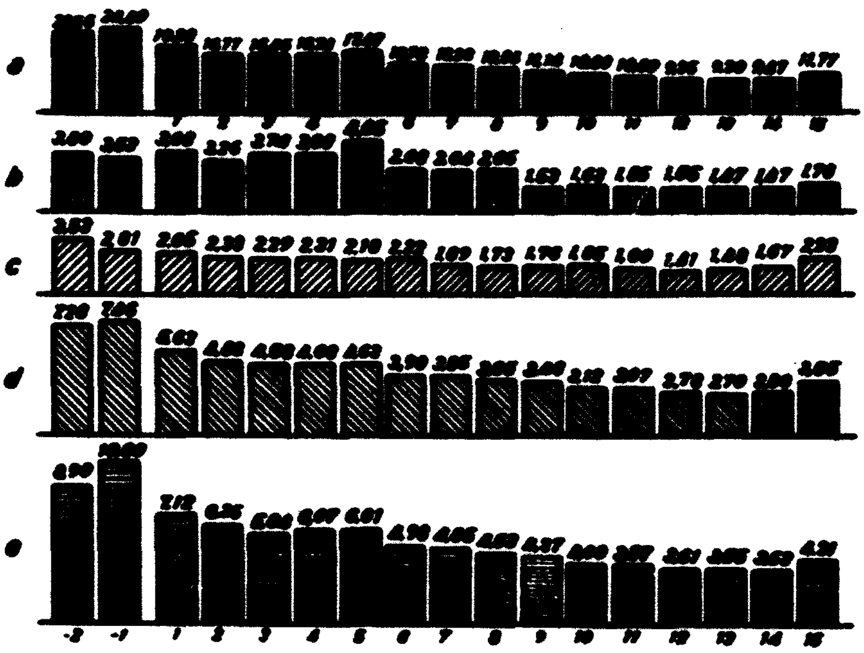
x = Storeys in order of construction.
y = Accumulated mean values of manhours per storey.

Figure 30

Manhours per square metre of walls per storey for the production of the raw structure (Federal Republic of Germany)

a : Fifteen-storey building.

b : Eight-storey building.



a

Source :[3]

-2 = Lower basement.
-1 = Upper basement.
1-15 = Storeys.
a = Manhours per square metre of walls for the production of the raw structures (= b+c+d+e).
b = Manhours per square metre of walls for the carrying out of the stairs and landings.
c = Manhours per square metre of walls for the carrying out of floors.
d = Manhours per square metre of walls for the carrying out of internal walls.
e = Manhours per square metre of walls for the carrying out of external walls.

b

Source :[3].

A, B and C = Three houses with 8 storeys (1-8) and basement (-1).
A = Manhours per square metre for the concreting of floors. Actual values on different storeys of building A.
A-B-C = Average manhours for square metre for the concreting of floors in buildings A, B and C, respectively.
I – Assembling the formwork.
II Reinforcing and concreting.
III Dismantling the formwork.

CHAPTER III

EFFECT OF REPETITION ON BUILDING COSTS

INTRODUCTION

The previous chapter has clearly shown the gain in labour consumption on site that can be attained by the repetition of identical building operations. This gain could be a target in itself. It should also be borne in mind that, even if no spectacular cost savings are achieved on the building site, the introduction of large series of building components and functional units has a substantial bearing on total building cost through the favourable effects of repetition on the production costs of building materials and components, as well as on the costs of design, programming and overhead. One of these aspects, namely, the effect of repetition on the production costs of building materials and components has been dealt with in a previous study by the ECE. /15/ Other cost elements affected by repetition will be discussed in chapter VI.

In most cases, the increased labour productivity attained by repetition of building operations on site is accompanied by a reduction of operational costs. The purpose of the present chapter is to study the nature and degree of this favourable economic effect. Unfortunately, very few data have been made available on the subject. Even relevant information contains figures that are of a very general character. Production in large series affects a number of cost components other than operational costs and, indeed, the total cost is affected by all factors of economic efficiency, of which repetition is only one. It is difficult therefore to draw firm conclusions from the figures supplied on total costs.

THEORETICAL DISCUSSION

The economic effect of repetition of building operations on site results from two different and equally important sources, namely,

(a) a decrease in operational costs, due to a more efficient organization and execution of the work (improved labour productivity and perfected equipment);

(b) indirect cost savings due to the reduction of construction time, achieved by the rise in labour productivity.

The savings in direct operational costs are due, on the one hand, to the gradual decrease in operational time attained in repetitive work, discussed in the previous chapter of this report, and, on the other, to a better organization and greater specialization of the work, justifying in turn better and more precisely adapted equipment for the execution of the work and also the introduction of new methods and techniques. Considerable savings could be attained by utilizing the first of these two effects only, i.e. without changing the organization and technology of the work. More spectacular savings will appear, however, only when the full advantages of large series are exploited by the greater specialization and better equipment of the workers. Such specialization would also have the additional advantage of enabling unskilled workers to be used in production to a wider extent. This effect is of particular importance in the building industry where, in almost all European countries, there is a serious shortage of skilled workers. In addition, the wider use of unskilled workers might lead to a further drop in labour costs, since normally unskilled labour is paid less than skilled workers. This is not always true, however; in the case of highly specialized "unskilled" workers such as concrete workers or crane operatives, the salaries can sometimes be higher than those paid to skilled craftsmen.

The indirect savings gained from repetition which are due to a reduction of construction time are substantial and of growing importance. First of all, improved productivity in the building industry enables an increase in national income and is thus of great importance to the economy as a whole. Furthermore, the reduction in construction time favourably influences a number of cost elements such as labour on-costs, costs (or rents) for machinery and equipment, capital costs during construction time, and so on. Moreover, through shorter construction time, investment will the sooner become effective.

The extent to which improved labour productivity may influence building costs, directly as well as indirectly, is to a large measure determined by the system of remuneration adopted. If a purely hourly wage system is employed, the entire economic gain from improved efficiency due to repetition will appear in the building costs. On the other hand, this system, where the earnings of the labourers are independent of the results of their work, does not greatly induce them to improve their ability. The extent of the repetition effect can therefore be expected to be considerably smaller than in a system where the workers have a fair possibility of sharing the benefits gained from an improvement of their output. Furthermore, the indirect savings of building costs, emerging from a reduction of construction time, will be comparatively smaller in a system which does not promote the highest possible degree of improvement. The advantages and disadvantages of a purely piece-rate system of remuneration are the reverse to those of the hourly wage system. Thus, the direct savings in terms of reduced wage costs per unit are comparatively small, while the indirect savings usually are substantial.

Which remuneration system gives the optimum results in terms of building costs depends on the conditions and circumstances of each case. Very often, a combination of hourly wages and a bonus for work executed has been found to constitute the most efficient solution. In some countries, hourly wages are paid during the operation-learning period and a piece rate for the remaining part of the work sequence, based on the capacity attained by the workers by the end of their operation-learning period. Thus, in most cases, the repetition of identical operations has a favourable effect, not only on labour costs but also on the wages of the workers.

According to experience gained in the Netherlands, a clear effect of repetition on labour consumption will be achieved only when a wage system is applied that offers the required incentive. In this country, a system has been successfully used based on the application to each task of a piece rate calculated from an estimated basic time consumption, plus an addition per dwelling, which decreases according to the serial dwelling number. These additions are fixed in such a way that the remuneration remains constant when the routine acquired complies with the expected calculated improvement in labour productivity.

The importance of the highest possible labour productivity and shortest possible construction time seems to be steadily growing, a trend which would appear to favour the use of piece rate remuneration in one form or another. On the other hand, increasing specialization and frequent organization of works according to firm schedules, based on pre-determined targets for each building team taking part in the production process, do not allow for much variation in the capacity of workers, and hence do not necessarily call for piece-rate remuneration.

Common to all wage-systems is the need for a comprehensive and penetrating knowledge of the effect of repetition on different kinds of building operation.

Quite apart from the possible savings in operational costs, emerging from the natural improvement of labour productivity as a result of the repetition of identical operations, it is possible to increase efficiency through the re-organization of the work according to new principles, to utilize the long series of identical operations for specialization of the work and to introduce new and better mechanical equipment. Such rationalization, of course, involves increased investments in mechanical equipment, i.e. higher capital costs per worker. These extra initial costs are recovered gradually through lower costs per unit. The optimum investment is therefore heavily dependent on the run size of identical operations. The importance of a correct predetermination of the run size should be stressed in this connexion. If, as sometimes happens, the run size is overestimated because new requirements call for new technologies, a real loss may easily result instead of the economic gain expected. The history of technical development shows many examples of technical improvements falling short of anticipated results because the run sizes were not large enough to justify the initial capital investment outlay. Moreover, a high degree of specialization calls for a high degree of co-ordination which sometimes implies an extension of construction time and higher overhead costs. The optimum level of investments and standardization, therefore, has to be carefully studied in each specific case.

RESULTS OF FIELD STUDIES

Information has been received from Czechoslovakia regarding calculated costs based on the detailed analysis of actual costs recorded from the construction of type buildings (type G-57) in the year 1959 and relating to an annual output of 350 - 375 dwellings. The reduction of different cost components and total costs, due to the effect of repetition on operational costs and to the acceleration of the production cycle, as calculated by the construction enterprises, is shown in table 3. The figures in the table record the influence of repetition on site operations only and thus do not cover the economies arising from the prefabrication of large series of components in efficient permanent factories. More detailed information on the relationship between run size and the cost of labour and mechanical equipment is provided in table 4. The impact of a shorter construction time on the cost of mechanical equipment due to a more rational utilization

Table 3

Relationship between run size and building costs in the production of dwellings in G57 type buildings (Czechoslovakia)

Run size (number of dwellings)	Index (a) of:						
	Run size	Total costs	Costs of materials	Labour costs	Cost of mechanical equipment	Other direct costs	Overhead costs
125	50	110.7	..	12.4	3.3	..	..
250	100	100.0	75.0	10.6	2.2	1.8	10.4
500	200	96.5	74.8	10.0	1.8	1.7	8.2
750	300	92.3	72.9	9.3	1.1	1.5	7.5
1 500	600	91.0	72.9	9.0	1.0	1.4	6.7
2 250	900	90.6	72.9	9.0	0.9	1.3	6.5

Source: Information supplied by the Government of Czechoslovakia.

(a) Reference run size = 250 dwellings.

Table 4

Relationship between run size and costs of labour and cranes in the production of dwellings in G57 type buildings (Czechoslovakia)

Run size (number of dwellings)	Cost per dwelling (Czech crowns)		Index of costs (a)	
	Wages	Cranes	Wages	Cranes
125	8 700	1 460	117	148
250	7 400	990	100	100
500	6 900	745	93	75
750	6 500	660	87	67

Source: Information supplied by the Government of Czechoslovakia

(a) Reference run size = 250 dwellings.

of the plant is particularly striking. It is estimated that the total costs could be reduced by 18 per cent if the run size were raised from 125 dwellings to 2,250 dwellings. A 6 per cent gain could already be achieved by doubling the production to 250 dwellings.

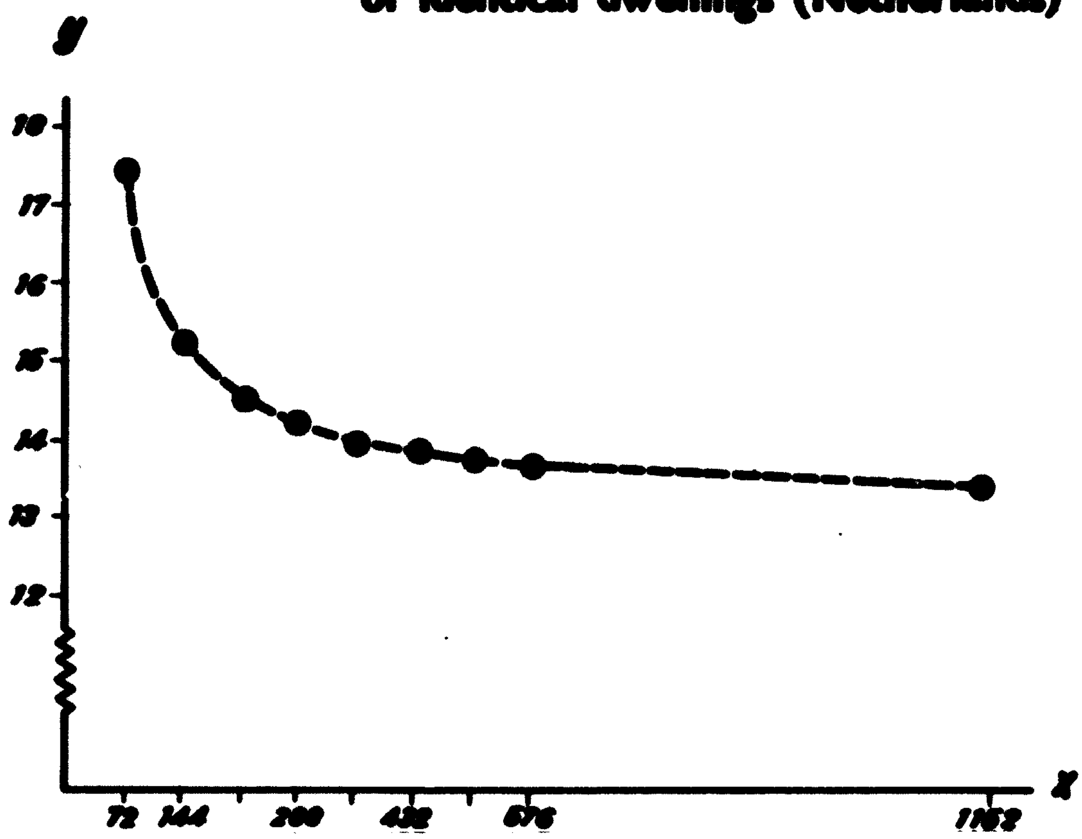
In the Netherlands, constant attention has for a long time been paid by the building research institute "Stichting Ratiobouw" to problems of efficient housebuilding. In this connexion, studies have been made, inter alia, into the effect of repetition on the average cost of dwellings. In a report published in 1962 [10], it was concluded that housing projects have to be split up into sufficiently large series of identical dwellings, since the size of the series has a favourable influence on both the average number of manhours and on the average building cost per dwelling. In a building organization producing about 1.5 dwellings per day or 300 dwellings per year, the calculated savings gained from an increase of the series of identical dwellings from 72 to 432 - without changing the output per year - amounted to no less than 3,500 fl. dwelling, which corresponds to a reduction of 20 per cent in the total building cost. A further decrease in building cost of about 3 per cent would be achieved if the series of identical dwellings were raised to 1,152 (see figure 31).

Some guidance to the effect of repetition on building costs could be derived also from a report prepared by the Institute for Building Research in Hanover [3]. The objects studied comprised about 500 terrace houses, erected in two phases in 1952 and 1953 on a site in a suburb of Hamburg. A substantial improvement of productivity of labour and decrease in costs were achieved in the second phase of the work. Thus the building costs per square metre of living floor space were reduced from 203 DM to 190 DM, i.e. by 6 per cent. A detailed analysis of the results attained in different kinds of building operation revealed that the reduction in costs could be referred almost exclusively to a saving in the cost of wall construction. The cost of this operation dropped by 16 per cent, while the others remained practically unchanged.

Favourable economic results of repetition have been reported also from Finland. On a building site at Helsinki, the manhours required and the salaries paid for the construction of six identical residential buildings were recorded. The buildings were six storeys high and had two entrances, each leading to

Figure 31

Average building costs per dwelling in the serial production of identical dwellings (Netherlands)



Source : [10].

x = Series of dwellings.
y = Average building costs per dwelling (1,000 guilders).

eighteen flats. The construction work was carried out in three groups of two buildings each. Groups 1 and 3 had the same master builder, the same supervisory staff and the same operatives, while group 2 consisted of entirely different labourers. All three groups had exactly the same mechanical equipment at their disposal. The following are the results achieved (in percentages):

	Manhours	Salaries
Group 1	100	100
Group 2	85	89
Group 3	72	82

In another example from Finland the effect of repetition was examined in the construction of a residential area over a period of four years. The objects of research were three-storey slab-like buildings, all of the same type. The development of manhours required and labour costs in the different stages of construction are given below:

	Construction stage	m^3	Manhours(%)	Salaries(%)
1.	(1961 - 1962)	22 300	100	100
2.	(1962 - 1963)	53 000	95	96
3.	(1963 - 1964)	54 330	85	88
4.	(1964 - 1965)	92 900	78	86

Over such a long period of time, some changes were naturally made in the working techniques, but the number and nature of all the various part operations remained the same.

CHAPTER IV

CONDITIONS NECESSARY TO ACHIEVE FAVOURABLE EFFECTS OF REPETITIVE WORK

INTRODUCTION

If an improvement in operational time and a decrease in building costs are to be obtained as a result of repetition, certain conditions must prevail. The most important of these conditions is continuity of work. The operations to be carried out must be identical (operational continuity) and they have to be executed by the same operatives and, as far as possible, without breaks (executional continuity). The fulfilment of these conditions is facilitated by:

(a) architectural and structural plans ensuring maximum identity of operations;

(b) adequate size of projects allowing for sufficient specialization as well as sufficient space for each of the work gangs involved;

(c) proper preplanning and organization of site works; and

(d) adequate day-to-day management and supervision of site work.

When operations of a repetitive character are carried out in a factory, it is merely a matter of thorough preplanning, careful organisation and observant control, to ensure that the work will run smoothly and without foreseeable disturbances. All the favourable effects of repetition may then be confidently expected.

Unfortunately, for operations on the building site, conditions are less simple and the problems related to production less easy to foresee and tackle. Building operations are indeed subject to many more or less disturbing influences, such as weather conditions, access difficulties, manpower instability, delays in the delivery of building materials and drawings, special problems arising when work has to be carried out far above ground level, and so on. Real operational continuity is also difficult to achieve, since the building necessarily has to be adapted to differences in the nature and slope of the ground and other site conditions.

It is not easy to find out exactly to what extent different adverse influences may affect the process of improvement expected as a result of repetition. Yet some indications are obtainable from much of the basic material for this report. A tentative analysis of these indications is presented below.

OPERATIONAL CONTINUITY

The basis of all benefits achievable from repetition of building operations is operational continuity, i.e. the works to be repeated have to be identical. This does not mean that the buildings or dwellings necessarily have to be completely identical but that their construction should be broken down into as many identical operations as possible. The Swedish report, already referred to [1], gives a good illustration of this: while the end products were different, almost all building operations were identical. On the other hand the organization of repetitive work is of course facilitated if the dwellings - or even the whole buildings - are identical. According to experience gained in the Netherlands, it is most important that the dwellings be identical. Even very small differences in end products sometimes imply substantially different production operations. Thus, for instance, limited differences in the dimensions of building units, particularly in units calling for the assembling of formwork, or differences in the joints between units, will each time necessitate a "re-thinking" of the organization of the work, as well as modifications in the elements of material or in the equipment employed, or both, which in turn will require the workers to recommence the improvement process again and again. The time consumption curve will accordingly be very irregular and quite unlike the improvement curves illustrated in chapter II.

An example of the influence of breaks in operational continuity is shown in figure 32, taken from a report from Finland. This illustrates the time consumption recorded for different building projects constructed by one and the same building firm. The basic types of the buildings were similar, but differences appeared, for instance, in the division of rooms in different floors of the same building. Generally speaking, no decisive effect of repetition could be observed.

The unfavourable influence of operational differences within a programme of buildings assembled from quite identical components can be seen from the French study, already referred to, regarding the construction of twenty blocks containing 1,010 dwellings (see figure 24). All the flats were identical except in number of rooms: four of the blocks contained one- and two-room flats only, while in the others there were dwellings of three, four or five rooms. One block (M) consisted of two storeys, while all the others had five; these dissimilarities - chiefly the last one - gave rise to considerable differences in the construction time per room. (In the comparison, the kitchen and bathroom in each flat were counted as together constituting one room) As can be seen, the break in operational continuity disturbed the general improvement curve, which nevertheless remains apparent.

A striking illustration of the importance of operational continuity has been supplied in a study undertaken in the Netherlands [10], from which figure 33 is reproduced. The information relates to the building of 230 similar one-family houses of various sizes. The first 126 houses had a cubic content of 225 m^3 each, then forty-eight were projected with a cubic content of 311 m^3 each, and finally fifty-six with a cubic content of 298 m^3 each. "The construction work was so organized that, when a gang of workers had completed its work in the last house of one type, it proceeded, five or ten minutes later, with the same job on the first house of the next type. When the gang changed over to another type of house, so many elements constituting what was to all intents and purposes the same job had to be modified that the gang again required a long time to get used to it. The planned differentiation in this particular field alone increased the labour costs by about 1,000 florins per dwelling."

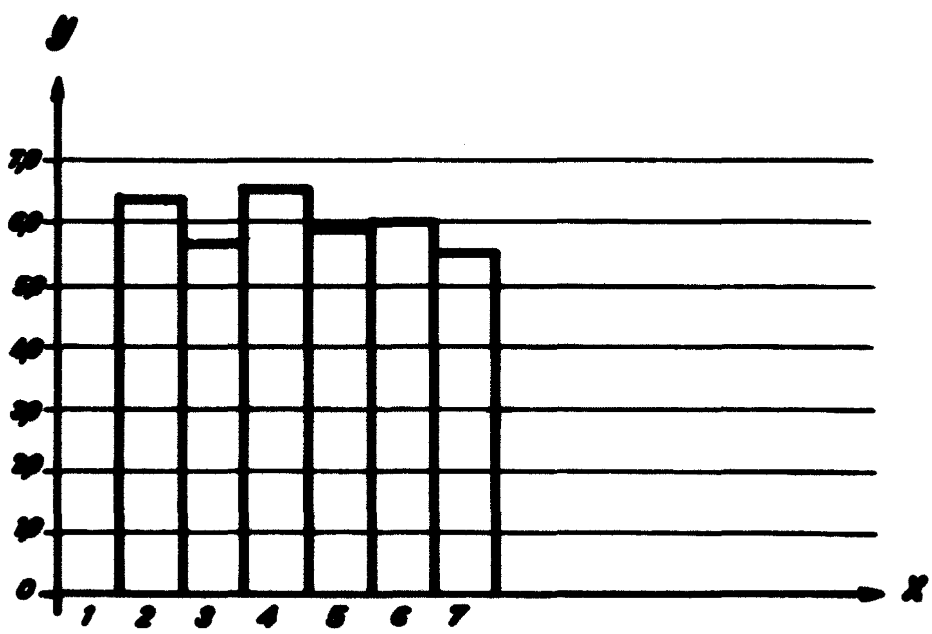
EXECUTIONAL CONTINUITY

If an interruption occurs in the course of the execution of a sequence of identical operations, owing to either a time break or a change - whether complete or partial - of the operatives concerned, the improvement curve will show a discontinuity of the general character shown in figure 34, taken from the Swedish report [1]. The figure illustrates a model used for the study of the influence of breaks in executional continuity. The additional time consumption created by the break (the hatched area in the figure) was found to be very substantial, a conclusion which was confirmed by observations of actual work processes. It was pointed out in the report that while supervisors usually know from experience that smooth-running operations are advantageous for both the contractor and the employee, there is perhaps not the same awareness of the effects of individual measures, especially concerning the re-allocation of labour. It may be just as expensive to undertake unconsidered re-allocations of labour as to let machinery stand idle.

Figure 32

Manhours per cubic metre of building in seven similar buildings

(Finland)

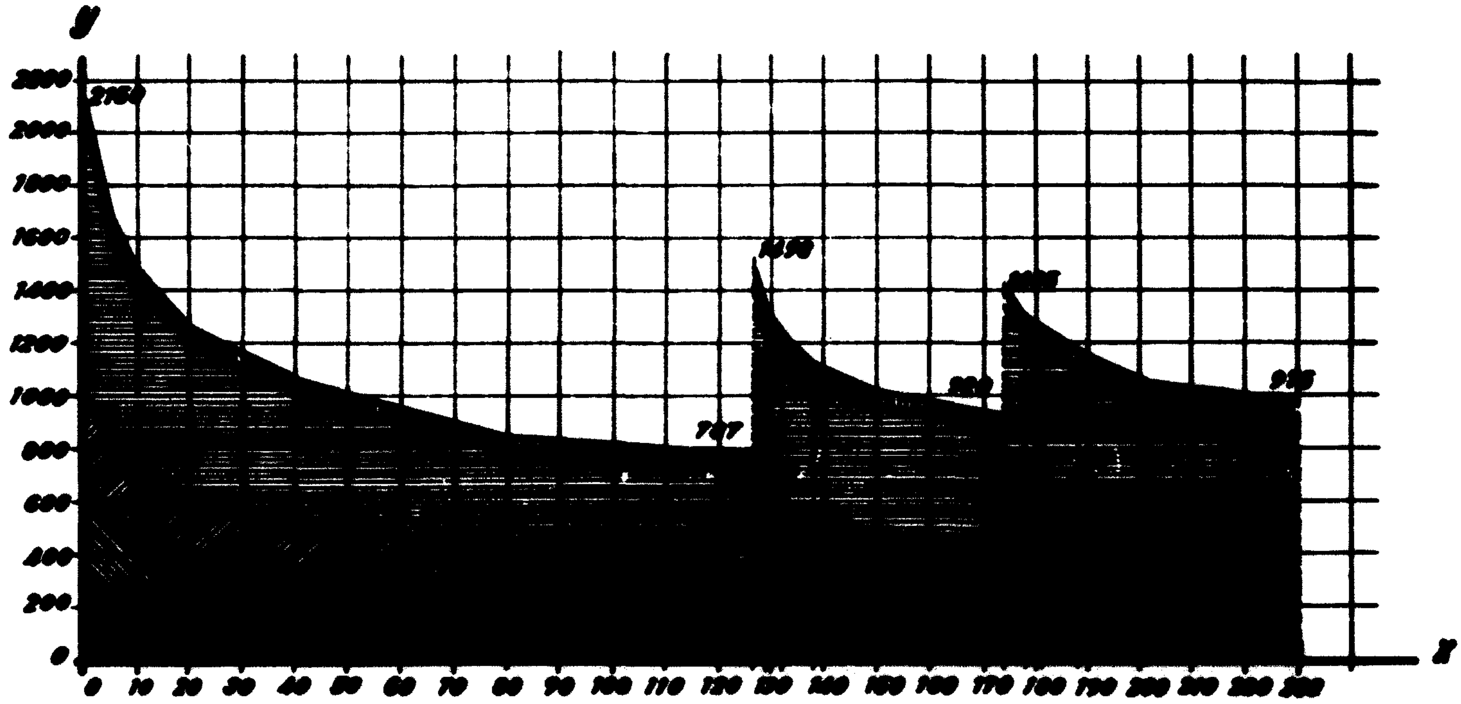


Source : Information received from the Government of Finland.

x = Buildings in order of construction.
y = Manhours per cubic metre of completed building.

Figure 33

Time consumption in the production of three series of similar dwellings (Netherlands)

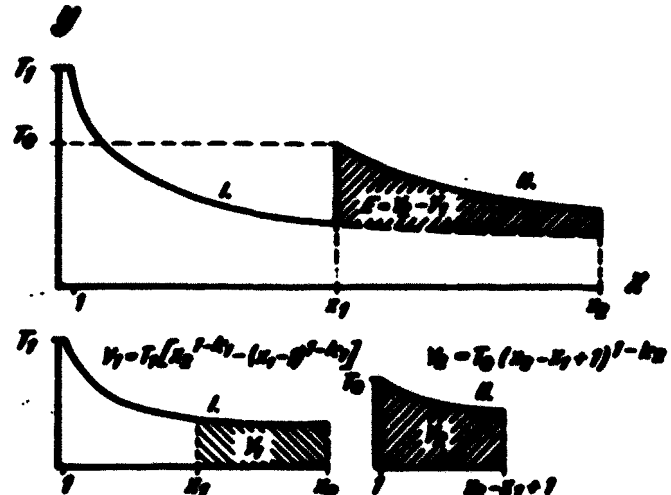


Source : [9].

x = Dwellings in order of construction.
y = Manhours per dwelling.

Figure 34

Theoretical analysis of the influence of breaks in time (Sweden)



Source : [1].

x = Number of units.
y = Time per unit.
E = Additional time caused by a break after the completion of x_1 units.

Time breaks

The most common break in executional continuity occurs when a team of workers performing a sequence of identical operations has to interrupt its work for any length of time. If the break is comparatively short and the work area left unchanged, as for instance, in the case of meal breaks or daily breaks, the workers will not lose much of their ability during the break and the improvement process will continue almost undisturbed. If, on the contrary, the break is longer and in particular if the workers are occupied on other kinds of activity during the break, or if the work area is being disorganized because of other activities, the interruption will result in a serious decrease in the capacity of the work team. The improvement process will have to re-commence with a capacity well below that achieved before the break. But the rate of improvement may probably be considerably faster in the second run. If the work sequence is repeatedly interrupted, the improvement curve will be saw-like, diverging substantially from that which would have been obtainable had the sequence not been interrupted.

The influence of time breaks on the process of improvement may be seen in figure 35, taken from the Swedish report [1]. The entire work was carried out in this case by the same operatives, but they were twice compelled to break off. These interruptions temporarily lowered their capacity in the work, probably because many of the dimensions they needed to have at their fingertips were forgotten. Another important factor was that the more or less rational environment in which they had worked before the interruptions deteriorated as a result of the work of other operatives.

An interesting attempt to estimate the influence of time breaks, on the basis of certain assumptions, was also made in the Swedish report [1]. The effect of interruptions after completion of the tenth and the twentieth operation was analysed for different kinds of operation (see figure 36). It was concluded, inter alia, that time losses due to interruption of work sequences will generally be greater the later the break occurs in the production process. The additional time will increase also with the relation between the stoppage time and the time spent on the work before the interruption. Interrupted production processes will, of course, lead to greater time losses in the case of operations where the effect of routine-acquiring is high than where it is low.

An illustration of the effect of a time break is provided also in the report received from the United Kingdom. In the concreting operation shown in figure 37 a crane breakdown caused a delay after the tenth pair of houses. When the work was resumed, the number of manhours per unit was considerably higher than before. This effect of lack of continuity preventing the continuation of improvement is shown also in figure 21; the last pair of houses on site D was started more than ten months after the previous pair.

Another example of the influence of breaks in time on labour productivity in repetitive work has been submitted by Finland and is illustrated in figure 39. The data refer to the construction of forty-five prefabricated one-family houses, and the operations studied were :

(a) installation of external wall elements (of about 1.5 ton weight);

(b) panelling of ceiling (light wooden elements);

(c) installation of partitions (light wooden elements); and

(d) installation of sockets.

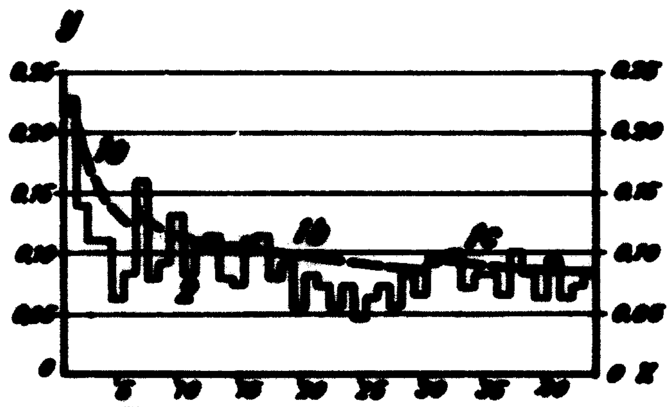
The construction work was carried out in two stages: the first comprising twenty-nine houses and the second sixteen. As can be seen from the figure 39, the break caused a rise in labour consumption for the first three houses in the second series.

Change of personnel

It is evident that a complete change of the work team occupied on the execution of an operation causes a recurrence of most of the problems of operation-learning and routine-acquiring faced by the original team of workers. On the other hand, the new team of workers can benefit from the proper organisation of the operation and its environment. It is also possible that some of the experience gained by the original workers could be shared by the new team. It is reasonable to assume, therefore, that the capacity of the new team will lie somewhere between the original and the ultimate capacities of the first team. If the original team is not entirely replaced, the effect on the improvement process will depend largely on the importance of the replaced operative(s). A change of the personnel performing simple work of a service character will have little effect on the work, while the replacement of the key worker in the team could be as important as a change of the whole team.

Figure 35

Effect of time breaks on time consumption in the serial execution of facing of outside wall (Sweden)



Source : [1].

x = House number.

y = Manhours per square metre.

1 = Accumulated mean value of operational times per unit :

a = between units 1 and 7;

b = between units 7 and 20;

c = between units 20 and 44.

2 = Operational time per unit.

Figure 36

Theoretical analysis of the effect of breaks after the 9th and 19th repetitions of identical operations (Sweden)

Source : [1].

x = Number of units.

y = Operational time per unit.

a = Break between 9th and 10th units.

b = Break between 19th and 20th units.

a_1 and b_3 = a 12 weeks' interruption.

a_2 and b_4 = an 8 weeks' interruption.

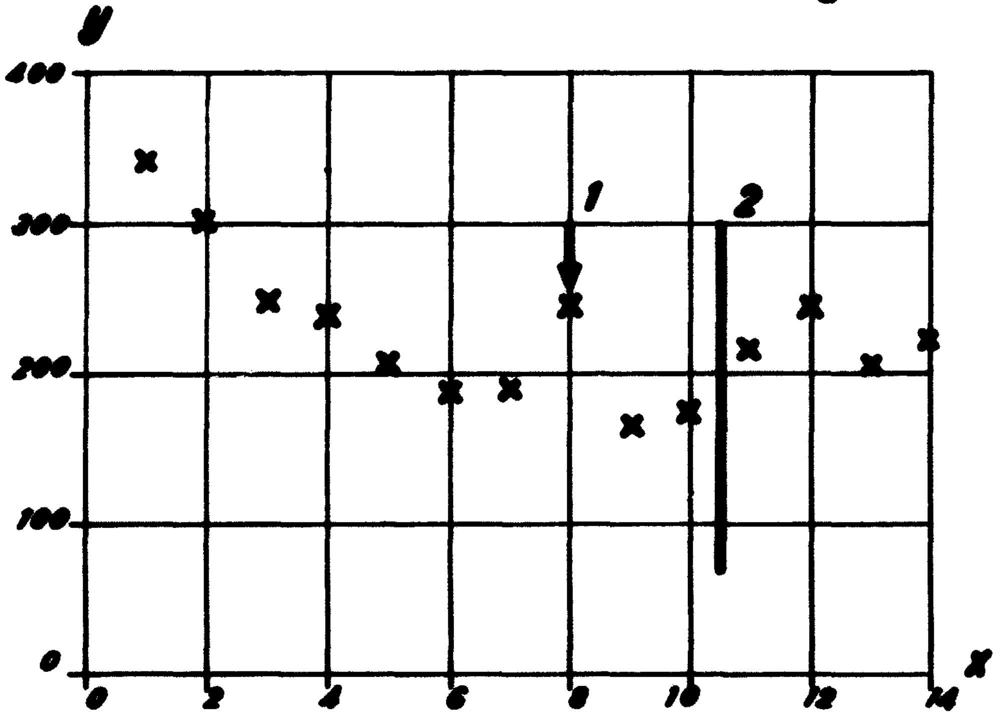
a_3 and b_5 = a 4 weeks' interruption.

b_1 = a 20 weeks' interruption.

b_2 = a 16 weeks' interruption.

Figure 37

Influence of bad weather and break in time on the operational time for concreting of first-floor walls and roof in non-traditional houses (United Kingdom)

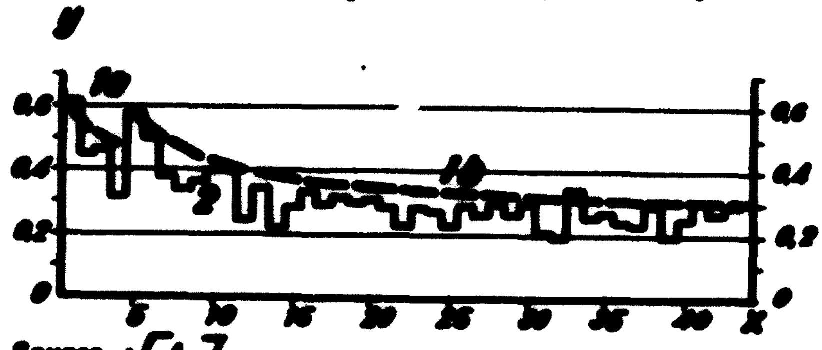


Source : Information received from the Government of the United Kingdom.

x = Pairs of houses in order of construction.
y = Manhours per pair of houses.
1 = Bad weather.
2 = Break in time.

Figure 38

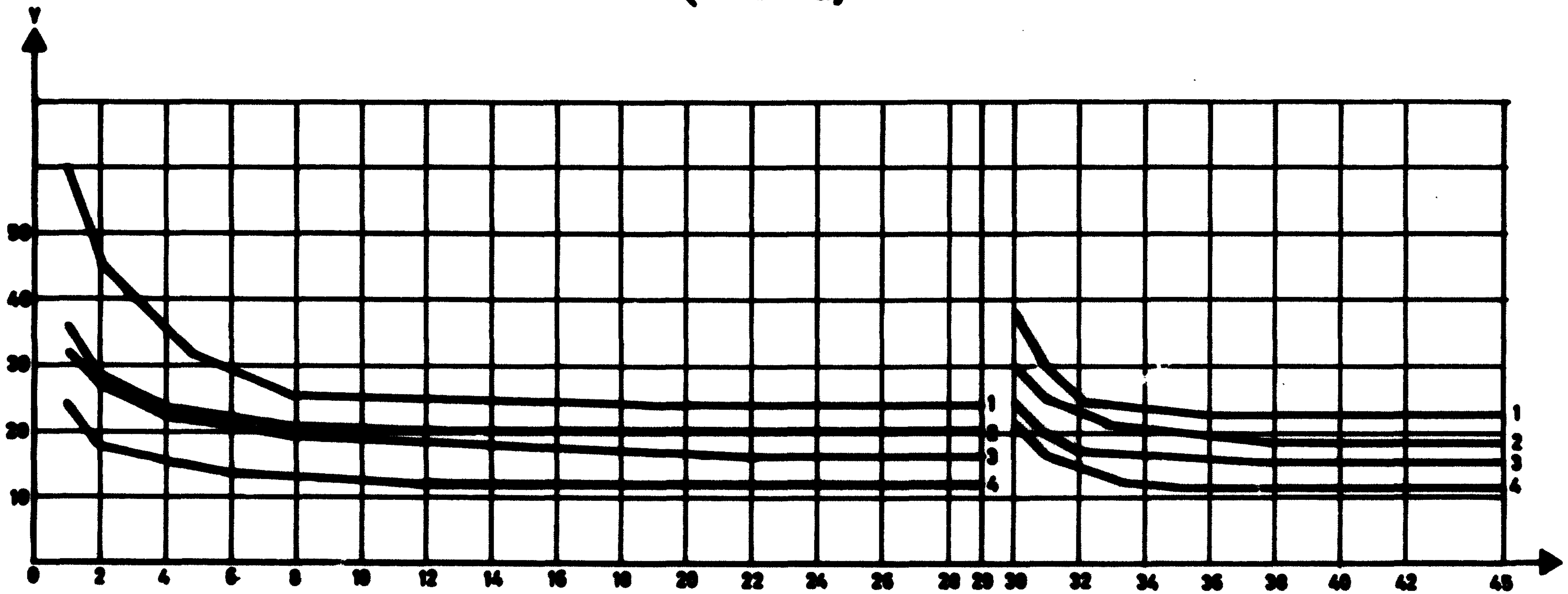
Effect of change in personnel in the serial roof-laying of one-family houses (Sweden)



Source : [1].

x = House number.
y = Manhours per square metre.
1 = Accumulated mean value of operational times per unit :
a = between units 1 and 5;
b = from unit 5.
2 = Operational time per unit.

Figure 39
Effect of breaks in time on labour productivity in the erection of forty-five one-family houses (Finland)



Source : Information received from the Government of Finland.

x = Number of houses.
y = Manhours.
1 = Outer wall elements.
2 = Ceilings.
3 = Wooden partitions.
4 = Socle elements.

The Swedish report /1/ gives a good example of the effect of changing personnel (figure 38). The operation studied was roof-laying and the change of personnel took place between the fourth and the fifth unit. The calculated total time loss caused by this change amounted to 47 manhours, i.e. more than 1 manweek. But this does not throw any light on what happened on the other jobs. It merely shows - but this is important - that the change of personnel was in fact justifiable only if a total time gain of more than 47 manhours could be expected to be achieved elsewhere. Such a saving is, however, almost impossible.

The experience gained in Sweden on this subject is confirmed by studies undertaken in the United Kingdom. It has been reported, for instance, that where there are constant changes in gang formation, as is sometimes the case on finishing operations, the improvement is modest if not nil.

SUFFICIENT WORK SPACE

If all the different teams occupied in the construction of a building project are to be able to work simultaneously on the same site, without losing any time, one after the other in long work sequences of identical operations, the site must provide adequate work space. This is an important fact to remember, in particular concerning multi-storey buildings, where the different teams immediately they have finished work on one storey should be able to start on the next. If the construction includes wet processes, for instance the drying and hardening of in situ cast concrete, it is necessary to extend the work space to take into account the time required also for these processes. If the work space is not sufficient, executional discontinuity in the operations will occur, with serious effects on labour productivity. The provision of sufficient work space is obviously a function of a project's size and nature and the degree of specialization applied in the work. In properly planned and co-ordinated work less work space is required.

A study carried out in the Netherlands clearly illustrates the importance of sufficient work space. The investigations revealed that the most economic total work space in the particular case studied comprised the combined floor areas of not less than twenty, and not more than thirty, flats. The project contained four blocks with eight flats per floor. As two blocks gave a work space of only sixteen flats the contractor discovered, after some time, the necessity for extending the work space to comprise twenty-four flats by including a third block in the building process. Later, he was led to include also the fourth and last block of the site, with the result that the labour and equipment had to be put to work alternatively on the construction of substructure and two different kinds of flat.(1) Moreover, the work space shrank towards the end of the work from thirty-two flats to twenty-four, then to sixteen and finally to eight because, owing to the method of work adopted, the operations had advanced to a higher storey in the first two blocks than in the third, while the fourth block was even further behind. The bad results of the organization of work adopted are shown in figure 40.

INFLUENCES OF EXTERNAL ORIGIN

The most important external factor influencing building operations is the weather. Rain, wind, snow and cold weather slow down the work rate and sometimes render any kind of organized work impossible. According to the experience gained in Finland, for example, the succession of seasons sometimes totally overshadows other factors affecting building work. If the work is completely stopped, this creates not only unemployment but also the disadvantages of breaks in continuity mentioned in the foregoing paragraphs. In any case, the work rate slows down, partly because of the decreased ability of the workers and partly as an effect of more direct influences - for instance, wind blowing the large elements handled by crane, or additional work necessary to safeguard the quality of the product in cold and snowy weather. The improvement curve shown in figure 13 could serve as an example of the influence of unfavourable weather conditions: the fifth and eighth operations were disturbed by rainy weather.

An example of the seasonal influence of inclement weather on the productivity of building operations is provided in figure 10, which is taken from a study made in France of the labour consumption required over a long period of time for erecting steel shuttering of the tunnel type. As can be seen, the number of working days as well as the labour productivity, is substantially lower in December, January and March than in the preceding and the subsequent months.

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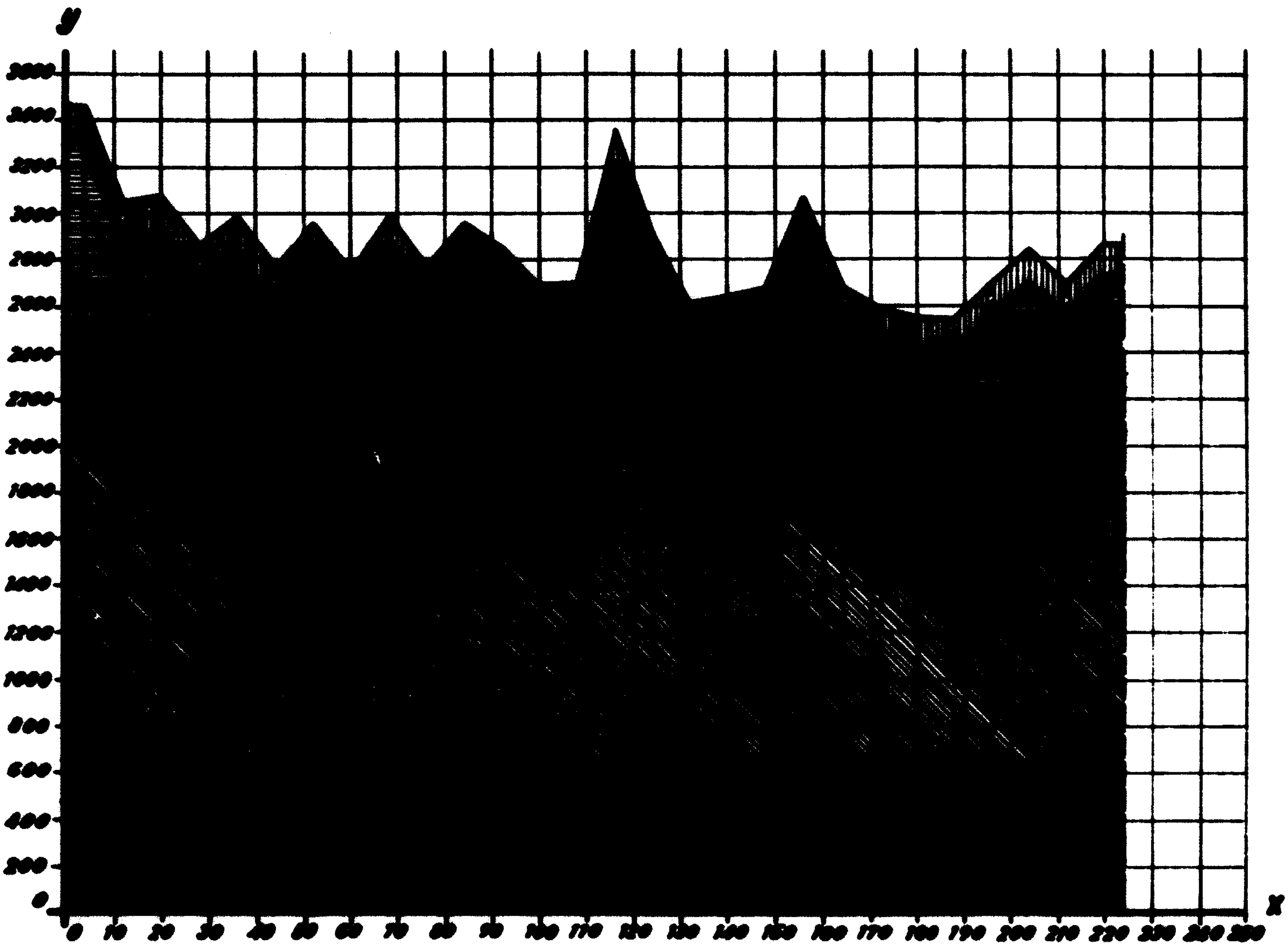
(1) The first three floors of the blocks contained portal-frame flats while the top floor flats were of a gallery type.

Figure 40

Influence of insufficient work space in the serial production of dwellings (Netherlands)



Source : [9].

x = Dwellings in order of construction.
y = Manhours per dwelling.

Another external factor subject to much discussion is the effect of the height of buildings. Some experts are of the opinion that this effect is negligible in the case of buildings of under twenty storeys or so. Others point out that several slightly unfavourable effects begin to occur as the number of storeys increases. Thus, for instance, the workers take more time to reach their work positions, the delivery of materials becomes more difficult and time-consuming, and the wind is more difficult to contend with. Although firm conclusions should not be drawn from the observations so far made, many studies show that the time required for the vertical transport of elements is generally of limited importance compared with the time for their loading and unloading. The influence of the wind is evidently conditioned by the type of lifting equipment used and the shape and weight of the element. A crane is of course more sensitive than a hoist, and a large, light element more seriously affected than a small, heavy one. This is confirmed by the French report /7/, in which curves were presented relating to the assembling of prefabricated panels and to the formwork and concreting for the in situ cast loadbearing structure of sixteen-storey buildings erected on a rather windy site. A slight increase in the operational time was observed for the panel-assembling work from the sixth storey upwards, while the concreting works were not affected by the increasing height of the buildings (see figure 9).

END EFFECT

When a series of operations is approaching its end, a certain increase is often observed in the operational time per unit, i.e. the last operations require more time than those immediately preceding them. This "end effect" may be due to the instinctive slowing down which occurs as one approaches one's goal. Moreover, at this stage, there is often a relaxation of supervision as well as a degree of disorganization, e.g. certain materials are already being directed to other tasks. Sometimes the end effect has been attributed to a growing fear among the workers that they may be unable to obtain a new job when the present one is finished. Finally, some experts consider that a certain amount of lassitude may be due to the frequent repetition of identical operations. With the number of repetitions usual in the building industry, at least in western Europe, however, the problems of lassitude would seem to be negligible.

Although much of the material supplied for this report clearly shows that the end effect has to be taken into account in the planning of building work (see figures 5, 28 and 29) it is far less important than the difficulties arising from the introduction of a new operation. What would seem to be an end effect could in many cases be attributed simply to the additional work required in connexion with the execution of the last operations in a series.

CHAPTER V

PLANNING AND ORGANIZATION OF REPETITIVE WORK

INTRODUCTION

It has been shown in the preceding chapters that substantial improvements in labour productivity and reductions of building costs can be achieved by the execution in sequence of even a limited number of identical building operations. It has also been shown that the favourable effects of repetition can be partly or even totally neutralized by the influence of a number of adverse factors. Of decisive importance for the success of repetitive site operations are the thorough preplanning and proper organization of the work. The present chapter is devoted exclusively to these questions.

In so-called "traditional" construction, particularly of single objects, knowledge about the work to be executed is generally limited while the factors influencing production are numerous. Detailed preplanning and systematic organisation of the work are therefore often impossible. In many cases the site work is started even before all drawings and specifications are available. In such circumstances efficiency of the building work will depend exclusively on the improvisation ability of the supervisory staff and on the workers' degree of flexibility and skill.

If, on the other hand, construction processes are highly repetitive, new and better forms of organisation can be applied and are indeed necessary. If the method of organization remains traditional, the favourable effects of repetition will be partly or entirely lost. Moreover, up-to-date methods of organization may help not only to realize the favourable effect of repetition but also to enhance it.

It may be recalled in this connexion that the initial rate of improvement of labour productivity attainable by repetition is considerably higher for simple operations than for more complex ones, and that a stable output is attained comparatively sooner for the former kind of operation. The possibilities of further improvement of labour productivity through the introduction of new techniques and more specialised equipment are also greater in the case of simple operations. It is natural, therefore, to try to divide the construction work into a large number of simple operations and thus to enable a high degree of specialization of the operatives. This, however, creates serious problems of co-ordination and is only feasible for large projects. The optimum degree of specialization is thus in each case largely dependent on the size of the building contract.

THE FLOW-LINE METHOD

In the case of highly repetitive construction processes, it has been found most effective to organize the work according to principles very similar to those used in the manufacturing industries for the mass production of consumer goods. As for site operations, the product cannot of course be moved from one working station to another; instead, the operatives have to move between different working areas. The most commonly used denomination of this method of organizing the work is the "flow-line method", but others such as "taktarbeit", "travail à la chaîne", "travail cadencé", etc. are also used. The flow-line method is based on the rhythmical execution of certain repetitive tasks by specialized gangs. The work is usually planned as follows:

(a) all the separate tasks, to be given to distinct operative-teams or to different contractors, are listed;

(b) among the operations listed a "key operation" is selected, i.e. the work for which a regular recurrence seems to be of primary importance (for example, the pouring of concrete walls and floors into large forms), and the corresponding cycle time is fixed;

(c) the whole planning of the different operations is then built up around the rhythm calculated, all the other operations being arranged by sizing the teams concerned, so as to enable them to follow the same sequence.

The choice of key operation is fundamental. As, in practice, it is not always possible to adjust the number of workers of a team according to theory - it is impossible to use less than one worker or to use a fraction of an operative, for instance - there is bound to be some slack in the use of manpower. In order to keep this to a minimum and to shorten as much as possible the total time on work, the key operation should be one of the "critical" operations in the sense of the Critical Path Method (CPM).

Due attention must be paid to the fact that the work teams should not impede one another. Only one team at a time should work at any one working station. In the planning of flow-line production, therefore, charts are used which show not only the development of production processes over time, but also relationships in space. In their simplest form, these charts are very similar in layout to an underground railway schedule: the line is divided into sections with a special signalling device so that one train may enter a new section only when the preceding train has actually left it (figure 41). But on a more complicated railway chart, there are trains running at different speeds, express trains overtake slow trains at certain stations, and even on single-track lines there are trains going in the reverse direction and crossing at special places. In the same way the simple planning of work described above may be refined by letting some operations proceed simultaneously at different speeds. This may lead to a greater efficiency of the workers. Likewise there may be trains travelling in reverse, that is workers doing some operation in reverse order. Of course the "crossings" must be judiciously located in order to avoid "collisions", i.e. one team of workers interfering with another.

In the early days of the flow-line method, great emphasis was laid on the standardisation of buildings or building units, and the specialization of building enterprises according to the standardized products was aimed at. During recent years it has become clear in several countries that strict specialization according to product is not always possible, nor does it always provide optimal results. The new concept of a flow-line consisting of standard specialized technologies to produce very different products has been introduced. This kind of organization is most valuable to building enterprises in medium-sized towns where the inclusion of widely different buildings in their investment plan is unavoidable. Experiments of this kind are being carried out, for instance, in Hungary.

There is the problem of how best to elaborate work schedules to take into account the successive improvement of labour productivity due to repetition. Theoretically, there are two possibilities, namely:

(a) to retain constant the number of workers carrying out the different operations and gradually decrease the time for each unit of the work process; or

(b) to retain a constant speed of the process and gradually reduce the number of workers performing the different tasks.

Both methods have their advocates. If the duration of the key operation is determined by a technological process (for instance, the time necessary for hardening concrete), or by the capacity of mechanical equipment, it would seem that the only possibility of utilizing the repetition effect is by reducing the number of workers. If technically feasible, however, it would seem more advisable to adapt from time to time the general work rhythm of the flow-line, since this measure does not involve breaking up the gangs or re-employing superfluous labour.

In practice, it is extremely difficult to estimate in advance the manhours required for the many different operations necessary to construct a building. For this reason, it has proved practical in some countries to train "emergency gangs" possessing a wide range of skills, who operate outside the flow-line organization and are able to help any specialized gang that happens to be behind schedule. Another possibility is to provide for so-called "bumper operations" in the flow-line.

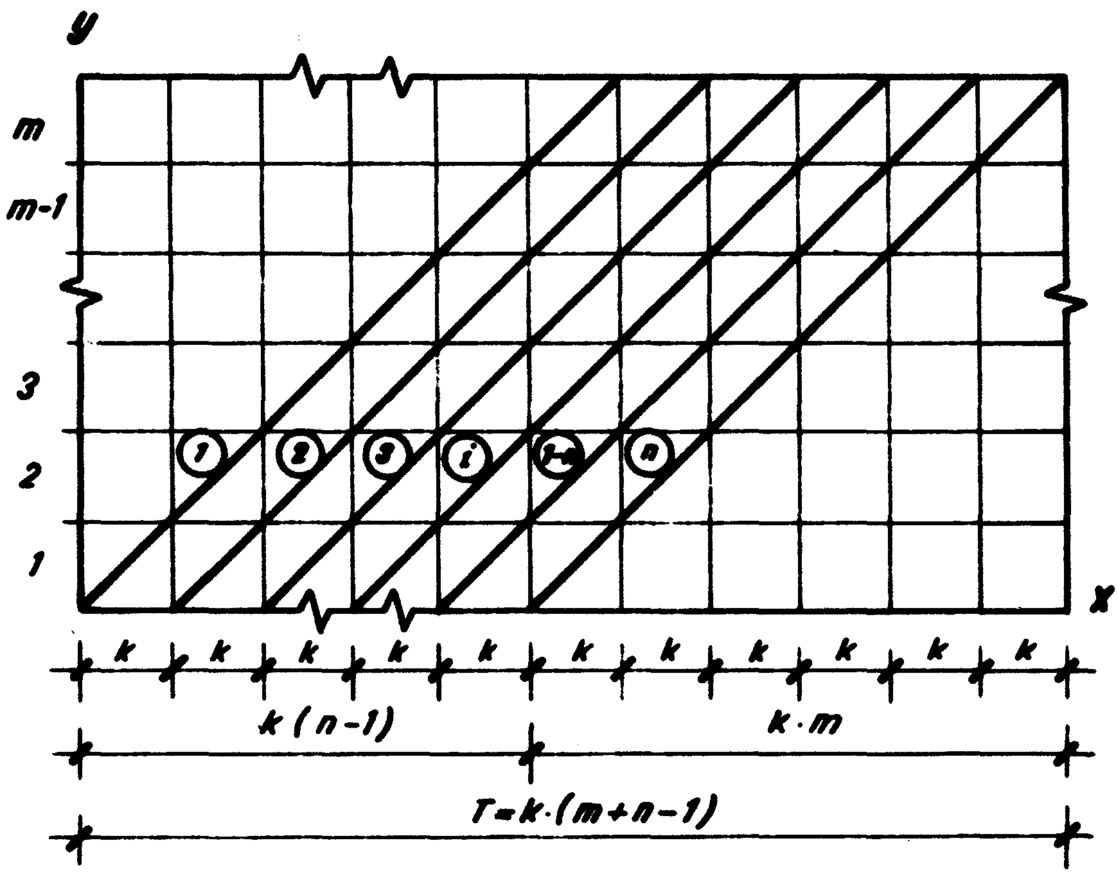
It might be suggested that a flow-line with an increasing speed of production be drawn up, according to the improved productivity obtained by repetition. This would mean, for example, the gradual shortening of the duration of repeated (cyclic) processes and the gradual increasing of labour productivity. Certain investigations have begun in Hungary concerning the possibility of organizing flow-line construction on the basis of mathematical models of the improvement curves. In view of the complexity of the flow-line planning method, however, it is not sure that the introduction of a new parameter of this kind would be justified. It must not be forgotten that highly automated production of consumer goods is scheduled over a certain period, on the assumption of a constant speed of processes. But this is done only after a certain running-in period, corresponding to the initial steeply falling phase of the improvement curve. Allowance for a similar running-in period might be suggested also when programming construction flow-lines.

PRACTICAL APPLICATIONS OF THE FLOW-LINE METHOD

It is in the socialist countries of eastern Europe that the flow-line method in construction has been studied and used the most. The concentration and centralization of investment programmes, of architectural and structural design work and of the construction industry itself, have enabled the repetition of operations on the building site in unprecedented series. A large share of housebuilding (40 - 80 per cent) is projected by state-owned architectural and structural project institutes

Figure 41

Planning chart for even rhythm flow-line construction (Ukrainian SSR)



Source : Information received from the Government of the Ukrainian SSR.

1 = 1st flow line.
2 = 2nd flow line.
3 = 3rd flow line.
i = ith flow line.
n-1 = n-1st flow line.
n = nth flow line.
x = Date of execution.
y = Consecutive working areas.

and carried out by state-owned building enterprises. Housing estates are big and usually there is only one firm working on each building site. The firm is thus able to evolve modern, industrialized methods of building and organization. The local authorities and central departments which invest in flats are directed by central governmental institutions (state committees for construction, ministries for construction, etc.), which impose on them the use of centrally designed type-projects.

Several means serve to attain a high degree of repetition in the planned economy countries:

(a) standardization and typification of building components and buildings;

(b) planning according to the principle that, within a certain area, only a few standardized technologies should be used;

(c) centralized long-term programming of capital investments, taking into account the principle mentioned under (b) and ensuring a rhythmical completion of buildings;

(d) specialization of building enterprises, each enterprise working in a limited area and on certain types of construction work only (e.g. the construction of housing estates);

(e) increase of the size of building enterprises and allocation of a constant (or increasing) amount of work to large enterprises.

While the long-term programming of capital investments in the socialist countries of eastern Europe does not form part of the flow-line method, it is highly sensitive to the requirements of flow-line production. The work is usually organised only when the long-term investment plans have been fixed, it being assumed, however, that full provision has been made for the application of the flow-line method. Once these plans have been fixed, the enterprises must decide how best to break down the production process by operation and by operators. A production rhythm has to be established and the processes must be co-ordinated in time and space. This problem has been thoroughly studied, in particular in Czechoslovakia, Eastern Germany, Hungary, the Ukrainian SSR and the USSR. A comprehensive theory, including a terminology of more than 150 concepts, and a series of formulae have been established. See reports /1i/ and /17/(1)

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(1) An abridged abstract of the latter report dealing with the economic effects of using flow-line methods in construction, is provided in annex IV.

The even-rhythm flow-line (see figure 41) is the simplest case, occurring very seldom in practice, normally only in the erection of identical buildings. Usually, the different elementary or specialized processes (flow-lines) have different characteristics that have to be taken into account. In this case an uneven-rhythm flow-line has to be planned according to the different volumes of work to be executed in the different working areas. Figures 42(a) and (b) show certain typical possibilities.

There are flow-lines of different complexities, namely:

(a) the elementary flow-line, consisting of the consecutive performance of a single elementary process (e.g. plastering) on a number of working areas;

(b) the specialized flow-line, which is an aggregate of elementary flow-lines united by a single system of parameters and a single flow chart and concerned with a common product in the form of an element or part (or installation) of a building;

(c) the whole-building flow-line, which is an aggregate of specialized flow-lines the joint product of which is a finished building (or installation) or a finished group of buildings (or installations); and

(d) the complex flow-line which is an aggregate of organizationally related whole-building flow-lines, linked by a common complex product (an entire housing estate, complex industrial enterprise, etc.)

Continuous flow-line production is carried out by specialized building organizations with a predetermined capacity and with the necessary equipment, material and technical resources and funds. The plan for organizing the work contains five main points, namely:

(a) planning the production programme of the building organization and its units in relation to the requirements of the continuous flow-line method;

(b) determination of the structure of the flow-lines (see below);

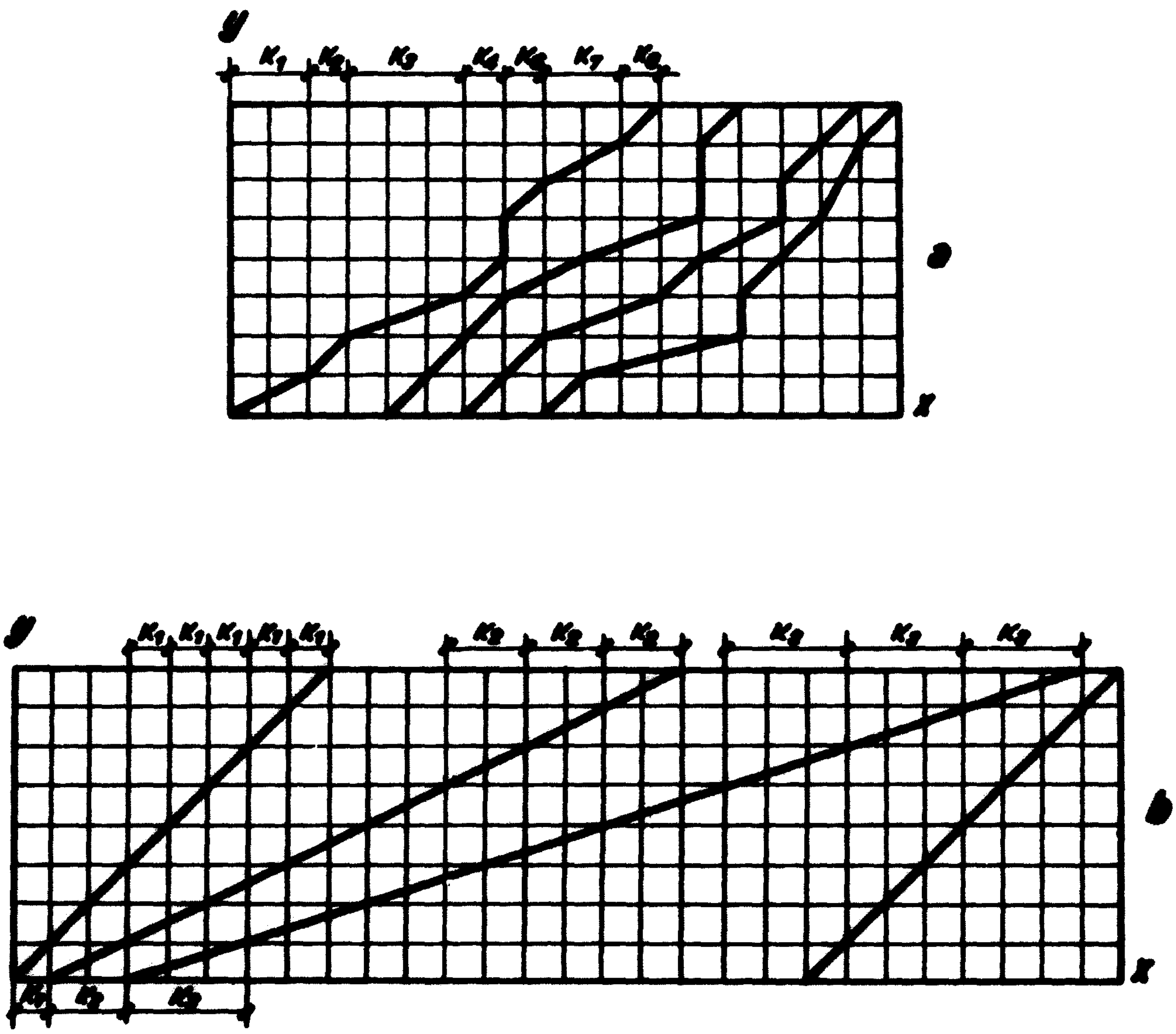
(c) determination of the duration and method of the operations in the flow-lines;

(d) determination of the requirements in terms of production resources (material, labour, equipment, etc.), the sources from which they can be met and the procedure and timing of their delivery; and

(e) determination of the structure of the building organization.

Figure 42

Planning charts for different types of uneven rhythm flow-line construction (Ukrainian SSR)



Source : Information received from the Government of the Ukrainian SSR.

x = Date of execution.
y = Consecutive working areas.

Long-term continuous flow-lines in construction are planned on the basis of the following main principles:

(a) production capacity is invariable and balanced between all parts of the construction process;

(b) the construction process is uninterrupted and its speed constant;

(c) construction firms use standardized building components and standardized technologies.

Several socialist countries of eastern Europe have worked out special instructions for the programming of housing construction according to the flow-line method. A Ukrainian publication [11] prescribes the following minimum standards as compared with normal values:

(a) a 15 - 20 per cent increase in labour productivity;

(b) normal values of the number of manhours per cubic metre of the built-up volume of buildings;

(c) a 15 per cent decrease in the duration of construction;

(d) a 5 per cent reduction in the catalogue cost of buildings;

(e) the completion of dwellings must be rhythmic and even, the number of dwellings completed quarterly being allowed to differ only by ±5 per cent from the average.

The methods described above are still under development, but they already form established means for the programming of housing production in eastern Europe. In recent years some up-to-date methods have been added. In the USSR and Hungary, work is being done on the use of mathematical analysis and computer techniques for determining optimal solutions for flow-line construction. There are reports from the Ukrainian SSR and Hungary on the successful use of electronic computers for the purpose of flow-line programming. In the Ukrainian SSR, for example, a solution has been found to the problem of calculating the optimum rate for the construction of housing estates, and methods have been devised for preparing charts for the long-term planning of construction by continuous flow-line. In Györ and Szolnok (Hungary), the flow-line programming of industrial and other buildings has been made by means of the Critical Path Method.

In 1963, as a result of flow-line construction, construction time at the Darnitsa housing development in Kiev, Ukrainian SSR, was reduced by 15 per cent, labour expenses by 13 per cent and building costs by 12 per cent, compared with the state norms. In the flow-line construction of the first unit of the artificial fibre plant in Cherkassy, Ukrainian SSR, construction time was three months less than the established norms; labour productivity was increased by 14 per cent and utilization of building machinery by 20 per cent; construction costs were also greatly reduced.

Spectacular results are reported also from other countries. In Czechoslovakia, labour costs in brick house construction decreased by 50 per cent, the cost per square metre of useful living space in brick houses by 17 per cent and in large panel houses by 16 per cent [12]. The average annual production per worker in Czechoslovakia has risen to 2.35 flats (in the case of large panel buildings, 2.82 flats) as compared with 1.40 flats by traditional construction. The construction costs per square metre of living floor area has at the same time been reduced from 1,839 crowns to 1,694.

In Hungary, an increase in labour productivity ranging between 20 and 40 per cent has been attained by using the flow-line method. The assembly time per dwelling decreased from 1.06 days under non-continuous organization to 0.56 - 0.83 days. A detailed mathematical analysis of the results, taking into account the effect of gradual improvement in labour productivity, showed that the number of manhours could be reduced still further towards the value of the ultimate operational time (0.33 days per dwelling).

From Bulgaria it is reported that the introduction of flow-line methods of construction so far has resulted in an increase in labour productivity of 8 - 20 per cent, a reduction in construction time of about 30 per cent and a decrease in building costs of 6 - 12 per cent.

A variant of the flow-line system, the "Taktarbeit", has been evolved in Western Germany [3]. Its use has so far been restricted to individual building sites but, if necessary, it could be further developed for use on a sequence of building sites. This system distinguishes between whole storey flow-lines (Grobtakt) and specialized flow-lines (Feintakt). The sequence of whole storey flow lines can be either horizontal or vertical. The specialized flow-lines can be repeated only horizontally. If the duration (cycles) of the individual flow-line processes is determined in advance, it is called a time flow-line (Zeittakt); if it is determined by the output of individual workers or gangs, it is called a gang flow-line (Kolonnentakt).

In the construction industry, unlike the manufacturing industries, the duration of the individual flow-line processes cannot be exactly determined [3]. It is only the formation of the gangs that are determined in advance; the duration of the individual processes will change during the execution of the building(s), e.g. as a consequence of bad weather but also of routine-acquiring (Einarbeitung). Therefore a certain flexibility must be foreseen in order that the work of the different gangs may be carried out without hindrance. The report cited, while pointing to the fact that the introduction of time flow-lines would mean an even higher level of organization, enumerates the difficulties involved: once the duration of the individual process has been fixed, an increase in the output of the gang can be achieved only by reducing the number of the workers per gang. But this contradicts the flow-line principle of operating with unchanged gangs.

In the Swedish report, an interesting attempt is made to find the relation between repetition and organization [1]. It is stated that the analysis of repetition "... can only be expected to be of real value when studies are extended to embrace whole groups of operations, their interdependence and co-ordination. In the long view the aim should be to analyse building projects in their entirety and, if possible, to create a functional basis for planning and for optimal use of all resources." The report contains a number of diagrams, similar to flow-line charts but illustrating also the effect of repetition by using, instead of straight lines inclined curves to represent the growth of operational speed (figure 43(a)).

In an ideally planned and systematically performed series of building operations, the workers' occupational pattern should follow a regularly serrated curve. If all production units are identical, the derivative of the curve will represent the operatives' capacity on the respective job. The derivative usually rises with the number of units. If the operative is moved to a new job before the original job has been fully completed, the routine-acquiring process will be interrupted and a maximal efficiency can no longer be expected. This is illustrated in figure 43(b), where the ideal case of two jobs, numbers 1 and 2, following each other is compared with the results achieved if a reallocation of workers is imposed in the course of execution. The considerable loss of time may be attributed to inability to maintain continuity of work; the possible results of the improvement process have not been put to use.

In reality, the occupational pattern was found to be considerably more disconnected than in figures 43(a) and (b). A couple of examples are shown in figures 44(a) and (b). The curves represent the performance of two wood-workers. Observations relating to the same jobs are encircled. There are only slight indications of serration. "Upon closer examination one observes that the greatest effects of the experience-learning process come at the points where the serrated pattern emerges most clearly, which supports the hypothesis of additional time for interrupted experience-learning processes." The correlations appear when comparing jobs 1, 3 and 6 in figures 44(a) and (b) with the routine-acquiring curves of figure 45.

Special studies have recently been undertaken in France with a view to finding the most practical ways of using the CPM and similar network analysis methods for organizing repetitive work. The results of these investigations have already been applied on several building sites, e.g. on the erection of a series of 264 identical single-family houses. Electronic computers were used in the planning of the work. The main difficulties were encountered in balancing the different gangs of operatives so as to minimize the amount of idle time. Major efforts were applied to making as many operations as possible simultaneously critical, in the sense of the CPM.

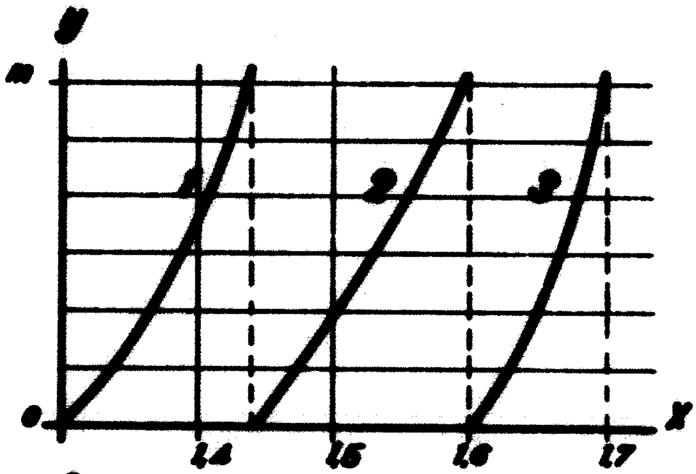
In Norway, the National Building Research Institute has worked out a model for use in the planning of building operations. The model takes into account the effect of repetition on labour productivity and provides a special yardstick which facilitates the planner's calculation of total construction time, including the correction for extra "running-in" time. Data on "basic operational times" for different kinds of building operation and for different sizes of gang are regularly collected by the Institute. The model's possibilities of being systematically and scientifically used are therefore constantly improving. Further experience is being gained by comparing the results actually achieved on the building sites with those calculated on the basis of the theoretical model. A brief report on the results so far obtained is given in one of the papers for the third CIB Congress [16].

Figure 43

Loss of time for non-continuous work compared with continuous work (Sweden)

a : Continuous work (ideal case).

b : Non-continuous work.



a

Source : [1].

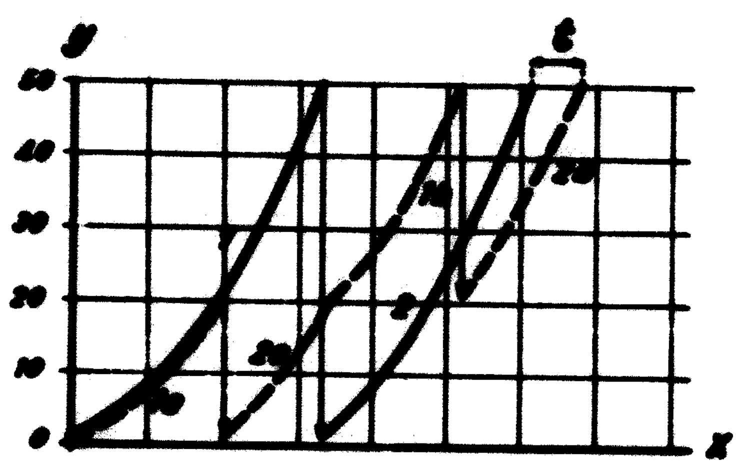
x = Date of execution (1.4 = 1 April, etc.).

y = Consecutive working areas.

1 = Task No. 1.

2 = Task No. 2.

3 = Task No. 3.



b

Source : [1].

x = Date of execution.

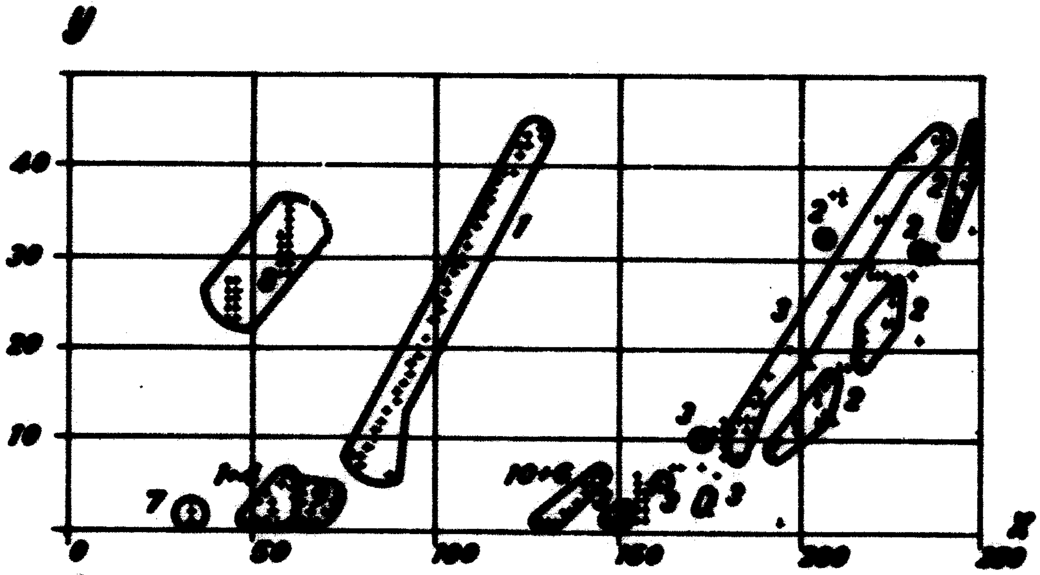
y = Consecutive working areas.

t = Loss of time for non-continuous work compared with the ideal case.

Figure 44

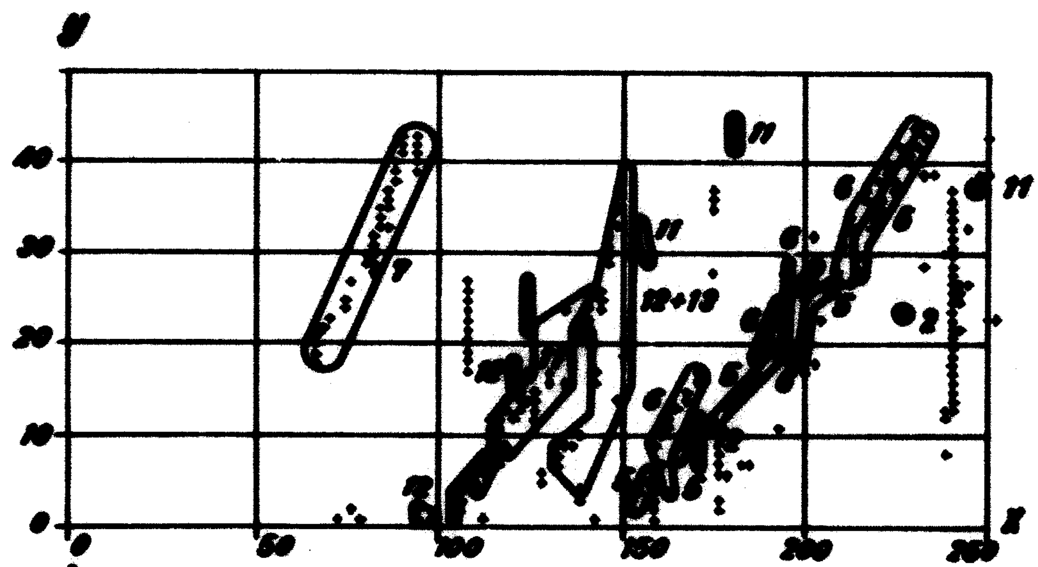
Observed continuity in work for different building operations (Sweden)

a : Operations Nos. 1, 2, 3, 4, 7, 8 and 9.
b : Operations Nos. 2, 5, 6, 7, 11, 12 and 13.



a

Source : [1].
x = Date of execution (number of working days).
y = House number.



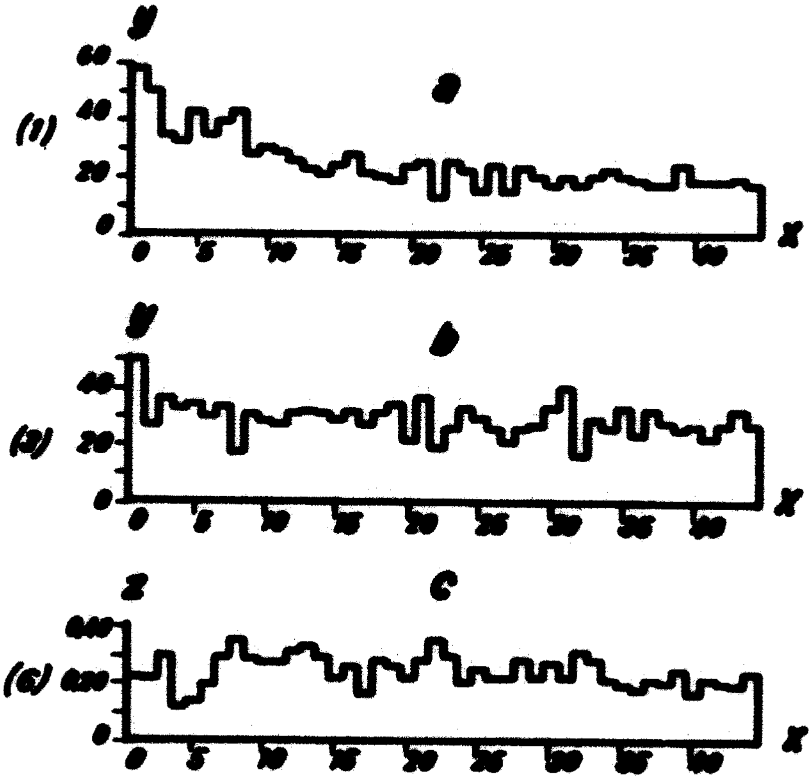
b

Source : [1].

1 = Sawing and erection of load-bearing structure.
3 = Fitting of mouldings and window-sills.
6 = Support-pole setting for non-bearing walls.
2, 4, 5, 7, 8, 9, 11, 12 and 13 = Other operations.

Figure 46

Observed improvement of labour productivity for three different building operations (Sweden)



Source :[1].

a = Sawing and erection of load-bearing structure (operation no. 1).
b = Fitting of mouldings and window-sills (operation no. 3).
c = Support-pole setting for non-bearing walls (operation no. 6).
x = House number.
y = Manhours per house.
z = Manhours per square metre.

CHAPTER VI

RELATED PROBLEMS

INTRODUCTION

An attempt has been made in the preceding chapters of this report to throw some light on the relationships between the nature and run size of building operations, on the one hand, and the time consumption, building costs and methods of organizing the work, on the other. The analysis has shown the difficulties of distinguishing clearly the influence of any single factors among the many which have a bearing on building production. The effect of repetition on building operations is only one, and perhaps not the most important, of the consequences of introducing large series of identical building components or functional units into the building trade. Furthermore, the effect of repetition, even in its widest context, is often overshadowed by other important factors influencing building production, some of which have been discussed in chapter IV. The present chapter analyses briefly certain other problems which are closely related to the subject of the report and to which attention has been drawn in some of the contributions received.

EFFECT OF REPETITION ON THE PROGRAMMING AND DESIGN OF BUILDINGS

The standardization and typification of building components, functional units and technologies have a favourable economic effect, not only on the production, transport and assembling of building materials and components, but also on the very programming and design of the buildings. Indeed, much of the standardization and typification work emerges from the efforts of big projecting enterprises to adopt a repeated application of successful technical solutions.

The elaboration of standard drawings, specifications and work instructions clearly calls for more careful study than the projection of individual projects. In Hungary, for instance, the fees for drawing up documentation on standardized components are 2.5 times higher than the ordinary design fees. These higher design fees are economically justified only if they can be economized by a repeated use of the type plans. If economic considerations are restricted to the design fees, this would mean that the original high design cost, plus the cost of the necessary adaptation of the standard drawings to the actual conditions in each specific case should be lower than the cost of individual design. It seems as if these requirements are often more than fulfilled in many of the socialist countries of eastern Europe, where, owing to typification and the use of standard drawings, the average proportion of total building costs devoted to the design of buildings has been brought down from around 5 to about 2 per cent. Substantial savings in design cost as a result of typification have been gained also in many western European countries, in particular in the field of single-family house design. In Denmark, France and Sweden, for example, there exists series of officially approved designs which are sold for a very low and fixed price.

The importance and steady increase of design and programming costs in many European countries, and the substantial savings in these costs which seem to be possible by an increased use of standard drawings, specifications and work instructions, indicate that it would perhaps be useful to devote further attention and study to this problem in the future.

The use of typified designs and standardized work descriptions does not only affect the building cost. It also facilitates considerably the administration and control of the whole building process. This is an important point, since the examination and approval of individual projects is a time-consuming task which often constitutes a bottleneck in the production process.

SIZE OF CONTRACTS

Higher labour productivity and lower building costs are more often observed in large contracts than in smaller ones. The favourable economic effect of the big contract can in some cases be traced to savings achieved by bulk purchase of building materials and components, i.e. by the effect of repetition away from the site, and to repetition in the execution of the building operations. In many cases, however, large contracts are split into too many different kinds of building for benefits of repetition to be gained. Furthermore, information on the economic effect of the size of contract is often based on statistical data collected from projects widely differing in nature and quality. It might well be, therefore, that differences in labour productivity or building costs between contracts of different sizes could be explained by systematic differences in the nature and quality of the products compared. The data received on the effect of size of contracts have for this reason not been considered relevant to the discussion of effects of repetition on building operations, but are set out separately below.

In the Netherlands, data on building costs are regularly collected by the Central Bureau of Statistics. The material, which is classified, inter alia, by size of contract, is from time to time analysed by the building research institute "Stichting Ratiobouw". In a report on such an analysis, published in 1961, the over-all mean value of building cost per dwelling erected in the years 1956 to 1958 was found to be about 21,000 florins for single-unit projects, while the corresponding figure for contracts comprising 200 dwellings or more was about 14,000 florins [13]. Another study covering the period 1957 to 1962 shows a similar picture [14]. Very marked differences in labour consumption were revealed, the number of manhours per dwelling ranging from 3,709 for single projects to 1,231 for projects containing 200 dwellings or more. These differences were, however, partly due to variations in the size of the dwellings, as revealed by the figures on manhours per cubic metre which still, however, range between 8.82 for single projects and 4.32 for projects with 200 dwellings or more (see table 5).

Table 5

Production and productivity at dwelling construction sites, July 1957 to September 1962 (Netherlands)

Size of contract (by number of dwellings)	Production (in dwelling equivalents)	Production (in thousands of cubic metres).	Thousands of manhours	Average number of manhours per dwelling equivalent.	Average number of manhours per cubic metre
1	51 533 (12.7%)	21 676 (16.4%)	191 147 (27.2%)	3 709	8.82
2	10 636 (2.6%)	3 958 (3.0%)	29 362 (4.2%)	2 761	7.42
3 - 5	12 724 (3.1%)	4 377 (3.3%)	28 343 (4.1%)	2 228	6.48
6 - 9	17 928 (4.4%)	6 017 (4.6%)	32 099 (4.5%)	1 790	5.33
10 - 19	37 201 (9.1%)	12 354 (9.3%)	58 291 (8.3%)	1 567	4.72
20 - 39	53 894 (13.3%)	17 328 (13.1%)	76 190 (10.9%)	1 414	4.40
40 - 99	83 305 (20.5%)	25 930 (19.6%)	111 730 (15.9%)	1 341	4.31
100 - 199	64 138 (15.7%)	18 999 (14.4%)	81 721 (11.6%)	1 274	4.30
200 or more	75 657 (18.6%)	21 584 (16.3%)	93 155 (13.3%)	1 231	4.32

Source: [14].

Information on the effect of size of contract on building costs has been received also from the United Kingdom. The total manhours required for that part of the work which was performed by the main contractor was collected for over 160 contracts of varying sizes. It was possible, by analysis of the data, to isolate the various factors which affected the labour expenditure required to build each house; the results for the effect of size of contract are given below:

Size of contract (houses)	Index of labour expenditure
4	109
10	104
20	100
40	96
80	93

SIZE OF BUILDING ENTERPRISES

The optimum size of building enterprises is a subject of frequent discussion. There is no doubt that the special features of the building industry provide its small firms with certain advantages that do not exist in most manufacturing industries. On the other hand, the large building firms offer greater possibilities of specialization and of utilizing the effect of repetition on building operations and processes on the site. There seems to be a steady trend in almost all countries towards more work being undertaken by very large building firms. So far, however, information is very scarce on the actual relationship between the size of building enterprises and the productivity in building production. Further clarification on this subject would be most desirable.

SIZE OF BUILDING COMPONENTS

With growing mechanization and prefabrication, a gradual increase in the size of building components can be observed. Thus, while the volume of a traditional burnt clay brick is approximately 2.10^3 cm^3, that of a modern hollow ceramic or concrete block is 10.10^3 cm^3 and that of large precast wall panels 2000.10^3 cm^3. The increasing size of building components characterizes a technical progress. Nevertheless there seems to be a contradiction in this evolution, since it leads to diminished possibilities of utilizing the effect of repetition in the production, transport and assembling of building components. More than 10,000 bricks are needed to build a flat, but only twenty to thirty panels. In order not to arrive at false conclusions, it is necessary, therefore to study the optimum size of building components, taking into account not only productivity on the building site, but also the possibilities of achieving maximum efficiency in the whole building process by using the largest possible series of identical items.

EFFICIENCY OF HOUSEBUILDING PLAN, DWELLING DESIGN AND SITE ORGANIZATION

As has already been stressed several times in this report, there are numerous factors influencing both the cost and the labour productivity of site operations. The influence of each factor can be scientifically detected by means of a multiple correlation analysis of statistical data, as illustrated in a study carried out in the Netherlands. The data collected referred to sixteen series of dwellings of traditional construction and the factors studied were:

(a) the efficiency of the housebuilding plan;

(b) the efficiency of the dwelling design; and

(c) the efficiency of the site organisation.

The calculation was carried out for the first, fifth, fifteenth, thirtieth, sixtieth, 120th and 240th dwelling of each series; the results are shown in table 6 and figure 46. Line 1 in figure 46 shows the decrease in the number of manhours per dwelling in the case of serial production of dwellings according to an inefficient housebuilding plan, dwelling design and organization of the site work. Line 2 shows the improvement in time consumption if the housebuilding plan is made efficient but the design and organisation is still inefficient. If also the dwelling design is rendered efficient the labour consumption decreases further, as is shown by line 3. An optimum result will be achieved if all the three factors are made efficient, as is shown by line 4.

Table 6

Relationships between labour consumption on site and the efficiency of housebuilding plan, dwelling design and site organization (Netherlands)

Line No. (see text)	Manhours per dwelling at serial number							Average
	1	5	15	30	60	120	240	
1	2 620	2 040	1 730	1 570	1 420	1 290	1 210	1 380
2	2 430	1 860	1 530	1 340	1 180	1 040	960	1 140
3	1 240	1 010	890	850	830	830	790	830
4	1 090	920	810	710	650	630	610	660

Finally, it may be of interest to present some results, achieved in terms of cost reduction, in the production of schools according to industrialized principles in the United Kingdom. The schools were built by a number of local authorities forming together a consortium (CLASP). The results could be considered as the combined effect, over a large building programme, of the application of standardized requirements, bulk purchase of components, a standardized system of design including modular co-ordination, constant efforts in terms of research and development, and the favourable influence of repetition of identical building operations on the site. As will be seen in table 7, the price of both primary and secondary schools for a typical authority in the consortium (Nottinghamshire) has shown a progressive reduction relative to the national average. The schools built by the authorities in the consortium are now about 10 per cent cheaper than they would have been without the repetition, continuity of work and development, both in design, manufacturing and site work, which the consortium has facilitiated.

Table 7

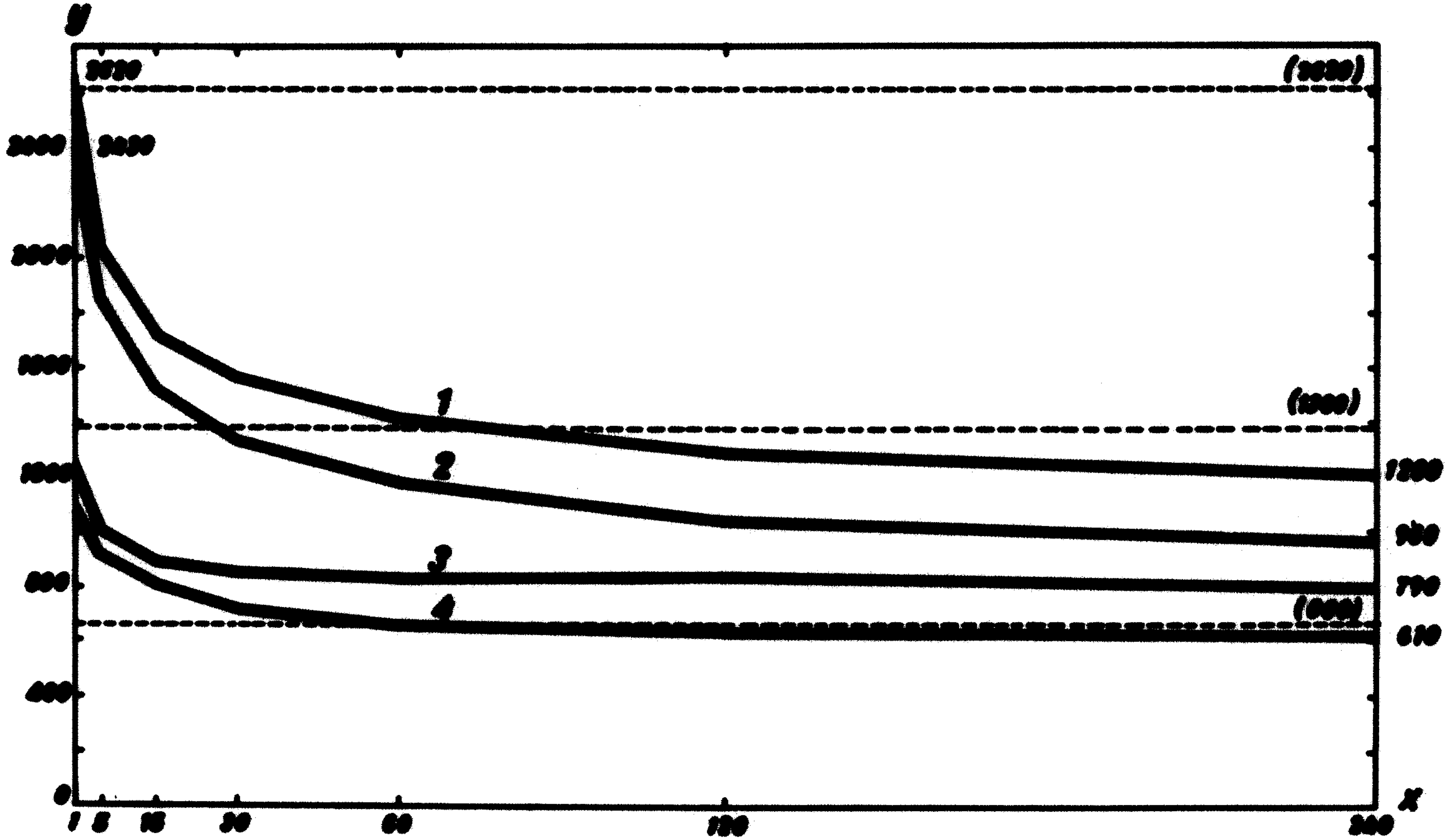
Nottinghamshire school prices as a percentage of national average, United Kingdom

Date	Primary schools	Secondary schools
June 1957	104	99
December 1957	97	99
June 1958	98	101
June 1959	97	100
June 1960	93	93
June 1962	94	92
December 1962	95	92

Source: Information supplied by the Government of the United Kingdom.

Figure 46

Relationships between labour consumption on site and efficiency of housebuilding plan, dwelling design and site organization (Netherlands)



Source : Information received from the Government of the Netherlands.

x = Series of dwellings.
y = Manhours per dwelling.
Line 1 = Serial production according to an inefficient housebuilding plan, dwelling design and organization of work.
Line 2 = Serial production according to an efficient housebuilding plan but inefficient dwelling design and organization of work.
Line 3 = Serial production according to an efficient housebuilding plan and dwelling design but inefficient organization of work.
Line 4 = Serial production according to an efficient housebuilding plan, dwelling design and organization of work.

ANNEX I

LIST OF PARTICIPANTS IN THE JOINT MEETING OF EXPERTS ON BUILDING COSTS AND INDUSTRIALIZATION OF HOUSE CONSTRUCTION HELD IN OCTOBER 1963

Chairman: Mr. V. CERVENKA (Czechoslovakia)

AUSTRIA	
Mr. R. BRAUNER	Director, Federal Ministry for Social Affairs
BELGIUM	
Mr. A. COCKX	Sécrétaire, Conseil professionel de la Construction
BULGARIA	
Mr. V. ROMENSKI	Chef de la Division de Logements et des Bâtiments publics, Comité d'Etat pour la Construction et l'Architecture
CZECHOSLOVAKIA	
Mr. V. CERVENKA	Director, Research Institute of Building and Architecture, Member of the CIB Executive Committee
DENMARK	
Mr. F. NIELSEN	Head of Production Division, National Institute of Building Research
FINLAND	
Mr. Per-O. JARLE	Professor, State Institute of Technical Research
Mr. E. NICKLIN	Director, Standards Institute of the Association of Finnish Architects
FRANCE	
Mr. J. RAMONET	Chef du Bureau des Travaux et Marchés HLM, Ministère de la Construction
HUNGARY	
Mr. G. SEBESTYÉN	Directeur Technique, Institut pour l'Organisation et l'Economie du Bâtiment
Mr. L. SOLTÉSZ	Ingénieur en Chef, Ministère de la Construction
LUXEMBOURG	
Mr. E. DAUPHIN	Attaché de Gouvernement, Ministère de l'Intérieur
NETHERLANDS	
Mr. A. SCHUIL	Central Directorate of Housing and Building

POLAND

Mr. W. SKOCZEK	Chef de la Section des Recherches du Prix et du Coût des Bâtiments, Institut de l'Habitat

SWEDEN

Mr. G. HELLSTEN	Chief of Section, National Swedish Institute for Building Research

SWITZERLAND

Mr. H. RITTER	Membre de la Commission fédérale pour la Construction de logements

UKRAINIAN SSR

Mr. N. KANUKA	Director, Research Institute of Housing in the Ukrainian SSR

UNITED KINGDOM

Mr. J.C. WESTON	Deputy Chief Scientific Officer, Building Research Station

INTERNATIONAL NON-GOVERNMENTAL ORGANIZATION

INTERNATIONAL COUNCIL FOR BUILDING RESEARCH, STUDIES AND DOCUMENTATION (CIB)

Mr. W.J. DIEPEVEEN	Director, Building Research Foundation, The Hague
Mr. G. HIERHOLTZ	Chef de la Division Productivité et chargé des affaires internationales, Centre Scientifique et Technique du Bâtiment, Paris
Mr. R. PAULICK	Vice-Président, Deutsche Bauakademie, Berlin
Mr. E. KIESER	Directeur de la Section de Construction de logements, Deutsche Bauakademie, Berlin
Mr. J. VAN NIEUWKERK	Stichting Ratiobouw, Rotterdam.

ANNEX II

LIST OF PARTICIPANTS IN THE FIRST SESSION OF THE WORKING PARTY ON THE BUILDING INDUSTRY, HELD IN GENEVA FROM 23 TO 27 NOVEMBER 1964

Chairman: Mr. Gyula SZEBESTYÉN (Hungary)
Vice-Chairman: Mr. Roger WALTERS (United Kingdom)

AUSTRIA

Mr. Adolf VLCEK	Director, Ministry for Trade and Reconstruction
Mr. Rudolf BRAUNER	Director, Federal Ministry for Social Affairs
Miss Elizabeth LANGER	Chamber of Commerce

BELGIUM

Mr. F.A.M. TACK	Sécrétaire général de la Société Nationale du Logement
Mr. Albert COCKX	Sécrétaire du Conseil professionnel de la Construction

BULGARIA

Mr. Solomon A. KUIUMDJISKY	Chief of Department, Institute for Typification and Industrialization of Building

BYELORUSSIAN SSR

Mr. Sergei KOROTKEVITCH	Deputy Chief, Department of Building Materials, Council of National Economics (Sovnarkhoz)

CZECHOSLOVAKIA

Mr. Vladimir CERVENKA	Director, Research Institute of Building and Architecture

DENMARK

Mr. Per K. BREDSDORFF	Director of Research, National Institute of Building Research
Mr. Marius KJELDSEN	Chief Architect of Section, Ministry of Housing

FEDERAL REPUBLIC OF GERMANY

Mr. Max STEINBISS	Chief of Section, Federal Ministry of Housing
Mr. Siegfried KAYSER	Federal Ministry of Economics
Mr. Gerhard BRAUN	Adviser, "Länder" Committee for Building Economy, Federal Ministry of Economics

FINLAND

Mr. Jlmari LEHTINEN	Supervisor, State Housing Board
Mr. Tuomas A. KALLIO	Assistant Manager of "RASTOR", Industrialization of Building

FRANCE

Mr. Gérard BLACHERE	Directeur, Centre Scientifique et Technique du Bâtiment
Mr. Serge Jean BERNIER	Conseiller technique au Cabinet du Ministère de la Construction
Mr. Georges HIERHOLTZ	Chef de Division Chargé des Affaires Internationales, Centre Scientifique et Technique du Bâtiment

HUNGARY

Mr. Gyula SEBESTYÉN	Technical Director, Institute for Building Economy and Organization
Mr. Tibor BENEDETTI	Chief of Section, Institute for Building Economy and Organization
Mr. Janos REGÖS	Member of the Permanent Mission to the United Nations, Geneva

ITALY

Mr. Enrico DE ANGELIS	Chief of Section, Central Statistical Institute, Rome
Mr. Pietro Natale MAGGI	Engineer, Centre for Applied Building Research, Milan
Mr. Guido DANDRI	Sécrétaire du Centre pour la Recherche économique et sociologique et du Marché du Bâtiment, Chef du Bureau d'Etudes économique de la Fédération Italienne des Constructeurs

NETHERLANDS

Mr. Andries SCHUIL	Head of Department of Technical Research, Ministry of Housing and Building Industry

POLAND	
Mr. Ryszard GERLACHOWSKI	Vice-Minister of the Building Ministry
Mr. Wladyslaw CZAJKA	Vice-Director, Institute of Housing
ROMANIA	
Mr. Dinu BLIADE	Directeur technique, Comité d'Etat pour la Construction et l'Architecture
Mr. Mihail ANASTASESCU	Chef de Section, Comité d'Etat pour la Construction, l'Architecture et la Systématisation
SPAIN	
Mr. Fernando AGUIRRE	Chef de la Division des Etudes spéciales dans le Bâtiment, "Instituto Eduardo Torroja de la construccion y del cemento"
SWEDEN	
Mr. Gustav CEDERWALL	County Governor
Mr. Olle WESTIN	Chief of Section, National Institute for Building Research
Mr. Lennart BERGVALL	Architect, Chief of Section, Housing Research Corporation
SWITZERLAND	
Mr. Heinz RITTER	Membre de la Commission fédérale pour la Construction de logements
Mr. Gunther SCHUMACHER	Collaborateur scientifique, Ecole Polytechnique de Zurich
UKRAINIAN SOVIET SOCIALIST REPUBLIC	
Mr. Nikolai KANJUKA	Deputy Director, Scientific Research Institute of Building Production
UNION OF SOVIET SOCIALIST REPUBLICS	
Mr. Juri RODIN	Chief of Technical Department, Housing Committee of "Gosstroi"
Mr. Boris ZAREMKA	Chief Expert of the State Committee on Civil Construction

UNITED KINGDOM

Mr. Roger T. WALTERS	Deputy Director-General of Research and Development, Ministry of Public Building and Works
Mrs. F.E. LEA	Chief Statistician, Ministry of Public Building and Works
Mr. David W. NUNN	Chief Quantity Surveyor, Ministry of Housing and Local Government
Mr. Geoffrey PENRICE	Chief Statistician, Ministry of Housing and Local Government
Mr. James B. DICK	Deputy Chief Scientific Officer, Building Research Station

UNITED STATES OF AMERICA

Mr. James R. DODGE	Director, Division of Technological Services, Office of International Housing, Housing and Home Finance Agency
Mr. Steward D. RIDDLES	Member of the Permanent Mission to the United Nations, Geneva

UNITED NATIONS SPECIALIZED AGENCY

INTERNATIONAL LABOUR OFFICE (ILO)

Mr. Michael O'CALLAGHAN	Civil Engineer, Industrial Committees Branch

INTERNATIONAL NON-GOVERNMENTAL ORGANIZATIONS

BATTELLE MEMORIAL INSTITUTE

Mr. Istvan E. AGOSTON	Economist
Mr. Jossef CSILLAGHY	Economist

INTERNATIONAL CONFEDERATION OF FREE TRADE UNIONS (ICFTU)

Mr. H. UMRATH	Secretary, Housing Committee

INTERNATIONAL COUNCIL FOR BUILDING RESEARCH STUDIES AND DOCUMENTATION (CIB)

Mr. Jan DE GEUS	Secretary-General

INTERNATIONAL FEDERATION OF BUILDING AND WOODWORKERS

Mr. H. UMRATH	Research Director.

ANNEX III

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ANNEX IV

ECONOMIC EFFECT OF USING FLOW-LINE METHODS IN CONSTRUCTION[1]

The use of flow-line methods in construction has the economic effect of increased labour productivity, a reduction in the amount of labour required in the erection of buildings and structures, a reduction in building time and improved utilisation of building machinery and other fixed and circulating capital goods. The net result is a reduction in construction costs.

The increase in labour productivity is achieved primarily through a reduction in losses of working time at construction sites as a result of improved organization of production and rhythm in the execution of work, the increased skill acquired by workers as a result of a high degree of specialization and repetition of function, and the greater mechanization of building operations.

On the assumption that:

E_t = the total economic effect of using the flow-line method;

E_w = the saving in direct expenditure on basic wages as a result of increased labour productivity;

E_{ow} = the saving in overheads, depending on wages as a result of increased labour productivity;

E_{ol} = the saving in overheads, depending on the number of workers employed (or the labour-intensiveness of operations) as a result of increased labour productivity;

E_{of} = the saving in conventionally fixed (partly constant) overheads as a result of reducing the building time;

E_{cc} = the saving in circulating capital as a result of reducing the building time;

E_{fe} = the economic effect caused by finishing an industrial object (building) earlier and bringing it into operation ahead of schedule;

E_{bm} = the saving in the cost of mechanization as a result of improved building machinery utilisation -

(1) Abridged abstract from the report of the Ukrainian SSR. [17].

the total economic effect of using the flow-line method can be calculated from the formula:

$$E_t = E_w + E_{ow} + E_{ol} + E_{of} + E_{ce} + E_{fe} + E_{bm}$$

The factors of the total economic effect can be calculated from the following formulae:

$$E_w = C \cdot W \left(1 - \frac{100 + w}{100 + p}\right)$$

where C = the cost of construction work (thousand roubles);

W = wages as a percentage of the construction cost;

w = the percentage increase in basic wages, related to the increase in labour productivity (taken from an empirically established graph not reproduced here);

p = the percentage increase in labour productivity under the plan for the flow-line organization of building operations.

$$E_{ow} = 0.15 \, E_w$$

where 0.15 is the coefficient used for calculating the saving.

$$E_{ol} = 0.4 \cdot q \cdot Q$$

where 0.4 roubles/8 hours shift is the estimated saving in overheads when labour-intensiveness is reduced by 8 hours (1 shift);

q = the percentage reduction in labour-intensiveness, related to the increase in labour productivity (taken from a graph not reproduced here);

Q = the standard labour-intensiveness of the buildings in 8-hour shifts;

$$E_{of} = O \left(1 - \frac{T_1}{T}\right) C$$

where O = the conventionally fixed overheads as a percentage of the estimated cost; this value is taken from a table, not reproduced here, where it is expressed as a function of the proportion of overheads to direct costs;

T and T_1 = the standard and actual building times in years;

$E_{cc} = {}_{eb} \cdot C_c (T - T_1) C$

where eb = the standard coefficient of efficiency (similar to the interest on capital) which in construction work is assumed to be 0.17;

C_c = the value of the circulating capital, expressed as a proportion of the annual value of construction operations;

$E_{fe} = e_i \cdot P \cdot (T - T_1)$

where e_i = the standard coefficient of efficiency in the branch of industry concerned;

P = the value (in monetary terms) of the industrial objects (building, etc.) brought into operation ahead of schedule;

$E_{bm} = A \quad \frac{1}{t_{bm}/year} \quad - \frac{1}{t'_{bm}/year}$

where A = the annual depreciation allowances for the stock of building machines and equipment used in flow-line construction;

$t_{bm}/year$ = the standard number of machine-shifts per year of the main building machines;

$t'_{bm}/year$ = the actual number of machine-shifts per year of the main building machines.

An example is given for calculating the economic effect of the flow-line method.

The plan for the organization of building operations calls for the flow-line construction over a one-year period of a housing development consisting of 15 five-storey large-panel houses.

Basic data are as follows:

The average value (price) of a house = 232,500 roubles.

Proportion of wages to construction cost: W = 11 %

The standard labour-intensiveness: Q = 5,804 eight-hour shifts per house

The standard overheads: = 13%

The standard building time for one house: T = 0.5 year

The planned building time for one house: $T' = \frac{4.5}{12}$ = 0.375 year .

The planned increase in labour productivity over the standard level = 15 %

$E_w = \frac{232.5}{1,025} \cdot \frac{11}{100} \left(1 - \frac{1.039}{1.16}\right)$ = 2.25 thousand roubles,

where 1,025 = is the coefficient for transforming price into costs (e.g. to deduct profits from price);

3.9 % = the percentage increase in wages;

16% = the percentage increase in labour-productivity.

$E_{ow} = 0.15\ E_w = 0.15 \cdot 2.25 = 0.34$ thousand roubles;

$E_{ol} = 0.4 \cdot q \cdot Q = 0.4 \cdot \frac{13.4}{100} \cdot 5,804 = 310$ roubles = 0.31 thousand roubles;

where q = 13.4 is the percentage reduction of labour-intensiveness (taken from a graph, not reproduced here);

Total economic effect of increasing labour productivity, calculated for one house:

$E_w + E_{ow} + E_{ol} = 2.25 + 0.34 + 0.31 = 2.90$ thousand roubles.

$E_{of} = 0.069 \left(1 - \frac{0.375}{0.5}\right) \frac{232.5}{1,025}$ = 3.91 thousand roubles.

where 0 = 6.9% = the percentage of the construction costs represented by the conventionally fixed overheads;

$E_{oe} = 0.17 \cdot 0.25 \cdot (0.5 - 0.375) \cdot 232.5 = 1.24$ thousand roubles.

where C_e = 25 %.

Total economic effect of reducing the building time for one house:

$E_{of} + E_{oe} = 3.91 + 1.24 = 5.15$ thousand roubles

$E_{bm} = 246 \left(\frac{1}{320} - \frac{1}{410}\right)$ = 0.17 thousand roubles.

where A = 246 thousand roubles

t_{bm}/year = 320 machine-shifts

t'_{bm}/year = 410 machine-shifts

Total economic effect of using flow-line methods for the development as a whole:

$E_t = 15 \cdot (2.90 + 5.15) + 0.17 = 122.5$ thousand roubles.

where 15 = the number of houses erected during the year.

The economic effect of using flow-line construction methods for the housing development in question may thus be calculated as follows:

$\frac{122.5}{232.5 \cdot 15}$ 100 = 3.53 % of the estimated value.