The Costing of Handling and Storage in Warehouses

2. High-bay Warehouses
The Costing of Handling and Storage in Warehouses

2. High-bay Warehouses
This is Part 2 of the report *The Costing of Handling and Storage in Warehouses*. The earlier Part I was published in 1970 and its subject was 'Conventional Warehouses' (HMSO, SBN 11 470219 5, £2 net). This second part of the report deals with the subject of 'High-bay Warehouses'.

As before, the author is C. E. Williams, BSc, DAE, FIMH, Senior Research Fellow, Materials Handling Research Unit (now Senior Research Officer, National Materials Handling Centre), Cranfield Institute of Technology, Cranfield, Bedford. The reasons for preparing and publishing this second part of the report remain exactly as set out in relation to the first part, and provides an initial comparison of the costs and cost performance of a sample of 'high-bay' warehouse systems with the sample of 'conventional' warehouses discussed in Part I.
The successful exploitation of available resources and the planning of future resources in any organisation depend to a large extent on the availability of accurate costs and on the way in which they are marshalled and related to activities and performance.

Sometimes it is erroneously thought by general management that the cost of assessing costs is higher than any resultant savings and may result in missing opportunities for advancing the technology and making the most effective long term use of resources.

The analysis of conventional warehousing costs discussed in Part I illustrated the wide variation which exists in this sector of industry. In that report an operational costing system was developed and used to establish costs of buildings, equipment and personnel in various warehouse systems. These costs were then related to the throughput of goods in the systems and revealed large differences.

This second report discusses the results of applying the same operational costing system to a sample of 'high-bay' warehouse systems and indicates a similar wide variation of costs and unit costs. The detailed analyses have been based mainly on 'unit load in—unit load out' systems, although some costs of order-picking systems have been collected and are discussed briefly. The design, evaluation and practical operation of the many kinds of manual and mechanised order-picking systems is so complex that it is to be the subject of a research programme to be started shortly by the National Materials Handling Centre.

The objectives of this second report have been:
1. To establish handling and storage costs in a sample of 'high-bay' warehouses.
2. To marshal the detailed costs data in a similar way to the data collected for the first report for 'conventional' warehouse systems and to attempt to indicate how the costs and unit costs compare between the two types of system.
3. To dwell more on the practical advantages, disadvantages and problems associated with the 'high-bay' solution and to deal with them in a more philosophical way rather than setting out all the cost data which has been collected. In both reports we have purposely tended to brevity rather than to include all detailed data and this may be at the risk of oversimplifying what is an extremely complex field.
4. To attempt to give a guide to company boards and general management when they are assessing:
   (a) The organisational problems and expense of introducing a uniform system of warehouse costing.
   (b) To indicate the use of such a system not only in comparing costs and unit costs of alternate or proposed and future planned warehouse systems, whether they be 'conventional' or 'high-bay' or highly mechanised or automated solutions but to use such costing systems to assist management day to day control of warehouse costs and finance.
   (c) The first and second reports have limited their terms of reference to an examination of warehouse costs only. These are often a large part of any total distribution syst they must be seen in relation to the costs and cost efficiency of the total distribution model concept.

Therefore, last but not least, an objective has been to point out that in designing new distribution, handling and storage systems it is essential that the 'big broad look' should be taken at alternative distribution models since transportation and retailing outlet costs can be just as large as warehouse costs and just as important to control.

This work would not have been possible without the help and time so readily given by many individuals and all the participating companies. My acknowledgements go to Mr. J. M. Williams, Director, The National Materials Handling Centre, Cranfield Institute of Technology for his help and encouragement in the continuation of the research into the costs and cost performance of warehouse and distribution systems.
Mrs. Brown and Mrs. Wilson for their help in typing the draft of this report.
Miss Brenda Clark, Cranfield Management Services Centre, who drafted the diagrams in this report.

C. W. WILLIAMS
Senior Research Fellow
Materials Handling Research Unit
Cranfield Institute of Technology
Cranfield, Bedford
June 1972
Contents

Introduction ................................................. 1

1. Warehousing and distribution—the need for sound financial policy and management decision .... 2

2. The development of a uniform system of costing for any handling and storage operation .... 12

3. The comparison of costs and cost performance of conventional and high-bay warehouses—results of the surveys .................................................. 32

4. The assessment of order-picking methods .......................................................... 44

5. Cost effectiveness of the uniform costing approach in individual companies .................. 48

6. The cost of warehouse buildings, storage space and associated land costs .................... 53

7. Control systems in warehouses .......................................................... 69

8. Conclusions .................................................. 78

Bibliography .................................................. 80

Appendix

Mini computers: the catalyst materials handling engineers have been waiting for (reprinted from Mechanical Handling, April 1970, by permission of the Publishers) ............. 81
Tables

Table 1 Rules of allocation of depreciation of equipment and building used in high-bay warehouses ............................... 15
Table 2 Warehousing—handling and storage, proposed categories of personnel, grouped according to function .................. 16
Table 3 Method used to collect details of wage payments in the various cost centres of warehouse systems ............... 17–20
Table 4 ‘Company’ annual costs £—straight line method ...................................................................................... 22
Table 5 'Company’ unit costs—straight line method—£ per cubic yard output ........................................................ 23
Table 6 'Uniform' annual costs £—straight line method ....................................................................................... 23
Table 7 ‘Uniform’ unit costs—straight line method—£ per cubic yard output ......................................................... 24
Table 8 'Company’ annual costs £—annuity method ......................................................................................... 24
Table 9 ‘Company’ unit costs—annuity method—£ per cubic yard output ........................................................ 24
Table 10 ‘Uniform’ costs £—annuity method ........................................................................................................ 25
Table 11 ‘Uniform’ unit costs—annuity method—£ per cubic yard ......................................................................... 25
Table 12 List of warehouses surveyed ................................................................................................................ 26
Table 13 High-bay warehouse, breakdown of total uniform annual cost .............................................................. 32
Table 14 A. Percentages of total annual cost in main cost centres of conventional warehouses ........................................... 39
B. Percentages of total annual cost in main cost centres of high-bay warehouses ...................................................... 40
Table 15 A. Percentages of total annual cost in conventional warehouses—breakdown between building, equipment, labour and control systems ........................................................................................................... 40
B. Percentages of total annual cost in high-bay warehouses—breakdown between building, equipment, labour and control systems ............................................................................................................. 41
Table 16 Annual cost of stacker cranes in high-bay warehouses as a percentage of total annual cost ...................... 42
Table 17 Development of cost formula (developed by Mr. E. Kay) for conventional warehouses ............................ 59
Table 18 High-bay storage units—a sample of dimensional and cost data .............................................................. 62
Table 19 High-bay storage units—a sample of dimensional and cost data (continued) ........................................ 63
Table 20 High-bay storage units—a sample of dimensional data .............................................................................. 64

Figures

Fig. 1 The wages climb ........................................................................................................................................... 2–3
Fig. 2 Supply and demand process ...................................................................................................................... 4
Fig. 3 Original pattern of distribution ................................................................................................................... 4
Fig. 4 Revised pattern of distribution ................................................................................................................... 5
Fig. 5 Relating the distribution/warehouse system to its trading accounts .......................................................... 10
Fig. 6 Warehousing storage—goods control system ............................................................................................... 21
Fig. 7 Applying the ‘uniform’ costing system to a warehousing system ............................................................. 29
Fig. 8 Warehouse performance—unit cost diagram ............................................................................................... 34
Fig. 9 Warehouse performance—unit cost diagram A ............................................................................................. 36
Fig. 10 Warehouse performance—unit cost diagram B ............................................................................................ 37
Fig. 11 Economies of scale in conventional and high-bay warehouses .................................................................. 38
Fig. 12 Design of order-picking systems—product data requirements

Fig. 13 An approach to selecting the appropriate methods of order-picking

Fig. 14 The total costs of picking one 'item'—a sample of manual and mechanised order-picking systems

Fig. 15 Warehouse performance—unit cost diagram

Fig. 16 Plan for establishing 32 cost estimates of modern conventional warehouse buildings

Fig. 17 Variation of capital cost (£) with volume and height of a modern conventional single storey warehouse

Fig. 18 Variation of cost per cubic foot (£) with volume and height of a modern conventional single storey warehouse

Fig. 19 High-bay warehouse units—variation of initial cost/cu ft of total volume with size

Fig. 20 High-bay warehouse units—variation of initial cost/cu ft of total volume with height of racking

Fig. 21 High-bay warehouse units—variation of initial cost/cu ft of total volume with density of unit load

PERT chart 1

PERT chart 2

Plates

Plate 1 High-bay warehouse under construction

Plate 2 Semi-automatic warehouse handling automotive products, programmed by punched cards

Plate 3 High-bay warehouse under construction and after completion

Plate 4 Automated warehouse

Plate 5 Automatic warehouse handling domestic appliances

Plate 6 Automatic warehouse equipment for the Scottish Gas Board

Plate 7 Order-picking from a retrieved pallet load

Plate 8 Medium height racking served by high rack stacking trucks

Plate 9 A two tier pallet pick up and deposit station situated at the end of the racking aisle

Plate 10 Stacker crane operating in a high-bay racking structure
Glossary of terms

Semi-manual refers to situations where work is done by humans using special tools, e.g. fork lift trucks, pallet trucks, conveyors.

Semi-automatic implies control by human intervention, but the majority of the work being accomplished by mechanical means.

Automatic implies operations which are machine controlled, but follow an invariable pre-set programme.

Automated implies automatic control which is in some way adaptive to changing circumstances, by means of a control feedback loop.

High-bay warehouse refers to any type of installation in which loads are placed in and removed from cellular static racking by means of stacking cranes running in narrow aisles.

Fixed costs are those which it may be difficult or impossible to change in the short term, for example, some equipment and building costs.

Controllable costs are those which may be directly regulated by warehouse management in the short or medium term. In the context of warehouse costing 'short term' could be less than a year, as little as daily. 'Medium term' could be 1–5 years, for example replacement of fork lift trucks. 'Long term' could be 5–50 years, for example replacement of buildings.

Variable costs are those which vary in direct proportion to activity. The total volume or weight of goods which goes into the warehouse will be broadly the same as that which comes out of the warehouse over a period of time. This is a similar concept to the output from a production line and so hereafter the terms throughput of goods or throughput will be used, but these will be synonymous with 'output of goods'.

Unit load generally implies the stacking of a number of the components or goods together for convenience of handling. A common example—'cartons stacked on any pallet'.

Cost performance is used in this report to denote the relation between costs and output of any warehouse system, for example 'unit cost' of item of goods passing through the warehouse system. This concept is of importance because research has shown that an examination of detailed warehouse costs in many instances yields little idea of whether they are low, average or high; neither have they been related to the output of goods from the warehouse.
Introduction

In this report the total volume of the annual throughput of goods can be measured in terms of the total number of unit loads multiplied by the average volume of the unit load or multiplying the total number of packages or cartons passing through in a year by the average volume of the package or carton. This is not always easy to establish and may involve studying a distribution of individual package sizes where a range of sizes in fact exists.

Similar considerations also apply when assessing the total weight of the goods throughput in a year.

Exclusion of stock control

It has been assumed that stock levels and their forecastable variations are acceptable to the particular management. It is clear that when examining the costs and finances of a total distribution system, the costs of stockholding must be taken into account. Often the savings in stockholding costs produced by optimising re-ordering cycles or stock levels can be significant in the overall cost model.

This investigation does not concern itself with stock control and does not deal with related costs such as ordering costs and stockholding costs.

However, the investigation still measures the costs of space required to hold the stock.
1. Warehousing and distribution—the need for sound financial policy and management decision

In many companies, materials handling, storage and distribution costs are greater than factory costs.

Warehousing and distribution networks together with their associated control systems have been overlooked in industry and commerce until the past few years, because much of the power of new technologies, new management techniques and fresh capital has been directed only at production processes.

Profit margins are being reduced and general management has realised firstly there is often greater potential for reducing costs in materials handling than in production processes; secondly, that the manipulation of handling, storage and distribution systems can increase not only sales but also gross profitability.

FIG. 1(a) The wages climb—costs per unit of output (1963 = 100)

Source: Department of Employment Gazette, June 1971
This increasing concentration by companies upon distribution/warehousing activities is influenced by:

Domestic and foreign competition causing smaller net profits thereby forcing management to look for fruitful areas of cost reduction previously not analysed.

Distribution frequently represents a large fraction of the total company cash flows and costs.

The advances in computer techniques, transportation methods, packaging, developments in handling and storing and public warehousing, have been rapid during the last few years and have provided new opportunities to improve systems and reduce costs.

Rising inventory costs when interest rates are high.

Steeply rising wages (see Fig. 1).

Management finding the task of understanding and controlling complex distribution becoming more difficult.

The growing need to place emphasis on high customer service.

The analysis of operating costs and capital investment is only part of the whole process of designing, installing and operating new warehouse and distribution schemes, but it is a very important part, and it is hoped to indicate to the reader the importance of establishing or
identifying within the company’s organisation, people capable of analysing and predicting future operating costs and capital investment as well as carrying out day-to-day management control of costs.

Figure 2 illustrates in a very simplified form a supply and demand network. It shows the main activities as goods transported to the warehouses, goods stored in warehouses, goods transported to depots or direct to customers or retail shops and the flows of information necessary to keep the whole scheme in continual and efficient operation.

**FIG. 2 Supply and demand process**

- MANUFACTURING PLANT or outside supplier
- Office
- Warehouse
- Customer or retail outlet

**FIG. 3 Original pattern of distribution**

- CWS Factories
- Merchant Suppliers
- CWS Warehouses
- Retail Society Warehouses
- Retail Society Shops

TO ALL SHOPS
In practice, the flows of goods and information will be more complex. This is simply illustrated in Fig. 3 which shows the basic flows of Co-operative Society goods in a large region of the country.

Figure 4 shows how a rationalisation of these flows of goods would take place with a regional warehousing policy, where central warehouses and many depots would be replaced by one large regional warehouse and distribution centre.

FIG. 4 Revised pattern of distribution

If the number of manufacturers' supply journeys is \( n \) and the number of retail supply journeys is \( m \), then the total number of journeys in Fig. 3 will be \( n \cdot m \), whilst the total in Fig. 4 will be \( n + m \). If \( n \) were 20 and \( m \) were 1000, the overall reduction in transportation costs would be very large.

Physical changes of large warehousing and distribution concerns will only be made if management are convinced that potential improvements in net profits may be expected from their investment.

Money is a major factor in management decisions of this kind. Fig. 5 shows the major centres of cost in a distribution network and relates them to a trading account of the wholesaling and/or retailing company operating the network. The actual values used are notional; they will vary greatly between actual distribution systems.

The chief accountant's interest will be in the values and trends of expense incurred in these main cost centres:
- Warehousing
- Transport
- Purchasing
- Selling
- Retailing
- General administration.

With this information the Board may try to reduce its operating costs and at the same time increase profits by pursuing several objectives:

To be able to exercise day to day management control of distribution and storage activities (mainly direct and indirect labour) which have controllable costs.

To be able to predict and subsequently control the medium-term costs of certain activities such as capital replacement policy and operating costs of fork lift trucks, computerised control systems and pallets.

To be able to predict and subsequently control the long-term costs of certain activities, such as warehouse buildings.

To be able to carry out sound financial analyses of new project investments to check that a satisfactory rate of return on the capital invested is likely to be achieved.

These financial objectives must all be matched against a fifth objective, less tangible and less easy to quantify, that is,
To be able to estimate the degree of service which should be offered service will have a marked effect on the level of expense incurred, for clearly it will never on the one hand, be economic to satisfy 100% of the demands of the customers on the system; however on the other hand, it would be shortsighted to economise to the extent where customers are highly dissatisfied, possibly leading to the loss of business. Such general considerations are obvious, but difficult to recognise, analyse in detail and to quantify into money terms.

The chief financial accountant may find in practice that the achievement of these objectives from his point of view will be more or less frustrated because:

He has not got an accounting system which collects, analyses and reports the costs of the main cost centres listed above, in the form required.

There may be no presentation of costs in detail at all; making analysis and management control of costs impossible.

The costs which are available, in whatever form they are presented, are not related to the key activities in the distribution network; therefore no assessment or control of unit costs of these activities is possible.

Often not only the accountant, but the rest of the general management have insufficient information whether the costs and unit costs are good, bad or average in comparison with their competitors.

Nevertheless the chief accountant will be faced continually with the need to assess new ideas, schemes, projects, replacement, usually presented by members of the Board, by technical management, by consultants, by systems analysts or by computer salesmen, each convinced that theirs is the panacea which will sweep away the company’s financial difficulties.

How can he check the financial, let alone the practical worth of these projects if he has no realistic costs or measures of unit costs? In many cases he cannot do an efficient job and may, with others, become a prey to grandiose schemes with little financial merit which, when subsequently installed, cause major problems for personnel management, for warehouse and transport management, for administration and for operatives.

There are, unfortunately, some instances where this has happened in the field of warehousing and distribution during the last few years, often resulting in the loss or waste of very large sums of money. While there are often understandable reasons for such incidents, they do generate a backwash of fear and distrust in the field. This is neither healthy in the long term for companies nor for suppliers and contractors of materials handling equipment and buildings.

The paramount importance of basic financial policy

The chief financial accountant still has to produce and present a profit and loss account as well as a balance sheet for his company every year, to show historically the value of sales, the gross and net profits, and how they compare with the previous years’ results.

He will often be limited in his opportunity to suggest how sales and gross profits can be increased and costs reduced. This may be the job of warehouse, transport, technical and engineering management, and they too may be limited in assessing changes and projects unless they also have detailed costs, and can agree with the accountants how they shall be considered and presented. Worse still, schemes may be forced through for prestige reasons or simply to ‘keep up with the Jones’s’. This can result in demoralisation of progressive management and technical staff and can lead to an atmosphere of lack of objectivity when management decisions are made for political rather than for financial, organisational and social reasons.

It seems important that financial policy should be determined after close co-ordination and co-operation of the accounting management with the other functions of management, particularly in relating costs to activities (e.g. order-picking, transport scheduling, computer stock control and so on). Furthermore, it seems important that an overall look should be taken at the entire operating or proposed system, rather than at small or isolated parts of such warehousing and distribution systems. Otherwise there is a danger that considerable amounts of capital may be spent in some parts of the warehousing and distribution system which when implemented may have the unexpected effect example, which is met, is where money is spent to improve an old warehouse or to replace it with a new structure when the overall better cost solution would have been to redesign and build several new warehouses in other geographical locations in order to reduce transportation costs. Such a philosophy is reported frequently in the materials handling technical press and in recent
textbooks; it is not the primary purpose of this report to enlarge upon methods and techniques for avoiding strategic mistakes of this kind.

It does not seem unreasonable to expect that a progressive management should make such an overall study of its system, embracing all the cost centres mentioned before—warehousing, transport, purchasing, selling, retailing, general administration and the control of information flows.

At any time, a firm may be faced with the question of a new warehouse and the senior management of the company will ask themselves or themselves be asked:

Is our existing warehouse(s) adequate or not, for existing and new products?

Should we have a new one or two or more?

Should they be designed to include only high throughput lines or all lines?

What kind of warehouse—with bulk storage, with simple racking, live storage, highly mechanised unit, or possible 'high-bay' unit?

How much might it cost?

Will its operating costs be good? Will they be significantly better than existing running costs?

Can or should the warehouse be operated on 1, 2 or 3 shifts; what differing men and operating restrictions would result, and what differences

Is there adequate knowledge of the flows and feedback of information which will be required to control and operate the new warehouse?

If there is knowledge of vital information flows, how can the use of sophisticated electronic office accounting machines or even the use of computers be justified?

What other practical restrictions or considerations exist which will enforce modifications to the ideal warehouse design, for example, site restrictions or local authority regulations?

What effect in it? Sometimes these considerations are so important that they can exercise an overriding influence on initial design solutions.

Even before management consider the problems of the warehouse(s) they must be careful to ensure that they have not ignored the associated transport and distribution systems for delivering the goods together with the problems of suppliers and their deliveries of goods to the warehouses. Management may have great difficulty in controlling suppliers and ensuring an even flow of vehicles into the unloading and loading docks.

Thus, they may be faced with more fundamental questions than those concerning the warehouse, for example:

How many warehouses?

Where should they be sited geographically?

Is one or more central warehouses a better solution than supplying from a central warehouse, smaller depots which in turn supply the customers?

What kind of transport system already exists or will be needed to ensure an adequate service to customers at competitive prices?

What problems exist or may be encountered in negotiating deliveries from suppliers? How will they affect the working of the unloading bays at the warehouse?

What kind of flows and feedback of vital information is required among the distribution system, the warehouse and the general administration organisation, to ensure adequate service to customers?

What transport restrictions exist which will influence the design of the system, e.g. national legislation on hours worked and distances travelled or national and local trades unions agreements?

There will be many other questions posed by study and analysis of the existing system and these cannot be answered singly or together unless accurate and up-to-date data can be supplied. Management cannot make sound decisions unless they have data in at least three areas:

*Products handled, stored and distributed.*
Service given by manufacturers supplying goods and to customers and retail outlets receiving the goods.

Costs and cost performance of the operations of distribution, handling and storage.

If they have some data, they are likely to ask more specific questions:

Products

What products are currently selling? What is the detailed breakdown of these products?
Is there a need to reduce the product range, or go for new products?
Will this change in the next few years? If so, how, why and when?
What is the best period of time into the future to consider?
Is the gross profitability on current sales satisfactory? Will it be satisfactory in several years time? If not, what can be done about it?

Service

Do service policies have an effect on demand. Is an optimum service time to customers provided? How can it be measured?
How can the effect on sales of varying service time be estimated?
Are the stock levels optimum for all individual products?
It is necessary to re-investigate stock levels and stock control methods?
What is an acceptable number of zero stock occasions that might occur?

Costs

Is there detailed, meaningful and up-to-date knowledge of all costs? Are physical distribution costs a significant percentage of the value of goods sold?
Is there detailed and meaningful knowledge of unit costs? If so, are they good, or average? If poor or even average, how can they be improved and by comparison with what?

Perhaps some analyses of projects can be carried out satisfactorily without reference to cost data, but certainly most of them cannot.

Warehousing and distribution—financial and management decision making

There are several distinct areas in warehousing and distribution where joint interest and responsibility for decision making demand the participation of the executive management and general financial management:

A. Investment appraisal

Here these managers should co-ordinate to assess data for three types of decision:

1. The decision as to whether a comprehensive review of the entire networks and systems should be made with recommendations to introduce new warehousing, transport and data control systems, the reasons for wanting to shoulder such a task would be to maximise profits from changes in product sales whilst at the same time cutting running and maintenance costs.

Such reviews are not to be undertaken lightly and may require several years of system and costing study. Some considerations are set out logically by James N. Arbury and Others.*

Arbury states that the total systems approach is still being applied by a few companies and these cases are based on a cost minimisation principle, whereas he believes that a system based on profit maximisation is more valid.

In his book he develops the theme that a profit-oriented approach is feasible and can be applied to a wide variety of companies, and he develops a basic framework for use in planning distribution policies.

Once the effect of service on demand is established, management must still determine the costs of providing various levels of service. The order cycle time starts when the customer first wants to place an order, rather than when his order finally reaches the manufacturer. A company's first task is to determine whether service is an important demand determinant in its industry. For a few companies, the answer may be obvious; usually the need for better service is not clear.

These considerations suggest that a comprehensive analysis of the whole distribution/warehouses network is essential to the long term economic solution and this is backed up by the latest experience of larger companies and consultants. This would entail:

(a) Analysis of the present and long term marketing objectives of the company and its separate groups.

(b) Analysis of present and future customer service demands in quantities of goods and times.

(c) Analysis of the distribution network to check and forecast the best means of transportation and the best siting of warehouses and depots to handle these products.

(d) Analysis of whether one or more warehouses gives the optimum solution, and whether they shall be of conventional design, mechanised or possibly even automated.

(e) Analysis of alternative ways of achieving good materials handling, storage and transportation—shall it be lorries or trains, fork lift trucks or high-bay warehouse, men or women order-pickers?

(f) Analysis of the distribution control system and the warehouse control system. Is a general purpose computer justified for the former or not; is a 'mini' computer justified for the latter or not?

(g) Analysis of the types of personnel required in the future to man these systems, their education and training, the impact on the present organisation, and the interest and co-operation of the trades unions.

(h) The allowance for unknown factors which always appear at some stage to upset planning inconveniently.

This is thorough and logical, as far as it goes, but many who have to carry out the analyses in practice find that they set up alternative distribution models and then cannot put accurate and up-to-date data into the models, whether it be product, service or cost data. In addition, these models can be very large and complex, and there may be fundamental problems in defining the true performance objectives for the models. There are usually factors which are difficult or impossible to put a cost to, but they may have an overriding importance in the end when management have to decide between alternative courses of action. The development of decision-making trees in this field offers interesting possibilities.

2. This is the type of decision to change systems, equipment or buildings within one or more of the main cost centres in the 'trading account' (see Fig. 5).

In the context of this report, decision-making might localise to whether to change to one or more warehouses, whether to build conventional warehouses or whether to have a high-bay warehouse, whether to have manual or mechanised order-picking and order-assembly equipment, whether to use computers big or small for the control of goods and handling equipment within the warehouse(s).

It seems important to establish costs of the alternatives to find what difference in unit costs is likely to arise, whichever scheme is finally adopted.

There may still be difficulties in finding cost data to use in such comparisons, but it is sometimes possible to establish in a relatively short time, fresh cost collecting systems which will produce the data in a usable form.

Such an approach has been made in many of the companies participating in these costing surveys; to make a one off record the results shown in Section 5.

3. The 'problem of replacement' decision. This may apply to fleets of vehicles, to handling equipment such as fork lift trucks, to pallets and to any item of capital equipment whose running and maintenance costs rise with time, or which may become obsolete technically.

It seems that discounted cash flow methods give a sounder assessment of optimum replacement time by taking into account investment grants and taxes; any such techniques have limited use if the detailed running and maintenance costs of the present and proposed equipment are not available or are inaccurate.
FIG. 5 Relating the distribution/warehouse system to its trading accounts

<table>
<thead>
<tr>
<th>TRADING ACCOUNT</th>
<th>YEAR</th>
<th>£</th>
<th>£</th>
<th>£</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPENING STOCK IN WAREHOUSE PURCHASES</td>
<td>50,000</td>
<td>480,000</td>
<td>330,000</td>
<td></td>
</tr>
<tr>
<td>LESS CLOSING STOCK</td>
<td>30,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COST OF PURCHASES</td>
<td>30,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PURCHASING</td>
<td>30,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WAREHOUSING</td>
<td>100,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GENERAL ADMINISTRATION (Routine level)</td>
<td>50,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SELLING</td>
<td>90,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRANSPORT</td>
<td>130,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RETAIL OUTLETS</td>
<td>100,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROVISION FOR FINANCIAL CHARGES AND ADJUSTMENTS (BOARD LEVEL)</td>
<td>500,000</td>
<td>500,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL COST</td>
<td>1,000,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GROSS PROFIT ON SALES</td>
<td>100,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The final selection from alternative projects may often be favoured because it represents a capital intensive solution in which extra capital invested in sophisticated buildings and equipment will save a number of personnel and will thereby show an overall favourable return for the capital employed. The evidence of this survey is that such reductions in personnel are often insufficient to balance the very high capital costs of current warehouse buildings and mechanised equipment.

Whichever scheme is selected under these categories, there is usually implied a future 'fixed' set of costs, the control of which is not possible in the short term; this emphasises the importance of sound selection of large and expensive buildings and equipment at competitive prices.

B. Management accounting

The short-term decision-making process will be concerned with controllable costs, which in practice will usually be direct labour and supervision. In administration they will relate to personnel in the control office, concerned with orders, pricing invoicing, stock control, purchasing and selling. The warehouse management should have direct control over the numbers of personnel employed on single or multi shifts. The activities of personnel may be studied and measured, possibly by an industrial engineering department if such exists within the company or group of companies. Management will be interested in wage rates, shift allowances, incentive bonuses as well as conditions of employment in other companies. Interfirm comparisons can provide useful information (confidentially and under company code numbers to ensure anonymity) which can guide management in deciding how their 'controllable' and 'fixed' costs compared with those of other companies in similar fields.

There is little information on cost performance of warehouse systems and the earlier part of this report dealing with conventional warehouses, appears to be one of the few sources of approach to the problem of assessing cost performance of warehouse systems with specific unit costs shown. This report is now available from HMSO (£2 net).*

This second part of the report attempts to carry these considerations further for high-bay warehouse systems, but makes no attempt to consider the problems of costs and cost performance of transport systems in distribution, although this is equally important. The lack of published cost data on warehouses, both conventional and mechanised, justified the limited inter-firm cost comparison which has been carried out on high-bay warehouses in Britain, Europe and the United States, results of which are presented and discussed later in this report.

2. The development of a uniform system of costing for any handling and storage operation

2.1. The requirements of a costing system for warehouse management

Section I has stated the need in any company for some system of cost control. When cost data is collected in the warehouse and in its administration offices, service systems and control systems, it will fall into three broad categories according to the purpose for which it is used:

A. For financial accounting, to support the presentation of the annual balance sheet and profit and loss account.
B. For management control, usually on a daily or weekly basis.
C. For making decisions, usually longer term, for example replacement of equipment, reduction of running and maintenance costs, new buildings.

The objectives of a costing system for a warehouse system will include:

1. To isolate all material handling costs, basically into labour, equipment and space costs.
2. To distinguish between 'controllable' costs (mainly direct and indirect labour) and 'uncontrollable' costs (mainly equipment, building and allocated services).
3. To collect and examine the rules of cost allocation and apportionment exercised by the particular company.
4. To define uniform rules of allocation and apportionment of warehouse costs which will be acceptable to most companies.
5. To define systematic main and sub cost centres for the various functions of handling and storage in any warehouse.
6. To collect existing costs within the defined cost centres for a suitable unit time. (In the survey the period of one year has been convenient, although shorter periods of collection, quarters, months or weeks might be more useful or effective in particular circumstances.)
7. To define the unit loads handled and stored and to measure their throughput in unit time (per year, month, week) in terms of volume or weight or any other unit which may be relevant.
8. To record how 'controllable' and 'uncontrollable' costs vary with levels of output, type of shift working, and any other factors which may be important in management control.
9. To report 'uniform' performance indices (cost per unit volume, cost per pallet load, cost per piece picked) which may be used to compare the efficiency of companies' warehouse systems.
10. To supply specific cost data for the evaluation of unit cost performance of alternative proposed handling and storage projects.
11. To supply data for the evaluation and appraisal of capital investment in new warehousing projects, in order to predict accurately the risk and the expected return on capital investment. (Discounted cash flow methods are recommended, after taking into account any investment grants and tax allowances which may be claimed.)
12. To supply cost data for any warehousing system in a form suitable for programming and which would print out as (i) the unit costs, (ii) relative costs in the relevant cost centres.

There are two kinds of costing system which can be considered for the cost analysis of a warehouse system:

(a) Product costing system

This would be used where the emphasis is on establishing and maintaining the unit cost of the various products of the particular industry, separated in terms of materials, labour and overhead expense.
(b) Process or operational costing systems

These would be employed where the range or type of product is small or where only one product is manufactured in regular batches or continuous flow. Here the emphasis must be on collecting and controlling the costs of producing the equipment and its ancillaries, also buildings and services.

In a warehouse system, there is a flow of goods whose throughput (= output) can be related to the operational costs. The goods may be isolated into several groups according to size, shape, weight, etc. and the costs of handling and storing the separate groups can be isolated.

There may be large differences in rates of throughput for the individual 'lines' of the product range of groups of 'lines' and it may be important to isolate the costs of high throughput items and medium/low throughput items, particularly if they are handled by different methods.

An operational costing system may be set up to carry out such analysis of costs and present the costs and unit costs in a form and with a frequency most useful to management, in order that they can use the data as a means of controlling handling and storing operations in the warehouse.

2.2. Steps in the establishment of an operational costing system

The detailed development of an operational costing system has been described in Section 4, commencing page 4, of The Costing of Handling and Storage in Warehouses—1. Conventional Warehouses, HMSO (1970). Nevertheless, the main steps are reiterated below:

(a) Establishment of a costing framework

The warehouse system to be cost analysed is isolated in terms of cost centres, which can be selected from a list. Under each cost centre the elements of cost may be completely isolated in as much detail as required. The specific elements of cost may be selected from a list, which together with the list of cost centres is shown in Part I.

(b) Collection of isolated costs

The individual costs will be collected for a unit time, for example for a year, quarterly, or 13 periods a year, or weekly. The frequency chosen will depend on the rate of throughput of information, the number of separate pieces of information to be handled, the frequency with which management require reporting of costs and unit costs and finally the cost to the company of cost data collection, analysis and reporting.

If the costs are not available in the form required, it will be necessary to modify or expand the present cost accounting systems.

(c) The relation of costs to activities and output of goods

Once the individual cost elements have been isolated in a satisfactory form they may be identified with the detailed activities of the warehouse, which have been analysed in Part 1, e.g. unloading, putting into main storage, transferring from bulk storage to order-picking positions, order-picking, order-assembly, loading, control, auxiliary services and returns, equipment maintenance.

In some of these functions (main cost centres) the performance may be identified with throughput of goods, measured in terms of weight or volume or number of packages or £ sterling wholesale or retail value. If the various costs, collected systematically for each main cost centre are divided by the appropriate output data for the same unit time, then the concept of the unit cost is realised and a means of monitoring performance at regular intervals is available.

(d) The establishment of 'company' and 'uniform' costs

The detailed accounting rules used by companies will differ as between companies, and it is important to find a uniform set of rules with which to operate upon the specific data from each
and all companies participating in a survey of the kind discussed in the earlier Part 1 and the present Part 2. Problems which are apparent before attempting to set up a uniform costing system are:

(i) In what form do we collect various categories of cost?
(ii) How do we treat capital costs?
(iii) How do we manipulate the costs of different handling and storage systems both within one company and between different companies?

In addition, we are faced with several factors which further complicate the comparison of unit costs.

(iv) The problem of inflation of labour rates, material and equipment prices.
(v) The problem of comparing the efficiencies of systems which contain equipment and buildings of greatly differing ages.

The solutions to these problems which have been adopted in the analysis of data received from all companies participating in the surveys has been described in detail in Part 1.

In addition, the tables of inflation rates used for handling equipment and warehouse buildings are shown in Part 1.

(e) Rules of allocation of depreciation of equipment and buildings used in high-bay warehouse systems

By 'rules' of allocation of depreciation, we mean, broadly:

(i) The method by which the capital cost of the item is 'written off' in the books. For example it might be the 'straight-line' method in which the annual increment of depreciation is the same for each year of the life of the item considered, or it might be the 'declining balance' method in which the annual increment of depreciation is a fixed percentage of the total balance of depreciation for each succeeding year.

(ii) The number of years considered for the purposes of 'writing off' the initial capital value of the item. This should correspond as closely as possible to the useful life of the item in a costing exercise.

Table 1 shows details of the rules of allocation of depreciation used by companies participating in the second survey who used high-bay warehouse systems. It also shows the 'uniform' lives of the assets selected after reviewing the specific data for each company's unit costs.

Table 1 may be compared with the corresponding table in Part 1.

(f) Transforming capital charges into annuities to produce depreciation costs

The 'annuity' method of calculating annual depreciation costs for capital assets (e.g. handling and storing equipment and buildings) which also include the cost of interest has been explained in Part 1.

In using the 'annuity' approach to uniform costing of warehousing systems, it is necessary to use a 'uniform' value for the rate of discount for transforming the capital sum into an annuity. It is proposed to use 100% in future analysis, but the computer program developed at the National Materials Handling Centre can re-calculate the costs at any required percentage very quickly.

(g) Treatment of building costs for high-bay and conventional warehouse structures

Some high-bay storage racking structures are still installed within tall conventional style buildings, but it is now general practice to construct the main storage section of high-bay warehouses in different fashion from 'conventional warehouses'.

Most high-bay units today are designed around a steel or a reinforced concrete racking structure, the building itself being merely the foundation plus a suitable insulated and weather-proof cladding around the outside of the racking, which results in a low construction cost.

These differences in design necessitate a different approach to analysing the costs. It was found
TABLE 1  Rules of allocation of depreciation of equipment and building used in high-bay warehouses
Summary of information collected from individual companies

<table>
<thead>
<tr>
<th>Company's code No.</th>
<th>7</th>
<th>12B</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>29</th>
<th>24</th>
<th>3</th>
<th>19</th>
<th>31</th>
<th>22</th>
<th>21</th>
<th>40</th>
<th>41</th>
<th>'Uniform' lives of assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranes</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Stacker cranes</td>
<td>10</td>
<td>15</td>
<td>16.5</td>
<td>15</td>
<td>15</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>15</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Fork lift trucks</td>
<td>12</td>
<td>12</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>4</td>
<td>5</td>
<td></td>
<td>15</td>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Hand and powered</td>
<td>3</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>8</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underfloor towing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driverless trucks</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trailers</td>
<td>10</td>
<td>10</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conveyors</td>
<td>10</td>
<td>5</td>
<td>16.5</td>
<td>15</td>
<td>15</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>Bins</td>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Racking</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Racking (high-bay)</td>
<td>20</td>
<td>15</td>
<td>20</td>
<td>30</td>
<td>50</td>
<td>6</td>
<td>8</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>40</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Wooden pallets</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel pallets</td>
<td>10</td>
<td>10</td>
<td>16.5</td>
<td>10</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Stillages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handling containers</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data processing</td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buildings high-bay</td>
<td>40</td>
<td>15</td>
<td>20</td>
<td>30</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td>Buildings conventional</td>
<td>40</td>
<td>25</td>
<td>40</td>
<td>30</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GS = General Services Computer  PC = Process Control Computer
convenient to separate the costs of the high-bay racking structure from the rest of the high-bay building. A detailed breakdown of a sample of these costs is shown in Section 6, and the costs per cubic footage for the racking alone and then the racking plus building (foundations, cladding, etc.), are given.

Where conventional building design is used for the main storage unit, the usual limitation on height is governed by the maximum practical operating height of the hoisting equipment used within; fork lift trucks for example. In practice this limits the height of such buildings to about 30 feet. The minimum height of high-bay structures is currently about 40 feet, with an average of about 70 feet and a maximum of 110 feet. There seem to be good reasons why even taller structures will be found to be economic and practical in the near future.

A high-bay unit usually has several conventional style building units attached which contain the handling equipment for unloading, packing, order-assembly, loading, etc., and the costs of these parts of the building would be handled in the way described above.

The cost of the land upon which the warehouses have been built has not been included in the cost performance of the warehouse systems as it does not have a direct bearing on the performance of the handling and storage system and does vary widely depending on locality, land scarcity and other factors. There is no reason why the land cost cannot be included in the overall costs of the warehouse system, but it does not seem logical to include this factor as one which would influence performance of the system in terms of cost per unit load. A note in Section 6 indicates that the actual cost of the land in terms of equivalent cost per cubic foot of storage space is a few percent. Generally, the savings in land costs which may accrue from building a high-bay rather than a conventional warehouse, are relatively small compared with the total costs of typical installations.

(h) Treatment of labour costs

The treatment of labour costs in the uniform costing system has been to try to break them down in a systematic way. The main factors which need to be identified are:

(i) The various categories of personnel which may be employed in any warehouse system.
(ii) The numbers of personnel which are employed on each shift in each of the categories (i) within each main cost centre (unloading, main storage, order-picking, order-assembly, loading and control).

<table>
<thead>
<tr>
<th>TABLE 2 Warehousing—handling and storage, proposed categories of personnel, grouped according to function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selected as far as possible to relate to present categories of personnel employed in both industrial and commercial warehouses</td>
</tr>
<tr>
<td>1. Storeman</td>
</tr>
<tr>
<td>2. Checker</td>
</tr>
<tr>
<td>3. Fork Truck Driver</td>
</tr>
<tr>
<td>4. Equipment Operator</td>
</tr>
<tr>
<td>5A. Order-picker (male)</td>
</tr>
<tr>
<td>5B. Order-picker (female)</td>
</tr>
<tr>
<td>6A. Packer (male)</td>
</tr>
<tr>
<td>6B. Packer (female)</td>
</tr>
<tr>
<td>7A. Control Clerk (male)</td>
</tr>
<tr>
<td>7B. Control Clerk (female)</td>
</tr>
<tr>
<td>8. Cleaner</td>
</tr>
<tr>
<td>9. Assistant Foreman or Charge-hand</td>
</tr>
<tr>
<td>10. Foreman/Supervisor</td>
</tr>
<tr>
<td>11. Warehouse Manager</td>
</tr>
<tr>
<td>12. Maintenance Technician Supervisor</td>
</tr>
<tr>
<td>13. Maintenance Engineer—Mechanical</td>
</tr>
<tr>
<td>14. Maintenance Engineer—Electrical</td>
</tr>
<tr>
<td>15. Maintenance Engineer—Electronics</td>
</tr>
</tbody>
</table>
(iii) The breakdown of weekly or annual payments for each category of personnel.

(iv) The differentiation, where applicable, between company and uniform labour costs for each handling and storage system studied.

(v) The effectiveness of each person, whatever his category, possibly measured for the purposes of an incentive scheme.

There has been insufficient time available whilst carrying out the survey to investigate the last factor, (v). In fact, few warehouses included in the surveys use incentives or any scheme other than measured day work. The survey has concentrated on collecting the numbers of personnel in each main and sub cost centre and establishing their company and uniform payments including, where appropriate, regular overtime working which would be identified with extra outputs of goods.

The categories of warehouse personnel used in the analysis of high-bay warehouses has been the same as used for conventional ones, except for the addition of four maintenance engineering categories which are shown on Table 2 above.

The breakdown of payments on a weekly and an annual basis has been carried out in a similar way to the data shown in Appendix 4 of the first report.

TABLE 3 Method used to collect details of wage payments in the various cost centres of warehouse systems

<table>
<thead>
<tr>
<th>Date</th>
<th>Company code No.</th>
<th>Period covered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary elements of cost—Direct labour</td>
<td>Indirect labour</td>
</tr>
<tr>
<td></td>
<td>No. of males/females in cost centre code No.</td>
<td>Rate p/hr</td>
</tr>
<tr>
<td>Element of cost code No.</td>
<td>101 Wages—normal hours or normal rate Based on 48 weeks actually worked per year</td>
<td></td>
</tr>
<tr>
<td>102 Wages—overtime hours or premium rates Time and one half</td>
<td></td>
<td></td>
</tr>
<tr>
<td>103 Wages—overtime hours or premium rates Double Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>104 Incentive bonuses where applicable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>105 Shift allowances where applicable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>106 Employers contribution to Soc. Security + Natl. Ins. + Grad. Pensions but excluding SET, REP and training levy</td>
<td>Standardised at £68 pa (male), £61 pa (female)</td>
<td></td>
</tr>
<tr>
<td>107 Holiday pay—based on 4 weeks per year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>108 Company merit awards and long service awards</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total cost/week of personnel category ( ) in cost centre ( ) = total p/hr x total clockhours

The recording of details of wage payments in each cost centre is shown in Table 3. An alternative approach is shown in Tables 3A, 3B and 3C. This method is being used in a current inter-firm comparison in the food distribution trade. The total weighted wage payments (p/hr) Table 3A are established each quarter and multiplied by the clock hours worked in each cost centre, Table 3B and 3C. This calculation may be carried out by computer.

The 'uniform' labour costs have been derived by taking the average rates per hour for the whole survey data, which in effect means that the uniform comparison is between numbers of personnel in each category multiplied by their hours worked, charged at average rates.
When the analysis of costs of conventional and high-bay warehouses was made, there was a general restraint on wages in the UK resulting in only a few percent increase per annum and our comparison has been reasonably accurate in this respect. During the last year there has been a steep inflation of wages in Britain and it will be necessary to revise our wage rates in order to continue to carry out valid analyses.

(i) Treatment of control system costs

There are two main types of control activity which may be encountered in any distribution/warehouse system:

**TABLE 3A Personnel wage payments**

Record payments in new pence per hour for each category of person

<table>
<thead>
<tr>
<th>Element of cost code No.</th>
<th>Category of personnel</th>
<th>Base rate</th>
<th>Average overtime</th>
<th>Average incentive bonus</th>
<th>Shift allowance</th>
<th>Co. long service award</th>
<th>Average guaranteed bonus</th>
<th>Company sick pay</th>
<th>Company over-heads</th>
<th>Total average cost/clock hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>825</td>
<td>Supervision</td>
<td></td>
<td>p/hr</td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Assistant Foreman/Supervisor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>826</td>
<td>Full Foreman/Supervisor</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>827</td>
<td>Warehouse Manager</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>801</td>
<td>Direct labour</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Warehouseman</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>802</td>
<td>Warehousewoman</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>803</td>
<td>Checker—Male</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>804</td>
<td>Checker—Female</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>805</td>
<td>Fork lift Trucks Driver—Male</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>806</td>
<td>Fork Lift Truck Driver—Female</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>807</td>
<td>Packer—Male</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>808</td>
<td>Packer—Female</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>809</td>
<td>Control Clerk—Male</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>810</td>
<td>Control Clerk—Female</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>811</td>
<td>Order-picker—Male</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>812</td>
<td>Order-picker—Female</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>813</td>
<td>Equipment Maintenance Mechanic</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>814</td>
<td>Equipment Maintenance Electrician</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>815</td>
<td>Charge-hand—Male</td>
<td></td>
<td>p/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Control of services*

Services may include activities such as:
- Processing customers sales orders and purchase orders
- Invoicing and pricing
- Stock control
- Vehicle scheduling
- Management reporting.
TABLE 3B  Personnel clock hours—supervision

Ref. Table 3A. For each personnel category listed in Table 3A, select those categories which are relevant to the company's warehouse operations and record the number of personnel employed in each category.

Record the total averaged weekly clock hours for all shifts for each entire category of personnel.

Apportion the total averaged weekly clock hours worked by each category, to the main cost centres in which personnel were employed.

<table>
<thead>
<tr>
<th>Category of personnel</th>
<th>Element of cost code No.</th>
<th>No. of personnel in category</th>
<th>Total averaged weekly clock hours worked by category</th>
<th>Apportion total averaged weekly hours worked to each relevant main cost centre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unloading</td>
</tr>
<tr>
<td>Supervision</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assistant Foreman/Supervisor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Foreman/Supervisor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warehouse Manager</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 3C Personnel clock hours—direct labour

<table>
<thead>
<tr>
<th>Category of personnel</th>
<th>Element of cost code No.</th>
<th>No. of personnel in category</th>
<th>Total averaged weekly clock hr worked by category</th>
<th>Apportion total averaged weekly hours worked to each relevant main cost centre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct labour</td>
<td></td>
<td></td>
<td></td>
<td>Unloading 000</td>
</tr>
<tr>
<td>Warehouseman</td>
<td>801</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warehousewoman</td>
<td>802</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Checker—Male</td>
<td>803</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Checker—Female</td>
<td>804</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLT Driver—Male</td>
<td>805</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLT Driver—Female</td>
<td>806</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packer—Male</td>
<td>807</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packer—Female</td>
<td>808</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Clerk—Male</td>
<td>809</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Clerk—Female</td>
<td>810</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Order-picker—Male</td>
<td>811</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Order-picker—Female</td>
<td>812</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance Mechanic</td>
<td>813</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance Electrician</td>
<td>814</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charge-hand—Male</td>
<td>815</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
These activities may be operated by increasing stages of complexity from manual means, to punched cards with up to date office equipment, or when justified economically by the size and complexity of the total operation, by a general purpose computer.

**Control of warehouse operations**

Warehouse control may include activities such as:
- Good receipt and location
- Goods retrieval and despatch
- Order-picking scheduling
- Order-assembling and packing scheduling
Control of handling equipment, e.g. stacker cranes, mechanised order-picking equipment.

The system chosen may vary in its complexity, but basically it only receives data on the goods arriving at the warehouse and uses this data to decide which goods go where in the warehouse and when. At the same time it receives data on the goods which are required to be retrieved from the warehouse and controls the order-picking, order-assembly and despatch of the goods from the warehouse to the depots or to the customers direct, but only to the point at which they await the outside transport to take them away from the warehouse.

A diagrammatic illustration is shown in Fig. 6.

The system may control the operation of the handling and storing equipment.

### Stages of increasing complexity

**In the Foreman's head:**
- look for the nearest 'cell'
- guesswork
- experience
- Foreman's own system.

**A set of rules on paper**
- with or without a simulation board in the office.

**A pack of punched cards**
- a tray of cards is a substitution for a simulation board.

**Off-line computer systems**
- batch processing of data.

**On-line computer systems**
- direct input of data from terminal to computer with automatic handling of data.

### Type of warehouse

**Conventional storage system**
Goods are moved by men possibly with the aid of tools such as FLT's, trolleys, movable ladders.

**Mechanised storage system**
Decision to movements of goods is made by men, possibly with the aid of office equipment or computers in which these machines carry out only calculations upon which decisions are based. Actual goods movement are carried out by machines which are minded by men (pressing buttons, or inserting punched cards into the machines which give the machines specific location and retrieval instructions).

**Automated storage system**
Machines are of same type as above (e.g. stacker cranes which are operated by computer or 'mini' computers which automatically follow a set of predetermined decision rules.) This is essentially a closed loop system but where the decision rules can be readily modified to meet the changing requirements of the warehouse.

The costs of such control systems for stages (1) (2) and (3) are usually modest but the use of computer control for stages (4) and (5) may introduce large elements of cost. The recent appearance of low cost 'mini' computers may revolutionise the facility and cheapness of warehouse control in the near future. It is now possible to use a 'mini' central processor costing as little as £1000 with associated interfacing costing say £20 000 to completely control the latest automatic warehouses. A more detailed appraisal of the development of systems for both 'control of services' and 'process control of warehouse operations' together with some ideas of costs involved with various degrees of sophistication, is given in Section 7.

### TABLE 4 Company 13. 'Company' annual costs £—straight line method

<table>
<thead>
<tr>
<th>Main cost centres</th>
<th>Unloading 000</th>
<th>Main storage 310</th>
<th>Order-picking 500</th>
<th>Packing and order assembly 110</th>
<th>Loading 010</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building depreciation and allocated service costs</td>
<td>19 922 000</td>
<td>72 550 000</td>
<td>43 616 000</td>
<td>11 001 000</td>
<td>15 942 000</td>
<td>163 031 000</td>
</tr>
<tr>
<td>Equipment depreciation, maintenance and running costs</td>
<td>2 884 000</td>
<td>97 113 000</td>
<td>16 250 000</td>
<td>35 367 000</td>
<td>3 718 000</td>
<td>155 332 000</td>
</tr>
<tr>
<td>Labour, direct and supervisory costs</td>
<td>109 140 000</td>
<td>107 868 000</td>
<td>129 836 000</td>
<td>214 011 000</td>
<td>66 161 000</td>
<td>627 016 000</td>
</tr>
<tr>
<td>TOTALS</td>
<td>141 289 614</td>
<td>297 184 060</td>
<td>203 135 544</td>
<td>278 817 460</td>
<td>91 898 322</td>
<td>1 012 325 000</td>
</tr>
</tbody>
</table>

**Note:**
1. Total control system costs are included and apportioned across equipment and labour costs.
2. The format is similar to that printed out by the computer.
TABLE 5 Company 13. 'Company' unit costs—straight line method—£ per cubic yard output

<table>
<thead>
<tr>
<th>Main cost centres</th>
<th>Unloading</th>
<th>Main storage</th>
<th>Order-picking</th>
<th>Packing and order assembly</th>
<th>Loading</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>000</td>
<td>310</td>
<td>500</td>
<td>110</td>
<td>010</td>
<td></td>
</tr>
<tr>
<td>Building depreciation and allocated service costs</td>
<td>0.047</td>
<td>0.171</td>
<td>0.103</td>
<td>0.026</td>
<td>0.037</td>
<td>0.383</td>
</tr>
<tr>
<td>Equipment depreciation, maintenance and running costs</td>
<td>0.007</td>
<td>0.228</td>
<td>0.038</td>
<td>0.083</td>
<td>0.009</td>
<td>0.365</td>
</tr>
<tr>
<td>Labour, direct and supervisory costs</td>
<td>0.257</td>
<td>0.254</td>
<td>0.305</td>
<td>0.503</td>
<td>0.156</td>
<td>1.475</td>
</tr>
<tr>
<td>TOTALS</td>
<td>0.332</td>
<td>0.699</td>
<td>0.478</td>
<td>0.656</td>
<td>0.216</td>
<td>2.381</td>
</tr>
</tbody>
</table>

Note: 1. Total control system costs are included and apportioned across equipment and labour costs.
2. The format is similar to that printed out by the computer.

Production of systematic cost arrays

By using the systematic approach advocated in the first report, arrays of 'company' and 'uniform' costs may be produced for the period of time chosen.

These costs may also be related to the throughput (= output) of goods measured in appropriate units—volume, weight or number of packages.

To illustrate a set of cost and cost performance arrays which include both 'straight line' depreciation of capital and also 'annuity' method depreciation of capital, a set of arrays for Company 13 is shown in Tables 4 to 11.

No account has been taken of investment grants, or employment premiums which might be available in Development Areas for two main reasons:

The grants may be increased, reduced or annulled at any time at short notice. (Since this was written, they have been abolished and replaced by tax allowances which are described in 'Investment Incentives', Command 4516, HMSO. These have been increased again since mid-July 1971.)

This is an attempt to compare the costs and cost performances of handling and storage systems and it would be unsound to include grants and premiums in some cases and not in others. (They would be included in investment appraisal analysis.)

TABLE 6 Company 13. 'Uniform' annual costs £—straight line method

<table>
<thead>
<tr>
<th>Main cost centres</th>
<th>Unloading</th>
<th>Main storage</th>
<th>Order-picking</th>
<th>Packing and order assembly</th>
<th>Loading</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>000</td>
<td>310</td>
<td>500</td>
<td>110</td>
<td>010</td>
<td></td>
</tr>
<tr>
<td>Building depreciation and allocated service costs</td>
<td>22 468-000</td>
<td>81 823-000</td>
<td>49 189-000</td>
<td>12 406-000</td>
<td>17 981-000</td>
<td>183 867-000</td>
</tr>
<tr>
<td>Equipment depreciation, maintenance and running costs</td>
<td>2 390-000</td>
<td>92 343-000</td>
<td>15 967-000</td>
<td>33 681-000</td>
<td>3 405-000</td>
<td>147 786-000</td>
</tr>
<tr>
<td>Labour, direct and supervisory costs</td>
<td>103 820-000</td>
<td>100 500-000</td>
<td>111 745-000</td>
<td>189 280-000</td>
<td>64 085-000</td>
<td>569 430-000</td>
</tr>
<tr>
<td>TOTALS</td>
<td>138 140-888</td>
<td>294 864-741</td>
<td>189 910-173</td>
<td>252 675-721</td>
<td>91 756-476</td>
<td>967 348-000</td>
</tr>
</tbody>
</table>

Note: 1. Total control system costs are included and apportioned across equipment and labour costs.
2. The format is similar to that printed out by the computer.
### TABLE 7  Company 13. 'Uniform' unit costs—straight line method—£ per cubic yard output

<table>
<thead>
<tr>
<th>Main cost centres</th>
<th>Unloading 000</th>
<th>Main storage 310</th>
<th>Order-picking 500</th>
<th>Packing and order assembly 110</th>
<th>Loading 010</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building depreciation and allocated service costs</td>
<td>0.053</td>
<td>0.192</td>
<td>0.116</td>
<td>0.029</td>
<td>0.042</td>
<td>0.432</td>
</tr>
<tr>
<td>Equipment depreciation, maintenance and running costs</td>
<td>0.006</td>
<td>0.217</td>
<td>0.038</td>
<td>0.079</td>
<td>0.008</td>
<td>0.348</td>
</tr>
<tr>
<td>Labour, direct and supervisory costs</td>
<td>0.244</td>
<td>0.236</td>
<td>0.263</td>
<td>0.445</td>
<td>0.151</td>
<td>1.339</td>
</tr>
<tr>
<td>TOTALS</td>
<td>0.325</td>
<td>0.693</td>
<td>0.447</td>
<td>0.594</td>
<td>0.216</td>
<td>2.275</td>
</tr>
</tbody>
</table>

**Note:**
1. Total control system costs are included and apportioned across equipment and labour costs.
2. The format is similar to that printed out by the computer.

### TABLE 8  Company 13. 'Company' annual costs £—annuity method

<table>
<thead>
<tr>
<th>Main cost centres</th>
<th>Unloading 000</th>
<th>Main storage 310</th>
<th>Order-picking 500</th>
<th>Packing and order assembly 110</th>
<th>Loading 010</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building depreciation and allocated service costs</td>
<td>38 960 000</td>
<td>141 883 000</td>
<td>85 295 000</td>
<td>21 514 000</td>
<td>31 178 000</td>
<td>318 830 000</td>
</tr>
<tr>
<td>Equipment depreciation, maintenance and running costs</td>
<td>3 300 000</td>
<td>121 293 000</td>
<td>27 553 000</td>
<td>46 261 000</td>
<td>4 945 000</td>
<td>203 352 000</td>
</tr>
<tr>
<td>Labour, direct and supervisory costs</td>
<td>109 140 000</td>
<td>107 868 000</td>
<td>129 836 000</td>
<td>214 011 000</td>
<td>66 161 000</td>
<td>627 016 000</td>
</tr>
<tr>
<td>TOTALS</td>
<td>160 835 904</td>
<td>394 169 070</td>
<td>257 809 119</td>
<td>299 348 125</td>
<td>108 658 782</td>
<td>1 220 821 000</td>
</tr>
</tbody>
</table>

**Note:**
1. Total control system costs are included and apportioned across equipment and labour costs.
2. The format is similar to that printed out by the computer.

### TABLE 9  Company 13. 'Company' unit costs—annuity method—£ per cubic yard output

<table>
<thead>
<tr>
<th>Main cost centres</th>
<th>Unloading 000</th>
<th>Main storage 310</th>
<th>Order-picking 500</th>
<th>Packing and order assembly 110</th>
<th>Loading 010</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building depreciation and allocated service costs</td>
<td>0.092</td>
<td>0.334</td>
<td>0.201</td>
<td>0.051</td>
<td>0.073</td>
<td>0.750</td>
</tr>
<tr>
<td>Equipment depreciation, maintenance and running costs</td>
<td>0.008</td>
<td>0.285</td>
<td>0.065</td>
<td>0.109</td>
<td>0.012</td>
<td>0.478</td>
</tr>
<tr>
<td>Labour, direct and supervisory costs</td>
<td>0.257</td>
<td>0.254</td>
<td>0.305</td>
<td>0.503</td>
<td>0.156</td>
<td>1.475</td>
</tr>
<tr>
<td>TOTALS</td>
<td>0.378</td>
<td>0.927</td>
<td>0.606</td>
<td>0.704</td>
<td>0.256</td>
<td>2.871</td>
</tr>
</tbody>
</table>

**Note:**
1. Total control system costs are included and apportioned across equipment and labour costs.
2. The format is similar to that printed out by the computer.
Therefore, it must be recognised that the 'uniform' costs presented in this and Part I of the report are quoted to compare systems rather than reproduce exactly the costs which the financial accountant of each company would present in practice.

Nevertheless, the evidence of this survey is that where tax allowances are applicable, they can make a significant reduction to the unit cost of handling, particularly where the investment in buildings and equipment is high as is the case in many high-bay warehouse systems. In a cost comparison between equivalent conventional and mechanised systems, this factor could help to sway the balance of costs in favour of the mechanised solution.

**TABLE 10 Company 13. 'Uniform' costs £—annuity method**

<table>
<thead>
<tr>
<th>Main cost centres</th>
<th>Unloading 000</th>
<th>Main storage 310</th>
<th>Order-picking 500</th>
<th>Packing and order assembly 110</th>
<th>Loading 010</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building depreciation and allocated service costs</td>
<td>40 894 000</td>
<td>148 924 000</td>
<td>89 528 000</td>
<td>22 582 000</td>
<td>32 726 000</td>
<td>334 654 000</td>
</tr>
<tr>
<td>Equipment depreciation, maintenance and running costs</td>
<td>2 798 000</td>
<td>116 271 000</td>
<td>28 716 000</td>
<td>44 595 000</td>
<td>4 624 000</td>
<td>197 004 000</td>
</tr>
<tr>
<td>Labour, direct and supervisory costs</td>
<td>103 820 000</td>
<td>100 500 000</td>
<td>111 745 000</td>
<td>189 280 000</td>
<td>64 085 000</td>
<td>569 430 000</td>
</tr>
<tr>
<td>TOTALS</td>
<td>157 031 323</td>
<td>389 294 225</td>
<td>244 830 773</td>
<td>273 006 820</td>
<td>107 980 858</td>
<td>1 172 144 000</td>
</tr>
</tbody>
</table>

*Note: 1. Total control system costs are included and apportioned across equipment and labour costs.
2. The format is similar to that printed out by the computer.*

**TABLE 11 Company 13. 'Uniform' unit costs—annuity method—£ per cubic yard**

<table>
<thead>
<tr>
<th>Main cost centres</th>
<th>Unloading 000</th>
<th>Main storage 310</th>
<th>Order-picking 500</th>
<th>Packing and order assembly 110</th>
<th>Loading 010</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building depreciation and allocated service costs</td>
<td>0.096</td>
<td>0.350</td>
<td>0.211</td>
<td>0.053</td>
<td>0.077</td>
<td>0.787</td>
</tr>
<tr>
<td>Equipment depreciation, maintenance and running costs</td>
<td>0.007</td>
<td>0.273</td>
<td>0.068</td>
<td>0.105</td>
<td>0.011</td>
<td>0.463</td>
</tr>
<tr>
<td>Labour, direct and supervisory costs</td>
<td>0.244</td>
<td>0.236</td>
<td>0.263</td>
<td>0.445</td>
<td>0.151</td>
<td>1.339</td>
</tr>
<tr>
<td>TOTALS</td>
<td>0.369</td>
<td>0.915</td>
<td>0.576</td>
<td>0.642</td>
<td>0.254</td>
<td>2.757</td>
</tr>
</tbody>
</table>

*Note: 1. Total control system costs are included and apportioned across equipment and labour costs.
2. The format is similar to that printed out by the computer.*

2.3. A survey of conventional and mechanised warehouses in UK, Europe and USA

The survey of the costs of warehouses has been carried out in two main parts:

Conventional Warehouse System, details of which were discussed in Part I of the report. The examples used were all situated in the United Kingdom.

Mechanised and High-Bay Warehouses, some details of which are presented in this Part II, and which are compared with the conventional ones. The examples used are situated in UK Europe and USA.

The range of types of goods which are handled in warehouses the world over is large and diverse
and it was not possible to pre-plan or survey a fully representative list of warehouses. In fact, companies were approached on an arbitrary basis, often by personal contact at top and middle management level. The types of warehouses surveyed are listed in Table 12.

It was important from the start that the co-operation and confidence of the companies willing to participate should be established and maintained by allotting to each company a code number known only to that company and to the authors, and that any information disclosed should be treated strictly confidentially.

This approach worked very satisfactorily in the UK, but perhaps understandably the overall response in Europe and the United States, was not so marked, and although a number of companies initially stated their willingness to participate, in the event, either no detailed cost information was subsequently received or insufficient for a detailed analysis.

**TABLE 12  List of warehouses surveyed**

(No identification or code numbers have been shown, to preserve the anonymity of individual participants)

<table>
<thead>
<tr>
<th>Type of product handled</th>
<th>Type of system</th>
<th>Location</th>
<th>Number surveyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal cans</td>
<td>C = conventional</td>
<td>UK</td>
<td>2</td>
</tr>
<tr>
<td>Camera parts</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Granules in bags</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Castings</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Books</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Household articles</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Groceries</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Tinplate</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I.C. engines</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Metal components</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Machine components</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Mail Order</td>
<td>M</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Metal pressings</td>
<td>H-B</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Shoes</td>
<td>M</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Groceries</td>
<td>H-B</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Groceries</td>
<td>M</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Metal pressings</td>
<td></td>
<td>Europe</td>
<td>2</td>
</tr>
<tr>
<td>Chemicals</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Castings</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Foodstuffs</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Camera parts</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Electric motors</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Metal components</td>
<td></td>
<td>USA</td>
<td>1</td>
</tr>
<tr>
<td>Groceries</td>
<td></td>
<td>M</td>
<td>1</td>
</tr>
</tbody>
</table>

**TOTAL NO. SURVEYED** 31

Nevertheless, thanks to the help of many people and organisations, enough data has been collected and analysed to form a basis for initial comparison of the costs of both conventional and high-bay warehouses.

In attempting to cover the field, the following factors were considered:

The types of commercial or industrial companies should be as diverse as possible, although the actual type and quality of goods handled and stores may have little or no bearing on the methods and efficiency of the handling and storage systems.

If possible, similar systems within the same group of companies should be compared.

This was achieved in the case of systems—

2A and 2B
5A and 10A
5B and 10B
3, 19 and 31
The survey should include several systems requiring order-picking and this has been achieved in systems 6, 9, 11, 12, 13, 14, 16H, 21, 30 and 32H.

Limitations of time and resources suggested that the sample of high-bay systems should be restricted to high and large units (over 45 feet and 1 million cubic feet). These larger systems do not usually include manual picking cranes; thus the survey does not include any data on manual picking crane systems with racking in the range of 20-45 feet in height. A separate cost analysis of these systems is to be undertaken shortly at the National Materials Handling Centre.

Ideally, the initiative to review the warehouse costing will start at Board level, and if the scale of operations justifies it, the appointment of a director or general manager to direct these operations as one of his duties will be a positive step towards implementing such modifications and additions to the organisation as may be required to improve investment appraisal and cost control. The 'warehousing' director will be able to confer with the financial director on the subject of whether existing financial management and cost accounting systems are adequate for the analysis and control of warehousing costs, and again, if they agree that improvements or modifications to systems and the personnel who have to run them are needed then the financial director should be in a strong position to initiate a plan, preferably in co-operation with the 'warehousing' director.

The initial period of meeting people, absorbing the 'flavour' of their particular organisation and company, and attempting to define exactly what was wanted and how to get it, took considerable time, bearing in mind firms' endemic problems—promotions, people leaving the company, sickness, holidays, weather, changes in priority in the accounting department—setbacks which may be encountered anywhere. However, a pattern emerged suggesting key points in the approach to carrying out an initial survey on warehousing, and which are now discussed, starting with the recommendation for setting up initially a 'team' to investigate the costs and unit costs of their company's warehouse system.

### 2.4. The importance of teamwork

The introduction of teams is suggested for tackling the planning, control and costing of warehouse projects. Just as factory management will normally convene regular production meetings to discuss how the performance of output is reconciled with forecasts or budgets, so warehousing management should require at least two teams with executive powers to be convened and to meet regularly. These will be,

- The day-to-day management control team and,
- The future projects team.

These teams would not necessarily be a fixed part of the organisation structure but would be superimposed on the regular structure to co-ordinate functionally the objectives.

#### Day-to-day management control team

**Objectives**

To combine expertise and data to set up short-term output targets for the warehouse and to control activities to hold to pre-planned targets. To combine expertise and data to overcome short-term technical and engineering problems.

**Members of the team**

The Warehouse Manager (may be Chairman)  
The Cost Accountant  
The Materials Handling Manager or Engineer  
Anyone else specially required.

**Meeting**

Weekly or fortnightly. Appointed secretary issuing brief progressing minutes promptly.

**Accountable**

To the 'Warehouse Director', probably at longer intervals.

#### Future projects team

**Objectives**

To discuss long-term output targets and to combine and co-ordinate
expertise and data in planning adequate future systems design(s) to meet
future targets.
To translate proposed system(s) design into practical personnel, equip-
ment and building terms.
To predict as accurately as possible the future capital investment and the
reductions in running costs inherent in future alternatives and additions.

Members of the team
The ‘Warehouse Director’ or Materials Handling
Manager (may be Chairman)
The Financial Accountant
The Management Services Representative
The Cost Accountant
The Industrial Engineer
Anyone else specially required.
(Some of these might be combined in smaller
cOMPANIES.)

Meeting
Monthly or two-monthly depending on the scale of operations and the
urgency.
Appointed secretary issuing detailed minutes of discussion and decisions.

Accountable
To the Board, through the ‘Warehouse Director’.
Other informal meetings and sub-groups would naturally arise from the
progress of the main teams.

One of the indirect benefits of operating in this way is that a spirit of co-operation and under-
standing is usually generated.

Whilst carrying out the survey, it was first necessary to seek the support of the director res-
ponsible for warehousing, to gain his co-operation in order to establish a team consisting of
the warehousing manager, the cost accountant, the materials handling manager, the engineer
and the industrial engineer.

Secondly, it has been experienced that such a team cannot obtain all the information required
in one quick operation, and that a process of mutual education and understanding must be
allowed to take place whilst the team are trying to extract the data required. Therefore a planned
series of visits was agreed to meet the team over a considerable period, absorbing only a limited
amount of ‘know-how’ and data at each session. After gaining some experience it was found
that the collection of data could be accomplished in three or four visits to each company. In
practice there will be some variation in the time required, depending on the ease or difficulty of
data collection.

Figure 7 shows diagrammatically a suggested approach to initiating and progressing an initial
cost analysis. Such an approach has proved satisfactory when working with the majority of the
companies in the surveys.

A standard questionnaire has been developed, asking for all the data required, but most
people’s reaction to questionnaires is similar to the writer’s; they either answer the question in a
superficial manner or the missive is consigned, possibly justifiably, to the wastepaper basket.
The questionnaire has been offered to firms only as an aide-memoire at some stage in the
investigation.

Introductory talk to explain the costing system
As a result of discussions with participating companies, a talk illustrated by slides has been
developed, lasting about one hour.

In several cases, the talk has been used as an introduction to the particular participating
company and has proved useful in describing the costing system and its objectives to groups of
top and middle management, industrial engineers, accountants, and systems analysts.

The talk has proved useful to indicate to personnel concerned with the detailed collection of
data, exactly what is required, right from the beginning of the investigation, and this helps a
survey to start quickly and to progress smoothly.

2.5. Notes on some problems encountered during the survey
Some of the practical problems encountered whilst the survey was carried out have been discussed
in Part 1. Some additional notes are added here.
FIG. 7 Applying the 'uniform' costing system to a warehousing system

STEP 1
Top management representative responsible for warehousing and distribution makes decision to carry out costing analysis

STEP 2
The costing team is selected and briefed with (1) objectives (2) details of the costing system

STEP 3
The team establishes the basic cost centre framework

STEP 4
The team members collect detailed data

STEP 5
The team transforms the collected data to standard form

STEP 6
The standard data is processed to print out 'Company' and 'Uniform' performance indices

STEP 7
Performance indices are compared with national survey data to pinpoint detail areas for possible improvement

STEP 8
The team reports to top management where possible improvements can be made

STEP 9
A plan of systems improvement and re-budgeting is established and backed at board level

Common problems were not necessarily present in all companies and it is not proposed to carry out or show any quantitative analysis of which problems emerged in any particular company. It seems more useful to say that any of these problems could arise in any company which decided to carry out a systematic survey along the lines advocated in this report, and they are offered as a tentative contribution to expediting a survey in any company which might wish to analyse its warehouse costs.

Problems of establishing main and sub cost centres

The first stage in initiating a costing investigation is to define and agree the main and sub cost centres of activity in terms of standardised system developed.
Usually these would not coincide with the existing accounting system's cost centres which are often not broken down into very much detail.

It is important to relate the collected costs to the relevant warehouse areas by using an \( \frac{1}{4} \) inch scale drawing and using physical areas, rather than supervisory areas.

Further, there are sometimes problems of defining interfaces between cost centres with no easily noted break-points from an industrial engineering viewpoint, since equipment and personnel will not always be confined entirely to each standard cost centre.

It may be that fewer than 15 or so main sub cost centres are needed to investigate and control warehousing systems and that 6-8 may prove to be sufficient. However, it was decided to establish a system which was as detailed as possible before embarking on the survey.

When specific data on allocated services is not available, then agreement with the investigating team must be sought to agree on sensible apportionment of the total annual budget for the factory or division. This has usually been done on a floor area (square footage) basis, or a space (cubic footage) basis.

The allocated services will be apportioned in direct proportion to the activity of the equipment in each cost centre. Far more precise apportionment is possible when the company's industrial engineering department has made studies of equipment and personnel activities, or where usage of company services is metered, e.g. heating and lighting.

Generally, the areas where there has been most difficulty in isolating costs have been:

- Allocated services costs—Building depreciation, rates, building and goods insurance, heating, lighting, building maintenance and cleaning.
- Fire detection and control systems costs—sprinkler system for example.
- Control system costs—for example, computer services, electronic control of stacker cranes.

Many of these costs have not been isolated because they were included in package deal prices from contractors, or, alternatively, they have been budgeted within group or divisional budgets and have not been individually isolated, measured and monitored.

Nevertheless, some of these costs can sometimes represent a significant proportion of the total costs of the warehouse system, and they may present an opportunity for reducing overall costs if they are reviewed systematically.

Establishing company rules of apportionment of costs

Difficulties have frequently arisen during the survey in establishing logical apportionment of costs between the main costs centres. In the case of buildings and allocated services the company may apportion costs on a square footage (area) basis, whereas we have transformed costs to a space (volumetric) basis for buildings and building heating.

The apportionment of labour cost is usually more straightforward; first line supervision generally know which personnel operate in the various cost centres.

The apportionment of equipment costs to main and sub cost centres is not always so straightforward and may need arbitrary but sensible agreement by the members of the investigating team.

Selection of the unit time for collection of cost and output data

It is necessary for the investigating team to decide at an early stage the period of time during which the expenses recorded for this survey are to be collected.

To start with, a convenient time is one year, and in fact the data collected for this survey was collected for the period 1968-69. In several cases the warehousing system had not been completed or was not yet in regular production use, so predicted or budgeted costs for the first year of steady operation were estimated.

In the time available, it has only been possible to take average annual values for detailed
cost and output data. The limitation is that both output and related costs may vary considerably from month to month; this will be so where the warehousing system is affected by seasonal trade. Most of the companies in the survey, surprisingly enough, experience quite steady throughputs of goods varying by only 10–15% throughout the year. A few are affected by strongly seasonal variations in trade and therefore throughput, and it is imperative that they calculate unit costs values related to highest and lowest outputs of goods at, say, quarterly intervals.

**Definition of unit loads and the problems of measuring and calculating the volumes and weights of goods passing through the warehouse**

It was explained in Part I of the report that volume and weight of goods seemed to correlate quite well as a measure of performance of a warehouse system, but that volume of goods has been selected as the principal unit of measurement because it was felt that the designs of the great majority of warehouse equipment and building were based upon the volumes of goods to be stored and the volumes of goods to be handled through rather than the weights of the goods.

The difficulties of defining the volume or weight of goods handled and stored through each warehouse system have varied. The specification, for example, of a standard pallet of carton goods is straightforward in terms of volume, weight and numbers, but in a mail order or supermarket order-picking and packing system it is not so easy to define and measure. The actual number of unit loads in terms of *packages* can be misleading because of a possible wide range of package size; this is one reason for preferring to estimate performance in terms of total volume or weight as well as numbers of unit loads.

To date, only the average annual volumes and weights have been used in the analysis, although the number of units handled may be a significant factor in order-picking and order-assembly cost efficiency. In some cases, two or more different types of unit load are handled and stored, mainly differing in the dimensions of the transporting medium. For example, automobile components may be handled in several sizes of steel cage pallet. It was considered logical to measure the actual volume of the goods handled and not the additional volume of the pallets or support for the goods. This would tend to show up system inefficiency if the pallet size/volume was relatively great compared with the volume of the goods carried on it, and this emphasises the need to reduce waste of space in the racking, whether it be conventional or high-bay, in order to get better utilisation of space and to reduce costs. Where irregularly shaped goods (e.g. motor car body pressings or metal castings, are stacked in wire-cage post pallets, then the full internal volume of the cage has been taken as the unit load volume).

Nevertheless, little difficulty has been experienced in the survey in arriving at reasonably accurate values for unit load volumes and weights, and even when the data has not been readily available, it has usually been possible to carry out some quick checks on current products to establish the data.

If a company decides to initiate a survey, it may need to monitor volumes, weights, densities and numbers of units loads, particularly when they are irregular in shape. Equipment which can measure some or all of these factors is now available on the market.

No specific investigation of the effect of the monetary value of goods handled has been made, but the survey has shown little evidence that the value of goods affects the methods used to handle and store them. With most products it is difficult to see how much bearing the value of goods could have on the activity (and thence cost) of handling and storing them.

Even warehouse insurance premiums appear to be geared more to the layout of the buildings and their fire detection and control installations than to the value of the goods stored. Where several different types of unit load are handled simultaneously, there appears to be no great difficulty in separating and apportioning the costs to each type of unit load, if this is required. This introduces the product costing concept, although the costing system described in this report is basically an operational costing system.
3. The comparison of costs and cost performance of conventional and high-bay warehouses — results of the surveys

3.1. Introduction

This section gives details of warehousing costs which have been collected in two sequential parts:

Firstly, a survey of Conventional warehouse systems costs.
Later, a survey of Mechanised and high-bay warehouse systems costs.

The costs and cost performance data have been collected, analysed and presented in the same way for all examples included in the surveys. The method of analysis and presentation has been described in Section 2 of this report and in sections 4, 5 and 6 of Part 1 of the report.

3.2. Detailed results from the surveys

In every example, the data was processed and run through the computer to produce four arrays of figures, similar in format to those shown in Tables 4-11, and including:

- The company's elements of cost for one year (1968/69)
- The company's performance indices (cost per unit load)—its unit costs
- The 'uniform' elements of cost.
- The 'uniform' performance indices (cost per unit load)—the unit costs which we think are meaningful as a comparison between the various companies' warehouses systems and between conventional and high-bay warehouse systems.

The data in the arrays used in the comparison of cost performance in this Section includes correction for inflation, but does not include corrections for the interest costs on capital equipment and building. The latter has been taken into account in the 'annuity' method, described in Section 2, but resources have been insufficient for analyses of all results using the 'annuity' method. However, sufficient analysis has been carried out to indicate the extra increments of cost which may arise by including the opportunity of cost of capital items (mainly equipment and buildings), estimated at an average of 10% increase.

An example of the differences between 'straight-line' and 'annuity method' costs is shown for Company 3, Table 13.

TABLE 13 Company 3, High-bay warehouse—breakdown of total uniform annual cost
(Calculated by 'annuity method').

<table>
<thead>
<tr>
<th>Cost centre</th>
<th>3 Shift operation</th>
<th>2 Shift operation (estimated)</th>
<th>1 Shift operation (estimated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. BY COST CENTRES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unloading</td>
<td>8%</td>
<td>7%</td>
<td>6%</td>
</tr>
<tr>
<td>Main store (high-bay)</td>
<td>61%</td>
<td>83%</td>
<td>84%</td>
</tr>
<tr>
<td>Order assembly</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Loading</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Control</td>
<td>5%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>2. BY ELEMENTS OF COST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building</td>
<td>43%</td>
<td>44%</td>
<td>45%</td>
</tr>
<tr>
<td>Equipment</td>
<td>46%</td>
<td>47%</td>
<td>48%</td>
</tr>
<tr>
<td>Labour</td>
<td>11%</td>
<td>9%</td>
<td>7%</td>
</tr>
</tbody>
</table>
In assessing unit cost performance, only the volume of the throughput of goods has been used, since as discussed in Section 5 of Part 1 of the report, it was considered that volume presented a more practical and meaningful index than weight for the majority of products encountered.

It is not proposed to publish the details of the arrays of results for all the cases, as they would be too bulky and would make only a limited contribution to the implications of the summarised results which are presented in this Section.

3.3. Results for conventional warehouse systems

3.3.1. The results for conventional warehouse systems are summarised in Fig. 8 which shows the value for each participating company of their volume performance indices. These exclude the increments for order-picking and order-assembly/packing, because they represent an important part of the total activity and cost of any warehouse system where they exist in that system. To look for general relationships between the cost performance of conventional and high-bay systems we have excluded those cost centres and restricted the comparisons to unit load in/unit load out systems. A brief discussion of order-picking costs and units costs is given in Section 4, but time has not allowed a systematic analysis of order-picking methods, costs and unit costs etc. in depth. It is expected that a two year programme of research of order-picking will be started shortly at The National Materials Handling Centre to follow up this work.

These values have been plotted against the absolute values of throughput of goods, to indicate any effects of economies of scale which might exist, and this aspect of the results is discussed again later in this section of the report.

For clarity, the corresponding ‘company’ values have not been shown on Fig. 8 although they are available. In most cases, the differences between the ‘company’ and ‘uniform’ volume performances indices for each company are not great, and generally much less than the difference among the performance indices of different companies.

The following assessment of results is based on the ‘uniform’ values of performance index rather than the ‘company’ values and the following points are of interest.

3.3.2. The range of values of volume performance index is large, being 40 to 1, even ignoring companies 5B and 10B which handle a very high density material and may be a special case.

3.3.3. Since the difference between ‘company’ and ‘uniform’ costs are relatively small, this tends to confirm that ‘uniform’ costing can be used to measure inter-company performance. If the uniform costing system is logical, the wide range of unit cost values is prima facie evidence that efficiency varies widely; part of the reason may be that too many companies are unaware of their handling costs and cost performances.

3.3.4. A glance at the distribution of results in Fig. 8 shows a general pattern, as if the points tend to fall in an envelope of curves similar to hyperbolae. This is interesting, since if a series of hypothetical systems had the same total costs, but it was possible to put a large range of throughputs of goods through them, say from one to ten times, then the volume performance indices would fall on such a hyperbolic curve. If the costs of each of the series of systems were halved then the volume performance indices (hereafter VPI's) would fall on a neighbouring curve, beneath the first curve, and with VPI values one half that of the first curve.

But in fact, we would not expect to be able to get more than a limited increase in output from any one system without some variation in cost, but we might expect that there would be economies of scale. For example, if we considered two hypothetical warehouses, one designed to handle and store five times the same kind of product as the other, then the larger unit might be expected to be relatively cheaper than the smaller. One would expect relative cost reductions in building foundations, heating plant, building space, mechanised handling equipment and control systems; and there might be some relative reduction in labour costs. Thus in Fig. 8, one might expect to find the unit cost of the goods throughput to reduce with increasing output, but what has not been generally known to date is (a) how they reduce in practice and (b) what an acceptable absolute value of unit cost should be at any level of throughput.

Figure 8 is an attempt to show what happens in practice, by recording the actual and ‘true’ unit costs of many kinds of warehouse systems.
Although all costing systems are arbitrary, we have tried to collect the 'true' costs in a logical and sensible way and also in a way that comparison of costs between different systems would bear examination.

The pattern of results indicates that there is considerable reduction in unit cost due to economy of scale, and suggests that it pays to be able to handle and store large outputs of goods. We have for convenience of discussion indicated three zones of cost in Fig. 8.

Zone A Companies with higher performance efficiency coupled with high throughputs.
Zone B Companies with average performance efficiency and with low to medium throughputs.
Zone C Companies with poor performance efficiency and with very low throughputs.

**FIG. 8 Warehouse performance—unit cost diagram**

<table>
<thead>
<tr>
<th>Vertical Scale: Values of Companies Volume Performance Indices (VPI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units: £ Sterling per cubic yard of goods throughput</td>
</tr>
<tr>
<td>All values represent unit load in/unit load out situations and do not include order-picking or order-assembly and packing activities. However, these separate values may be shown and are indicated</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Horizontal Scale: Values of Average Annual Volume of Throughput Goods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit: 100,000 cubic yards</td>
</tr>
<tr>
<td>Three zones are shown:</td>
</tr>
<tr>
<td>Zone A - Higher performance efficiency coupled with all throughputs</td>
</tr>
<tr>
<td>Zone B - Average performance efficiency with low to medium throughputs</td>
</tr>
<tr>
<td>Zone C - Poor performance efficiency with very low throughputs</td>
</tr>
</tbody>
</table>

- 'O' Conventional warehouse installation
- 'X' High-bay warehouse installation
- ']' Number of shifts per 24 hrs
There can be two main reasons why performance may fall in the undesirable zone C.

(a) The level of throughput of goods is much too low for the general concept of design of the handling system, or for some reasons is not maintained at the design level.

(b) The costs of some or all of the functions in the handling system are too high, and this may be readily pinpointed by referring to the summarised computer print-outs. Here the problem may either be that the design concept is extravagant or inefficient for the level of goods to be handled or specific prices asked and paid for buildings, equipment or labour are too high.

There seems to be a case for suggesting that it should be possible to design, build and operate handling systems which can fall within zone A and zone B.

Further there seems to be no reason why the future performance cannot be predicted to avoid designing a system whose unit costs might fall within zone C.

It therefore seems logical to extend the full cost performance analysis in each case to producing 'design' unit costs as well as 'operation' unit costs. The former would reflect the design/cost efficiency of proposed alternative schemes, before commitment, and using the design volume of throughput of goods, whilst the latter would show the actual performance efficiency after the chosen scheme was in daily operation, based on what was actually spent on all elements and related to the actual throughput of goods achieved in practice.

The values of unit cost shown in Fig. 8 and subsequent diagrams are 'operation' values.

One of the most important objectives for planning and costing 'teams' is that they should analyse 'design' unit costs before commitment, to avoid saddling themselves with systems which have poor unit costs for any size of output of goods.

3.3.5. Where results are directly comparable as in the case of companies 2A and 2B; 5A and 10A; 4, 8 and 12A and 14 and 30, similar systems are used to handle and store almost identical types of goods, and significant differences in unit cost still occur.

For example, 2A has a unit cost nearly twice that of 2B; as a result, Company 2, having participated in the survey, are taking general and detailed action in considering how to bring the VPI's of 2A and their other warehouses down to the value of 2B, or lower if possible, and they are presently looking at systems designs of alternative handling and storage systems to this end.

In a similar way, Company 5A has a VPI twice that of Company 10A, both companies being in the same group, and they are studying the detailed data to establish where these differences arise. Again, within the same group of companies, 10B shows a unit cost twice as great as 5B and a similar investigation will be carried out.

Company 11 has a very high unit cost and this is due mainly to three factors:

Firstly, the handling and storage systems were installed in a speculative warehouse, which has been rented at high rates.

Secondly, the wage rates which are paid are very high due to long standing agreements with the particular trade union.

Thirdly, the actual throughput of goods is only about one half that which was designed and anticipated.

Company 14 shows a high overall unit cost, and this is partly because the utilisation of space is poor, and partly because the variation of throughput of goods is unavoidably very great.

Company 13 is a partly mechanised system but again suffers from variation in throughput seasonally. Nevertheless, the system is efficiently designed and it replaces a number of old fashioned warehouses. This rationalisation alone has resulted in very large savings in running costs. The result shown is provisional and needs re-checking when the Company is in full operation.

3.3.6. Summarising, by using the method of analysis and presentation of cost performance shown in Fig. 8, large differences in unit cost are shown to exist, even between almost identical handling and storage systems within a group of similar factories.

There are also interesting relationships between values of unit costs and the absolute volumes of
throughput of goods. It might have been that the scatter of results on Fig. 8 was random, so that throughput would have no bearing upon the expected range of unit cost. However, this is not the case, and although it seems possible to have good, bad or average unit cost values at low throughputs, it seems unlikely that average or poor unit cost values will be encountered at medium and high throughputs.

This suggests that it is possible to design and operate a conventional warehouse system with low unit costs no matter what may be the level of output of goods, but that a detailed analysis of costs and unit costs for planned alternative schemes may avoid selecting one with poor cost performance.

FIG. 9 Warehouse performance—unit cost diagram A

VERTICAL SCALE: VALUES OF COMPANIES VOLUME PERFORMANCE INDICES (VPI)
UNITS: £ sterling per cubic yard of goods throughput
ALL VALUES REPRESENT UNIT LOAD IN/UNIT LOAD OUT SITUATION AND DO NOT INCLUDE ORDER-PICKING OR ORDER-ASSEMBLY AND PACKING ACTIVITIES

HORIZONTAL SCALE: VALUES OF AVERAGE ANNUAL VOLUME OF THROUGHPUT OF GOODS
UNIT: 100,000 CUBIC YARDS

THREE ZONES ARE SHOWN:
ZONE A - HIGHER PERFORMANCE EFFICIENCY COUPLED WITH ALL THROUGHPUTS
ZONE B - AVERAGE PERFORMANCE EFFICIENCY WITH LOW TO MEDIUM THROUGHPUTS
ZONE C - POOR PERFORMANCE EFFICIENCY WITH VERY LOW THROUGHPUTS

O CONVENTIONAL WAREHOUSE INSTALLATION
X HIGH-BAY WAREHOUSE INSTALLATION
3.4. Unit costs of mechanised and high-bay warehouse systems

3.4.1. Following the train of thought from the last paragraph, one might expect that where the designers have produced a system which is more capital intensive, then the proportion of equipment, building and control system costs to labour costs will be higher in a high-bay system than in a conventional warehouse system. Absolute values of costs will follow the same trend. As the system design becomes more mechanised or more automated, so capital investment rises and the proportion of 'uncontrollable' costs to the 'controllable costs' rises.

In fact, a company is usually trading a rise in 'fixed' costs against a reduction in operating variable costs in the hope that the net result will be favourable in profit terms. Since there is often an implication that the size and scale of the operation are increasing, then it is often

FIG. 10 Warehouse performance unit cost diagram B

VERTICAL SCALE: VALUES OF COMPANIES VOLUME PERFORMANCE INDICES (VPI) UNITS: £ Sterling per cubic yard of goods throughput
ALL VALUES REPRESENT UNIT LOAD IN/UNIT LOAD OUT SITUATIONS AND DO NOT INCLUDE ORDER-PICKING OR ORDER-ASSEMBLY AND PACKING ACTIVITIES. HOWEVER, THESE SEPARATE VALUES MAY BE SHOWN AND ARE INDICATED
HORIZONTAL SCALE: VALUES OF AVERAGE ANNUAL VOLUME OF THROUGHPUT OF GOODS UNIT: 100, 000 CUBIC YARDS
THREE ZONES ARE SHOWN:-
ZONE A - HIGHER PERFORMANCE EFFICIENCY COUPLED WITH ALL THROUGHPUTS
ZONE B - AVERAGE PERFORMANCE EFFICIENCY WITH LOW TO MEDIUM THROUGHPUTS
ZONE C - POOR PERFORMANCE EFFICIENCY WITH VERY LOW THROUGHPUTS

○ CONVENTIONAL WAREHOUSE INSTALLATION
X HIGH-BAY WAREHOUSE INSTALLATION
[ ] NUMBER OF SHIFTS PER 24 HRS
assumed that the net costs of a large operation will be lower than those of a series of small operations.

The detailed results shown and discussed do not bear out this theoretical reasoning in all cases surveyed. As will be seen from the results, there does not seem to be, as there often is in production processes, such a clear-cut argument that mechanisation in warehousing will necessarily produce significantly lower unit costs.

It is a common experience in factories to find that the change from hand operation to jig or semi-automatic operation, or from semi-automatic operation to fully automatic operation produces significant reductions in unit cost values. In addition, the payback on initial capital is often as short as one to five years; the projects look well worth while right from the start.

Is this so in the case of mechanising handling and storage systems? If it were generally then on the unit cost diagram Fig. 9 on p. 36, one might expect to find a pattern of points as illustrated idealistically. The circles and dots would be the overall scatter of unit cost values for conventional systems and the crosses would be the scatter of values for mechanised and high-bay systems. This would be reassuring.

What appears to be the case is shown in Fig. 10. Again, the dots are conventional values (as for Fig. 8) and the crosses are the high-bay warehouse system values. A simplified picture of the patterns of unit cost is shown in Fig. 11.

The high-bay values of unit cost not only follow closely the overall shape of the curve and zones for conventional systems, but they also follow generally the envelope curve for the 'conventionals', indicating that the hoped for, possibly expected, low value of total unit cost has not been achieved in all examples.

At one extreme we have Company 18 whose high unit cost is mainly due to having separate racking within an expensive production style of building coupled with low throughput on one shift working, whilst at the other end of the scale we have Company 3 which shows a unit cost as low as might be reasonably achieved in any circumstances. This is a modern system using all the latest techniques of high-bay warehouse design, handling a very high throughput of large pallets with high-speed stacker cranes operated by complex computerised controls. It is significant that it operates and has been designed to operate on three shifts per day. To illustrate the effect on the unit cost of operating such a system on two or even one shift per day the corresponding values
have been plotted in Fig. 10. This shows that the unit cost would approximately double by operating the system on one rather than three shifts per day.

On the other hand Companies 22 and 24 which are modern high-bay units operated only on daywork, and with relatively small throughputs yield low unit cost values.

An interesting example is Company 7 operated on two shifts per day whose unit cost value seems significantly higher than that which one might expect from the overall pattern of Fig. 17. This design was a fairly early high-bay and a considerable part of the high total cost follows from the high-bay racking. This was because the problems of stressing steel in such structures was not properly understood at that time and a large factor of safety was built in.

Company 16 has a high-bay warehouse which is separated into two systems, one for very high throughput products and one for medium throughput products. The value of unit cost for the high throughput system is not particularly good; however this system has been a pioneer attempt to automate distribution on a large scale. As a matter of interest the major issue of economics does not rest with the decision to have a high-bay storing and order-picking system rather than a modern conventional one, but rather with the overall economies which lie potentially in a centralised warehouse system rather than a multi-depot system. In addition, the better bulk buying policies made possible by centralisation should bring significantly increased marginal profits. This would probably have been the case if the warehouse had been conventional rather than highly mechanised. The return on the initial capital outlay of whichever kind of central warehouse has been selected, depends on the economies of buying in the overall distribution network, and illustrates again the importance of examining the whole distribution and warehousing operation rather than parts of it in isolation.

3.4.2. Shift operation

It has been demonstrated that a large reduction in unit cost is possible by operating high-bay or highly mechanised warehouse systems on two or three shifts per day rather than on daywork only.

**TABLE 14A Percentages of total annual cost in main cost centres of conventional warehouses**

<table>
<thead>
<tr>
<th>Company code No.</th>
<th>Unloading 000</th>
<th>Main storage 310</th>
<th>Order-picking 500</th>
<th>Order-assembly 110</th>
<th>Loading 010</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>90</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>33</td>
<td>37</td>
<td>17</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>2B</td>
<td>22</td>
<td>60</td>
<td>7</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>58</td>
<td>30</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td>11</td>
<td>24</td>
<td>34</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>5B</td>
<td>19</td>
<td>38</td>
<td>22</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>38</td>
<td>22</td>
<td>30</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>66</td>
<td>28</td>
<td>4</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>10A</td>
<td>15</td>
<td>50</td>
<td>31</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>10B</td>
<td>6</td>
<td>31</td>
<td>26</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>30</td>
<td>31</td>
<td>14</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>12A</td>
<td>14</td>
<td>20</td>
<td>26</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>7</td>
<td>35</td>
<td>14</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>16</td>
<td>29</td>
<td>19</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong> (no order-picking)</td>
<td><strong>21</strong></td>
<td><strong>57</strong></td>
<td>-</td>
<td><strong>16</strong></td>
<td><strong>6</strong></td>
</tr>
<tr>
<td><strong>Range</strong> (no order-picking)</td>
<td>5 to 33</td>
<td>50 to 90</td>
<td>-</td>
<td>2 to 30</td>
<td>3 to 23</td>
</tr>
<tr>
<td><strong>Average</strong> (with order-picking)</td>
<td>16</td>
<td>40</td>
<td>22</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td><strong>Range</strong> (with order-picking)</td>
<td>6 to 38</td>
<td>24 to 66</td>
<td>4 to 35</td>
<td>0 to 30</td>
<td>0 to 23</td>
</tr>
</tbody>
</table>

All costs used are 'uniform'.

39
This is perhaps not an unexpected observation but it is surprising what a large proportion of all examples in the surveys, whether conventional or high-bay, are operated only on one shift per day.

Allowing for the fact that in practice there may sometimes be good reasons or impossible restrictions which would obviate two or three shift working, there seems a case for exhorting

**TABLE 14B  Percentages of total annual cost in main cost centres of high-bay warehouses**

<table>
<thead>
<tr>
<th>Company code No.</th>
<th>Unloading 000</th>
<th>Main storage 310</th>
<th>Order-picking 500</th>
<th>Order-assembly 110</th>
<th>Loading 010</th>
</tr>
</thead>
<tbody>
<tr>
<td>3(3)</td>
<td>10</td>
<td>80</td>
<td>—</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>7(2)</td>
<td>6</td>
<td>88</td>
<td>—</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>12B</td>
<td>38</td>
<td>45</td>
<td>—</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>16H</td>
<td>21</td>
<td>23</td>
<td>36</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>16L</td>
<td>32</td>
<td>32</td>
<td>25</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>7</td>
<td>86</td>
<td>—</td>
<td>—</td>
<td>7</td>
</tr>
<tr>
<td>18</td>
<td>24</td>
<td>56</td>
<td>—</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>21</td>
<td>10</td>
<td>15</td>
<td>38</td>
<td>31</td>
<td>6</td>
</tr>
<tr>
<td>22</td>
<td>10</td>
<td>62</td>
<td>—</td>
<td>2</td>
<td>36</td>
</tr>
<tr>
<td>24</td>
<td>7</td>
<td>87</td>
<td>—</td>
<td>—</td>
<td>6</td>
</tr>
<tr>
<td>29</td>
<td>14</td>
<td>41</td>
<td>33</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>32H</td>
<td>28</td>
<td>22</td>
<td>19</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>Average (no order-picking)</td>
<td>14</td>
<td>72</td>
<td>0</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Range (no order-picking)</td>
<td>6 to 38</td>
<td>45 to 90</td>
<td>—</td>
<td>1 to 10</td>
<td>4 to 36</td>
</tr>
<tr>
<td>Average (with order-picking)</td>
<td>21</td>
<td>26</td>
<td>30</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>Range (with order-picking)</td>
<td>10 to 32</td>
<td>15 to 41</td>
<td>19 to 38</td>
<td>7 to 31</td>
<td>4 to 7</td>
</tr>
</tbody>
</table>

All costs used are 'uniform'.

**TABLE 15A  Percentages of total annual cost in conventional warehouses**

Breakdown between building, equipment, labour and control system

<table>
<thead>
<tr>
<th>Company code No.</th>
<th>Building costs</th>
<th>Equipment costs</th>
<th>Labour costs</th>
<th>Control system costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39</td>
<td>44</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>2A</td>
<td>15</td>
<td>22</td>
<td>40</td>
<td>23</td>
</tr>
<tr>
<td>2B</td>
<td>19</td>
<td>35</td>
<td>33</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>49</td>
<td>32</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>5A</td>
<td>33</td>
<td>24</td>
<td>35</td>
<td>8</td>
</tr>
<tr>
<td>6B</td>
<td>18</td>
<td>22</td>
<td>53</td>
<td>7</td>
</tr>
<tr>
<td>6*</td>
<td>21</td>
<td>13</td>
<td>63</td>
<td>3</td>
</tr>
<tr>
<td>8*</td>
<td>22</td>
<td>25</td>
<td>44</td>
<td>9</td>
</tr>
<tr>
<td>9*</td>
<td>33</td>
<td>12</td>
<td>47</td>
<td>8</td>
</tr>
<tr>
<td>10A</td>
<td>45</td>
<td>29</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>10B</td>
<td>12</td>
<td>48</td>
<td>37</td>
<td>3</td>
</tr>
<tr>
<td>11*</td>
<td>30</td>
<td>33</td>
<td>31</td>
<td>4</td>
</tr>
<tr>
<td>12A</td>
<td>21</td>
<td>17</td>
<td>58</td>
<td>4</td>
</tr>
<tr>
<td>Average (no order-picking)</td>
<td>29</td>
<td>30</td>
<td>34</td>
<td>9</td>
</tr>
<tr>
<td>Range (no order-picking)</td>
<td>12 to 39</td>
<td>17 to 44</td>
<td>11 to 58</td>
<td>4 to 23</td>
</tr>
<tr>
<td>Average (with order-picking)</td>
<td>24</td>
<td>22</td>
<td>47</td>
<td>8</td>
</tr>
<tr>
<td>Range (with order-picking)</td>
<td>19 to 33</td>
<td>13 to 35</td>
<td>33 to 63</td>
<td>3 to 13</td>
</tr>
</tbody>
</table>

* System includes order-picking. All costs are 'uniform'.

40
PLATE 1 High-bay warehouse under construction.
The racking is 110 ft high

PLATE 2 Semi-automatic warehouse handling automotive products, programmed by punched cards
PLATE 3  High-bay warehouse under construction and after completion

(Photograph by Dexion-Comino International Ltd.)
PLATE 4  Automated warehouse
60 ft high and 400 ft long

(Photograph by courtesy of Redman Fisher Engineering Ltd)
PLATE 5  Automatic warehouse handling
domestic appliances

(Photograph by Redman Fisher Engineering Ltd.)
PLATE 6  Automatic warehouse equipment for the Scottish Gas Board

(Photograph by courtesy of British Monorail Ltd.)
PLATE 8  Medium height racking served by high rack stacking trucks

PLATE 9  A two tier pallet pick up and deposit station situated at the end of the racking aisle
PLATE 10  Stacker crane operating in a high-bay racking structure
TABLE 15B Percentages of total annual cost in high-bay warehouses
Breakdown between building, equipment, labour and control system

<table>
<thead>
<tr>
<th>Company code No.</th>
<th>Building costs</th>
<th>Equipment costs</th>
<th>Labour costs</th>
<th>Control system costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3(3)</td>
<td>40</td>
<td>39</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>7(2)</td>
<td>24</td>
<td>60</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>12B</td>
<td>19</td>
<td>42</td>
<td>24</td>
<td>15</td>
</tr>
<tr>
<td>16H*</td>
<td>29</td>
<td>27</td>
<td>39</td>
<td>5</td>
</tr>
<tr>
<td>16L*</td>
<td>25</td>
<td>22</td>
<td>50</td>
<td>3</td>
</tr>
<tr>
<td>17</td>
<td>32</td>
<td>59</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>18</td>
<td>9</td>
<td>41</td>
<td>44</td>
<td>6</td>
</tr>
<tr>
<td>21*</td>
<td>13</td>
<td>16</td>
<td>66</td>
<td>5</td>
</tr>
<tr>
<td>22</td>
<td>32</td>
<td>46</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>24</td>
<td>18</td>
<td>56</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>29*</td>
<td>22</td>
<td>53</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>32H*</td>
<td>13</td>
<td>33</td>
<td>38</td>
<td>16</td>
</tr>
<tr>
<td>Average (no order-picking)</td>
<td>26</td>
<td>49</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>Range (no order-picking)</td>
<td>9 to 40</td>
<td>41 to 60</td>
<td>7 to 44</td>
<td>4 to 11</td>
</tr>
<tr>
<td>Average (with order-picking)</td>
<td>20</td>
<td>30</td>
<td>43</td>
<td>7</td>
</tr>
<tr>
<td>Range (with order-picking)</td>
<td>13 to 29</td>
<td>16 to 53</td>
<td>22 to 66</td>
<td>3 to 16</td>
</tr>
</tbody>
</table>

* System includes order-picking.  All costs used are 'uniform'.

companies to take the big, broad look at their overall distribution as well as warehousing system to see whether the interface between the two could not be redesigned to accept multi-shift working, and to look at cost models of the alternatives before committing themselves to any one method of operation.

3.4.3. Breakdown of cost in conventional and high-bay warehouse systems

The observations in the preceding sections refer broadly to the overall picture of the total VPI's. It is of interest to look in a little more detail at the breakdown of cost. Tables 14A and 14B show the breakdown of the total annual 'uniform' costs between main costs centres, and Tables 15A and 15B show the breakdown of total annual 'uniform' cost between (a) and building plus allocated services, (b) equipment, (c) labour plus supervision and (d) control system.

Average values are shown but they must be treated with caution because the spread of results is large in nearly all categories of cost.

By far the greatest costs lies in the main storage cost centres, followed by unloading, which suggests that these areas are the ones which should demand particular attention in the general analysis of warehouse system costs. When order-picking is included in the system, it represents up to a third of the total cost and must also rate for priority attention in cost analysis and control.

For high-bay systems (Tables 14B and 15B) there appears to be a shift of costs from unloading and order-assembly activities into main storage and control system of the high-bay systems. When order-picking and order-assembly activities are present, a greater percentage of total cost appears to be present in these activities in the high-bay systems.

The proportion of cost attributable to warehouse process control systems is relatively small and it appears to be more important when selecting a control system that it should give reliable operation to 'design' specification, without commissioning difficulties, than that its initial cost should be very low.

Nevertheless, the cost of the control systems for many large high-bay systems remains a high
figure and there is considerable debate currently amongst designers and users whether the extra costs of employing a completely automatic control system rather than a mechanised one with several operators in attendance are justified. It is expected that a research programme examining the cost effectiveness of control systems will be started shortly at The National Materials Handling Centre to attempt to evaluate various approaches to the control problem of high-bay warehouses.

It is of interest to note that in many examples the 'fixed' costs, represented by building, equipment and control system costs are a larger part than the 'controllable' costs represented by labour costs, on average, approximately 60% to 40%. This is surprising for systems which are not highly mechanised.

This suggests that in some examples, there is less potential opportunity for sweeping cost reduction by mechanising at the expense of direct labour than might be expected, and this might make some difficulty in justifying such mechanisation on the grounds of unit cost reduction alone.

As might be expected, a change to a high-bay system produces a shift of cost into building and equipment at the expense of labour. There appears to be only a relatively small reduction in the proportion of building cost when a high-bay system is specified, the reduction in labour cost compensating almost entirely for the increase in equipment costs. This is rather surprising; for example Table 16 indicates that the stacker cranes alone do not represent a very large percentage of the total average annual cost of equipment. This suggests that whilst there may be considerable savings in using tall high-bay structures and stacker cranes, these savings can be offset by not having corresponding savings in the building, equipment and labour in the other main cost centres. This may be the reason why some of the high-bay units fail to show a significant overall saving in unit cost compared with modern conventional warehouse systems, which has been discussed with reference to Figs. 9 and 10 earlier in this section.

This emphasises the necessity for overall examination of warehouse designs if a long-term minimum cost solution is required. Whilst day-to-day control of labour costs is vital, the overall picture suggests that the long-term aim in design and implementation of a warehouse operation should be to give equal weight to cost reduction of buildings, equipment as well as efficient utilisation of labour.

It has not been possible for various reasons to publish the details of several direct cost comparisons between conventional and mechanised (mostly high-bay) solutions to handling and storing identical ranges and throughputs of products. Some of these direct cost comparisons have been carried out by user companies and some at the Centre. In many cases where the high-bay solution was chosen no cost analyses were carried out to try to check whether the high-bay solution would be better, cost-wise, than the equivalent conventional warehouse system solution. This was unexpected and the Centre is currently conducting research work to try to find out only such detailed cost and investment analyses as do not appear to be carried out at a preliminary stage between system suppliers and users.
The evidence of the several detailed analyses which we have knowledge of is that there does not appear to be a significant reduction in costs when a high-bay solution is used. Nevertheless, there may be many excellent reasons other than purely cost ones why a high-bay solution may be the most suitable, for example, shortage of land, very high throughputs of goods, convenience of interfacing real time process control and stock updating with general computer services and production control, etc., or the present and future policy of the company may be to reduce manpower in view of general inflation if it is not strictly justified economically at the present moment.

3.4.4. Summary of results

It seems that a high-bay system is not necessarily more cost efficient than a modern conventional system; also bear in mind that most 'conventionals' on the unit cost diagram are operated on one shift whereas the high-bays are nearly all operated on two shifts, a few on three. Further, if the costs were recalculated by the 'annuity' method the 'high bays' would generally look even more unfavourable by at least 10% average increase in the unit cost values.

Thus the development of high-bay systems apparently does not necessarily promote lower unit costs, and it appears that it would be instructive to examine further the areas of cost to find detailed factors which need the attention of the designer, the suppliers of equipment, buildings and control systems, and the company's industrial engineers.

If one has large throughputs, the system is likely to be cost efficient.

If one has low throughputs, the system can either be cost efficient or cost inefficient.

So the decision to have a high-bay system or not depends on how efficiently the system can be operated in practice, not only at the time of installation but well into the future.

3.4.5. Future research

The work described in this part of the report represents an early stage in the full development of systematic cost analysis and planning for warehouse systems.

We have examined a number of handling and storage systems to attempt to find relationships between the 'true' costs of the 'designed' and 'actual' efficiency of these systems.

We believe, apart from a very few special cases, that the sterling value of the goods handled is of minor importance in its effect upon the system design and thence the cost of handling and storing such goods. Therefore, we have ignored the value of stock holding of the goods; the interest values depend partly on how well stock-levels have been optimised in the systems surveyed, and in a full financial accounting analysis such costs will be significant and must be taken into account. For example, if the overall economics of say four regional warehouses are better than one central regional warehouse, one would expect that the total stockholding of the four must be greater than that on the one central warehouse and such differential costs must be offset against the balances of the handling, storing and transport costs.

We have attempted to isolate high throughput systems from low throughput systems although in many cases all goods are handled by the same system; this may account in some cases for poor overall cost performance.

We think the form and shape of the warehouse building has an influence on the handling and therefore the handling costs; we think therefore that it is unsound to separate building (space) costs from handling costs.
4. The assessment of order-picking methods

4.1. Introduction

Generally, the design of a warehousing system will contain either of these basic facilities:

- Handling goods in and out as unit loads, with intermediate storage.
- Handling goods in as unit loads. After storage, separating the parts of each unit load and regrouping them in preplanned orders to be distributed to customers.

In this section we are primarily concerned with the second category and with the various problems of order-picking and order-assembly, and with investigating the efficiency of the many varied methods which have been and are still being developed to improve speed of picking and order-assembly, and just as important to attempting to find the cost efficiency of the various methods.

It has been shown in Section 2 that it is possible to isolate the elements or cost for the activities of order-picking, order-assembly and packing in a systematic form. It is proposed to indicate the means of analysis of such costs in terms of cost efficiency of picking, etc., and to indicate our progress in the comparison of order-picking cost efficiency.

The VPI's plotted on Figs. 9 and 10 in Section 3 include only the activities of unloading, storage and loading of unit loads. Nevertheless, it is known that additional costs of order-picking and order-assembly can form a very large proportion of the total unit cost.

The discussions in this section will not then be directed towards mechanised or high-bay systems which are designed for unit load out goods (nearly always pallets), but at the more complicated systems for withdrawal of unit loads and splitting them down into pre-determined orders.

The design of such systems will depend on an accurate analysis of the product profile together with the details of the speeds of order-picking and order-assembly required.

The type of order-picking system selected will depend on a number of basic factors indicated in Fig. 12.

FIG. 12 Design of order-picking systems—product data requirements

4.2. To date, a number of interesting approaches to mechanised order-picking have been developed and many are in production use. A diagrammatic illustration of the variations of order-picking technique for various categories, pharmaceutical products and spare parts.
An approach to selecting the appropriate methods of order-picking

**FIG. 13**

**UNIT LOAD IN**

**CONVENTIONAL**

- **HIGH VOLUME**
  - **LOW-MED. THROUGHPUT**
  - **BULKY OR LOW THROUGHPUT ITEMS**

**MANUAL O/P**

- **PARALLEL**
  - **SMALL NUMBER OF CUSTOMERS OR SMALL NO. OF ‘LINES’**
  - **LARGE NUMBER OF CUSTOMERS + LARGE NO. OF ‘LINES’**

**HIGH-BAY**

- **LIVE STORAGE AND MANUAL OR MECHANISED O/P**
  - **FOR VERY HIGH TURNOVER AND FEW ‘LINES’**

**SLAVE TROLLEY TRANSPORTER**

- **MECHANISED O/P**

**OTHERS**

- **MEDIUM VOLUME**
  - **HIGH THROUGHPUT TO HIGH VOLUME THROUGHPUT**

*IF IT IS NOT JUSTIFIED TO MECHANISE BULK STORAGE AND HANDLING, THEN IT IS PROBABLY NOT JUSTIFIED TO MECHANISE ORDER-PICKING AND ORDER-ASSEMBLY.*

* IT IS NOT USUALLY POSSIBLE TO FILL EACH PICKED PALLET LOAD
The following list includes many of the current methods of mechanised order-picking:

- Manual stacker crane, picking from cell storage
- Manual stacker crane, picking from live storage
- Pre-routed manual truck, feeding to endless conveyors
- Manual truck
- Manual pick to conveyor
- Computer controlled picking tucks
- Mechanised live storage and order-assembly
- Carousel
- Manual pick from stacker crane
- Gathering tower
- Slave transporter trolley feeding picking lift.

Associated sorting systems (order-assembly) may be:

- Tilt-tray
- Tilt band
- Driverless tugs and trailers
- Manual from conveyors.

There is a large range of order-picking systems available, whether the system required is basically a manual one or a mechanised one. The impression gained from this survey is that when an order-picking function has been required it has been chosen for reasons other than cost efficiency in many cases.

Designers and users primary concern seems to be to adopt an order-picking system which will operate without bottlenecks and get the order to scheduled transport without delay. Secondly, few clients have estimated what their true order-picking costs should be or would be, or have been estimated.

**FIG. 14** The total costs of picking one 'item'—a sample of manual and mechanised order-picking systems

These costs include contributions from building, equipment and labour and are average annual costs
able to compare the relative order-picking costs of different methods beforehand. It seems that little experience is available as to the predicted costs and unit costs of the many order-picking methods available for wide ranges of product.

In addition, there appears to be much conflicting opinion as to the most suitable method within the one company. For example, one very large group of food distributors have adopted a major plan of putting three completely different systems of mechanised order-picking into three of their large distribution centres and although this plan has been adopted after several years of study they have not costed the various methods or have much idea which will produce the best cost performance (in terms of say unit cost per case picked).

There is a tendency to move towards more mechanised order-picking systems for several reasons:

There is a growing need to reduce labour costs because of the rapid rise in wage rates. This is even more urgent in the USA where wage rates can be as much as four times those for the equivalent job in the UK.

Absenteeism, which can be as high as 20%, can seriously disrupt a high throughput distribution centre.

There is a general tendency for productivity per employee to go down, for example due to shorter working hours.

Nevertheless, the capital costs and the running and maintenance costs of many mechanised order-picking systems are high, and there may be an additional requirement for a small computer to process the orders. The average percentage of order-picking costs is around 30% of the total costs in the sample of this survey, whilst the associated order-assembly costs average 17%. This underlines again the need to predict the true costs of both these activities for alternative groups of products and systems before final commitment to design.

Figure 14 shows a selection of total order-picking unit costs collected in the surveys and indicates that a very marked economy of scale may exist. However, although a quantity of data on order-picking costs and outputs have been collected it is recognised that a systematic study of the whole field of order-picking and order-assembly methods is required before authoritative conclusions can be drawn.

It is hoped that an intensive programme will commence shortly at the National Materials Handling Centre to collect and analyse the true costs of order-picking and order-assembly, to compare manual with mechanised methods and to attempt to establish which types of system will give lowest unit costs for order-picking and order-assembly. At the same time a study would be made of other factors which can affect adversely picking performance, e.g. fatigue, design of work places, machine unreliability.
5. Cost effectiveness of the uniform costing approach in individual companies — feedback from the companies

5.1. The questions

Any director or responsible manager may well pose the following questions before taking action in reviewing handling and storage costs:

A. It is worth while carrying out the first costing survey in part or all of my organisation?
B. If I do, how long will it take, who will be involved, how much time will be required and what will be the cost?
C. When I have assessed the results, what potential savings seem possible over the short-term and the long-term and how does their magnitude relate to the cost of the initial survey?
D. If I am encouraged by any possible justification for more permanent implementation of new or modified costing systems, what organisational changes will be required, what will be the effect on personnel, can I budget extra expenses which may be incurred and set them against accurate predictions of savings in handling and storage? What methods are available to aid prediction?

5.2. Survey impressions

Unfortunately it is not possible to answer A. Only the person concerned can judge; however he may be encouraged by the experience of others (see the report by company A on page 49 and company X on page 50). The benefit obtained by carrying out the initial survey will presumably vary considerably amongst different companies; it can only be suggested that the company tries it.

Referring to B the amount of time required to carry out the initial survey does not seem to be great in most cases. Probably half a dozen meetings of the investigating team over a period of several weeks will suffice, with a total of perhaps 25 to 200 man hours collecting and sorting data behind the scenes. The collation and transformation of results to feed into the simple computer program takes some hours, the punching of the paper tape one hour and the computer run several minutes.

The potential savings C, which may be revealed by the exercise of carrying out the survey in a company, will fall into four categories:

1. Savings in direct and indirect labour
2. Savings in equipment maintenance and running costs
3. Savings in building and allocated services costs
4. Savings in the warehouse control system costs and possibly in the associated and interfaced distribution network costs, whether the control of such a network is computerised or not.

Taking each in turn:

1. This category represents the immediate or short-term area of potential saving. Potential savings may take the form of looking for ways of reducing the number of personnel and supervision employed in some or all main cost centres, or by comparing wage rates with survey or national averages (see Appendix I in Part I of the report).
   Note: these rates must be increased by around 3% per annum to bring to present-day values, and since around September 1969 there have been a round of wage increases which average much more than 3% per annum and may be as high as 15% per annum (see Fig. 1 in Section I).
   Another attack upon costs in this category is to consider whether method study can simplify manual operations and whether a further stage of employing work-measurement can be beneficial.
   Another key factor to be considered is that of the number of shifts which are worked or
can be worked. The evidence of this survey is that two or three shift working can significantly reduce unit costs of handling and storage—perhaps this is a glimpse of the obvious—but the fact remains that the majority of the companies in the survey only operate on daywork.

It is appreciated that this may be enforced by inability to interface with the distribution network on double-days or night-shifts, or it may be impossible to recruit sufficient personnel for these shifts, or there may be other reasons. Nevertheless, this does seem to be an area which requires further research, and a careful review on the part of any company engaged upon cost saving and expansion of throughput.

2. This category represents the medium term area of potential savings. These largely will be achieved by studying the maintenance and running costs of equipment and comparing them with other users data or by comparison with national standards.

More far reaching, critical assessments of alternative methods and associated equipment may be carried out, using up-to-date replacement analysis techniques, to establish whether better equipment could be used and to establish the optimum time of replacement.

3. This category represents the medium and long-term areas of potential savings. It would involve a critical examination of heating, lighting, insurance premiums etc., and last but not least the basis upon which the rateable value of the buildings had been assessed.

But an overriding consideration would be whether a new building design would reduce these allocated services costs. Would the situation justify even a high-bay warehouse building or a slave transporter trolley system, both of which would require a fresh look at the detailed costs and return on proposed capital outlay? Perhaps even one large structure could replace several smaller ones.

4. This category represents a medium-to long-term area for potential savings. It might involve a review and detailed analysis of the existing warehouse control system and/or the interfaced paperwork systems of selling, ordering, distribution, invoicing, etc. Probably, O & M methods of investigation would probably be used, in the first instance to establish what the true requirements of the present or the proposed systems would be. Would a mini-computer system be justified to operate some or all of the warehouse equipment and to control location and retrieval of goods, or would it be better both financially and organisationally to avoid such complications and potential problems?

Such investigations might of necessity cross the interface to the distribution network control systems and pose similar questions. Certainly, this is the most difficult area to enter, particularly where the size and complexity of the systems are large, and one where the most difficulty may be experienced in producing clear-cut economies. The problems of assessing the economic justifications in the areas where computers are or could be employed are discussed in Section 7.

Referring to D, the question of how to set up the teams to investigate the economics of warehouse and distribution networks will clearly depend upon the type of business, its present organisation chart, its size and complexity, whether or not it already has a work study or industrial engineering department, whether top and middle management attitudes are rigid or flexible towards setting up teams which will operate to some extent outside and between existing departments and groups and whether top management fear it would be upsetting or too costly to attempt such exercises.

The overwhelming evidence of this survey is that people are very willing to join the teams to examine the costs and thence the production performance. The amount of time they have needed has been modest, and can often be shared between accounting and work-study departments and the warehouse manager and his immediate staff. For example, the experiences of two companies are encouraging:

Initial report by Company A

Although the warehouse cost analysis project involved Company A in many hundreds of man hours of work, they considered it was well worth it from these viewpoints:

1. Their existing costing system was very inadequate, and has now been investigated by the Management Accountants Department. The cost centres involved in the project are considered to be entirely logical and can be incorporated with many other proposals for a better management information system.
2. Company A have been encouraged to do useful work in finding out what their warehousing is costing. Factors that were not previously clearly shown are now apparent; for example, the high costs of mobile handling equipment became apparent.

The only minor disadvantages found by company A were:

Defining interfaces between cost centres with no easily defined break-point.
Assigning the man hours, equipment and unit loads correctly to one of 10–15 cost centres used in that warehouse area.

However, both these were easily overcome.

The methods used by Company A in tackling both the large and small warehouses were:

Obtain a thorough understanding of the scheme's requirements. They thought a one hour talk to the ‘team’ who would carry out the cost analysis would be useful.

Draw a flow diagram for the warehouse, getting line management to agree to it, thus identifying cost centres.

Decide which sub cost centres and primary costs are applicable to each cost centre. This was done by discussion with line management or by measurement.

Correctly apportion man hours, equipment, overheads, etc., between cost centres. This was done by measurement or discussion.

Decide the number of unit load modules, and measure the quantity of each applicable module for each cost centre.

Put costs to the above and complete the forms.

For subsequent routine information, Company A thought that a simpler system grouping two adjacent cost centres together would be used. This would give line management the basic information needed, and if deviations were to be investigated, the information used to compile the original system could be used, or a special investigation made. Company A considered that generally 6–8 main cost centres would supply routine information quite adequately. Company A claim that they have rapidly saved far more money than the investigation cost them and are now using the information to systems design a new handling and storing system.

Report by Company X
Application of the 'uniform costing system' to a proposed handling and storage system for Company X

Company X have decided to move a large part of their existing production, handling and storage facilities into a completely new building complex a few miles away. The concept of the building itself was more or less established by the architects before the details of the production, handling and storage had been settled. The equipment will be operated on two shifts, and it is the management's aim to use the most advanced and economic techniques available.

The design of the handling and storage layouts was left until somewhat after the layout of the production equipment and was partly in the hands of management consultants. The initial concepts of the handling and storage fell into two flows of finished goods, which could be conveniently treated separately, both as systems and for costing purposes—a high user and a low user concept. Company X's two systems are:

A. A flow of pallets from the production machines into a live-storage system, employing stacker cranes for input and output, because the rate of throughput of goods is very high and only around three days' stock is held under normal conditions. Then the pallets pass through order-assembly and are loaded with the pre-assembled goods from system B into waiting vehicles for despatch to wholesale and retail outlets. System A handles about 90% of the total volume of goods.

B. Pallets of goods are taken from the end of the production machine lines and are conveyed on hand pallet trucks to a small store, where they await selection and transportation to a series of order-picking modules, where orders of much less than one full pallet load are picked, put on to pallets and pass on to be order-assembled with the full pallet loads of system A. System B handles the remaining 10% of the volume of goods.

Whilst the consultants were investigating alternative types of equipment, the management asked them what the unit costs of the handling and storage systems would be. They found some
difficulty in answering this question and after some deliberations, invoked the aid of the 'uniform costing system'.

With the agreement of the management, preliminary discussions took place with the warehouse management who were to take over the systems with the engineers and with the accounts department. A team was not set up formally, but in effect, it existed, co-ordinated by the management consultants.

The detailed costs data was collected in four or five sessions, although most of it was predicted

FIG. 15 Warehouse performance—unit cost diagram

VERTICAL SCALE: VALUES OF COMPANIES VOLUME PERFORMANCE INDICES (VPI)
UNITS: £ Sterling per cubic yard of goods throughput
ALL VALUES REPRESENT UNIT LOAD IN/UNIT LOAD OUT SITUATIONS AND DO NOT INCLUDE ORDER-PICKING OR ORDER-ASSEMBLY AND PACKING ACTIVITIES, HOWEVER, THESE SEPARATE VALUES MAY BE SHOWN AND ARE INDICATED.

HORIZONTAL SCALE: VALUES OF AVERAGE ANNUAL VOLUME OF THROUGHPUT OF GOODS
UNIT: 100,000 CUBIC YARDS

THREE ZONES ARE SHOWN:
ZONE A - HIGHER PERFORMANCE EFFICIENCY COUPLED WITH ALL THROUGHPUTS
ZONE B - AVERAGE PERFORMANCE EFFICIENCY WITH LOW TO MEDIUM THROUGHPUTS
ZONE C - POOR PERFORMANCE EFFICIENCY WITH VERY LOW THROUGHPUTS
information. Nevertheless, the team was satisfied that it was accurate enough to be useful and meaningful. The information was processed by the methods described in this report and presented for discussion.

The main features which were immediately highlighted were:

Firstly,

(a) The unit cost of system A was good (see Fig. 15). However, the percentage of labour proposed in several of the main cost centres appeared excessively high.

(b) The unit cost of system B was average to poor and the additional order-picking costs appeared extremely large compared with the general range of VPI's (see Fig. 15).

Further examination of the predicted personnel requirements then showed that very large economies could be effected in system A, of the order of around £40 000 per annum.

Secondly, a further saving of many thousands of pounds would be possible by mechanising the system for transferring the pallets from the production machines to the live storage unit.

Thirdly, the analysis shows up the large costs of the present modular system of order-picking. This prompted the company's industrial engineers to look again at the possibility of mechanising the order-picking system. Such a scheme, if feasible in practice, might reduce the manual order-picking costs by around 50% for a very modest capital investment.

The unit costs were then recalculated using the corrected data and re-plotted on the unit cost diagram, showing a significant reduction in the predicted values for both system A and system B.

The whole exercise took only odd hours over a period of several weeks, and was considered amply justified; the Board had their minds put at rest that ultimate performance should be good, the warehouse management had gained knowledge and confidence in getting to grips with the situation which would be presented to them when they had to take over, the industrial engineers were able to re-examine important possibilities for the order-picking operation, and the consultants could continue to develop the details of the handling and storage systems in collaboration with the firm.
6. The cost of warehouse buildings, storage space and associated land costs

6.1. It has been established in previous sections that the true costs of the warehouse buildings and their associated allocated service costs (e.g. rates, insurance, heating, maintenance) are significant compared with equipment and labour costs.

It seemed important, therefore to establish the elements of typical warehouse buildings and to find out how they affect the cost of space, mainly in relation to height and volume of the space required for various parts of warehouse systems.

Another factor, not necessarily directly associated with the costs of the warehouse building itself, is the cost of the land selected as the site for the warehouse. An investigation of the variation of the cost of land between countries and within the British Isles has been carried out and its place in the overall costs of warehouse systems is discussed later in this section.

The investigations described in this section were carried out jointly with Mr. E. Kay, Senior Research Fellow, Materials Handling Research Unit, Cranfield Institute of Technology.

6.2. Classification of warehouse buildings

6.2.1. The analysis of the factors mentioned above is not straightforward in the case of warehouse buildings because these vary considerably in size, shape and specification depending on the type, volume and densities of products handled, the type of handling and stacking equipment and the interfacing of the warehouse handling system with any associated transport system. Last but not least, the individual whims and prejudices of the client, the consultants and the architects may have a significant effect on the looks, layout and costs of the final building.

Nevertheless, one of the objectives of our investigation was to find any general factors which might exist and to attempt to quantify them, with the aim of predicting future costs of handling and storage space requirements.

6.2.2. The number of sections of the warehouse building will depend on the functions present, such as, unloading, main storage, order-picking, order-assembly, packing, loading, offices, computer room, equipment maintenance area and spare pallet storage area. The design, shape and size of each section will vary, but two main categories of structure have developed to accept some or all of these functions:

(a) Modern conventional structure

This is usually one storey high with heights commonly in the range of 10-30 feet but sometimes up to 50 feet, and sometimes with mezzanine floors to make betterutilisation of space. Good examples are Freeman’s mail-order warehouse at Peterborough (30 feet high) and Sainsbury’s new warehouse at Charlton, where good design of a mezzanine floor in parts of the warehouse has saved space.

(b) ‘High-bay’ structure (known as ‘high-rise’ in the USA)

Here the emphasis is upon increased height in order to obtain the full benefits of mechanised stacking equipment (e.g. stacker cranes) and to reduce building costs. A further advantage is that relatively less site area is required compared with the equivalent conventional storage building.

This type of structure is normally only used for the main storage area but in some cases other functions, order-picking and order-assembly, have been integrated in the equipment and building design to save space; an example is the new CWS regional warehouse at Birtley. Another example is the high-bay warehouse at Perkins Engines Ltd. Peterborough, a straightforward design with no requirement for order-picking.
Normally, the unloading and loading functions do not require great building height, so inexpensive bays to cover these functions are attached to the main high-bay structure.

### 6.3. Specification for a modern conventional warehouse building

Discussions with architects and construction consultants experienced in this field, illustrated the possibility of establishing a standard specification for a conventional warehouse building, and the problem was analysed independently with two such groups. The detailed data collected is exhibited and discussed later in Section 6.4.

The first step was to attempt to produce a standard specification for a typical conventional warehouse and two such specifications are shown overleaf. They serve to show the many detailed differences which can occur in drawing up a standard specification for a typical modern conventional warehouse building.

The next step was to establish 32 sets of relative dimensions for the proposed specifications of the conventional warehouse buildings so that the cost estimates by consultants and Architects would be comparable. These 32 sets of dimensions are shown in Fig. 16.

### FIG. 16 Plan for establishing 32 cost estimates of modern conventional warehouse buildings

<table>
<thead>
<tr>
<th>Volume (million cu ft)</th>
<th>Height (ft)</th>
<th>12</th>
<th>24</th>
<th>36</th>
<th>48</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
</tr>
<tr>
<td></td>
<td>2:1</td>
<td>3:1</td>
<td>4:1</td>
<td>2:1</td>
<td>2:1</td>
</tr>
<tr>
<td>1</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
</tr>
<tr>
<td></td>
<td>4:1</td>
<td>2:1</td>
<td>3:1</td>
<td>4:1</td>
<td>4:1</td>
</tr>
<tr>
<td>4</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
</tr>
<tr>
<td></td>
<td>2:1</td>
<td>4:1</td>
<td>3:1</td>
<td>2:1</td>
<td>2:1</td>
</tr>
<tr>
<td>16</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
</tr>
<tr>
<td></td>
<td>3:1</td>
<td>2:1</td>
<td>4:1</td>
<td>3:1</td>
<td>3:1</td>
</tr>
</tbody>
</table>

The entries in the table are the ratios of length to depth of the ground plan e.g. 1:1 or 4:1

In addition, both consultants and architects who drew them up emphasised that in practice, other important factors may come into play in arriving at a final design for the warehouse building many of which might nullify or oppose the logic of attempting to produce a building which optimises the efficiency of handling and storage within it. Such factors might be:

**Client idiosyncrasies** These might be susceptible to a slow process of education.

**Limitations of site itself** These are of shape, access and foundations.

At present, normal sub-soils do not need special foundations (e.g. piling to take the load of existing fork lift trucks). Normally, foundations contribute only about 2% to the total cost. There will be exceptions; for example, Sainsbury's warehouse at Charlton, which had to be on 15 feet of silt.
### Standard specification for a modern conventional warehouse building by architects X

<table>
<thead>
<tr>
<th>Ground Conditions</th>
<th>Normal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services</td>
<td>Mains, sewers, water and electricity exist to the boundary of the site.</td>
</tr>
<tr>
<td>Foundations</td>
<td>Normal mass concrete foundations with strip footings under external walls.</td>
</tr>
<tr>
<td>Floor Slab</td>
<td>8&quot; double reinforced floor slab with ½&quot; monolithic surface suitable for fork lift trucks, all laid on suitable hardcore beds.</td>
</tr>
<tr>
<td>Frame</td>
<td>Light steel frame with lattice trusses and steel purlins for roof deck. All steelwork galvanised.</td>
</tr>
<tr>
<td>Roof Structure and Covering</td>
<td>Standard galvanised roof decking covered with ½&quot; insulation board and two layers of built up felt roofing and covered with chippings. All to be laid flat but to slight falls.</td>
</tr>
<tr>
<td>External Walls</td>
<td>To be of 4½&quot; external facing bricks p.c. £20 per 1000 with a cavity and 4&quot; lightweight block internal insulating skin, all with necessary wall splitters.</td>
</tr>
<tr>
<td>Doors</td>
<td>Main doors to be sliding folding electrically operated shutter doors, Secondary doors and any doors in internal partitions sliding folding hand operated shutter doors.</td>
</tr>
<tr>
<td>Internal Partitioning</td>
<td>The internal partitioning around the loading bay is of light vertical steel channels infilled with 2&quot; wood wool slabs held in place by softwood blocking pieces bolted to steel channels.</td>
</tr>
<tr>
<td>Lighting</td>
<td>Fluorescent lighting set on a suitable grid for stacking.</td>
</tr>
<tr>
<td>Heating</td>
<td>To maintain a 55°F temperature.</td>
</tr>
</tbody>
</table>

### Standard specification for a modern conventional warehouse building by consultants Y

- Covered loading docks are required and it seems reasonable to provide the same capacity loading dock for warehouses of similar total volume. Loading docks should be 16' clear height x 8' deep with a 20' sliding folding door at each end with a bank height of 4'.
- A structural grid of say 60' x 20' max. ranging down to 50' x 15' min. should give minimum cost practical structures. A normal portal frame in uncased steel (cased stanchions) and cold rolled Zed purlins.
- Main Warehouse: 22½° pitch with asbestos cement standard six sandwich construction on purlins at 5' 6" max. pitch. Glass fibre and nylon translucent sheets in pepper pot fashion to approx. 5% of roof area. Roof ventilators to approx. 1% of roof area. Galvanised sheet valley and caves gutters. Plastic downpipes.
- Main warehouse: Assume 11" brickwork up to 8' 0" high with Watford tile sandwich construction above on sheeting at 6' 0" pitch. No windows in walls.
- Loading Bay: Assume metal decking on castella beams 2% domelights and 2% ventilations.
- Loading Bay: As for main warehouse at ends with mechanically operated sliding folding doors (one each end) 20' wide x 16' high. Long wall to be 11" brickwork up to 8' high with 4" band of continuous glazing above and asbestos cement sheets above.
- Mass concrete min. 4' deep with bearing pressure of 2T/C.
- 6" reinforced concrete on 9" hardcore for 12' stacking height; 12" reinforced concrete on 18" hardcore for 60' stacking height (adjust for intermediate cases).
- All concrete with float finish and surface hardener.
- Assume 15 lumens in warehouse, 10 lumens in loading bay.
- No heating to be provided.
- Assume full sprinkler protection throughout.

---

55
Special piling might add 10% to the total cost. If the piles are only say 12 feet deep, then it is not too expensive, but if 30 to 40 foot piles are required it would be. The basic problem in poor soil is the floor slab. For a typical warehouse the centres of the pile caps would be say 25 feet by 50 feet, with the 50 foot dimension subdivided into three with smaller numbers of piles at the sub-centres.

Other factors, such as planning authority requirements, foundation materials, ground drainage and site levelling will affect the designs and costs:

**Equipment**
The client will tend to look at the worst examples and experience; reliability will weigh heavily.

**Ancillary functions**
Cloakrooms, offices, boilers, etc. An architect consultant would say they must be in the centre of the building, which might seriously compromise the efficiency of the layout.

**Fire regulations and requirements**
Considerations such as fire wall to contain fire within compartments. These regulations can inhibit flexibility considerably, and additionally, the insurance companies may impose their own restrictions such as sprinklers. These considerations are touched on later.

**Positions of external services**
They may influence design.

**Comfort conditions for goods and staff**
Much prejudice is met here.

**Maintenance costs**
The problem of extra initial capital costs versus long-term day-to-day running costs.

**Layout to suit external traffic**
This is usually based largely upon hunch, but it need not be with the application of operational research techniques. However, the new transport regulations may heavily influence the overall analysis.

**Future expansion plans**
Different companies have different policies.

**Pilferage**
This is an important emotional and practical aspect of many warehouse managers' thinking in operating the warehouse. This may affect the design of doors as part of the security precautions, and a lot of money could be spent on this factor.

**Lighting**
How many lumens are required? 25-30 lumens may be necessary. It might be better to evenly cover around 50% of the roof area with translucent sheets; artificial lighting need only be enough (say 10-15 lumens) to allow a man to read tickets.

**Heating**
It would be useful in reducing costs to persuade the client to accept no heating of the warehouse but to radiant heat only the loading/unloading bays. The more automatic you get the less intelligent it is to heat. If heating is required for the product, then it is better to insulate with heavy material which picks up heat from the sun in the daytime and gives it out at night.

After this formidable array of factors, some emotional and some practical, it is perhaps not surprising that the final designs of some warehouse buildings fall somewhat short of ideal, particularly in respect of containing the optimum shape of storage of the goods or the most efficient equipment for handling them. Nevertheless, these are factors of importance if both the initial capital cost and the subsequent running and maintenance costs are to be kept to a minimum.

It should be noted that one specification omits sprinklers but retains means of heating, whilst the other specifies sprinklers but omits means of heating. These probably roughly cancel one another out cost-wise.

**6.4. Discussion of costs of modern conventional warehouse building**

The costs of the specifications tabulated in this section are shown in Figs. 17 and 18. These show how (a) the initial cost and (b) the initial cost per cubic foot of space vary with increasing height and increasing volume. The following points are clear from examination of the figures:
1. The cost per cubic foot of space in the modern conventional warehouse building falls dramatically with increasing height of the structure (for any volume), in one case to around only one third in increasing the height from 12 feet to 60 feet.

2. There is some reduction in cost per cubic foot with increasing volume particularly in the range of 100,000 to 1,000,000 cubic feet total capacity.

3. There is a small but significant increase in cost per cubic foot of space in departing from a square floor plan to one which has a ratio of 2:1 in length to breadth. This increase would be more marked if the ratio increased to 3:1 and 4:1 (these results have not been shown).

4. There exists a large difference in the absolute values of cost per cubic foot of space between the two sets of values submitted by the architects and the consultants. This is intriguing and important.

FIG. 17 Variation of capital cost (£) with volume and height of a modern conventional single storey warehouse
For example, as can be seen from Fig. 18:

(a) The cost per cubic foot at 12 feet building height differs by around 100%.
(b) The cost per cubic foot at 24 feet building height differs by around 25%.
(c) The cost per cubic foot at 48 feet building height differs by around 20%.

Whilst the two specifications differ a little in detail, it is surprising that their respective cost values should differ so much and by varying proportions, in one case as much as two to one in value.

FIG. 18 Variation of cost per cubic foot (£) with volume and height of a modern conventional single storey warehouse

One possible explanation is that the costs are not so much true costs as reflections of prices.

Traditionally, the analysis of cost of building has been carried out by quantity surveyors who use their own specialised forms of quoting costs, for example in terms of superficial area of, say,
brickwork or wall and floor covering. Usually, the costs are not broken down into labour and materials and other factors separately, but an on-cost is added finally to produce a price. This is often what the market will stand and is therefore a market price. The percentage of this on-cost (or gross profit margin) will vary very considerably and this will have a significant effect upon the cost per cubic foot of space.

The cost data assembled by consultants $y$ was used in evolving a formula for the cost per cubic foot of conventional warehouse building space, knowing the height $z$ and the cost parameters $a$, $B$ and $A$. Table 17 shows the formula.

The close correlation between the actual costs produced by consultants $y$ and the costs produced by the formula.

The values of the parameters evolved from consultants $y$'s data.

A further set of data which is relevant to this discussion is shown in Table 4 of Part I of this report which is reproduced on page 60. This shows the variation in overall warehouse building cost per square foot between twelve warehouse buildings in various parts of Great Britain (not including code number 7 and 12 which are partly high-bay structures) and shows a range of £2.80 to £6.00 per square foot with an average of £3.80 sq ft (all 1968 prices).

If an average height of building 20 feet is selected then this is equivalent to around 14.5 pence per cubic foot which is considerably higher than the equivalent values of Fig. 18.

An interesting point which shows up in Table 4 of Part I is that the costs of building maintenance per square foot per annum at an average value of 18p/sq ft are approximately 1/10 of the average annual cost per square foot of the building cost if depreciated over 40 years.

This seems to indicate that it does not seem worth while to produce an initially expensive design with the long-term aim of reducing subsequent annual maintenance.

### Table 17 Development of cost formula (developed by Mr. E. Kay) for conventional warehouses

<table>
<thead>
<tr>
<th>$V + z, \text{ etc.} +$</th>
<th>$\text{C}_{\text{1M}}$</th>
<th>$\text{C}_{\text{1b}}$</th>
<th>$\text{C}_{\text{1M}}$</th>
<th>$\text{C}_{\text{1b}}$</th>
<th>$\text{C}_{\text{4M}}$</th>
<th>$\text{C}_{\text{4b}}$</th>
<th>$\text{C}_{\text{16M}}$</th>
<th>$\text{C}_{\text{16b}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>new pence</td>
<td>new pence</td>
<td>new pence</td>
<td>new pence</td>
<td>new pence</td>
<td>new pence</td>
<td>new pence</td>
<td>new pence</td>
<td>new pence</td>
</tr>
<tr>
<td>12 ft</td>
<td>12.1</td>
<td>12.1</td>
<td>9.8</td>
<td>9.8</td>
<td>10.2</td>
<td>10.2</td>
<td>9.15</td>
<td>9.2</td>
</tr>
<tr>
<td>24 ft</td>
<td>7.9</td>
<td>7.95</td>
<td>6.9</td>
<td>7.0</td>
<td>7.3</td>
<td>7.2</td>
<td>6.65</td>
<td>6.6</td>
</tr>
<tr>
<td>36 ft</td>
<td>7.3</td>
<td>7.2</td>
<td>6.05</td>
<td>5.9</td>
<td>6.05</td>
<td>6.1</td>
<td>5.2</td>
<td>5.3</td>
</tr>
<tr>
<td>48 ft</td>
<td>7.1</td>
<td>7.15</td>
<td>5.2</td>
<td>5.25</td>
<td>5.4</td>
<td>5.5</td>
<td>4.65</td>
<td>4.4</td>
</tr>
<tr>
<td>60 ft</td>
<td>4.8</td>
<td>4.8</td>
<td>5.2</td>
<td>5.15</td>
<td>3.75</td>
<td>3.70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values of parameters

<table>
<thead>
<tr>
<th>$A$</th>
<th>-4.5121</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>310.8971</td>
</tr>
<tr>
<td>$b$</td>
<td>273.425</td>
</tr>
<tr>
<td>$B$</td>
<td>2.1874</td>
</tr>
</tbody>
</table>

including code number 7 and 12 which are partly high-bay structures and shows a range of £2.80 to £6.00 per square foot with an average of £3.80 sq ft (all 1968 prices).
## Allocated services—cost factors (TABLE 4 reproduced from Part 1)

(Shillings/sq ft except where otherwise stated)

<table>
<thead>
<tr>
<th>Company code No.</th>
<th>1</th>
<th>2A</th>
<th>2B</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>501 Building cost*</td>
<td>3.78</td>
<td>3.7</td>
<td>1.32</td>
<td>5.0</td>
<td>6.3</td>
<td>2.66</td>
<td>5.0</td>
<td>4.88</td>
<td>2.63</td>
<td>3.56</td>
<td>3.77</td>
<td>3.75</td>
<td>3.58</td>
<td>2.9</td>
<td>3.60</td>
</tr>
<tr>
<td>502 Building maintenance</td>
<td>0.309</td>
<td>0.104</td>
<td>0.0796</td>
<td>0.444</td>
<td>0.270</td>
<td>0.810</td>
<td>0.453</td>
<td>0.129</td>
<td>0.272</td>
<td>1.0</td>
<td>0.341</td>
<td>0.147</td>
<td>0.363</td>
<td></td>
<td></td>
</tr>
<tr>
<td>503 Building cleaning</td>
<td>0.921</td>
<td>0.226</td>
<td>0.093</td>
<td>0.054</td>
<td>0.825</td>
<td>0.272</td>
<td>0.465</td>
<td>0.0515</td>
<td>0.018</td>
<td></td>
<td>0.343</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>504 Building hire/rental</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>505 Rates</td>
<td>3.57</td>
<td>4.0</td>
<td>0.073</td>
<td>0.098</td>
<td>2.0</td>
<td>3.25</td>
<td>3.5</td>
<td>1.95</td>
<td>0.58</td>
<td>1.20</td>
<td>2.81</td>
<td>1.5</td>
<td>2.26</td>
<td>2.25</td>
<td>2.074</td>
</tr>
<tr>
<td>506 Building insurance</td>
<td>0.096</td>
<td>1.19</td>
<td>0.376</td>
<td>0.48</td>
<td>0.12</td>
<td>0.36</td>
<td>0.27</td>
<td>0.23</td>
<td>0.06</td>
<td>0.097</td>
<td>0.5</td>
<td>0.155</td>
<td>0.115</td>
<td>0.311</td>
<td></td>
</tr>
<tr>
<td>507 Heating$</td>
<td>0.0304</td>
<td>0.074</td>
<td>0.0500</td>
<td>0.0269</td>
<td>0.0155</td>
<td>0.0766</td>
<td>0.0657</td>
<td>0.099</td>
<td>0.0357</td>
<td>0.0261</td>
<td>0.0488</td>
<td>1.1</td>
<td>0.018</td>
<td>0.0266</td>
<td>0.121</td>
</tr>
<tr>
<td>508 Lighting</td>
<td>0.031</td>
<td>0.074</td>
<td>0.068</td>
<td>0.053</td>
<td>0.044</td>
<td>0.095</td>
<td>0.570</td>
<td>0.091</td>
<td>0.090</td>
<td>0.0112</td>
<td>0.6</td>
<td>0.095</td>
<td>0.22</td>
<td>0.157</td>
<td></td>
</tr>
<tr>
<td>509 Ventilation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.095</td>
<td>0.095</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>516 Janitor service</td>
<td>0.055</td>
<td>0.515</td>
<td></td>
<td>0.085</td>
<td>0.227</td>
<td>0.276</td>
<td>0.343</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Equivalent current initial cost of building in £/sq ft.
$Heating factor given in shillings/cubic ft.

Company No. 3 not shown but with value of 3·5 shillings/sq ft.
Perhaps the wide variation in price to build a modern conventional warehouse is not so surprising, bearing in mind that the Building Research Station have investigated the number of hours required to build a standard specification of a semi-detached dwelling in Great Britain and have found this figure to vary from around 600 to 2000 hours. Presumably the final prices asked reflected these differences in some way.

Mr. E. R. Skoyles of the Building Research Station, has been active for many years in calling for a review of traditional quantity surveying methods for building construction. He has ceaselessly advocated the development and introduction of the production approach to replace conventional bills of quantity surveying practice in order to be able to obtain more accurate estimates of cost, not only in terms of labour and materials but also in terms of relating architects design to cost and site erection efficiency. He also hopes to improve the specification of materials handling on site coupled with management planning of the whole job of designing, specifying, tendering, contracting and erecting a building.

Such general considerations no doubt extend to warehouse buildings, whether they are of conventional or high-bay design. Basically there would appear to be three main factors which might be considered in attempting to find a design for a modern conventional warehouse at minimum cost:

1. To try to use a design with maximum possible height for a given required volume of storage, consistent with maintaining efficient handling of the goods inside.
2. To try to use a square floor plan, where this is consistent with optimised handling and storage design within*.
3. To consider very carefully the price which is being asked in relation to the specification under consideration, preferably in terms of cost per cubic foot of space.

Where justified, it would seem sensible to adopt simple designs with minimum heating and finish requirements to reduce the initial capital cost, bearing in mind that the useful life of warehouse buildings may be shortening in practice because of more rapidly changing requirements of the markets for the products being stored, handled and distributed today and in the near future.

6.5. Specification for a high-bay warehouse structure

It was explained in sub-section 6.2 that it may be convenient or necessary to design and build the main storage volume of the warehouse system to a much greater height than the other parts of the system, mainly for reasons of cost reduction in building, permitting maximum utilisation and efficiency of mechanised handling equipment and to save ground area, which may or may not be of first-rate importance.

The development of the so called 'high-bay' storage structure has passed through several stages to reach the present state of development and it may well be that it will undergo more modifications and developments within the next few years.

These stages are:

1. The earliest attempts, for example the book warehouse at Guttesho, West Germany, equipped with early stacker cranes in which separate steel racking was provided with very wide aisles by today's standards. The racking is not high at some 40 feet and it is enclosed by a conventional brick and concrete warehouse building.
2. More sophisticated design of the racking to increase the stacking height and to reduce the aisle widths in conjunction with improved stacker crane design and operation. The racking is still free-standing within the building and a number of good examples have been built in the USA.
3. The combination of the steel racking structure with outside weather cladding to virtually eliminate the conventional building work. The racking must be more carefully stressed as it has to withstand snow loads, wind pressure and the greater loads imposed by the greater stacking heights required to utilise the stacker cranes to their fullest. The increased stacking heights also contribute to relatively smaller ground areas being required. The racking supports the entire outer cladding of the building and the cladding may not only give

* A Mathematical Model of a Warehouse, by E. Kay, June 1968.
<table>
<thead>
<tr>
<th>Company</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of 'high-bay' main storage unit</td>
<td>ft</td>
<td>110</td>
<td>80</td>
<td>112.5</td>
<td>61</td>
<td>60</td>
<td>36</td>
<td>46.5</td>
<td>80</td>
<td>45</td>
<td>69</td>
<td>98</td>
<td>64</td>
<td>45</td>
<td>57.5</td>
<td>65</td>
</tr>
<tr>
<td>m</td>
<td>33.5</td>
<td>25</td>
<td>34.3</td>
<td>18.3</td>
<td>11</td>
<td>14.2</td>
<td>14.2</td>
<td>25</td>
<td>14</td>
<td>21</td>
<td>3065</td>
<td>19.5</td>
<td>14</td>
<td>175</td>
<td>19.8</td>
<td>29</td>
</tr>
<tr>
<td>Length of 'high-bay' main storage unit</td>
<td>ft</td>
<td>537</td>
<td>453</td>
<td>478</td>
<td>415</td>
<td>195</td>
<td>212</td>
<td>173.5</td>
<td>276</td>
<td>84</td>
<td>262</td>
<td>218</td>
<td>167</td>
<td>151</td>
<td>285</td>
<td>528</td>
</tr>
<tr>
<td>m</td>
<td>141.3</td>
<td>149</td>
<td>126.5</td>
<td>59.4</td>
<td>64.6</td>
<td>52.9</td>
<td>86</td>
<td>26.3</td>
<td>80</td>
<td>68</td>
<td>52</td>
<td>47</td>
<td>86.9</td>
<td>160.9</td>
<td>18.3</td>
<td></td>
</tr>
<tr>
<td>Width of 'high-bay' main storage unit</td>
<td>ft</td>
<td>131</td>
<td>86</td>
<td>88</td>
<td>135</td>
<td>69</td>
<td>94</td>
<td>20</td>
<td>64</td>
<td>64</td>
<td>41</td>
<td>30</td>
<td>96</td>
<td>51</td>
<td>80</td>
<td>97</td>
</tr>
<tr>
<td>m</td>
<td>39.9</td>
<td>26.9</td>
<td>27.5</td>
<td>30.5</td>
<td>21</td>
<td>28.6</td>
<td>6.1</td>
<td>20</td>
<td>20</td>
<td>12.5</td>
<td>9.3</td>
<td>30</td>
<td>16</td>
<td>4.9</td>
<td>29.6</td>
<td>18.3</td>
</tr>
<tr>
<td>No. of aisles</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>9?</td>
<td>1</td>
</tr>
<tr>
<td>No. of cells</td>
<td>14 756</td>
<td>5 824</td>
<td>8 960</td>
<td>11 700</td>
<td>5 410</td>
<td>2 700</td>
<td>870</td>
<td>7 000</td>
<td>2 380</td>
<td>(2 733)</td>
<td>2 850</td>
<td>3 800</td>
<td>4 000</td>
<td>(6 120)</td>
<td>10 670</td>
<td>3 794</td>
</tr>
<tr>
<td>Volume of main 'high-bay' unit 000 cu ft</td>
<td>7 738</td>
<td>3 355</td>
<td>4 820</td>
<td>2 531</td>
<td>807.3</td>
<td>717</td>
<td>161</td>
<td>1 377</td>
<td>215</td>
<td>741.6</td>
<td>684</td>
<td>1 102</td>
<td>168</td>
<td>1 311</td>
<td>3 329</td>
<td>342</td>
</tr>
<tr>
<td>000 cu m</td>
<td>219</td>
<td>95</td>
<td>136.5</td>
<td>71.7</td>
<td>22.86</td>
<td>20.3</td>
<td>4.56</td>
<td>39</td>
<td>11</td>
<td>21</td>
<td>19.37</td>
<td>31.2</td>
<td>4.76</td>
<td>37.12</td>
<td>94.27</td>
<td></td>
</tr>
<tr>
<td>Cost of racking only (1969)</td>
<td>£</td>
<td>485370</td>
<td>383 000</td>
<td>510 000</td>
<td>525 400</td>
<td>73 000</td>
<td>81 350</td>
<td>18 200</td>
<td>89 000</td>
<td>32 940</td>
<td>109370</td>
<td>?</td>
<td>125 000</td>
<td>20 830</td>
<td>71 875</td>
<td>208 330</td>
</tr>
<tr>
<td>Cost of building only (1969)</td>
<td>£</td>
<td>537 660</td>
<td>2 200 000</td>
<td>378 000</td>
<td>350 075</td>
<td>159 470</td>
<td>102 650</td>
<td>35 800</td>
<td>130 900</td>
<td>61 415</td>
<td>55 730</td>
<td>?</td>
<td>20 000</td>
<td>47 500</td>
<td>332 490</td>
<td></td>
</tr>
<tr>
<td>Cost /cell of building + racking</td>
<td>£</td>
<td>69.3</td>
<td>103.5</td>
<td>99.1</td>
<td>75</td>
<td>43</td>
<td>68</td>
<td>62</td>
<td>31</td>
<td>39.6</td>
<td>30.4</td>
<td>40.0</td>
<td>38</td>
<td>17</td>
<td>66</td>
<td>49.5</td>
</tr>
<tr>
<td>Cost of 'high-bay' building + racking (1969)</td>
<td>£</td>
<td>1 023 030</td>
<td>603 000</td>
<td>888 000</td>
<td>875 475</td>
<td>232 470</td>
<td>184 000</td>
<td>54 000</td>
<td>219 000</td>
<td>94 355</td>
<td>165 100</td>
<td>115 000</td>
<td>145 000</td>
<td>68 330</td>
<td>404 365</td>
<td>524 990</td>
</tr>
<tr>
<td>Cost/cell of racking only</td>
<td>£</td>
<td>33</td>
<td>37.6</td>
<td>31.7</td>
<td>45</td>
<td>13.5</td>
<td>30</td>
<td>(21)</td>
<td>12.7</td>
<td>13.85</td>
<td>20</td>
<td>?</td>
<td>32</td>
<td>5.2</td>
<td>21.75</td>
<td>19.52</td>
</tr>
<tr>
<td>Cost/cu ft of racking only</td>
<td>£</td>
<td>0.0627</td>
<td>0.0652</td>
<td>0.0590</td>
<td>0.2076</td>
<td>0.0904</td>
<td>0.1134</td>
<td>0.1134</td>
<td>0.0646</td>
<td>0.1532</td>
<td>0.1475</td>
<td>?</td>
<td>0.1134</td>
<td>0.240</td>
<td>0.0626</td>
<td>0.28</td>
</tr>
</tbody>
</table>
TABLE 19  High-bay storage units—a sample of dimensional and cost data [contd.]

<table>
<thead>
<tr>
<th>Company</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>% utilisation of storage cube (ratio of rack storage to total W/H vol.)</td>
<td>66%</td>
<td>66%</td>
<td>66%</td>
<td>—</td>
<td>63%</td>
<td>60%</td>
<td>58%</td>
<td>56%</td>
<td>65%</td>
<td>63%</td>
<td>60%</td>
<td>53%</td>
<td>56%</td>
<td>55%</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td>(D) Total cost/cu ft</td>
<td>0.132</td>
<td>0.117</td>
<td>0.117</td>
<td>0.346</td>
<td>0.29</td>
<td>0.25</td>
<td>0.33</td>
<td>0.16</td>
<td>0.44</td>
<td>0.22</td>
<td>0.158</td>
<td>0.13</td>
<td>0.41</td>
<td>0.31</td>
<td>0.158</td>
<td>0.65</td>
</tr>
<tr>
<td>cost/cu m</td>
<td>4.67</td>
<td>4.15</td>
<td>4.15</td>
<td>12.2</td>
<td>10.24</td>
<td>8.83</td>
<td>11.6</td>
<td>5.65</td>
<td>15.54</td>
<td>7.77</td>
<td>5.3</td>
<td>4.6</td>
<td>14.5</td>
<td>10.9</td>
<td>19.4</td>
<td></td>
</tr>
<tr>
<td>Cost of land</td>
<td>£/sq ft</td>
<td>0.298</td>
<td>0.117</td>
<td>—</td>
<td>8.000</td>
<td>—</td>
<td>8.000</td>
<td>—</td>
<td>—</td>
<td>0.177</td>
<td>7.710</td>
<td>—</td>
<td>—</td>
<td>417</td>
<td>—</td>
<td>8.000</td>
</tr>
<tr>
<td>£/acre</td>
<td>13.000</td>
<td>5.096.5</td>
<td>—</td>
<td>8.000</td>
<td>—</td>
<td>8.000</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>(C) Cost of land for area of high-bay</td>
<td>£/sq ft</td>
<td>£/cu m</td>
<td>£/sq ft</td>
<td>£/cu m</td>
<td>£/sq ft</td>
<td>£/cu m</td>
<td>£/sq ft</td>
<td>£/cu m</td>
<td>£/sq ft</td>
<td>£/cu m</td>
<td>£/sq ft</td>
<td>£/cu m</td>
<td>£/sq ft</td>
<td>£/cu m</td>
<td>£/sq ft</td>
<td>£/cu m</td>
</tr>
<tr>
<td>0.00270</td>
<td>0.0953</td>
<td>—</td>
<td>—</td>
<td>0.00176</td>
<td>0.00016</td>
<td>0.0565</td>
<td>0.565</td>
<td>—</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratio C/D %</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Location</td>
<td>UK</td>
<td>W Germany</td>
<td>W Germany</td>
<td>UK</td>
<td>UK</td>
<td>UK</td>
<td>UK</td>
<td>Switzerland</td>
<td>Switzerland</td>
<td>W Germany</td>
<td>Switzerland</td>
<td>W Germany</td>
<td>W Germany</td>
<td>USA</td>
<td>USA</td>
<td>UK</td>
</tr>
<tr>
<td>Is order-picking included in the warehouse system?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Racking integral with the building</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
### TABLE 20 High-bay storage units—a sample of dimensional data

<table>
<thead>
<tr>
<th>Company</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of different unit loads</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Unit load with</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inches</td>
<td>79</td>
<td>99</td>
<td>72</td>
<td>48-5</td>
<td>48</td>
<td>24</td>
<td>31.5</td>
<td>31.5</td>
<td>31.5</td>
<td>39.4</td>
<td>47-25</td>
<td>31-5</td>
<td>44</td>
<td>54</td>
<td>48</td>
</tr>
<tr>
<td>mms</td>
<td>2009</td>
<td>2500</td>
<td>1829</td>
<td>1219</td>
<td>1219</td>
<td>609</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>1000</td>
<td>1200</td>
<td>900</td>
<td>1117</td>
<td>1371</td>
<td>1219</td>
</tr>
<tr>
<td>Unit load depth (into racking)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inches</td>
<td>54</td>
<td>57</td>
<td>48</td>
<td>22</td>
<td>40</td>
<td>40</td>
<td>47-25</td>
<td>47-25</td>
<td>47-25</td>
<td>47-25</td>
<td>39.4</td>
<td>47.25</td>
<td>54</td>
<td>46</td>
<td>40</td>
</tr>
<tr>
<td>mms</td>
<td>1372</td>
<td>1700</td>
<td>1219</td>
<td>558</td>
<td>1016</td>
<td>1016</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1000</td>
<td>1200</td>
<td>1371</td>
<td>1168</td>
<td>1016</td>
</tr>
<tr>
<td>Unit load height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inches</td>
<td>64</td>
<td>87</td>
<td>36</td>
<td>41</td>
<td>60</td>
<td>30</td>
<td>61</td>
<td>35-5</td>
<td>39-4</td>
<td>65-75</td>
<td>59</td>
<td>31-5</td>
<td>68-5</td>
<td>52</td>
<td>60</td>
</tr>
<tr>
<td>mms</td>
<td>1626</td>
<td>2200</td>
<td>914</td>
<td>1041</td>
<td>1524</td>
<td>762</td>
<td>1500</td>
<td>900</td>
<td>1000</td>
<td>1670</td>
<td>1500</td>
<td>800</td>
<td>1524</td>
<td>1320</td>
<td>1524</td>
</tr>
<tr>
<td>Unit load volume (including pallet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cu yds</td>
<td>5.85</td>
<td>12.2</td>
<td>2.666</td>
<td>0.9376</td>
<td>2.469</td>
<td>0.673</td>
<td>1.946</td>
<td>1.130</td>
<td>1.255</td>
<td>2.621</td>
<td>2.354</td>
<td>1.004</td>
<td>2.334</td>
<td>2.765</td>
<td>2.469</td>
</tr>
<tr>
<td>cu m</td>
<td>4.48</td>
<td>9.3</td>
<td>2.039</td>
<td>0.7168</td>
<td>1.887</td>
<td>0.472</td>
<td>1.488</td>
<td>0.864</td>
<td>0.960</td>
<td>2.004</td>
<td>1.800</td>
<td>0.768</td>
<td>1.784</td>
<td>2.114</td>
<td>1.887</td>
</tr>
<tr>
<td>*Unit load weight (max.) (including pallet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lbs</td>
<td>3000</td>
<td>5600</td>
<td>2600</td>
<td>975</td>
<td>4480</td>
<td>1120</td>
<td>2205</td>
<td>3968</td>
<td>1764</td>
<td>1102</td>
<td>2205</td>
<td>2205</td>
<td>2000</td>
<td>3000</td>
<td>4500</td>
</tr>
<tr>
<td>kgs</td>
<td>1364</td>
<td>2540</td>
<td>1270</td>
<td>578</td>
<td>2032</td>
<td>508</td>
<td>1000</td>
<td>1800</td>
<td>800</td>
<td>500</td>
<td>1000</td>
<td>1000</td>
<td>816</td>
<td>1361</td>
<td>2040</td>
</tr>
<tr>
<td>*Unit load density</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lbs/cu yd</td>
<td>513</td>
<td>—</td>
<td>975</td>
<td>9787</td>
<td>1814</td>
<td>1814</td>
<td>1133</td>
<td>3511</td>
<td>1405</td>
<td>420</td>
<td>936</td>
<td>2196</td>
<td>771</td>
<td>1085</td>
<td>1822</td>
</tr>
<tr>
<td>kgs/cu m</td>
<td>304</td>
<td>—</td>
<td>578</td>
<td>580</td>
<td>1076</td>
<td>1026</td>
<td>672</td>
<td>2083</td>
<td>833</td>
<td>250</td>
<td>555</td>
<td>1303</td>
<td>451</td>
<td>643</td>
<td>1080</td>
</tr>
</tbody>
</table>

* Where more than one size largest runner is taken.
complete weather protection, but if so designed will provide adequate thermal insulation for all, or at least the great majority of, the year.

4. The current developments which include even higher utilisation of space such as the slave trolley transporter system, the use of reinforced concrete pre-cast modules and even more careful design and stressing of steel racking structures to reduce material usage and thereby cost.

At the same time, it is of growing importance that the fire detection and control systems should be integrated with the structural design from the start, particularly with intermediate-level sprinkler systems. Tables 18, 19 and 20 give some data on a sample of high bay storage units in several countries. The largest by volume is approaching the 10 million cubic feet size, and heights are now up to 100 feet.

FIG. 19 High-bay warehouse units—variation of initial cost/cubic foot of total volume with size

Figure 19 shows the total cost per cubic foot of high-bay space and also the cost per cubic foot of high-bay racking plotted against the size (volume) of the various high-bay storage units.

It is interesting to note that:

(a) It appears that it is likely to be significantly more costly to build high-bay racking as a freestanding structure within a separate building, because the cost of the high conventional building is relatively high. This confirms that modern design of high-bays in which the racking is an integral part of the building is significantly cheaper, although the cost starts to rise steeply when the total volume of the storage unit is less than approximately 1½ million cubic feet. A frequent comment made in connection with the decision to build a high-bay warehouse is that it was necessary because of shortage of land; whilst this is undoubtedly true in most cases, there is often an implication that this is a justification for saving money by using less land. This may be misleading and even dangerous, for far more money is in the balance if the high-bay is not the best and most efficient system design for the particular goods handled and the operations involved. This is another factor which must be considered in the complex process of decision-making as to which design of warehouse should be ultimately selected.

The bearing that the land has upon the decisions is further complicated by the fact that the land will often be an appreciating asset. Often competing demands exist for the surplus land between production/factory interests and warehouse/distribution interests, and the demand by production for more space to expand wins the day. It seems important for the
warehousing/distribution organisation to beware of accepting a high-bay approach purely for these considerations without at least examining whether its operating costs and efficiency will be adequate when the high-bay is in regular use.

(b) The integral racking accounts for approximately half of the total cost. Again, the relative costs climb steeply below 1 million cubic feet.

(c) There do not appear to be any marked economies of scale of 2 million cubic feet. The designer can take the view that to go very large will not produce additional striking savings in high-bay building cost.

(d) The results give a reasonably accurate price per cubic foot and per 'cell' for high-bay storage units (based on 1969 price levels).

FIG. 20 High-bay warehouse units—variation of initial cost/cubic foot of total volume with height of racking

Figure 20 shows the total cost per cubic foot of the high-bay structures and also the cost per cubic foot of the high-bay racking plotted against height of the high-bay unit.

It is interesting to note:

(a) The cost per cubic foot reduces steeply between 40 feet and around 100 feet in height. After 100 feet, it levels off, suggesting that to build much over 100 feet is unlikely to produce any worthwhile relative cost reductions.

(b) The ratio between 'racking only' and 'building only' costs does not appear to alter with height and remains at approximately 50:50.

(c) The results from Figs. 17 and 18 have been plotted on Fig. 20 and indicate that the high-bay structure only begins to show cost advantage over around 60-70 feet. This suggests that it may be relatively uneconomic to design and build high-bay structures in the range of around 40-60 feet in height. Bearing in mind the comments on the data collected for Figs. 17 and 18 earlier in this section, it seems that more research is needed to clarify absolute values of cost per cubic foot of storage space and per storage position. In fact this research has now been resumed at the National Materials Handling Centre.

Figure 21 shows the variation of the total cost per cubic foot of high-bay storage space with
the density of the unit loads stored. This suggests that one gets more for one's money by using heavy unit loads, for the cost per cubic foot of space only increases at half the rate of the unit load density. Again, more research is required to confirm and enlarge the data available.

Finally, it is not amiss to make a brief comment on the relative importance of the cost of land used for the sites of conventional and high-bay buildings. Table 19 shows (three examples) the initial cost (or current value) of the land upon which the high-bay warehouses were built as a percentage of the total cost of the high-bay unit. These percentages are very small, 1/2-2%, where the cost per acre is about twice the average price for the sample shown. This suggests that the cost of land is of little importance in the overall economic cost model for a high-bay warehouse. Suppose we argue that we have saved two-thirds of the area which we should have required if we had built a conventional warehouse instead of the equivalent high-bay. Take a large example—Company 3—where the saving in land area would be say 130,000 square feet. This saving is approximately £25,000 if costed at £8000 per acre; whilst this saving is considerable, when it is considered as an annuity over the (say 25 years) life of the warehouse, it is equivalent to approximately £2400 per annum. This is very small when compared with the total annual running costs of Company 3's high-bay warehouse—approximately £250,000 per annum on three shift operation which is very efficient.

FIG. 21 High-bay warehouse units—variation of initial cost/cubic foot of total volume with density of unit load

It appears that the actual cost of the land upon which warehouses are built is relatively unimportant in relation to the values of their operating costs, whether they be cost efficient or cost inefficient. There may be a good reason to wish to conserve land for other purposes, particularly if it is scarce or if to build a conventional warehouse would mean moving to another inconvenient site, when a high-bay unit would just fit into the present site, but this is a management decision which should be made in conjunction with the prediction and assessment of the cost performance of both the conventional and the high-bay warehouse systems in question. It might still prove a very expensive mistake to save land and build the high-bay if its operating costs could never be good for the products and their throughputs compared with the conventional system.

When the apparent justification for building a high-bay warehouse is quoted as 'a shortage of land', this could and should be only part of the story of management decision-making.

When one reads that the Swiss build high-bays because they are short of land, and that land is very expensive there and little of it is level, it is as well to bear in mind that land near medium
sized towns can cost as little as £8000 per acre, and also that our survey indicates that some Swiss high-bay units are cost efficient.

Conversely, there are to date relatively few high-bay units in the United States, and those mostly of modest height and built inside conventional buildings. This is not because there is necessarily plenty of land or that land is cheap; land near cities, where much industry is sited, can be just as expensive as it is in industrial sites in Europe. It is more because people in the United States have been relatively slow in recognizing the cost benefits which can accrue from building high-bay units high and at the same time operating them efficiently, when designers in Europe have gone ahead faster and gained expertise in a field where many have learned to tread warily. The United States is now developing and building some fine examples of large, high, and even automated high-bay units, some of which have been described recently in their major handling magazines.

6.6. *Fire detection and control in conventional and high-bay warehouses*

The warehouse designer is faced with these questions amongst many others:

1. Is fire detection and/or control required for the warehouse building and the products handled and stored within?
2. If so, which are the methods and equipment available?
3. Which is the cheapest system which will give a stated level of protection against loss and damage to both products, buildings and to personnel?

The full analysis of the problem is not usually straightforward or easy for the architect, the engineers or the client; it becomes even more obscure in the case of the high-bay storage unit.

The many factors involved and their translation into terms of cost have been closely studied at the National Materials Handling Centre and a separate booklet* will be published shortly on this subject.

---

* The Problems of Fire in High-Bay Warehouses, by C. E. Williams, published by the National Materials Handling Centre.
7. Control systems in warehouses

7.1. Objectives

In any warehouse and associated distribution network, there must exist a system of control of incoming goods, outgoing goods, transportation, and information; it may be more or less adequate.

It seems almost impossible to generalise about the form which any warehouse and distribution network might take, since the number and type of warehouses employed and their relation to the location of suppliers and consumers will depend upon the type of goods handled, their rates of throughput, the local service demands imposed by suppliers and consumers upon the network, and many other special and detailed factors.

The size and complexity of each warehouse will depend on the volume of all commodities which need to be stored, their rates of turnover, and the degree to which incoming goods have to be broken down and sorted into outgoing orders. Figure 2, Section 1, a simplified model, showed not only the flow of goods, largely from suppliers via the warehouse to the consumers and retail outlets, but also the main lines of information flow which constitute the control system. In practice there may be many suppliers both within and outside the company organisation and many consumer outlets, again within or outside the company. The goods may flow through several warehouses or some goods may flow directly between supplier and consumer (there still exists a need to keep control of these goods and to integrate this control with that of the goods passing through the warehouses).

A typical example of the complexity which may exist in practice is shown in Figs. 3 and 4 of Section 1. Figure 3 illustrates the CWS retail food and groceries network before the new regional warehouse concept at Birtley, and Fig. 4 the changes which the Birtley approach will make to the warehouse and distribution network and to the associated information flows, and thereby to the associated information control system.

There are basically two separate control systems which may operate in most warehousing/distribution networks:

(a) The warehouse control system
This has been described in Section 2, sub-section 2.2.(i).

(b) The transport and distribution control system
Several similar operations will be controlled by these control systems:

(i) The supply of goods from manufacturing plants and suppliers to the central warehouse (internal supply loop).
(ii) The supply of goods from the central warehouse or depots to the customers or retail outlets (customer supply loop).

It is not the function of this report to discuss these control systems in any detail, although they are important in their influence on the service given to the customer and on the cost efficiency of the entire distribution network.

Some of the additional functions listed below may be encountered and may justify the use of a larger computer (and therefore 'easier to use' computer) than would be justified for functions (a) and (b) alone:

Customer's orders
Marketing methods and salesmen's operations, routes and routines
Orders to suppliers and manufacturers to replenish stock levels at the warehouse
Pricing and invoicing
Stock control and recording
Auditing
Planning
Management and administration
Management analysis of operations data and subsequent management reporting.

Such functions may be extremely complicated in larger organisations particularly where computer control is used. (This does not imply that the operation of a computer is necessarily more expensive than simpler methods which the computer may have replaced.)

In assessing the efficiency, costs and cost performance of warehouse control systems, we could be examining two situations:

1. Reviewing the service efficiency and cost efficiency of an existing control system.
2. Designing a new control system to operate a new warehouse and distribution network, and wishing to predict its future costs and cost effectiveness.

To do either, the following approach may be considered:

(a) Determine that the information flowing around the system is essential and adequate.
(b) Study alternative ways of handling the information such that the present and future service demands will be met.
(c) Analyse the economics of the alternative ways available to carry out efficient control and compare:
   (i) Policies: whether to rent, lease or buy control equipment.
   (ii) Initial capital expenditure: which will be incurred in introducing control equipment, bearing in mind the latest investment grants and tax allowances, etc.
   (iii) Maintenance and running costs.
   (iv) Incidental costs: which may be incurred by required new buildings or room for the equipment, and by the organisational/personnel changes which may become necessary when new control systems and equipment are introduced.
   (v) Commissioning costs: which may be much greater than expected or budgeted, and which may not include the costs of design errors, poor reliability, problems of correcting and modifying hardware and software.

7.2. The type of control system for the high-bay warehouse—computerised or non-computerised

It was stated in Section 7.1 that there are basically two separate control systems which may operate in most warehousing/distribution networks.

(a) The warehouse control system

In the context of the high-bay warehouse system, this is likely to be concerned with the control of location and retrieval of goods by stacker cranes, slave transporter trolley systems or other mechanised means.

(b) The transport and distribution control system

In the context of the high-bay warehouse system, this is likely to be concerned with activities such as:

(i) Feeding information from (a) to general services for stock updating and stock control.
(ii) Producing order-picking lists from customers' order.
(iii) Producing programmed instructions for stacker cranes, etc., to operate them to the pre-prepared order-picking lists.
(iv) Interfacing data on stock held and picked with sales operations—invoicing, pricing, delivery notes, accounts payable and receivable.
(v) Control of transport and distribution operations, management information and many other subsidiary functions which might be required no matter what kind of warehouse operation is envisaged.
There are several distinct stages in the sophistication of equipment and methods which can carry out these activities:

1. Simple systems employing tickets, clerical labour and possibly small printing machines.
2. More complex systems, employing office machinery of considerable speed and complexity, but still controlled by clerical personnel. The volume and rate of interchange of information may be very large, but its control is still largely by people’s decision.
3. Systems employing ‘hard-wired’ equipment but no computers; for example, operator control of stacker cranes using punched cards to locate and retrieve pallets of goods. The punched cards can be sent by pneumatic tubes, for example, to a central office to provide data to interface with operations (b)(i) to (v).
4. Systems employing minicomputers, possibly interfaced with compatible storage facilities; teletype, punched card, punched paper tape or mark-sense input; printer or magnetic tape output. These systems may be used to control stacker cranes only or can be interfaced with off-line or on-line activities (b)(i) to (v) above.
5. Large and complex systems controlled by general purpose computers, in which control is largely exercised by pre-arranged computer programs. The actual operation may be off-line (processing the information in batches or at night) or fully on-line where the computer continuously monitors the information from feedback information. The actual control of location and retrieval of goods in the warehouse may be a part of the routine of the general computer service.

In the past, it used to be fashionable to have a computer, and this desire to acquire one and to possess one was often based on specious reasoning, not the least motivation being ‘to keep up with the Jones’s’. Because the motivation was ‘let’s have a computer’, the subsequent analyses and surveys were coloured by the initial feeling that a computer was inevitable and excuses were made for having one. A survey of opinion amongst computer users indicates that we are a long way from achieving the most effective use of the computer power that is available to business.

It has been reported in the press that a committee of the American Congress which examined the use made by US business of computers stated that as more business operations become more mechanised or computer based, fewer companies actually use the computer as a cost-effective tool.

Management consultants often confirm this view, and one declared that computers are over-sold and over-employed and argued that companies use computers in the wrong areas—payroll, order processing and inventory, instead of in the high pay-off areas of production control, transportation, and above all as an aid to management decision-making. In Britain, while a few companies are grouping with the problems of applying computers to the profit-creating functions of business, there are few that would care to set down the costs and benefits on a balance sheet, even if they could.

Nevertheless, the ‘fashion’ aspect of acquiring a computer is dying, and companies should now be in a better position to merit their figures and to make decisions on a sounder business basis. ‘Do we really need it?’ ‘Can we really afford it?’

Unfortunately, the purely financial aspects of justification for computers are not the whole story and there remain social, organisational and technical problems to be recognized and remedied. Such problems are dealt with in Living with a Computer by Enid Mumford, in which she describes some of the experiences of nine industrial and commercial firms when they planned and installed computers.

She found that planning was not begun soon enough and was not sufficiently comprehensive: there was a lack of communication and consultation with staff and a lack of early planning of re-education and re-training of staff. Most of the firms did not appreciate from the start that the whole process of introducing and developing the use of computer might take over two years.

Her book underlines the lack of appreciation of the true problems by top management. The effects are problems because the causes were inadvertently set up at the beginning when it was already too late.

The approach of pre-supposing that a computer is coming or is inevitable is probably the wrong-one and results almost automatically in a faulty approach to the analysis of the information and information flows in a warehouse/distribution network.
It does not seem unreasonable to suggest that a company, either on its own, or with the aid of consultants, should fully analyse the present and proposed systems before committing the company to any more elaborate system (up to and including computer operation).

What seems to go wrong is a lack of appreciation of the need to plan backwards from the desired end-point in time, even if this is several years in the future, which it almost inevitably is when a new information system is required and implemented.

**PERT CHART 1**

This suggests that a critical path plan (PERT Chart) approach could be useful, even in a crude form in setting down the actions necessary to satisfy the basic question—"What has to be done?"

The approach which too often seems to be made is illustrated in a simplified PERT Chart 1.

No conscious effort may be made to set down a PERT Chart, which seems all too often to be the case, then this chart 1 is the kind of thinking which pervades the company. It should be stressed that some real effort should be put into preparing a PERT chart, or else, as is so often the case, one merely has a nebulous diagram such as is illustrated in PERT Chart 1 to go on with.

It will be appreciated that enormous pressure can be exerted by computer manufacturers to place an early order for a machine to get delivery by the desired date; system study can easily become an investigation of how to use the 'committed' computer. Furthermore the 'desired'
It would seem much better to consider delaying the decision until all the information is collected; even though there is a risk of not receiving a machine on time. In any case, the final management decisions as to the exact specification of the machine and its exact delivery date may be postponed by alternative courses of action. For example, computer bureaux service may be retained, or a machine may be rented.

To rent may be more expensive initially but it can often be a wise decision since it will ensure that both hardware and software are exactly what are required for the present and in the long term; if they are wrong or inadequate then they can be changed without total commitment. After a year or two of full operation the long-term decision to lease or buy (or occasionally to throw it out altogether) may be taken confidently with the experience and backing of most personnel and management associated with its day-to-day operation, and no less important, the cost advantage can be fully and accurately assessed.

In carrying out such a cautious approach, even if it does take more time, at least everyone concerned is more likely to support a final scheme which goes most of the way to satisfying (a) economic, (b) technical, (c) organisational and (d) social problems, which either exist beforehand or develop during the investigation and installation of the new system.

In order to attempt to overcome some of these problems an alternative course of planning is proposed, as illustrated in Preferred PERT Chart No. 2.

The effective use of critical path analysis in planning and installing a computer is described in Chapter 6 of Computer Applications in Management by C. R. Dennys*, entitled 'Project Planning by Computer', and he illustrates a PERT Chart for the computer installation for the Electrical Trades Union.

The dangers have been stated of assuming that a computer will be needed and installed at too early a stage in the investigation of the design of handling and storage system.

Losty†, when dealing with the feasibility study, is at pains to point out a number of salient aspects:

'... we pass to the procedure for selecting a computer, designing and implementing a system... assuming that the decision favours a computer.'

Losty points out that a form of Parkinson's Law can also apply to computers—'Work expands to fill the time available.' 'Extra jobs are often loaded on to them because time is available, resulting in high costs on the computer and no advantages. Indeed it is not unknown for a substantial part of any cost saving or earlier jobs to be dissipated on later jobs better left off the computer.'

He proposed broadly the following stages which correspond closely with the Preferred PERT Chart 2 approach:

Preliminary survey
Feasibility study
Costing analysis
Selecting a computer—if required.

Losty says that in any case, 'The object of a preliminary survey is to recommend whether a full feasibility study is justified. It should indicate the scale of the computer system required, and give some idea of the magnitude of the costs involved—a study which is too superficial is likely to be unduly optimistic about the benefits of a computer, whereas a study which is too detailed will bog down in difficulties which it is not appropriate to consider so early in the study.'

7.3. **Control systems, computerised or non-computerised: sources of cost data**

The application of sophisticated equipment to the design of warehouse control systems is a relatively new development: to date there are only a few examples of installations which are fully on-line computer controlled. There are only a small number of organisations which have experience of designing, installing and operating complex control systems for mechanised warehouses, with regard to both hardware and software.

These areas are very much for the specialist, and in this report it is proposed only to give some sources of expertise and also some sources of cost data. The detailed compilation and analysis of the costs of alternative schemes must be carried out between the Company and, for example, its development engineers, the O & M and systems analysis consultants and suppliers of hardware and software.

If 'order-picking,' 'order-assembly' and 'packing' activities are present then the control system may also be required to give commands to these areas, and these commands may or may not be on-line with the input and output demands of the main storage function.

The costs of the control system will vary considerably with the degree of innovation called for; in this survey, most of the control system costs were small compared with the costs of the other main cost centres (unloading, main storage, order-picking, order-assembly, loading, auxiliary services). In fact, it seems more important that the control system should firstly be designed as an integral part of the warehouse system and should fulfil its 'service' demands with great reliability, than that its design and reliability should be cut down to secure a minimum price. A correctly designed control system with built-in flexibility and reliability should more than pay for itself in at least two ways:

1. **Firstly**, if the pre-programmed goods location systems of each 'line' are correctly designed, this will result in considerable cost reductions in the total volume of storage and stock levels required.

2. **Secondly**, an efficient control system for location and retrieval of goods avoids the necessity to recruit extra staff for peak times and emergencies to handle temporarily stored goods and deal with 'bottlenecks'.

Although the proportion of the control system costs to the total warehouse cost may still be modest, the absolute value of control system cost may itself be a large sum of money, and it will be worth while to isolate the elements of cost of the control system in more detail. When studying the predicted costs of alternative control systems proposals for the new warehouse, whether they be modern data processing office equipment, batch control computer or on-line computer, it may be possible to make a sounder decision based on a review of alternative proposed costs and cost benefits.

The evaluation of alternatives is no simple matter particularly if computers are included in the alternatives. An excellent exposition of the problems of evaluating cost effectiveness and cost benefits of computers in general is given in 'The Evaluation of Investment in Computers', by Prof. T. W. McRae, Graduate School of Business Administration, University of Witwatersrand, South Africa, published in *Abacus* (Australia), September 1970.

For example, if we consider the case of a large high-bay warehouse with several stacker cranes, we may be able to compare several possibilities for on-line real time control of the cranes.

1. **(a)** A 'hard wired' system without computers, in which operators place punched cards into the stacker cranes themselves at the ends of the aisles for location and retrieval of unit loads. This system has the merits of simplicity and cheapness.

2. **(b)** A general purpose computer, part of whose capacity can be programmed for the on-line real time control of the cranes. However, it may not always be possible to justify economically the high initial capital cost, running and maintenance costs of such a system, even if it can be justified to use some of its spare capacity for invoicing pricing, order processing and stock control.

3. **(c)** A mini-computer, compatible with data input and output systems, extra disc and tape storage can be used with just as good reliability as a larger general purpose machine. There may be extra problems of interfacing and programming in machine language but these can be exaggerated and the total order of cost can be of an order 5–10 times cheaper than solution **(b)**.
For example, the central processor of the 'mini' can cost as little as £1000 and the associated interfacing with development and programming costs as little as £15 000-£25 000. Updating of stock levels does not have necessarily to be on-line and can be put in to magnetic tape and transferred to other computers in the organisation some time later. Although immediate on-line facilities can be available for solution (b), the initial cost of the general series machine may well be in the range £50 000-£250 000 and depending on the levels and complexity of control and override required by the company can sometimes require multiplexing and a lot of special interfacing between the main computer and the process control logic on each crane.

Unfortunately, it is a fact that when one looks at the plain economic justification of replacing the several operators in solution (a) who put the punched cards in the control boxes on the cranes by fully automatic means, there is never a reasonable return because the costs, complications and commissioning problems of doing so are usually so great that there must be very good reasons for wanting to do so other than the economic justification.

Perhaps the single most important item of cost which should be estimated and budgeted is the commissioning of the control system; in large and complex systems this can be very large and cover several years in calendar time. Unfortunately, this cost is often not appreciated or budgeted and can cause considerable subsequent embarrassment to both company and systems suppliers.

A list of elements of cost is shown below which could be used for systematic analyses of control systems.

List of elements of cost for the analysis of computerised process control and service control systems for mechanised and automatic warehouses

<table>
<thead>
<tr>
<th>Code No.</th>
<th>Description</th>
<th>Type of Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>601</td>
<td>Computer processor unit</td>
<td>Depreciation</td>
</tr>
<tr>
<td>602</td>
<td>Tape unit</td>
<td></td>
</tr>
<tr>
<td>603</td>
<td>Disc pack unit</td>
<td></td>
</tr>
<tr>
<td>604</td>
<td>Drum unit</td>
<td></td>
</tr>
<tr>
<td>605</td>
<td>Printer unit</td>
<td></td>
</tr>
<tr>
<td>606</td>
<td>Tape reader unit</td>
<td></td>
</tr>
<tr>
<td>607</td>
<td>Tape punch unit</td>
<td></td>
</tr>
<tr>
<td>608</td>
<td>Card reader unit</td>
<td></td>
</tr>
<tr>
<td>609</td>
<td>Card verifier unit</td>
<td></td>
</tr>
<tr>
<td>610</td>
<td>Teletype unit</td>
<td></td>
</tr>
<tr>
<td>611</td>
<td>Visual display unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Repeat 621-631</td>
<td>Hire</td>
</tr>
<tr>
<td></td>
<td>Repeat 641-651</td>
<td>Lease</td>
</tr>
<tr>
<td>661</td>
<td>Software</td>
<td>Annual cost</td>
</tr>
<tr>
<td>662</td>
<td>Tapes</td>
<td></td>
</tr>
<tr>
<td>663</td>
<td>Discs</td>
<td></td>
</tr>
<tr>
<td>664</td>
<td>Paper tapes</td>
<td></td>
</tr>
<tr>
<td>665</td>
<td>Cards</td>
<td></td>
</tr>
<tr>
<td>666</td>
<td>Paper</td>
<td></td>
</tr>
<tr>
<td>667</td>
<td>Interfaces</td>
<td></td>
</tr>
<tr>
<td>680</td>
<td>Computer room</td>
<td>Depreciation</td>
</tr>
<tr>
<td>681</td>
<td>Computer installation and commissioning</td>
<td>Initial cost</td>
</tr>
<tr>
<td>682</td>
<td>Computer fire detection and control</td>
<td>Depreciation</td>
</tr>
<tr>
<td>683</td>
<td>Computer air conditioning</td>
<td>Depreciation</td>
</tr>
<tr>
<td>684</td>
<td>Computer power</td>
<td>Annual cost</td>
</tr>
<tr>
<td>685</td>
<td>Computer maintenance</td>
<td>Annual cost</td>
</tr>
</tbody>
</table>

Categories of personne
Card Puncher—Female
Operator
Junior Programmer
Senior Programmer
Systems Analyst
Senior Systems Analyst
Computer Manager
Computer Engineer
It is interesting, for example, that one can employ a manually operated stacker crane for picking at a cost of say £13,000 but if one requires to automate its operation the cost can be £35,000; the basic substitution can never be justified on purely economic grounds.

An interesting divergence in philosophies can be found in the published papers of the Conference on Electronic Control of Mechanical Handling, 6-8 July 1971, organised by The Institution of Electronic and Radio Engineers; in particular:

"Electronic Control of Cranes in High Bay Warehouses", by M. J. Osborn, MIEE
"Computers for Control of Automatic Warehouses", by John R. Sheard
"Automation in Materials Handling and Distribution", by George J. Savery, BA, MA (Cantab).

These papers demonstrate the current divergence in philosophy and practical approach to which kind of control system is best for any particular mechanised or automated warehouse.

It appears that considerable caution is needed on the part of both companies’ representatives and suppliers of control hardware and software when faced with the decision, particularly if a solution is required at reasonably low cost with a demonstrable adequate return on capital to be employed.

7.4. Proposed plan of action by the company

As this field is still rapidly developing, it seems in order to suggest some areas which require attention by the company which may be prepared to consider accepting a sophisticated control system to operate its handling and storage system:

(a) It should seek advice from a range of organisations specialising in O & M systems analysis to arrange for a full analysis of its existing and future flows of information both in and outside the present or proposed warehouse(s). This should lead to a feasibility study showing alternative systems and equipment of varying degrees of complexity, with their respective capital, rental, leasing, running and maintenance costs.

The positive advantages of initial systems analysis/O & M study cannot be over-stressed because they usually lead to a simplifying of the existing paperwork control system and thereby frequently eliminate the need to computerise.

(b) Before committing itself to a particular type or system the company should weigh carefully not only the costs and the benefits of improved speed of processing the records required to maintain any warehouse/inventory system which may be promised, but also the organisational and social problems which may arise from the introduction of new systems into the existing plant.

(c) The company should recognise that after installation of complex control systems, there is likely to be a running-in period which may be as long as a year. The earlier planning can be carried out and provision is made for the extra expense which may be incurred, the less will be the practical difficulties which will be experienced in installation and production operation.

(d) A senior member of the company’s departmental staff concerned should liaise closely with a competent programmer/analyst during the design stage. In addition, it may be helpful if a team is set up early on in the overall design stage, consisting of representatives of the company, e.g. programmers, system analysts, O & M specialists, possibly outside consultants, hardware and software suppliers (preferably before commitment to any one set of equipment). Such a team should meet regularly to ensure that the ultimate decisions are agreed jointly.

(e) The recent development of ‘mini’ process-control computers which are cheap and reliable even when peripherals are included, could revolutionise the field of mechanised and automatic control, since their overall operating costs should be low compared with the major handling and storage costs of medium and large warehouse installations. It should be borne in mind that stock control is the area which is likely to show the highest potential savings for any company. Therefore, if the company introduces a system using ‘mini’ computers, it should endeavour to ensure that the information which is collected by the ‘mini’ computer will be available for routine stock control, possibly on some other general
purpose computer. Indeed, it should be asserted that the main justification for any data processing computer should be the reduction of stock levels.

(f) The decision to rent, buy or lease may be crucial. If there is doubt as to whether the proposed systems will operate efficiently from the start or whether they will have enough of the right kind of capacity in the future, then it will be important to consider renting equipment for some considerable time. When the right kind of equipment has been tried in production use to the satisfaction of most personnel, then it may be replaced by new equipment purchased outright, or second-hand equipment if available, or equipment leased.

Some sources of information on control system costs

National Computing Centre

British Computer Society

Choosing a Computer by Clare Smythe, published by Data Systems (£1).
This book, updated to 1969, gives data on equipment from a large range of suppliers of visible record computers, punched card computers, 'mini' computers, magnetic file computers. It also contains detailed accounts of analysis of costs and the pros and cons of renting, buying and leasing.

Business Equipment Buyers Guide, published by Digest Data Books Ltd.

Mechanical Handling, October 1968. 'Computers in handling systems'.

Mechanical Handling, April 1970. 'Mini-computers; The catalyst materials handling engineers have been waiting for', by Rex Ingram and Dave McQue.
This article gives a very useful introduction to the possibilities of using 'mini' computers in handling systems. It also gives a valuable table of the current range of 'mini' computers with their specifications and prices. The article is reprinted in this report as an appendix.

Lists of O & M computer consultants and software bureaux, taken from Choosing a Computer 1969.

Financial Times, 29 May 1970 'Hand-me-down computers' by Geoff Slocombe.
This is a review of the advantages of purchasing second-hand computers. This represents a limited list of contacts and cost information which may be of assistance to potential clients who may be interested in employing sophisticated equipment for their warehouse control system. We can take no responsibility for omissions or errors, although every effort will be made to correct, modify or enlarge these lists in future editions.
8. Conclusions

8.1. Part 1 and this Part 2 of the report are a review of the surveys in which detailed cost data was collected for a sample of conventional and a sample of high-bay and mechanised warehouse systems. The cost data was marshalled in the same way for all systems using a uniform costing system. At the same time an attempt has been made to relate these true costs to throughput of goods and there is an indication of the possibility of securing large economies of scale where outputs are great. No attempt has been made to publish all the data because its inclusion would make little impact on the conclusions drawn from its analysis, and in fact it is being re-analysed currently at the National Materials Handling Centre as part of further research programmes relating systems designs to costs and performance. The unit cost of handling and storage achieved in practice will depend on many factors but it appears that to achieve minimum values the following factors are of prime importance:

(a) The handling system must be as simple as possible and related in scale to the throughput handled; the costs of equipment should be minimised, as they are frequently of the same order as labour costs. This applies particularly to mechanised order-picking systems which often represent a large proportion of the total costs of distribution machines.

(b) The storage building should be designed as high as possible consistent with reasonable handling costs because the cost of space reduces markedly with height. The costs of buildings should be minimised as they are frequently of the same order as labour and equipment costs. This applies equally to high-bay storage and to conventional storage.

(c) Labour costs represent an important part of total warehousing costs.

The wage payments vary considerably for each category between companies and geographical areas.

(d) Control system costs are not usually large except where complex general purpose computer systems are used for real time on-line control coupled with general services function. In such special circumstances, a careful appraisal of the future cost effectiveness and cost benefits is advisable before commitment, although the advent of 'mini' computers suitably interfaced with input and output equipment promise a cheap and reliable solution for many systems.

The factors (a) to (d) may best be exploited by consideration of entirely new warehouse systems and buildings rather than limited efforts to improve the cost efficiency of existing outmoded and poorly designed systems. Although it has not been the brief of these reports to discuss associated transport and distribution systems, such exploitation should be considered only after a review of the service requirements of these distribution systems together with a systematic analysis to find the best locations for the optimum number of new warehouses.

8.2. Even where very similar conventional systems for handling and storage systems identical products were cost analysed, differences in unit costs of 2:1 were found. This and other evidence indicates that frequently companies do not know the true efficiency of their handling and storing systems.

In few cases have the detailed costs and cost efficiency of mechanised and high-bay systems been systematically analysed before a decision was made to adopt them and this appears to have been for a number of reasons:

(a) Lack of cost data on previous or existing systems.

(b) Lack of appreciation as to what costs to include.

(c) Difficulties in deciding what costing systems to use in order to marshal and compare costs and relate them to throughputs.

(d) Conscious or unconscious desire on the part of both systems suppliers and users not to predict and analyse costs. This may spring from a basic uncertainty as to which kind of handling and storing system to opt for anyway; there exists for example, a bewildering array of order-picking systems, warehouse buildings and computers to choose from with little published data on their respective costs, unit costs, cost effectiveness and cost benefits.
(e) Difficulties in establishing cost effectiveness and cost benefits are other good reasons for opting for a high-bay solution, e.g. reduction of total labour force, shortage of land, need for rapid and precise interchange of product, stock-level and pricing information and need to interface such information with real-time process control on the one hand and the company's general services computers on the other.

(f) Conflicting myths, stories and evidence about former and current mechanised and high-bay warehouses which often appear to produce emotional bias and prejudice both for and against various systems whether they be simple, mechanised or automated.

8.3. We believe that some, if not all, the problems (a) to (f) can be overcome and that a systematic cost analysis of alternative systems before commitment is not only imperative but can be carried out at modest expense and effort and that such an approach will often show the way to large savings of capital and running costs.

8.4. The knowledge of systems, their performance and related costs acquired by the National Materials Handling Centre has been vital in helping to draw these broad conclusions. Nevertheless, it is recognised that a great deal of further research is necessary before complete solutions to warehouse designers and related costs and unit costs is possible. To this end, new research programmes are proceeding at the Centre, concentrating on warehouse buildings, computer control systems, order-picking and management decision-making.
Bibliography


Regional Employment Premium. Department of Employment and Productivity.


'Tendering Documentation with a Production Bias', BRS Digest 97.


SKOYLES, E. R. 'The Operational Bill Comes into its Own', BRS News 13.


Management Information Systems and the Computer, Part I and II. The Institute of Cost and Works Accountants.


Appendix

Mini-computers: the catalyst materials handling engineers have been waiting for

Rex Ingram and David McQue

It is goodbye to rigid complex and expensive relay panels and wired logic systems and welcome to the new adaptable, low cost computers which can be used to control handling systems with a facility undreamed of until recently. Complete with basic accessories they cost on average about £5000 each and can be used in conjunction with a large commercial computer or as part of a team of other minicomputers. The big advantage apart from cheapness is flexibility: you can modify or extend the complete handling system without disrupting work in progress or making expensive wiring alterations. Furthermore if you're starting off with a minicomputer you're not committing yourself to a particular scale of operation. The modular basis upon which minis work makes it possible to expand your system when you want to.

Most manufacturers are prepared only to sell computers and few are willing, or even able, to offer any kind of assistance with their use. No doubt the situation will change, but it is now largely up to the customer to install his own system. Thus, if a materials handling man is to make the best use of the new tools available he will have to learn more about computers than he might have thought necessary. That is not a bad thing. Certainly those people who have purchased minicomputers during the past two years, while the market was preparing for its current boom, seem to have managed well enough.

MINICOMPUTERS ARE MINIATURE VERSIONS OF LARGER COMMERCIAL COMPUTERS. Some are faster and most are very much cheaper. Most minicomputers can be purchased in a minimum useable form for about £5,000, or less, whereas most commercial computers cost at least ten-times, and some, a hundred times as much.

Minicomputers live in a different environment from commercial computers being at home in machine-shops among the swarf, on process lines or in warehouses. One battery powered machine is currently being trekked around the Arctic on a sled, and at Cranfield, minicomputers have often been transported in the boots of motor cars.

Because of their performance, low cost and indifference to atmospheric environment, minicomputers, are ideally suited for use in materials handling and this may well prove to be one of the commonest applications. Most materials handling equipment control has until quite recently been performed by special purpose electrical systems, eg relay panels or wired logic systems. Such systems have many disadvantages. Control is necessarily inflexible and of limited development potential. Making alterations to a special purpose electrical system entails halting the machines being controlled and while it is out of action rewiring and extending, and then retesting, the whole control unit. That can be expensive and consequently the improvements to a control system which become obvious once it has been in operation for some time are often not incorporated. Fault finding in a control unit of that kind can be a lengthy process.

Now that minicomputers are available to replace relay panels and the like, the benefits of computer control can be obtained very cheaply. Modifications can be made simply by altering a program, and that can be done without halting the equipment being controlled for more than a few seconds of machine time.

*At the time of writing this feature, Rex Ingram was a research fellow in the materials handling unit at the Cranfield Institute of Technology. David McQue is an instrumentation engineer in the Instrumentation Section at Cranfield, where he has been involved with minicomputers for the last 3 years.
All the information in the table is taken from manufacturers literature. An explanation of the terms used in this table are to be found in the glossary on page 129 and in the text of the article. So that the prices of the different computers could be compared directly, the price shown is for a CPU, 4K store of 16-bits, i.e. 4K 1024 words each of which comprises 16 binary digits (bits), together with an ASR33 Teletype. Where the computer is a word length of 8-bits, or the store size is quoted in bytes (1 byte = 8 bits), then an 8K store is used for the comparison. Where the word length is 12-bits the price of the store was scaled up to give the price of a store equivalent to 1K of 16-bits. The three small machines in the list are intended to be used as dedicated controllers and the price for them is with a store of 1K of 16-bits, or equivalent.

<table>
<thead>
<tr>
<th>MANUFACTURER/ SYSTEM</th>
<th>PRICE OF STANDARD CONFIGURATION (£)</th>
<th>WORD LENGTH BINARY DIGITS (BIT)</th>
<th>MEMORY RANGE Minimum to maximum core memory capacity in Kbytes (B) or words (W)</th>
<th>CYCLE TIME OF MEMORY (µsec)</th>
<th>ADD TIME (µsec)</th>
<th>No. OF HARDWARE REGISTERS</th>
<th>No. OF INDEX REGISTERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arcturus 18-C</td>
<td>£3,900</td>
<td>16</td>
<td>4-64W</td>
<td>0</td>
<td>9</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>Burst-Hill 204</td>
<td>£3,800*</td>
<td>16</td>
<td>1-1W</td>
<td>50</td>
<td>160</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Computer Automation</td>
<td>£9,770</td>
<td>18</td>
<td>4-16B</td>
<td>80</td>
<td>240</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Data General Nova</td>
<td>£10,950</td>
<td>8</td>
<td>4-16B</td>
<td>27</td>
<td>80</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Digico Micro 16</td>
<td>£11,990</td>
<td>16</td>
<td>4-16W</td>
<td>80</td>
<td>160</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Digital Equipment Ltd</td>
<td>£10,000</td>
<td>16</td>
<td>4-16W</td>
<td>2</td>
<td>510</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Data General Super Nova</td>
<td>£13,750</td>
<td>16</td>
<td>4-32W</td>
<td>0</td>
<td>8</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Data General Super Nova</td>
<td>£13,750</td>
<td>16</td>
<td>4-32W</td>
<td>0</td>
<td>8</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Digital Equipment Ltd</td>
<td>£10,000</td>
<td>16</td>
<td>4-16W</td>
<td>2</td>
<td>510</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Digital Equipment Ltd</td>
<td>£10,000</td>
<td>16</td>
<td>4-16W</td>
<td>2</td>
<td>510</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Ferranti Argus 600</td>
<td>£2,920*</td>
<td>8</td>
<td>1-8B</td>
<td>40</td>
<td>92</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Hewlett Packard</td>
<td>£7,000</td>
<td>12</td>
<td>4-32W</td>
<td>1</td>
<td>30</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Honeywell</td>
<td>£5,824</td>
<td>16</td>
<td>4-16W</td>
<td>1</td>
<td>32</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Interdata MOD 3</td>
<td>£6,134</td>
<td>16</td>
<td>4-64B</td>
<td>1</td>
<td>28</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Interdata MOD 4</td>
<td>£7,583</td>
<td>16</td>
<td>4-64B</td>
<td>1</td>
<td>31</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Intertechnique Multi-8</td>
<td>£5,340</td>
<td>8</td>
<td>4-32B</td>
<td>1</td>
<td>50</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Lockheed</td>
<td>£11,950</td>
<td>16</td>
<td>4-64W</td>
<td>1</td>
<td>20</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Micro Computer Systems</td>
<td>£4,490</td>
<td>8</td>
<td>4-65B</td>
<td>1</td>
<td>30</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Motorola MDP-1000</td>
<td>£5,980</td>
<td>16</td>
<td>4-16W</td>
<td>22</td>
<td>43</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Raytheon</td>
<td>£11,250</td>
<td>16</td>
<td>4-16W</td>
<td>15</td>
<td>30</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Varian</td>
<td>£9,400</td>
<td>16</td>
<td>4-32B</td>
<td>15</td>
<td>45</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Varian</td>
<td>£6,200</td>
<td>16</td>
<td>4-32B</td>
<td>15</td>
<td>45</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Westinghouse P3000</td>
<td>£15,000</td>
<td>16</td>
<td>4-64W</td>
<td>3</td>
<td>60</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>Xerox Data System CE16</td>
<td>£11,990</td>
<td>16</td>
<td>4-16W</td>
<td>80</td>
<td>160</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Xerox Data System CF16</td>
<td>£10,000</td>
<td>16</td>
<td>4-16W</td>
<td>2</td>
<td>53</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

4 Store cycle: Fast Stores are generally more expensive and more critical of electrical environment, slow stores have greater tolerances and require fewer, if any, adjustments.

10 Power failure/Auto restart: essential—otherwise even a momentary power loss (1/25th sec) can cause data loss and program destruction. O=Optional S=Standard P=Partial N=Not available.

14 This price is for 1K Store of 16 bit words (or equivalent) of 1/T and Computer main frame. These are micro-computers and are really best suited for uses requiring minimum storage (1K or less) and are not really suitable for expansion beyond 1K, although this is generally possible.

15 12-bit words.

16 One core store Index Register per Program Level.

17 256 devices total. Only one per level except for lowest level. Expendable to 64 levels.

18 Total number of devices on all levels.
## MINI-COMPUTERS

### INPUT/OUTPUT

<table>
<thead>
<tr>
<th>JUVER/</th>
<th>VALUE/</th>
<th>UTILITY/</th>
<th>ATOMIC</th>
<th>ESTART</th>
<th>STORAGE</th>
<th>PROTECTION</th>
<th>INITIAL</th>
<th>PROGRAM</th>
<th>LOAD</th>
<th>BLOCK</th>
<th>HESITATE/</th>
<th>LEVELS OF</th>
<th>DEVICES</th>
<th>POLLING</th>
<th>SPECIAL</th>
<th>SOFTWARE</th>
<th>FEATURES</th>
<th>PACKAGES FOR</th>
<th>USE ON STANDARD</th>
<th>CONFIGURATION</th>
<th>Assembly (A)</th>
<th>Debug (D)</th>
<th>Sourcecoded Edit (E)</th>
<th>Fonnat (F)</th>
<th>Utility routines (U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>N</td>
<td>M</td>
<td>1/2</td>
<td>S</td>
<td>N</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Optional micro program bus</td>
<td>Automatic increment/decrement</td>
<td>ADU</td>
<td></td>
<td></td>
<td>ADU</td>
<td>ADEU</td>
<td>ADEU</td>
</tr>
<tr>
<td>S</td>
<td>O</td>
<td>M</td>
<td>1</td>
<td>S</td>
<td>N</td>
<td>1</td>
<td>1024</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Multiplying/dividing standard</td>
<td>ADU</td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>M</td>
<td>1/2</td>
<td>N</td>
<td>S</td>
<td>3</td>
<td>32</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Automatic input/output</td>
<td>ADU</td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>M</td>
<td>1/2</td>
<td>N</td>
<td>S</td>
<td>3</td>
<td>32</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Above, plus relative addressing and scan instruction</td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>M</td>
<td>1/2</td>
<td>N</td>
<td>S</td>
<td>3</td>
<td>32</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compound Instructions</td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>P</td>
<td>A</td>
<td>1/2</td>
<td>O</td>
<td>N</td>
<td>1</td>
<td>256</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Software compatible with Micro 16</td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>M</td>
<td>1/2</td>
<td>S</td>
<td>S</td>
<td>1</td>
<td>62</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>As above</td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>M</td>
<td>1/2</td>
<td>S</td>
<td>S</td>
<td>1</td>
<td>62</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Wire decimal arithmetic</td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>N</td>
<td>M</td>
<td>1</td>
<td>O</td>
<td>N</td>
<td>1</td>
<td>64</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>A</td>
<td>1/2</td>
<td>O</td>
<td>N</td>
<td>1</td>
<td>64</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>P</td>
<td>M</td>
<td>1</td>
<td>S</td>
<td>N</td>
<td>1</td>
<td>64</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>P</td>
<td>M</td>
<td>1</td>
<td>O</td>
<td>N</td>
<td>1</td>
<td>64</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>S</td>
<td>A</td>
<td>1</td>
<td>S</td>
<td>S</td>
<td>5</td>
<td>1024</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>P</td>
<td>M</td>
<td>1/2</td>
<td>S</td>
<td>O</td>
<td>8</td>
<td>256</td>
<td>H</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>O</td>
<td>M</td>
<td>1/2</td>
<td>N</td>
<td>S</td>
<td>1</td>
<td>256</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>M</td>
<td>1/2</td>
<td>N</td>
<td>S</td>
<td>1</td>
<td>256</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>M</td>
<td>1/2</td>
<td>O</td>
<td>N</td>
<td>1</td>
<td>256</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>M</td>
<td>1/2</td>
<td>N</td>
<td>S</td>
<td>3</td>
<td>32</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>M</td>
<td>1/2</td>
<td>N</td>
<td>S</td>
<td>3</td>
<td>32</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Additional Features:**
- 16 general-purpose registers with core
- Both models have variable word length
- Microprogrammable
- 4 program levels standard
- 256 32-bit microprogrammable locations
- Word length dual environment
- Hardware, multiply and divide, real-time clock
- Machine hardware identical w/ computer
- Automation 816, 216
How a minicomputer might control a simple overhead power-and-free sorting conveyor system:

Empty carriers would circulate on the conveyor until switched into one of five loading spurs. When loaded they would leave by way of the exit conveyor to an external process. The empty carriers would be returned on the return line and be recirculated until needed again. Each of the loading spurs would be numbered for identification and would have a reader capable of sensing the single digit that identifies the carriers. There would be 100 carriers in the system of 10 different types.

In a conventional control system using relay logic there would be a ten-position selector switch at each loading spur. The foreman or operator would select one particular type of carrier by setting the switch to the appropriate position, and only that type would be switched into the spur until the switch was reset. With only five spurs in the system, only half the carrier types could be loaded at the same time. That could lead to holdups in production further down the line and poor utilization of equipment, but the situation could not be avoided with such a simple conventional control system.

A minicomputer could be used as an alternative to the relay logic. Provided the carriers could be identified as they passed each reader, any or all the types of carrier could be switched down any spur. The computer could deal with all the readers, the diverters and the console which would be used to put instructions into the system. In most cases the cost of the computer system required to perform such an operation would be competitive with that of relay control systems. The computer system would certainly be more effective. The computer could, for example, load carriers according to type, as required.

Should the system be expanded to include several hundred spurs and readers, and several thousand different types of carrier, the system might become more complicated but the computer could still cope.

Because of their low cost one minicomputer can be used to control all the mechanical functions previously conventionally controlled. Or, alternatively, several computers can be used, each one assuming responsibility for a limited number of tasks. Since control is provided by programs which may be varied, a minicomputer can provide precisely the degree of control required and all desirable features can simply be programmed in. In other words minicomputers can be used as individuals, each doing their own jobs, or one machine can be used for everything. Separate computers can be made to 'talk' to each other and information collected from one part of a handling system can be made available to a computer controlling another part.

Which type of system?

Computers are already used in materials handling and warehousing and wired logic and similar control systems have been completely superseded in some newer automated warehouses. But the computers which have been used have not always been ideally suited to their applications. They have tended to be smaller versions of standard computers. And physically quite large. That has meant that only a single central computer could be used, because of the cost.

Another drawback with the more expensive and previously available machines is that very fast computers with store cycle times of less than 1 microsecond, are extremely sensitive to their electrical environment and may be affected by signals from other electrical or electronic equipment. That is one reason why large commercial computers need special air-conditioning and mains filtering.

Minicomputers generally have much slower store cycle times and are therefore not nearly so critical. Computers which have been used in warehousing so far have tended to fall into the gap between minicomputers and large well-protected commercial machines. They have been both very fast and comparatively unprotected. And because single computers were used, long cables had
After some experience has been computed, computers is that they can be part of past large electrically operated to be laid from remote areas, usually those problems have been overcome, the computers used have often been so fast and large that they have tended to be grossly under-utilized.

The advent of the minicomputer means that, not only is it now feasible and economical to computerize large sections of materials handling and warehousing, but to do it with computers which might have been designed specially for the job!

Another advantage of minicomputers is that they can be part of modular control systems. It is possible to buy a first machine and install it to perform a particular task. After some experience has been gained with it a second machine can be installed to do something else, while communicating with the first, and so on. That means that a company with no experience of computers can start to reap the benefits of computer use while taking the minimum risk. That risk is now at least ten-times less than in the recent past.

Instead of using one large computer, several minicomputers can be used and still cost less. The various machines can each be responsible for their own tasks and yet communicate with each other. This reduces total cabling and solves other environmental problems, but also means that it is quite realistic to have a spare minicomputer sitting on the shelf. Should any computer in use then break down it can be quickly replaced, and returned by post to the manufacturer for repair, while the system being controlled continues operating.

One of the new minicomputers has all of its electronics and store mounted on a single 15 in square printed circuit board. That could probably be returned to the manufacturer in an envelope with a 5d stamp!

**When a minicomputer can be cheaper than hiring**

One way in which warehouses can make use of a commercial computer is by having a terminal connected to a computer terminal some distance away. It now seems, thanks to minicomputers, that it could be cheaper to use a minicomputer instead of hiring time that way. Since most companies are security conscious and are loath to pass detailed information to a remote computer such a possibility will be widely welcomed. Even if the large computing power of a commercial machine is still required a minicomputer can be used to communicate and act in concert with it.

**Materials handling the largest application**

Probably the largest application area for minicomputers will be in the control of materials handling equipment. Stacker cranes, driverless towing tractors and conveyor diveters are all suitable subjects. Code-readers can be serviced and remote memory provided. Already some newer warehouse systems are making good use of the power of minicomputers. Bagshawe & Co is, for example, using one to control its new automated high density pallet storage system. The fact that minicomputers can be linked in modular fashion is of particular relevance in that application.

One driverless tractor manufacturer is using minicomputers in the control system it incorporates into some of its installations.

At Cranfield minicomputers have been used on a package coding research project to handle the data collected by code-reading devices.

**How to choose them**

Fortunately, minicomputers are fairly easy to understand. What is much less easy is to decide which minicomputer to buy. In the table on pages 126, 127 are some details of a selection of the minicomputers available at the moment. Such is the rate of growth in the field that in the USA the number of manufacturers has risen from under 20 to nearly 50 in little over six months.

The main two types of minicomputers are: Special purpose computer (SPC), and General purpose computer (GPC).

The SPC, as its name implies, is generally dedicated to a particular task and is not intended to be quickly moved from one job to another. It is normally used to control a single job, rather than several at the same time. Because of this the SPC has programs stored in such a way that they are not electrically alterable, that is they can only be altered by physically rewiring the appropriate part. A core store memory of that type is known as read-only memory (ROM).

The GPC has programs which are electrically alterable and compiles much more with the common conception of a computer. A GPC normally has more core store memory than an SPC simply because it is designed to do rather more.

Although a GPC is able to deal with many different tasks at the same time and can be quickly and cheaply re-programmed, it can still be dedicated to a particular job in the same way as an SPC, even though this would not make full use of it.

The list of computers (page 126) is primarily of GPC, but some can be SPC. Each manufacturer has designed his machines to obey his own type of command system, so each has its own 'Assembler Language'. There is no common language.

**Price.** Some manufacturers appear to offer minicomputers at very low prices, but generally on closer inspection what they are offering is only the basic unit to which must be added a teletype before use.

To be able to use a minicomputer the minimum requirements are a central processor (CPU), a core store memory and some means of communicating with the computer. The latter is invariably a teletype machine which allows program tapes to be prepared and read, and output from the computer to be punched on to paper tape or printed out by the printer. The keyboard is the main method of communicating with a computer. (The usual input/output form is a paper tape, rather than punched cards.) Some manufacturers list each of the above items separately, others merely quote a price in its minimum form.

Much the most significant cost of any installation is the cost of the peripherals used, and in choosing a minicomputer that is one of the first things to be examined. Most installations would not need the enormous storage capacity of a disc, for example, but if one was needed it would cost about £20,000. Peripherals must be examined very carefully indeed. As the price of computers has tumbled, the cost of printers, discs and drums has become disproportionately high. But the future trend in the cost of these items should only be downwards.
Mini-computers

Useful facts about operating them

The most important operational aspects to consider when a mini-computer is controlling a mechanical handling operation

**Word length.** The word length of a computer, or the register lengths used in normal working, have a considerable effect on how the computer functions. Typical word lengths on minicomputers are 8, 12 and 16 bits. On commercial machines the word lengths are 24 or 32 bits. A computer with a word length of 8 bits, or with core store organized in 8-bit words, is said to be a byte machine. Most minicomputers are now using 16-bit organization. This allows a large integer range without double length working and also allows a useful instruction set which greatly assists programming.

**Memory expansion.** This represents the range of core store size that is available with each computer. Most minicomputer stores are built up in blocks of 4K words, but some use 8K bytes, which are half the size, and generally the computer can be expanded to at least 8K words in the basic cabinet. Thereafter additional cabinets are required. It is important to realize that the most expensive part of any computer is its core store.

**Store cycle time.** The faster the store on a computer, generally the more expensive it becomes and more critical of its electrical environment. The most important question to be asked under this heading is whether a job could not be done by a slower store. That can be calculated by examining the task, estimating how efficient it can be programmed on the computer being studied and deciding whether the computer is unnecessarily fast.

**Add time.** The add time is one of the indications of how efficient the computer is. It should not generally need to be more than two store cycles long. But that is only a very approximate yardstick and only of use when comparing like with like. Some smaller minicomputers show up badly in this respect, but they have not been designed to handle data at fast rates. There being no advantage in their case.

**Hardware registers.** A large number of hardware registers makes programming more efficient because there is less need to shuffle intermediate results between store and accumulator register, and these results can be left temporarily in their own accumulators. The results can then be operated on by register to register instructions instead of register to store instructions which take twice as long.

**Index registers.** Where repetitive operations have to be performed on lists of data, a loop of instructions can be set up and an index register incremented or decremented each time round the loop.

**Levels of indirect addressing.** It is useful while programming to be able to directly address the whole core store. In most computers—and minicomputers are no exception—that is not always possible. The reason is that there are typically only 9-bits or less in each instruction word of 16-bits that can be used for specifying a

---

**The terms Computer People use**

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Add time</strong></td>
<td>the time taken to perform a typical arithmetic operation.</td>
</tr>
<tr>
<td><strong>Accumulator Register</strong></td>
<td>A collection of switching circuits which hold an operand.</td>
</tr>
<tr>
<td><strong>Bit</strong></td>
<td>A binary digit. Binary arithmetic is not here explained.</td>
</tr>
<tr>
<td><strong>Block Transfer</strong></td>
<td>A method of moving a group of sequential words from the core store peripheral device.</td>
</tr>
<tr>
<td><strong>Byte</strong></td>
<td>Eight binary digits.</td>
</tr>
<tr>
<td><strong>Core Store</strong></td>
<td>One of several devices used by a computer for storing programs and data.</td>
</tr>
<tr>
<td><strong>Disc Store</strong></td>
<td>A means of storing binary data on a magnetic surface in the form of a disc.</td>
</tr>
<tr>
<td><strong>Drum Store</strong></td>
<td>Another form of data storage on a magnetic surface.</td>
</tr>
<tr>
<td><strong>Interrupts</strong></td>
<td>A means of interrupting lower priority programs for real time working.</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>Short for Kilo, but because binary arithmetic works out factors of 8 instead of 10 means 1024 4K 4096</td>
</tr>
<tr>
<td><strong>Language</strong></td>
<td>A method of coding a computer by using groups of letters rather than numbers.</td>
</tr>
<tr>
<td><strong>Levels of indirect addressing</strong></td>
<td>A hardware facility for storing list references. Used as a means of addressing a large store with an economical word length.</td>
</tr>
<tr>
<td><strong>Page</strong></td>
<td>The area of a store which is directly addressable in a computer.</td>
</tr>
<tr>
<td><strong>Peripheral</strong></td>
<td>Any device external to a computer.</td>
</tr>
<tr>
<td><strong>Polling</strong></td>
<td>A method of determining the source of an interrupt signal.</td>
</tr>
<tr>
<td><strong>Power Failure Protection/Automatic Restart</strong></td>
<td>A means of ensuring that in the event of a power failure programs are not corrupted.</td>
</tr>
<tr>
<td><strong>Program</strong></td>
<td>A sequence of instructions.</td>
</tr>
<tr>
<td><strong>Power Failure Protection/Automatic Restart</strong></td>
<td>A sequence of instructions.</td>
</tr>
<tr>
<td><strong>Software</strong></td>
<td>Another word for programs.</td>
</tr>
<tr>
<td><strong>Store Cycle Time</strong></td>
<td>The time taken to interrogate a store and put it back, as it was.</td>
</tr>
<tr>
<td><strong>Storage Protection</strong></td>
<td>Means of arranging for certain areas of a store to be switched to read only.</td>
</tr>
<tr>
<td><strong>Storage Register</strong></td>
<td>A group of related memory cores making up a word in a word store.</td>
</tr>
<tr>
<td><strong>Word Length</strong></td>
<td>A group of binary digits which can be used to represent an instruction or a number.</td>
</tr>
</tbody>
</table>