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EFFECTIVE USE OF MACHINE TOOLS
AND
RELATED ASPECTS OF MANAGEMENT
IN
DEVELOPING COUNTRIES

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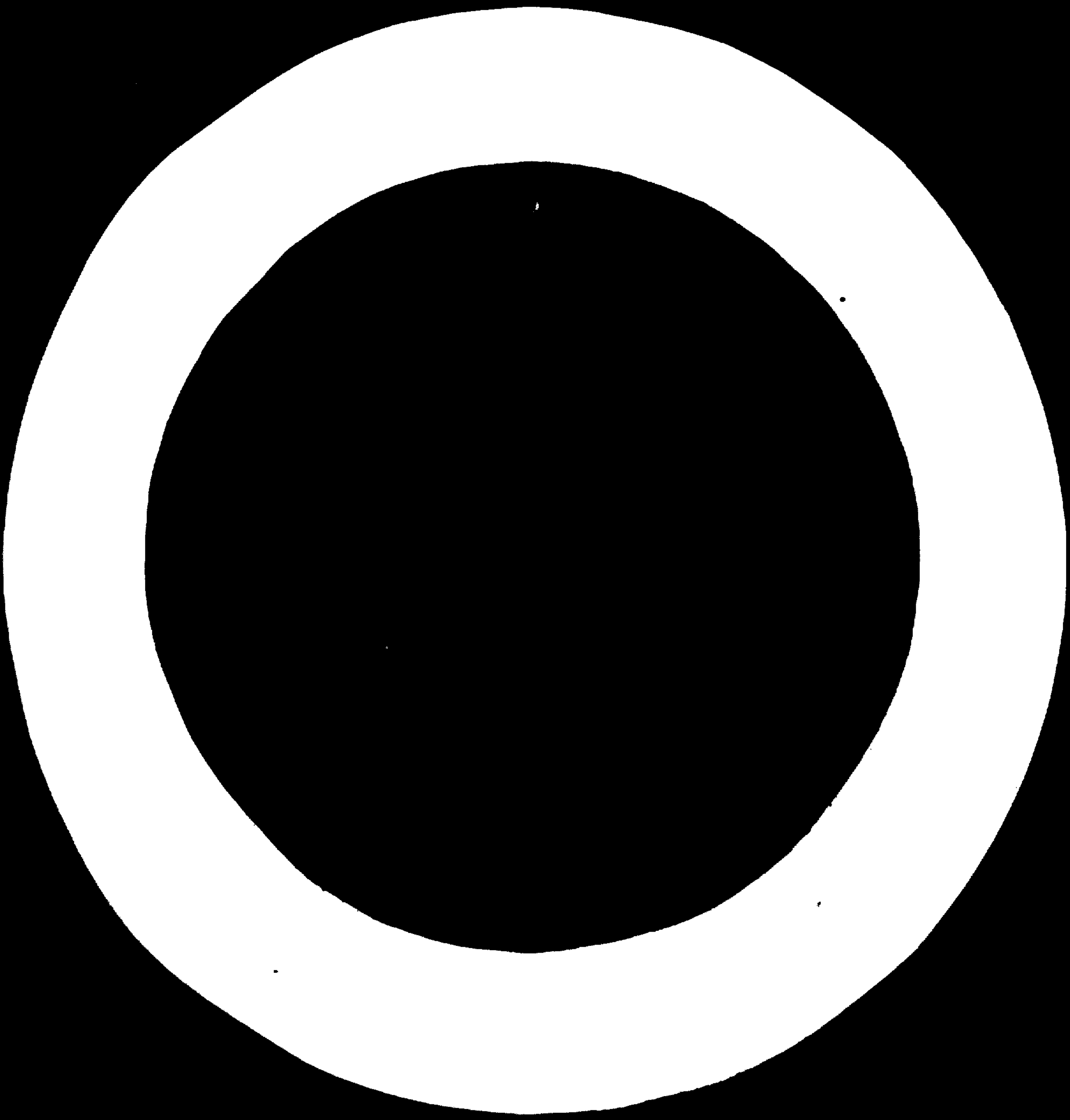

Foreword

The machine tool industry was one of the key subjects discussed at the Interregional Symposium on Metalworking Industries in Developing Countries, held in Moscow under the auspices of the United Nations in 1966. Machine tools play a key role in the expansion of manufacturing industry, because of the importance of metalworking in this sector of the economy in nearly every country where industrial production has been established. Wise selection and efficient operation and maintenance of machine tools are of great importance from the earliest stages of industrial development. Although relatively few developing countries may find it advantageous to manufacture machine tools, most of them are concerned with these matters as users of machine tools.

An earlier publication[1/] dealt with selection and acceptance testing of machine tools. The present publication is a companion volume dealing with their effective use, which term is used here in a broad sense: it includes not only ensuring that the operation of machine tools is technically efficient (which involves correct maintenance procedures), but also exercising related functions of management concerned with minimizing production costs and developing products suitable for the production facilities of the firm and its markets.

This study was produced in co-operation with the UNIDO secretariat by three consultants: Professor A. C. Schmidt of the Department of Industrial Engineering, The Pennsylvania State University;

[1/] UNIDO, The selection and acceptance testing of metal-cutting machine tools: a practical guide for developing countries (United Nations publication, Sales No.: E.71.II.B.3).

Professor Frank R. Bacon Jr. of the Graduate School of Business Administration, Michigan State University; and Mr. Robert Krammer, Vice-President of Seatech Engineering, Inc., Southfield, Michigan. Mr. Schmidt has had many years of practical experience in machine tool design and operation in countries where the engineering industry has reached various stages of development. Mr. Bacon has 20 years experience in the United States and other countries of marketing and related research in regard to engineering products manufactured by small and large firms. Mr. Krammer was for many years a chief engineer of materials handling and also a consultant; his experience likewise includes work in other countries in addition to the United States.

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EFFECTIVE USE OF MACHINE TOOLS AND RELATED ASPECTS OF MANAGEMENT IN DEVELOPING COUNTRIES

Introduction

In a world of rising expectations, —all countries look for rapid progress in their industrial development. As regards the metalworking industries, this means exploiting to the fullest extent the available resources of machine tools as well as the human resources. The existing stock of machine tools and related equipment in the factories and workshops of a developing country is a precious part of its total industrial resources, because capital is a scarce factor. Yet it is an observable fact that, all too often, the engineering plants in developing countries operate at well below 100 per cent of their capacity.

The principal reasons for this state of affairs are as follows:

- Technical weaknesses in the production process, such as improper use of tools, dies, jigs and fixtures;
- Lack of availability of critical raw materials, for example, special steel alloys;
- Inability to import production material, or tools and instruments used as ancillaries of the machine tools, owing to a national shortage of foreign exchange;
- Lack of skilled personnel capable of operating the machine tools;
- Poor planning and inefficient management of production;
- A seasonal pattern of work tied to agricultural activities, resulting in an unbalanced jobbing load;
- Machine tools out of action due to delays in repair work after breakdown or because they have become obsolete and await replacement.

The second and third of these reasons may be connected with deep-seated difficulties in a country's economic development, examination of which lies beyond the scope of this study. Directly or indirectly, the remaining reasons come under discussion in the chapters which follow.

The situation of the metalworking industries in the developing countries is by no means uniform. In some countries there is already a substantial demand for various types of industrial equipment from the agricultural and mining sectors, but relatively few production facilities to meet this demand. In other countries the problem is that production facilities, sometimes including facilities for manufacture of machine tools, have been installed with capacity in excess of the requirements of the domestic market, so that it would be desirable for engineering firms to develop export sales. There are also developing countries in which domestic production capacity broadly matches demand over a wide range of industrial equipment, but the industry is not internationally competitive and relies on tariff protection from the competition of imports. Government policy should be devised to deal with the actual situation in each specific country, but in this study, inevitably, the treatment of machine-tool problems can be discussed only in terms of the general principles involved.

The information given in this publication applies primarily to shops employing between five and one hundred people; the great majority in every country of the enterprises that stand in need of help have shops in this size range.

Enterprises using exclusively imported technology - for example, most subsidiaries of established foreign enterprises and domestically owned firms operating under foreign licence agreement - often mirror the manufacturing operations in the headquarters factories of the parent organization and may attain similar levels of productivity. This study is not expected to be of great interest in such enterprises; on the other hand, the independent enterprise which started as a small workshop and has grown into a small or medium-sized factory is likely to find much advice from which it can benefit.

Inevitably, nearly every kind of metal product made in a developing country is already manufactured in other countries which have decades of manufacturing experience and possess a more advanced technology. There may be a tendency to believe that it will never be possible to offer effective competition in international markets, in view of the advantages which these countries possess. There is no magic, however, in the manufacturing practices of the developed countries. The improvements needed in the factories of developing countries, in order to make them more competitive, can be achieved by management and engineers with the will to progress, working with the type of enthusiastic foremen and production personnel usually found in countries starting to build an industrial economy.

Attention to the technical characteristics of machine tools must never be allowed to obscure the importance of human factors in manufacturing industry. In the industrially advanced countries, managements run regular training programmes for all grades of personnel, in order to improve the productivity of the workpeople engaged in various tasks. If muscle power is to be replaced by machine tools and other capital equipment in the developing countries - because in the long run there is no other way of improving productivity and the standard of living - then the organisation of personnel training is even more necessary for them than for other countries. The replacement of human strength by machine power does not tend to reduce employment opportunities, as is sometimes feared. Instead, the level of skill of the work force and also of the management is upgraded, resulting in substantial gains in productivity. Such has been the experience in the industrially advanced countries. The results of similar programmes in the developing countries, when properly organised, have been equally impressive.

CHAPTER 1 TYPES OF MACHINE TOOLS AND THEIR APPLICATIONS

Recent developments in machine tools and their tooling

The constant search for greater output of goods from the expenditure of human energy stimulates design improvement and increased usage of machine tools. We see therefore in the industrialized countries machine tools which eliminate all unnecessary human effort. Manufacture has become more efficient through this mechanization. The primary field for the application of special machine tools has hitherto been mass-produced goods and the economics achieved are generally clear-cut. During the last 15 years, however, machine tool designers have directed their efforts mainly towards more automatic general-purpose machine tools. This trend is likely to prove advantageous since, even in the industrialized countries, components produced in batches of 5 to 100 workpieces - not mass-produced components - account for the largest part of total output.

In the latest, advanced factories of the aero-space industries the need is not mass production, but fabrication in limited numbers of complicated parts made from special alloys which are difficult to work. To satisfy this demand machine tools had to be developed which eliminated most of the idle machine time and the operator fatigue which causes errors. In the process, the control elements of the machine tools have become more important: through numerical and computer techniques contours can be expressed in mathematical terms and then automatically produced without previous layout. However, even these very expensive machine tools are more economical than the older types in many metalworking shops if properly used. Even in the USA and Europe, however, the majority of machine tools are still built to standard designs without numerical controls. Good and profitable usage of all types of machine tools depends on itemized planning and tooling. This is especially true for numerically controlled machine tools, which often have pre-set tooling for numerous tool changes, effected automatically during the manufacture of a complicated workpiece.

Numerically controlled machine tools cannot be unconditionally recommended for factories in developing countries. Those of advanced design require a strong factory organization, programming and tooling services which seldom exist in developing countries. However, machine tools with simple two-axis numerical controls have already been produced in large numbers and are rugged as well as economical in normal workshop service. Before acquiring such equipment, particularly for use in a developing country, it is desirable to check that the controls have been subjected to practical tests under similar climatic conditions.

The general use of carbide tooling has introduced more stringent requirements regarding the power and rigidity of machine tools, which have incidentally permitted better quality production from tooling made of other materials.

It is observable that the machine tools in developing countries are generally of low power, 3 HP or less. There is little appreciation of the fact that a high-powered machine tool also uses only one operator and occupies the same floor space, but has an output several times greater (roughly in proportion to its greater power) if it is equipped with proper carbide tooling. Continuous advances in the technique of carbide machining during recent decades have created a situation in which the machine tools in current use, especially in developing countries, are often not the most suitable models for production requirements.

The erroneous impression has been created that even the most difficult steel machining jobs could be mechanized by using carbide tools with negative rake angle at very high cutting speeds. Many over-enthusiastic reports of the use of this technique were to blame. However, much helpful information is being published that derives from actual production experience and experimental tool evaluation conducted in industrial laboratories.

Good tool design and efficient use of machine tools are intimately related. Neither a high-powered, well-designed machine combined with a weak, inadequate tool nor a well-designed carbide tool combined with an underpowered, insufficiently rigid machine can achieve optimum production.

Even the most expensive machine tool can yield very competitive costs if it is properly tooled and worked continuously for 3 shifts, 7 days a week. This requires:

- An adequate work schedule;
- Shop organization, including communications, control and storage facilities; and
- Good maintenance services.

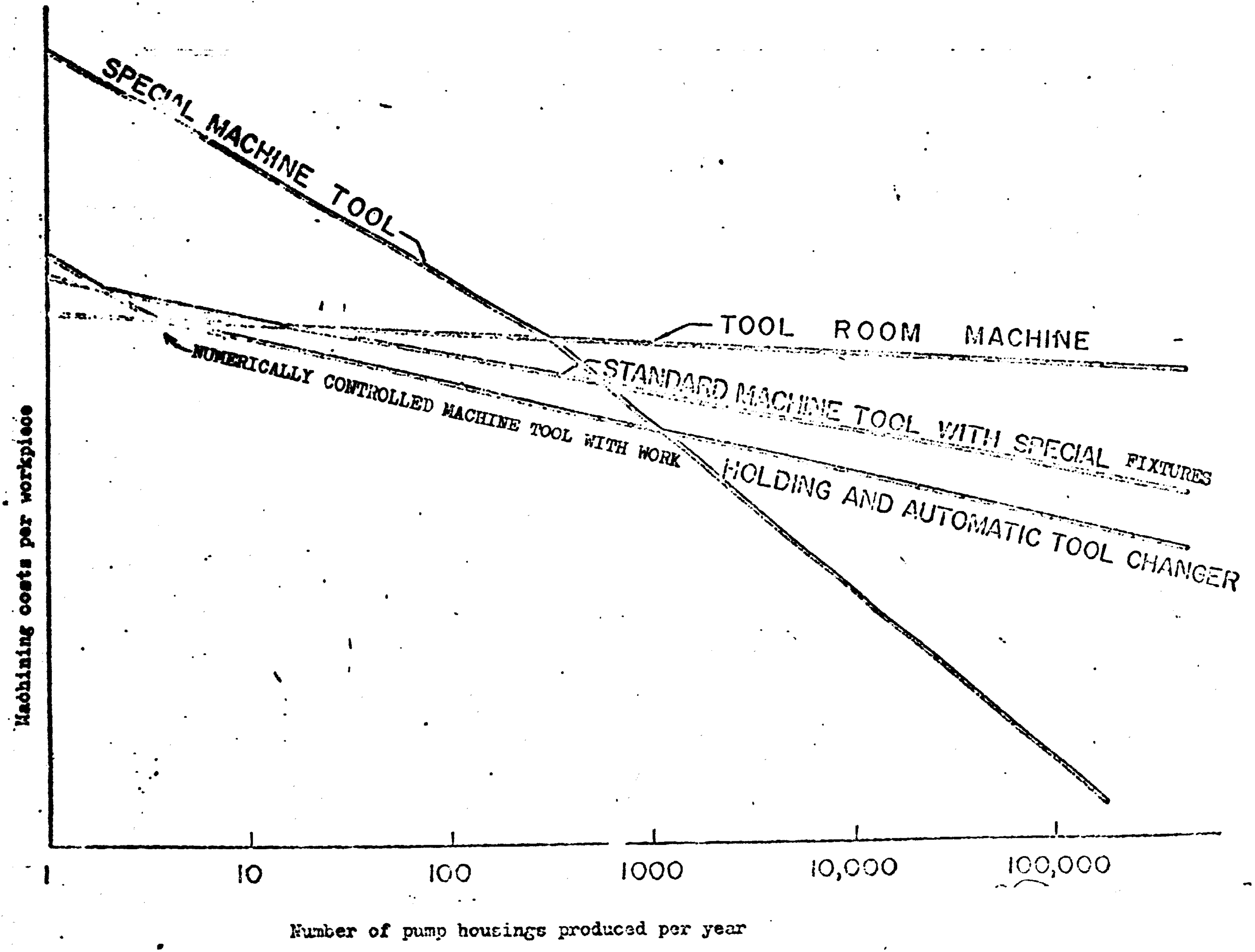
Unless all three requirements are met, however, the machine can become a money-losing proposition.

The relative merits of different types of machine tool are graphically illustrated by figure 1 below, which shows unit production costs of pump housings. In this example, the housing is of malleable iron and requires milling, boring, reaming, drilling and threading operations in various positions and of various dimensions. In all, 30 tools are needed for as many manufacturing operations.

The number of workpieces that have to be made will determine the best machine for the job. If only one or two pump housings are to be produced, toolroom methods using standard machine tools are usually the most suitable. One can already envisage designing and making special attachments to standard machine tools, provided at least 10 housings are required. If a numerically controlled machine with automatic tool changer is available, it will result in lower machining costs when the production run exceeds 5 workpieces. If the product is required in large numbers, a special machine may be justified The larger the number of workpieces produced per year the lower the machining cost per workpiece. Even with toolroom methods there will be a steady but small reduction in machining costs as the number of workpieces produced increases, because the operator will learn in time to make better use of the machine tool and tooling, but the costs will remain comparatively high.

As soon as the number of workpieces to be produced is sufficient to justify the expense of special

Relationship between type of machine tool, number of workpieces and cost



fixtures, the cost per workpiece can be reduced considerably. For small lots, however, numerically controlled machines are often still more economical than standard machine tools with special fixtures.

If the individual workpiece is very high-valued, it may even be justifiable to use a numerically controlled machine when only a single workpiece is to be produced, because this machine eliminates human errors completely and thus avoids the possibility of making scrap. Having programmed all operations, it may be necessary to check them regarding sequence, dimensions and accuracy by using an imitation workpiece. This procedure is preferable to running the risk of ruining a workpiece in which material and machining costs have already amounted to several thousand dollars. However, for production in really large numbers, a special machine tool will be the most economical, for pump housings or any other workpiece.

Accuracy and performance

The many types of standard machine tools may be classified as follows:

- Class 1: High-precision machine tools for instrument manufacture and the toolroom. Some of these machines have to be placed in air-conditioned rooms and mounted on isolators or special foundations; otherwise it might be difficult to maintain their extreme accuracy.
- Class 2: Precision machine tools for the toolroom and for production to close tolerances.

- <u>Class 3</u>: Machine tools for the maintenance shop and auxiliary production.
- <u>Class 4</u>: Machine tools for the field repair and fitting shop.

Machine tools of these different classes may look alike at first sight and have the same features and power. They will differ in the quality of their output as well as the workmanship expended on their construction and have to be employed only within their specific range of accuracy. To obtain precision workpieces with a class 4 machine tool would require a degree of skill from the operator which is very scarce and the product would still be more costly than the same work done on a class 2 machine tool. On the other hand, the class 2 machine will cost twice as much as a class 4 machine of identical size and power, with a similar function.

The need to maintain high accuracy calls for a specific maintenance programme, relating to the accessories and tooling as well as the machine tools. The organization of maintenance and repair is discussed in chapter 2. It is also important to take measures which minimize wear and tear. Thus, care should be taken to avoid work that in size and weight is beyond the capacity of the machine tool.

The uncontrolled emission of grinding dust quickly ruins good machine tools. Surface grinders, cylindrical grinders and tool grinders are often installed without providing for the collection of their grinding dust, which then settles on the other machines in the shop. No harmful effects will be noticeable at the start, but within one year all precision machine tools will be affected to such a degree that sliding surfaces become worn and bearings are loose. The fine particles of grinding dust mix with the lubricant and act like a lapping compound.

Similar damage can be suffered when a precision shop is located in a desert area or even when it is exposed to winds that come off a distant desert. In such cases too it will be observed that precision machine tools can be ruined beyond repair within a comparatively short time. Special care has then to be taken that no openings in the walls, roofs or windows permit the entry of air loaded with gritty dust.

Machine tools are the principal investment in a metalworking shop. The utmost care should therefore be exercised in comparing the performance specifications of alternative models before purchasing a machine tool and in verifying that the machine finally purchased meets the specification claimed by its manufacturer.[2]

The output of a machine tool is judged mainly by its chip-making capacity (measured in cubic inches per minute) and its accuracy under full load. In the case of grinding and finishing machines, performance can be expressed in terms of the finish obtainable (measured in microinches) over a certain number of square inches of surface per minute. Jig borers and other high-precision machines are specified by size of workpiece and the tolerances obtainable.

When buying a new machine tool, a test report should be obtained from the manufacturer. The report includes operating accuracies of spindles and tools, as well as tool performance. The data contained in such test reports are quite standardized. A good machine tool can suffer occasional 100 per cent overload without damage.

When a new machine tool has been placed in the production line, it should be observed for some time to verify its performance under shop conditions. Many companies will not instal a new machine in the shop immediately, preferring to instal it for some time in an experimental section. This permits a better evaluation of its performance and provides a chance to develop improved methods of production based on the machine's capabilities. During the experimental period, it is best for the new machine tool to be worked by the operator who will later use it in the production shop. He should be thoroughly familiar with the operating instructions issued by its manufacturer. If these are missing, as is the case often with second-hand machines, they should be obtained by writing to the manufacturer.

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[2] See UNIDO, The reflection and acceptance testing of metal-cutting machine tools. A practical guide for developing countries (United Nations publication, Sales No.: E.71.II.B.3).

Special-purpose machine tools

When the number of workpieces to be produced is sufficiently large, it may be justifiable economically to invest in a machine tool specially designed for the purpose or consisting of an assembly of standard machine tools, which processes a single type of workpiece in a sequence of operations. In either case, it is essential to allow for a certain period of testing and "trouble shooting" after installing the machine. A more extended period will be needed than for the shop testing of a standard machine tool.

When the special-purpose machine tool is built as a unit by a particular manufacturer, a thorough acceptance test should be required before despatch, machining a large number of sample workpieces. There are inevitably some new, unproved features in a special machine tool, unlike a standard machine tool which should be built solely with components that have been found reliable over many years of shop service. It will be much easier to correct any shortcoming at the place of manufacture, before despatch, than to wait until the machine is in the purchaser's workshop.

In most cases the tooling for special-purpose machine tools will be standard. Should special tooling be required, at least as much effort and attention should be devoted to the design features of the tools as to those of the machine. Where complicated tooling or form tooling is involved it should be designed, built and tested before the machine tool design is started. It has been known to happen that a special-purpose machine tool failed to perform as expected because its planned tooling could never be made to work. Tool development should also come first in cases where an unusual spindle has to be designed for the tools or where the rest of the machine tool is built around the special tooling.

Other points to consider carefully in the design of special-purpose machine tools are ease of lubrication and ease of servicing the hydraulic, pneumatic and electrical servo-mechanisms, which should also be accessible for routine inspection. Repair work should be possible without tearing apart the whole machine. Disregard of service requirements at the design stage makes even minor repairs very costly, the entire machine has to be shut down to effect them.

The best machine tool, whether standard or special-purpose, can be rendered inefficient by incorrect floor mounting. When the shop floor stands on solid ground it should be possible to level the machine directly by grouting or set-screws and good performance can generally be expected. However, it must be remembered that floor and building vibrations caused, for example, by forging hammers, trucks passing along an adjacent road, or even overhead cranes, can affect the quality of the surface finish and the dimensional accuracy. In such circumstances it is generally possible to improve the suspension of the machine tool by fitting elastic mounts made either of rubber, glass fibre, springs or pneumatic elements. Special care will have to be taken if the factory floor lies over a swampy area or loose sand. The machine tool builder may be able to make specific recommendations regarding the type of foundation necessary in difficult situations, in order to keep the machine tool stable in the presence of outside disturbances, as well as to isolate vibrations originating within the machine tool. A special foundation will increase costs, however, and will usually reduce the mobility of the machine which production changes may make desirable.

When a multiple story building has to be used, the heaviest machines are installed on the ground floor for obvious reasons. Lighter machines can go on the higher floors, which always bend to some extent under the weight of the machines. Any ordinary floor is subject to low frequency vibrations - about 20 cycles per second. If elastic mounts are used they should have a different natural frequency from that of the floor in order to eliminate resonance. Such special mounts under individual machine tools make possible a more flexible approach to plant layout.

Programmed and numerically controlled machine tools

The fact that most machine tools actually work only 20 to 50 per cent of the available operating time has offered a powerful challenge to modern machine tool designers. The increasing use of carbide tools meant that the machine time lost in set-up, tool changes, workpiece handling and positioning was even more valuable. The designers responded by developing power-driven feeds, regulated spindle speeds, anti-backlash screws, rapid traverse and multiple stopping and tripping devices. From these improvements the programmed machine tools evolved during and after the second world war. The features of the first models included automatic start and stop of the main spindle; chucking tables with movable clamping and rapid traverse; and controlled feeds in longitudinal, vertical and transverse directions. The required process sequences were usually programmed by inserting plugs into specified connecting points on the programme board of the machine's control equipment.

Another technique, the attachment to machine tools of tracing units, had developed successfully in previous years, mainly because of the need for production of more and larger dies. In this type of machine tool the tool path is controlled by a template or master form. The technique grew in step with the automobile industry after the first world war and its use was helped by the relative scarcity of skilled tool and die makers.

During and after the second world war the aircraft industry expanded rapidly in volume and grew in technical sophistication. Many complicated parts had to be made of high-strength materials and machined with great accuracy. Consequently, many new machine tools were designed with features for obtaining high precision automatically or at least without using a highly skilled mechanic as operator. Such was the genesis of numerically controlled machine tools. As with most advances in technique, the principle of the various control devices is not new. Controlling a machine by numerical values or symbols can be traced back to the Jacquard loom and the pianos played mechanically with the aid of perforated paper rolls. Magazine feeds and carriers to transfer workpieces were already to be found in certain types of automatic turret lathe about 1914. There were also many attempts in that period to control the tool path and workpiece dimensions during operation of the machine by automatic and numerical devices. In most cases the high accuracy and repeatability required of machine tools were lacking, because the servo-mechanisms then available could not satisfy these requirements. However, after small, powerful electro-hydraulic servos had been successfully developed for use in aircraft they were adopted by machine tool manufacturers, together with electronic controls.

Numerical control systems are units which convert symbols on punched cards or perforated tapes, or data on magnetic tape, into electric pulses that control the various mechanical functions of the machine tool. Today most numerical control systems use a standardized, 1-in. wide, eight-track perforated paper tape as input for the control unit of the machine tool. Numerical control is a form of automation which reduces set-up time, selects tools for the successive operations and prescribes their action. It is generally used to produce parts which must be identical. The tape with the control information can be stored for any length of time until needed for future orders or it can be despatched to a far-distant factory, where it can be used to produce parts of equal shape and accuracy.

All the motions of a machine tool for which the operator used to turn a crank or handwheel can now be effected by power devices and controlled by tape through a self-contained control unit. Before a tape can be perforated for use as a control device, a programmer must determine all the operations to be performed, the tools required and their settings, as well as all the machine motions.

The motions of a spindle or table occur along one, two or three axes. A milling machine or drill usually has " 2-axes controls", that is, the table movements are controlled in the longitudinal and transverse direction. If the spindle of a vertical milling machine or drill is also controlled for the depth of cut or hole, the machine is then said to have "3-axes controls". Such machines, in which the tool or workpiece can be moved by numerical controls from one position to another in prescribed sequence, to perform operations at particular points, are said to have point-to-point programming.

There are even more sophisticated machines with continuous path control, in which the tool can be made to follow a definite curve, which may be defined mathematically, as in cams and similar contours. The machine tool may also incorporate control of a circular motion - for example, motion round a vertical axis - in which case it may be said to have "4-axes controls"; and if it also controls the motion of a table or spindle around a horizontal axis, it may be said to have "5-axes controls".

Tool preparation has to be stringent for numerically controlled machines. Accurate presetting of tools is necessary and the requirements are listed in coded form, together with all operations to be performed, in optimum sequence, on a planning sheet from which the tape is punched, the more difficult programmes being prepared with the aid of a digital computer. Using these techniques complicated parts can be machined more accurately, using continuous-pass machines and programmes specially developed for the purpose. The most versatile machines perform the functions of several types of machine tool - boring, drilling, milling, threading, turning and surface finishing. They have automatic tool changers and the tools employed must be well engineered and pre-set. In these cases, a single machine is equivalent, from an investment point of view, to a complete manufacturing set-up, and this is how the machine tool user should view it. The user in a developing country must judge the usefulness and value of a modern machine tool from an intrinsically different position from his counterpart in an industrialized country. The latter can usually foresee many orders for complicated workpieces, the former can rarely do so.

The application of numerical controls is not confined to machine tools which remove metal in chips. Multiple punch presses, coil winders, flame-cutting machines and wire-drawing machines are other examples of their use. Even transfer machines are often equipped with numerical controls and the number of applications is growing daily.

The operation of numerically controlled machine tools requires some new skills which can be developed most effectively and in comparatively short time by upgrading capable men already employed on the production line. As a rule, less mechanical skill is required of the operator, who now becomes the supervisor of a greater production output from the same floor space. The good millwright who has been responsible for conventional machine tools, is familiar with various types of tooling, tool materials and work-holding devices, and knowledgeable about feeds and speeds, can become an efficient programmer of numerically controlled machines with relatively little training. Once trained, such men represent a valuable investment in personnel, difficult to replace. An enterprise must therefore be careful to ensure their continued employment or it will sustain losses difficult to make good.

Unconventional machining processes

The traditional or conventional method by which a machine tool removes metal is by shaving away thin slices, or chips, of the workpiece. In the last decade several important processes have been developed that are not based on mechanical cutting actions; they depend instead on chemical and electrical actions. These new processes are collectively described by the term unconventional machining.

As yet, the amount of machining done by these methods is a small fraction of the total in industrially advanced countries and a negligible fraction or none in most developing countries. Their use is growing, however, with the demand for manufacture from high-strength materials of products with complicated shapes. This is especially evident in the aerospace and electronics industries. They tend to be employed in applications where conventional cutting tools would not function or would have such a short life as to be uneconomical, and in some applications for which no cutting tools exist. Several of these unconventional processes have been developed to the point where they are competitive with traditional methods of material removal and even, in certain circumstances, more economical.

The principle of electrical-discharge machining (EDM) is well known and was first applied in the USSR. A narrow gap is maintained between the tool (an electrode carrying a pulsating high-frequency current) and the workpiece, while both are submerged in a dielectric fluid. Spark discharge between electrode and workpiece erodes the latter. The fluid is kept circulating in order to remove the debris. EDM is employed to make large one-piece dies for the automotive industry. Electrodes can be made of a number of metals and alloys or of graphite. The workpiece has to be a conductor of electricity. Where a male part is already in existence, it can be provided with a special tip and used for die sinking. The metal removal rate and surface finish can be controlled in this process, which is capable of achieving tool room accuracy.

Electro-chemical machining (ECM) is a related electrolytic machining process which was first applied to the grinding of hard-to-machine material, especially carbide tools. The main advantage it offered was more efficient use of the diamond grinding wheel, thereby lowering costs. A gap is maintained between tool and workpiece by the metal-bonded abrasive in the grinding wheel. The process itself is the opposite of electro-plating and there is no tool wear. A direct current is made to flow rapidly in an electrolyte between the tool (cathode) and the workpiece (anode). ECM is also widely used for contoured cavity die sinking and making other special shapes such as parts with long, non-round holes. The accuracy of the finished workpiece is dependent upon the dimensional accuracy and surface quality of the tool (cathode), which is made of corrosion-resistant metal; the speed at which the electrolyte flows between tool and workpiece to remove the sludge which is formed; and the current capacity of the equipment. Another application of the ECM process is to manufacture workpieces of irregular geometric shape. Their dimensions can be held accurate to within 0.0002 in, where conditions are favourable. There are no sparks or arcs to cause localized heating in the machined surface and no burrs are formed. Since equipment and tooling are expensive, the process is generally not used for small quantities of parts.

Chemical milling has been used industrially for about 30 years and equipment for this process has been marketed during the last 10 years. An acid or alkaline solution is used to etch a prescribed pattern into or through a metallic workpiece. The desired pattern can be obtained by masking the rest of the workpiece with a chemically resistant film, exposing only the portions to be etched away. An alternative etching process uses photographic techniques and is variously known as photoforming, photofabrication, photochemical blanking or even, confusingly, chemical machining. In this process a photo-sensitive coating is applied to the workpiece, which is then exposed to light through a negative; the coating is then washed off the area to be etched in a developing solution. Small parts made of almost any thin metal sheet can be produced in large volume relatively quickly and the process is often competitive with stamping.

The application of ultrasonics to precision machining has progressed with the need to drill or shape at an economic cost workpieces made of non-machinable material such as tungsten carbide, ceramics, glass and quartz. The heart of the equipment is a magnetostriction transducer, which converts high-frequency electromagnetic into mechanical vibrations. The toolholder is attached to the transducer and a tool of the desired shape is thus made to vibrate at high frequency and low amplitude in contact with the workpiece in an abrasive slurry. The tool is usually made of mild or stainless steel and the commonest abrasive is boron carbide powder.

In the electron beam machining process, electrons are accelerated and focused in a narrow beam onto a spot, by means of a magnetic field. The electron beam heats, melts or vaporizes a localized area of the workpiece, which usually is placed in a vacuum chamber. The beam can cut holes and hairline slots or weld with a deep, narrow seam. Some of the first applications were the drilling of small holes in jewels and spinning nozzles, and the welding of the covers of atomic fuel elements.

Two types of machines employing laser beams have found industrial application in micro-machining and micro-welding. The pulsed ruby laser was the first to become commercially available, followed recently by the CO_2 laser with continuous light beam. A laser beam will vaporize, melt and weld any material used in engineering; it is possible to use it with the workpiece placed under a translucent cover rather than in a vacuum chamber.

CHAPTER 2 TECHNICAL FACTORS IN MACHINE TOOL OPERATION

Machining capacity

The concern of a machine tool buyer is that the equipment should satisfy his specific production requirements at a competitive cost. Although many new trends are discernible in recent designs, most basic features of machine tools remain the same.

Machine tool design is the fruit of experience gained in production shops as well as laboratory research. The main trends in design have been the provision of more power and greater rigidity, together with a wider range of fee rates and speeds. Other developments have been greater safety and ease of operation, more specialized control and drive mechanisms, and improved accessibility for maintenance. Cutting speeds with carbide tooling range in practice approximately as follows: steel, 300 to 800 feet per minute; cast iron, 200 to 500; and aluminium and magnesium, up to 20,000. Much higher speeds are obtainable when cutting the light metals, because they require less power per cubic inch machined per minute than do steel and cast iron. Tool temperatures run higher when machining ferrous materials, resulting in more rapid tool wear.

The amount of power required at the cutter to remove a cubic inch of material per minute depends basically upon the kind of material being cut, particularly its microstructure, but the feed per tooth and the cutting angle of the tool exert a certain influence. Power consumption is not appreciably affected by the kind of material used for the cutting edge of the tool (high-speed steel, cast alloy or carbide) or by the application of a cutting fluid. However, the use of cutting fluid often increases tool life (number of pieces completed per tool) and may improve the finish.

The power required for a machining operation consists of that needed for actual cutting or removal of metal and that needed to overcome friction in the spindle and feed mechanisms. For optimum performance, the rated horsepower of the driving motors should exceed the power required. Both the machine and the motors can be operated above rated loads for short periods of time, but it is not good practice to operate with continuous overloads. In most instances safety devices are built into the machine tool to prevent serious damage through overloading - for example, shearing pins and declutching mechanisms.

Data on the power required at the cutter to machine a representative range of metals, together with recommended cutting speeds, have been assembled in table 1. The values tabulated allow for the efficiency of machine tool drives; they are based on a cut 1/8 in deep, taken with a tool having 0 degree rake angle, and a feed (chip load) of 0.010 in per revolution.

A 10 degree negative rake angle at the cutting edge requires approximately 10 per cent more power than a 0 degree angle. Likewise, power required will decreas by about one per cent for each degree of positive rake angle.

If the feed per revolution is more than 0.010 in, the power required per cubic inch per minute will decrease slightly; on the other hand, it may increase by 20 per cent or more if the feed per revolution is reduced to 0.0002 or 0.001 in. In fact, a fine chip is generally the least economical way of machining in terms of horsepower required per cubic inch removed per minute and in terms of tool wear.

A greater depth of cut decreases slightly, and a shallower cut increases slightly, the power required per cubic inch per minute.

Table 1

Machining capacity in relation to rated horsepower and recommended cutting speeds - selected materials

terial to machined	Cubic inches of metal removed per minute		Recommended cutting speeds, feet per minute	
	3 hp machine	15 hp machine	High-speed steel tools	Carbide tools
luminium	5	30	600-2,000	1,000-8,000
rass, soft	5	30	500-1,500	350-1,000
ronze	3	18	200-300	200-800
ronze, hard	1.5	9	100-200	125-350
ast iron, soft	3	18	100-120	250-400
ast iron, chilled	1.5	9	50-70	150-250
alleable iron	2	12	100-120	300-400
teel, soft	2	12	100-150	350-750
teel, medium	1.5	9	80-100	250-400
teel, hard	1.0	6	30-60	150-300

To check whether a 3 hp lathe or milling machine is adequate for machining a workpiece of steel, 0.20 per cent C, Bhn 170, we should proceed as follows. This material falls in the category of soft steel, of which 2 cubic inches per minute can, according to the table, be removed by a 3 hp machine tool. Expressed in inches, the depth of cut multiplied by the width of cut multiplied by the feed per minute should, therefore, not exceed 2 units. This amount can be removed in the form of chips during continuous machine tool operation. Note that a 15 hp machine would remove 6 times as much material as a 3 hp machine, since the drive mechanism of the higher-powered machine tool is more efficient.

It should be remembered that tools wear continuously during production runs and become blunt. Even when no breakage of the teeth occurs, power consumption rises by up to 50 per cent on account of wear, before the stage is reached where the tool is changed. For this reason, it is inadvisable to set up a machine tool for a relatively large number of workpieces on a basis which involves a power overload from the very beginning.

Modern machine tools are built with very rigid frames in order to be as free as possible from vibration. There are other factors, however, which influence the rigidity of the total set-up: cutters, spindles, position of tool, support of tool, the design and position of the fixture clamping the workpiece. These are points which are mainly under the control of the operator and the supervisor. Many companies have found it worthwhile to organize a programme to train their key men in the utilisation of modern machine tools and cutters.

The performance of old machine tools can sometimes be improved during a general overhaul by eliminating loose bearings, slides and gears. Old milling machines are often "updated" by fitting a flywheel, which, however, must be of the right size and properly located, otherwise it may damage the machine or cause deflections in its members which are detrimental to tool life. Milling machines with built-in flywheel have special controls for starting and stopping the spindle and feed mechanisms.

Carbide tools are nowadays often designed to give positive radial rake angles and variable small negative rake angles at the cutting edge. These tools have found general acceptance in industry and are now made by a number of companies. They enable the tools to be adapted easily for cutting steels of various hardness and other materials. They can be operated with less power and have a longer life than many other types of cutters. Since they also exert less thrust, it has been found advantageous to use them in milling welded steel structures, which bend and vibrate excessively if milled with ordinary carbide cutters. Mechanically held carbide tool tips, which can be indexed to change the cutting edge, have also gained wide acceptance, because they eliminate the cost of regrinding. They are used mainly as single point tools, but also in milling cutters.

Cutting speeds and feed rates of machine tools have been increased to such an extent that the actual cutting time is only a small part of the floor-to-floor time in most cases. Reduction of the time required for loading, locating and clamping the workpiece, positioning it for cutting, shifting levers for starting and stopping now offers the most scope for lowering machining costs. The production capacity of machine tools can be greatly increased by automatic pacing of the cutting operation and provision of automatic cycle controls to reduce idle time. The addition of an automatic cycle mechanism makes a standard machine more adaptable to large series production, since it eliminates many fatiguing motions otherwise required of the operator. The mechanism determines the hourly production rate, even in short runs. Numerical control of the machine tool can achieve similar results.

Special fixing devices are required for workpieces that are not rigid owing to their shape or, for other reasons, are difficult to hold by ordinary clamping. Various interchangeable, universal workpiece holders are commercially available today. They permit wide possibilities of set-up and ensure rigid holding and quick handling of workpieces in a great variety of configurations.

While carbide tools make higher rates of production possible, they tend to become blunt in a shorter time than cutters of high-speed steel; however, they produce more workpieces per tool setup, which is the main consideration. The number of workpieces produced per tool depends also upon tool design and the machine tool. Each shop should have experienced setters to select the best feed rates and assure that operating with non-rigid fixtures, loose bearings, loose ways etc. is not allowed to happen. With proper attention, a gradual improvement in the production figures will generally be achieved by changing to carbide tooling. Careless handling of carbide tools, selection of the wrong grade of carbide, incorrect grinding, using the tools until they flake or chip are the kinds of error that are committed and can make this type of machining uneconomical.

Most machine tools are now built with the stringent requirements of carbide machining in mind. This has meant increased power and rigidity, which also made possible higher feed rates and speeds with tools of high-speed steel (HSS) and cast alloy materials. (The latter are by no means obsolete, having been improved during the last few years, and a wide variety of grades are available). In form cutting, in particular, HSS and cast alloy tools are preferred because they can be more easily shaped and reground. Sometimes carbide and HSS tools have to be run together on the same machine. Grades of carbide have been developed for use at the lower, HSS cutting speeds, because the usual carbide grades tend to flake and chip if used at these speeds.

Since higher cutting speeds generally produce a better surface finish, it is possible with carbide tooling to machine the surfaces of bearings with a sufficient degree of accuracy. A reduction in the feed per revolution also serves, within limits, to improve surface finish. The surface finish required must be kept in mind when setting up a machining operation. For example, if we use a carbide face mill on a heavy steel workpiece, with a feed of 0.015 in per tooth, a cutting speed of 350 feet per minute, and 0.300 in depth of cut, the surface finish is comparatively rough - about 80 microinches rms profilometer reading. A feed of 0.005 in per tooth, a cutting speed of 500 feet per minute, and only 0.060 in depth of cut would result in a better surface finish - about 45 microinches rms profilometer reading.

The hardness number of the workpiece material can be used to make approximate preliminary estimates of feeds and speeds required. Thus, while it is economical to cut steel of 200 Bhn with a carbide tool at 500 feet per minute and a feed rate of 0.010 in per revolution, the same material heat-treated to 300 Bhn would require a reduction in the cutting speed to about 300 feet per minute and in the feed rate to about 0.008 in per revolution. If the hardness is increased to 400 Bhn the machining problem becomes more difficult: not only is it necessary to decrease the cutting speed to about 140 feet per minute and the feed rate to 0.004 in per revolution, but the machine tool specification becomes more stringent.

Resurfacing used die blocks requires highly rigid bed-type machines operating at relatively low feed rates and speeds.

It is economical to resharpen a carbide tool when it has worn 1/64 of an inch on the flank, which the operator can easily measure with a marked rule. Using the tool beyond this point increases the risk of breakage and makes regrinding more expensive, more than offsetting the gain from a longer production run per tool setup.

Another recent development is the so-called throw-away tool: the carbide tool tip is mechanically clamped and when the edge is worn it is indexed and a new edge starts cutting. A square insert provides 8 cutting edges, a triangular insert 6 cutting edges, with negative rake. There is no break in production for regrinding.

The modern machine tool cuts metal in fundamentally the same way as the first tools devised by man to fashion metal objects, separating the metal by means of a harder material. This is still the essential function of most machine tools. The new materials with high-strength properties of which workpieces are made, and the demand for much speedier operation have made it more difficult to perform this function. It is in the small region at the cutting edge, a few thousandths of an inch in depth and length, that most of the mechanical power applied by a machine tool is used in the cutting process. The harder the workpiece material the more power is required per cubic inch removed per minute and the more heat is generated in the tool, the chip and the surface of the workpiece.

Many factors contribute to economical operation, not the least of which is the correct application of engineering principles to the complete tooling of the machine in the shop. As yet, no "wonder" cutting fluid, no "miracle" tool material, no "atomic disintegrator" or "magic angle" has been discovered which will result in high, accurate production and do away with the exacting requirements for the machine, its tools and the setup for machining.

Wheel speed in grinding operations

Grinding was for long thought of mainly as a finishing operation. In recent years, however, wheel speeds have increased in both rough and precision grinding operations, because higher speeds make it possible in many cases to remove metal rapidly and economically.

Currently, there is a great interest in Europe in precision grinding with vitrified-bond wheels operating at peripheral speeds of 12,000 feet per minute or higher. In the United States, only a very limited amount of production grinding has been done thus far at such speeds - some thread grinding and internal grinding at 12,000 feet per minute and grinding of hardened bearing races at up to 16,000 feet per minute. These are all special operations performed on machines suitably equipped for the high speeds.

Grinding wheel strength

Wheels have to be tested at a speed 50 per cent higher than the maximum permissible operating speed, for example, at 18,000 for use up to 12,000 feet per minute.

Conventional vitrified wheels in the softer grades or coarser grit sizes are not strong enough to be used at high speeds. Since fracture due to excessive speed always starts at the hole, where the stresses are the highest, strengthening the portion of the wheel adjacent to the hole is one way of overcoming the problem. The strengthening can be done by impregnating the central part of the wheel with a suitable reinforcing material. Japanese experience shows that wheels in soft grades and coarse grit sizes reinforced with high-strength resin can be safely used at high speeds. This makes high-speed grinding a much more promising technique than if only hard, fine-grit wheels could be used.

Use of high grinding speeds

The principal advantages of high wheel speed derive from the fact that the grinding forces are inversely proportional to the wheel speed, other things being equal. Increasing the wheel speed reduces wheel wear and the deflection of the workpiece, thus improving the surface finish. However, a higher wheel speed also raises the temperature of the work surface, unless the work speed can be increased in the same proportion. High-speed grinding also requires a greatly improved coolant system, since conventional nozzles do not get the grinding fluid into the grinding contact area at high wheel speeds.

With higher wheel speed one can either improve workpiece quality without reducing the rate of metal removal or obtain the same quality with a higher removal rate. The latter is achieved by increasing the feed rate until the grinding forces are as great as they were at the lower wheel speed. This statement is valid provided that the workpiece can withstand the higher grinding temperatures associated with the higher rate of metal removal.

Because of the appreciably higher equipment costs, high-speed grinding can be justified only if it makes possible sufficiently higher rates of metal removal. If the equipment can be justified on this basis, then its use can also be justified to improve quality, if necessary.

High speed grinding is considered very promising by the automotive industry, in the light of the results already obtained. Its acceptance as a manufacturing process will depend on a careful evaluation of the total costs involved in obtaining the product quality required for each potential application.

New equipment will be needed for operations at 12,000 feet per minute, since it is not considered practical to rebuild existing equipment to achieve this speed. Any change to high wheel speeds, if it is found worthwhile, will be gradual.

Use of low grinding speeds

Experience has shown that there are special situations in which high wheel speeds are detrimental, the best results being obtained at speeds below 6,000 feet per minute.

In vertical-spindle, rotary-table grinding, the speed generally does not exceed 4,500 feet per minute. Higner speeds are likely to glaze the wheel unless a considerably softer material than normal is employed. Most of the abrasion in this type of operation is done by loose grains, which excise most of the chips and also bring about most of the wheel wear, since they knock other grains out of the wheel, thereby replenishing the supply of loose abrasive material. A properly selected wheel functions in this instance primarily as a controlled supply of loose grains. The grinding action in this type of operation is quite different from the usual one and an increase in wheel speed can prevent it from taking place.

A reduction in wheel speed normally increases wheel wear and decreases the grinding ratio - the amount of metal removed relative to the amount of wheel wear - by making each abrasive grain do more work. However, in a surface grinding operation on a high-vanadium (5 per cent), high-speed steel such as T15, the grinding ratio increases as the wheel speed is reduced from 6,000 to 3,000 feet per minute and then decreases rapidly with further reductions in wheel speed. The extremely hard vanadium carbide particles in the steel apparently become less resistant to severance by the abrasive grains as the wheel speed is reduced. This phenomenon more than compensates for the increased wear that normally occurs with diminishing speed. Below 3,000 feet per minute, the normal wear relationship starts to take effect.

The same phenomenon occurs, but to a much lesser degree, in ordinary high-speed steels, where the grinding ratio may remain more or less constant as the speed falls from 6,000 to 4,000 feet per minute, below which figure it decreases.

When grinding titanium and its alloys, it has been found that a chemical reaction can take place between the surface of the metal and the abrasive grain owing to the high temperature generated momentarily at the point of contact; this leads to extremely high wheel wear. Other metals that respond similarly are zirconium and uranium. The reaction can be inhibited by a combination of greatly reduced wheel speed (generally 1,500 to 2,000 feet per minute when the abrasive is aluminium oxide) and the use of certain chemically active grinding fluids , leading to an increase in the grinding ratio by a factor of 20 or more. The grinding fluid produces ionic barrier layers on the surfaces of the metal and the abrasive, which decrease the probability of contact and hence of chemical reaction between metal and abrasive. A low wheel speed provides the time needed for the fluid to form fresh layers to replace those dispersed in the course of grinding and also reduces the contact temperature, thus helping to decrease the chemical reaction. The effect of lower temperature is relatively slight in the absence of a suitable, chemically active grinding fluid.

Low wheel speeds also minimize the residual tensile stresses caused by grinding heat, which adversely affect the resistance of the metal to fatigue. An established procedure often employed in the aerospace industry is to grind at only 2,000 feet per minute with a soft wheel and to take progressively lighter cuts when approaching final size. It is not at all clear why such a low wheel speed should be necessary to prevent the formation of residual tensile stresses, when one recalls that hardened steel bearing races are being groun t 16,000 feet per minute with apparently no harmful effects from grinding heat.

Another grinding operation in which low speed has been found necessary is abrasive-belt grinding of stainless steel slab. The belt has to be run at only 2,800 feet per minute, at which speed an extremely high rate of metal removal is achieved. Abrasive belts normally run at double this speed, i.e. about the same speed as conventional vitrified wheels.

While high-speed grinding certainly shows a great deal of promise, these examples illustrate the conditions under which low speeds have demonstrable advantages.

The role of cutting fluids

The primary function of a cutting fluid is as a coolant of the tool, the chip and the workpiece. By lowering the termperature at the interface between tool and chip it enables the tool to last longer before regrinding. In addition, the use of a cutting fluid usually improves the surface finish of the workpiece and washes away the chips. Many different cutting fluids have been developed for the various machining operations, since no single fluid gives the best performance for all operations.

The most common cutting fluids are water solutions and emulsions, which are most effective in operations such as turning steel with single-point HSS tools. Turning operations with carbide tools are generally done without a coolant, although a stream of compressed air is then usually employed to blow the chips in a definite direction.

The addition of sulphur, chlorine or phosphorous products to a water emulsion gives it more of the properties of a lubricant. Cutting fluids of this kind can be used with advantage in drilling, thread milling and broaching, because a great deal of friction is generated in these operations on the non-cutting surfaces, especially the land of the twist drill. In such cases, the lubricating action of the cutting fluid may reduce the frictional forces of the cutting process as well, thereby reducing the power required by the tool. This phenomenon does not take place in turning operations, because a single chip is formed in this case under high pressure per unit area at fairly high speed. The lubricating action of oil and of water emulsions with sulphur or chlorine additives occurs in turning operations only at low cutting speeds (about 10 to 20 feet per minute) which are rarely employed in practice. Hence the cutting fluids usually chosen for turning act mainly as coolants. A good coolant can be made by adding to water an anti-rust agent, for example, 0.1 per cent sodium nitrate, and substances to lower the surface tension of the fluid and inhibit the growth of bacteria.

Mineral, animal, and vegetable oils are used as cutting fluids. Sometimes different oils are mixed in various proportions to produce a fluid of a certain viscosity for a particular job application or to improve the lubricating action of the fluid. Sulphur, chlorine and phosphorous products are also added to cutting oils because they improve the lubricating power at higher pressures and temperatures. Sulphur is usually incorporated by adding sulphurised mineral oil or a sulphurised fat to a plain mineral oil. There is a tendency for sulphur to stain non-ferrous metal and even steel surfaces. Oils containing sulphur should therefore be used with caution if discoloration of parts is objectionable.

Cutting oils with a high concentration of chlorine and sulphur compounds are used on thread milling, gear shaving and some automatic screw machines, as well as in heavy broaching operations. For thread grinding, a light mineral oil is used when a good surface finish is required. Kerosene is an effective cutting fluid in the machining of aluminium and copper. No oils, water solutions or emulsions should be used when machining magnesium because this increases the risk of fire caused by idling tools rubbing against the workpiece or making very fine chips. (When machining aluminium, the tools should always take a heavy chip and never be permitted to run idle over the workpiece; continuous removal of chips and dust from the machine tool is a further safety measure which is strongly recommended.)

Coolants are applied in mist form, especially in high-speed milling operations, to give a better surface finish or when a stream from a nozzle cannot be used because the liquid would be ejected all over the shop by the machining operation. Whether in mist or liquid form, the coolant should be applied generously, so that it can carry away much of the heat generated during the cutting action.

Most machine tools have built-in storage tanks and circulating pipes for cutting fluids. These items should be periodically cleaned to remove residues and minimize the risk of rancidity, mould and odour. A high-velocity filtration system can be installed, to remove efficiently from cutting fluids all fine particles, whether magnetic or non-magnetic

The use, reclamation, and eventual disposal of cutting fluids can be quite complex and is an important factor in the economics of metalworking. Many factories have found it advantageous to train at least one man in all aspects of the use of cutting fluids, because he can then significantly lower manufacturing costs and increase operating efficiency.

Disposal of used cutting fluid

In most developing countries the problem of environmental pollution is still largely ignored. Metalworking plants contribute to such pollution by indiscriminate discharge of used oil and cutting fluids as well as through smoke and dust. The consequences of such actions may initially be confined to causing annoyance to workers and neighbours. In time, however, the effects of pollution can reach overwhelming proportions, as many industrial countries have now discovered, endangering the health of everybody and destroying natural resources such as pure water, forests, fisheries and agricultural land.

It has been discovered that it costs much less to prevent pollution than to eradicate it. Every industry in every country should feel it has a responsibility to preserve the natural heritage and act accordingly; otherwise, it will bring about its own destruction within a measurable period of time. If the issue of pollution is tackled at the start of industrialisation by a developing country, reasonable solutions may be worked out before the problem becomes well-nigh unmanageable. The hazards to public health in many industrialised countries which have been created by inadequate control of pollution provide a clear warning to the developing countries. The level of the costs which industrialized countries may have to incur to turn back the tide of pollution would represent a disastrously heavy burden for any developing country which allowed itself to get into a similar situation.

Maintenance and repair

Machine tools represent a major investment when equipping a metalworking shop. It is imperative to keep them in good repair. Well built machine tools may endure many years of use and abuse with negligible maintenance but nobody can count on that. Most small enterprises encounter slack periods during which they overhaul and paint their machine tools. Even in these cases, work should follow a definite schedule. In addition to replacing breakages, there should be a thorough accuracy check and the wear and tear of bearings, slides, gears, belts and motors should be examined. Loose motor mountings and worn belts can cause vibrations. Machine tools cannot function at full capacity if there is insufficient or uneven tension in the belts.

An old machine tool may be basically sound, in which case a thorough overhaul, including replacement of worn elements, may restore it to full working condition. Before starting an extended repair job on a particular machine tool, the manufacturer's maintenance manual should be consulted. (If it has been lost, another copy is obtainable from the manufacturer.) Rebuilding a used machine tool is a demanding task; in the industrially advanced countries there are shops which specialize in this complex precision work, often equipping old machines with modern features and then selling them with a guarantee, like new machine tools. Such activities could be an important step on the road to becoming machine tool manufacturers, for suitably equipped workshops.

When the performance of a machine tool begins to deteriorate, there are several possible reasons. The following advice regarding operation and maintenance will, if followed, avoid most problems and cure many others.

1. First check that the machine is level and is not rocking on the floor, which may be due to the foundation settling. The test requires a precision level on cross-slides and bed.
2. Make certain the machine tool is not disturbed by external shocks produced by road traffic, forging presses, cranes and the like, which result in rougher surface finish and lower accuracy. Use rubber, springs, felt, pneumatic or fibreglass mounts if necessary to absorb vibrations transmitted from the surroundings.
3. A regular schedule of lubrication for the machine tool and its motors will avoid some breakdowns. Make certain the correct lubricating oil is used.
4. Make sure the machine tool is clean before starting a new job. Remove all chips and dust from the machine after finishing the job, but never clean the machine while it is running, because damage and personal injury can result.
5. To avoid cuts and infection, never remove chips with the bare hands; use a brush or cloth.
6. Do not extend an arm over cutters or workpieces while they are revolving.
7. Use a feeler gauge or a piece of paper when checking close adjustment of cutters and workpieces.

8. Keep tools and workpieces in a place where they cannot be damaged or become covered by chips and will stay clean. Chips should be periodically removed, so that large amounts do not accumulate near the machine.

9. Make sure that dust and chips cannot enter the coolant reservoir or pipes or settle on precision slides and surfaces of the machine tool. It is good practice to cover all open slides.

10. The spindle and spindle nose of a machine tool are among its most precise elements. Particular care should be taken that they are not subjected to hammer blows or damaged by cutting tools or chips.

11. Before mounting tools on the machine tool check that they are free from chips, dust and nicks. Fine chips between tools and their fixtures will cause inaccuracies and sometimes permanent damage.

12. When using a lathe, keep the tool overhang and the extension of the tail stock as short as possible in order to avoid impairing the over-all stiffness and hence the performance of the lathe. Lathe tools should be mounted on the centre line; if the cutting edge is above or below centre line the tool angle i affected.

13. When mounting a milling cutter on an arbor, place the cutter as close as possible to the spindle nose and position the table near the column. Make sure

the horizontal cutting force acts to push the cutter into the spindle. A staggered tooth cutter will work better in deep slots. A cutter with wide tooth spacing is usually better than one with many teeth, it uses less power and makes for better chip flow. All cutters should run concentric otherwise some teeth will be overloaded and others idle.

14. Handle large milling cutters with a piece of cloth, not with bare hands, as a protection against cuts.

15. Always make sure that the workpiece is in the correct position and clamped tightly without deflection, and that there is no interference between tools and holding devices. Insert metal shims or cardboard to protect highly finished surfaces when tools or holding devices are clamped on to them.

16. Never place rough castings or forgings on precision ways or similar surfaces of the machine tool, without interposing protective material.

17. For small adjustments to the positioning of cast iron and steel workpieces use a lead hammer, for aluminium and magnesium workpieces use a leather or plastic hammer.

18. Before starting the cut, make sure that speed and feed rate are correctly chosen. Failure to do so may damage the workpiece, break the cutter or produce an unsatisfactory surface finish.

19. Check the functioning of all feed stops and make sure rapid traverse is disengaged before the tool starts cutting.

20. If a coolant is used it should be applied plentifully. Cast iron is usually cut dry, however.

21. Adjust and clean slides and bearings at regular intervals to ensure that speed and precision of performance are maintained.

22. When setting up the machine tool for its next operation, do not place tools on the floor but in a rack where they cannot be damaged or fall on to concrete.

23. "Good housekeeping" procedures and adequate lighting in the machine shop ensure good workmanship. Precision finishes on machinery and tools must be protected. Doors and apertures on machine tools and control cabinets must be closed when work is in progress to prevent the ingress of flying chips.

24. Machine tool operators should always wear safety glasses. They should be capable of undertaking adjustments and minor repairs to keep the machine tool in good working condition. A plant maintenance man should be charged with major repairs and overhauls.

25. The diffusion of dust from grinding machines must not be left uncontr
it damages not only other machine tools but also the lungs of the operators who are forced to breathe it.

CHAPTER 3 PRODUCTION MANAGEMENT

Economics of investment in production equipment

Investment decisions in connexion with production equipment are among the most difficult to take in any country or economic system, but especially in developing countries. The business risk varies from one location to another and from country to country. Calculations relating to the whole expected lifetime of production equipment cannot easily allow for the effects of possible monetary inflation or deflation. To acquire equipment not made at all in the particular country, special costs may have to be incurred for an import licence. Import duties for machines and materials and even the whole taxation structure may change during the lifetime of a machine in a completely unpredictable manner. The exchange value of a so-called strong currency can also change, with results in a some far-away country more detrimental than in the country of issue.

When a machine tool has been used for a number of years it may become obsolete. In other words, competitive enterprises start using machines which have new design features yielding higher production of similar parts. It is not always easy to identify obsolescence because machine technology generally develops slowly, with no sudden increases in productivity. Over the long term, operations must yield sufficient profit to permit the acquisition of equipment incorporating new technological advances, without which it may be impossible to keep many manufacturing operations competitive.

Faced with thi situation, some companies rent machine tools on an annual basis instead of buying them, a procedure which also releases additional funds for use as working capital. Renting has another advantage: it allows a company to judge the worth of a new type of equipment by practical tests, before having to decide whether to buy it. If the company then buys the equipment, an allowance is usually made of part of the rental already paid.

Because of the inevitable, if sometimes slow, obsolescence of production equipment consideration has to be given to depreciation charges from the day a machine enters the shop. In industrialized countries many types of machine tool are considered obsolete after 10 years of service. Some special-purpose machine tools may be written off in a year or two years, where they achieve a large enough increase in productivity compared with a standard machine. The engineering service cannot be expected to forecast the rate of obsolescence accurately. The accountancy service will try to err on the safe side, so that no piece of equipment proves to be obsolete before it has been fully written off. These judgements are of great importance where obsolescence may occur long before the equipment is worn out physically.

A more easily identifiable phenomenon is the deterioration of a machine because of many years of use and abuse. A number of items each contribute a small amount to the lower performance, which can be observed and judged well by the operator or foreman. For example, a machine tool may no longer completely finish workpieces but can only be used for roughing operations; or additional grinding operations may be required because a lathe no longer holds exact sizes; or only highly skilled operators are capable of turning out workpieces that pass inspection without rework; or jobs, sometimes even those to relatively low standards of accuracy, take a long time to set up and require special adjustments to the machine tool.

Another indication of deterioration is when a repaired machine breaks down after, say, three weeks use and it then takes another three weeks to repair it again. (This can also happen to relatively new machine tools which are heavily over-loaded or have some weak design features.) Other danger signals are tools that do not last as long as expected, because of chatter and vibrations, or instrument dials that no longer read accurately because of worn screwr and loose bearings.

It is sometimes possible in the metal fabrication business to operate at a profit old equipment that was written off a long time ago, but such situations are not typical nor do they remain very competitive for long.

A well built machine tool should be 100 per cent effective during the first few working years. Then it will start to deteriorate and its output rate will decrease, or it will require more operator effort to hold accurate dimensions. Fatigue may then lower operator efficiency too. Figure 2 is a schematic illustration of machine tool deterioration and obsolescence. Most machine tools will perform well for 10 years if properly maintained. By that time, obsolescence may enter noticeably into the picture and compel a cost comparison with newer machine tools to be carried out. Obsolescence and deterioration are immutable facts of life in machine tools and are recognized in the tax laws of industrialized countries by concessions in favour of industrial re-equipment. Special tax credits encourage machine tool modernization, improve profitability and promote the over-all expansion of a country's manufacturing capacity.

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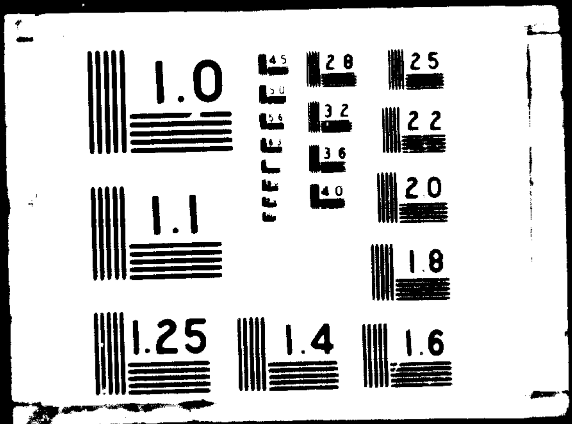
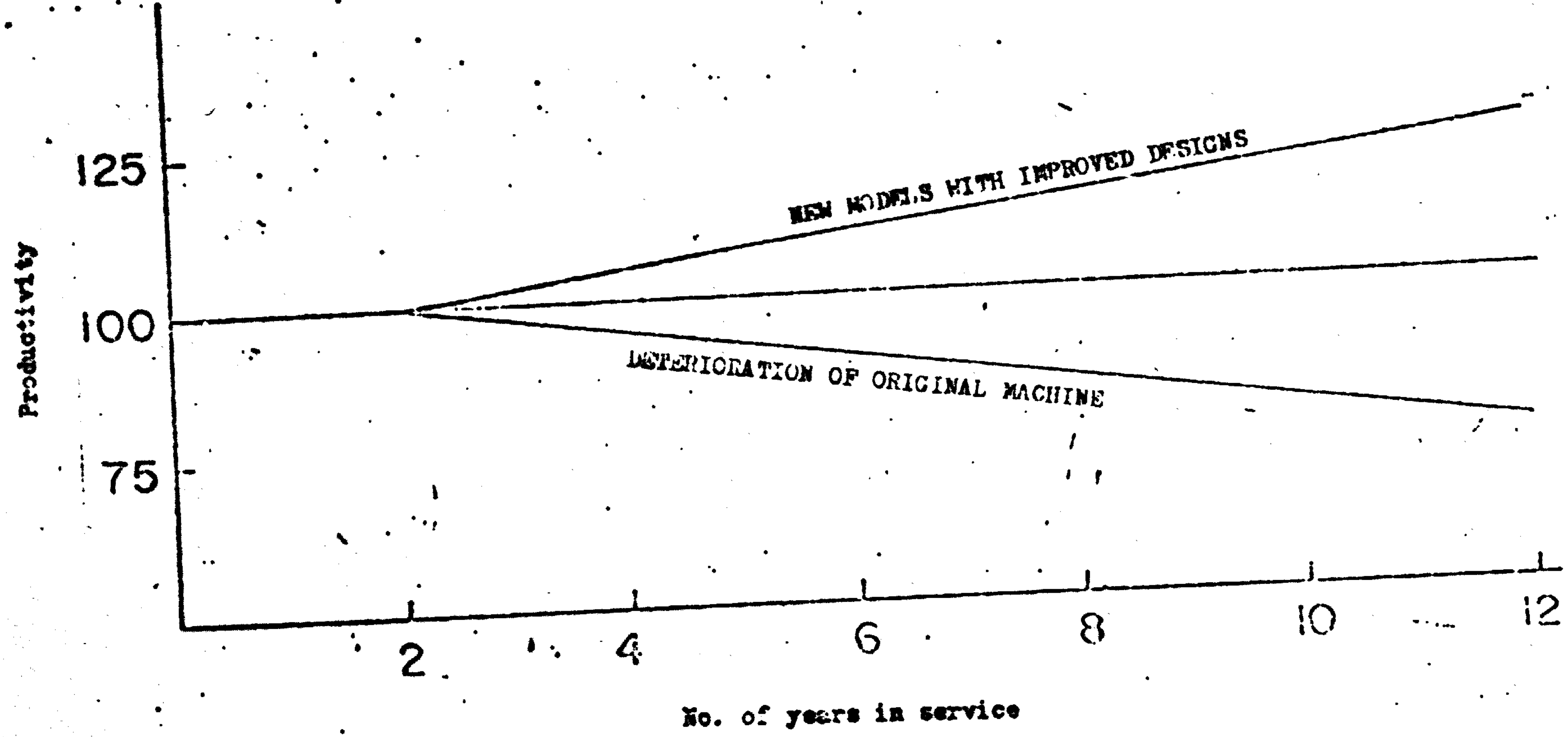


Figure 2

Machine tool deterioration and obsolescence



Productivity of machine tool when new equals 100. Due to wear and tear with time the machine tool deteriorates. Improved designs may permit operation with greater efficiency and thus cause a degree of obsolescence

A rational investment programme must assess the probable savings in cost that various proposals would achieve, on the basis of which a detailed schedule of investment priorities for equipment and machine tools should be drawn up. It is a rare situation in which investment resources are available for all projects capable of reducing costs.

All kinds of fixed and variable costs of production, not only the costs of obsolescence and deterioration, must be included in the assessment. To arrive at realistic cost figures is difficult, even in an industrialized country. Formulae and charts for determining the running costs of newly developed production equipment are of use only in the particular markets in industrialized countries for which they are prepared. Despite all the difficulties, however, costs must be estimated as closely as possible.

It must not be overlooked that the costs of installation, rearrangement of, and alterations to buildings and existing equipment should be added to the purchase price of new equipment - and the receipts (if any) from sale of equipment which it replaces should be subtracted from this sum - before calculating the financial charges.

There are numerous valid reasons for installing new production equipment:

IN LATER YEARS

To reduce existing machining costs;

To improve quality of products;

To make the products competitive with imported items;

To augment existing capacity;

To make the products competitive with those of other plants in the country;

To overcome a shortage of skilled manpower;

To eliminate heavy and undesirable manual labour;

To simplify difficult machining operations; and

To start a new type of production, e.g., with new materials.

An investment in new equipment to replace obsolescent or worn-out equipment has to be evaluated by several criteria.

First and foremost, the new equipment proposed should show substantial cost savings on the production of items made by the existing machinery, in view of the margin of error inherent in estimates relating to a lengthy future period.

Secondly, the management has to decide what its business goals are and whether they are consistent with amortizing the new equipment during the following years.

Whatever the economic justification, the commonest procedure is to divide the earnings before or after taxes by the sum invested, in order to arrive at the return on invested capital. (Where production facilities have been the limiting factor on the volume of sales and the new equipment enables output to be increased, the calculation of earnings must allow for expansion of sales as well as any changes in unit costs.) Profit expressed as a percentage of sales has some utility as a measure of the effectiveness of the particular machinery used in the business. In either calculation, profit should be struck after charging the cost of wear and tear and obsolescence of machinery and tooling. When this is done, it is often realized for the first time that there is really no profit at all.

These crude measures of the return on investment can be compared with the return which could be earned from alternative machine replacement projects or investments to create additional capacity. They have some shortcomings, however. They make no adjustment for future changes in the value of money and they do not allow for the time factor when savings are realized. The savings in earlier years can be reinvested to provide further income. A more sophisticated approach, called discounted cash flow, can be used to allow for these factors and hence to refine the estimates of the return from investment in new machinery or in other projects.

A manufacturing enterprise should be regarded as a processing operation which adds value to raw materials such as steel, cast iron and plastics. The difference between the value of its output and the cost of material etc. employed, measures the success of the operation. Net income should provide directly for progressive company growth or be large enough to serve as an inducement to investors and government agencies, by demonstrating that this particular enterprise car survive on its own and even prosper.

Workshop location

The construction or acquisition of a new shop or plant may represent an investment of considerable magnitude and care must be taken in selecting the site and the location. If the size of the intended operation justifies a detailed investigation and the choice of location or relocation is free, the following check list may prove a useful guide to determine their suitability.[3]

Labour force characteristics

Resident or transient; incidence of absenteeism; housekeeping habits; acceptance of technological change.

Demographic and manpower statistics relating to population, by age and sex; numbers employed in manufacturing, agriculture, etc.; availability of skilled, semi-skilled and unskilled labour; seasonal employment; unemploymen willingness to work shifts. These statistics should cover an area within reasonable commuting distance from the proposed workshop.

Assess the influence of established industries in the area. This affects wage rates, working hours and shift pattern; competition for skills, unionization, productivity, security, lay-off provisions and even what may be accepted as industrial accident rates. It is worth checking whether there is a local industrial pace-setter with which the new establishme will be forced to compete.

Management potential

Whether prospective workers in the area progressively undertake new responsibilities. Prospects for recruiting managers, scientific and technical manpower locally. Extent to which local people are trainable.

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[3] Based on "Plant site selection guide", Factory Management and Maintenance, May 1957.

Local amenities

Volume and types of residential housing. Facilities for education, health, welfare, culture and recreation. Attitude of the community to newcomers.

Taxes, town planning and industrial zoning regulations

Tax reductions and exemptions to promote industrial location. Property and other local taxes.

Local regulations regarding smoke emission, liquid and solid waste disposal, unsightly property, and creating a nuisance to neighbours. Building codes and building inspection. Present and likely future codes to control environmental pollution, and arrangements for their enforcement.

Services

Electric power, fuel oil and water supply facilities.

Transportation services: proximity to railroad, existence of spur lines and structure of railroad rates; route schedules, rates and access roads for truck traffic, also weight and size restrictions and techniques used at transfer points; airport location, air feeder lines and facilities for air shipments.

Local availability of numerous commercial services: a major repair shop; an industrial distribution network; local trucking service; maintenance shop for electric motors; suppliers of lubricants, steel, lumber, engineering sundries and stationery; architects and engineers; contractors.

Quality of postal, police and fire services.

Raw material supply

Proximity of sources, their reliability and extent to which already committed to other industrial consumers. Prices, delivery periods, conditions of sale, transportation cost. Rate of depletion of sources. For key components, existence of suppliers (preferably more than one) and rapid transport possibilities. Present or future subcontractors.

Consideration of a specific site

Character of site; topography and physical climate; area available, its layout and orientation; drainage and liability to flooding; what services are in place; subsoil and foundations; existence of gullies, streams, etc; risk of blowing sand and need for grading and landscaping; whether pipelines and other services must be relocated; cost of site; existence of restrictive covenants on use of site; and, of course, cost of site.

It is of primary importance to ensure that adequate areas are available for plant, offices, auxiliary buildings, yard, vehicular and/or rail traffic, not only to meet immediate needs but also to cater for plant expansion in accordance with business forecasts, without relocation. The calculation of the site area required proceeds as follows:

Covered area requirements

1. List present manufacturing and storage areas.
2. Estimate all requirements for which there is no precedent or which are expected to arise at some future date.
3. In the light of the shift pattern now used or expected to be used in future, calculate the additional areas required for expansion of operations.

4. Allow a reasonable addition for interior aisles; depending on the process and area configuration this could be as much as 25% of manufacturing and storage areas.
5. Add areas for auxiliary services: power, compressed air, water, steam, fuel storage. tool stores, equipment storage, repair shop, treatment of waste air, water, fluids etc.
6. Add areas for offices, including engineering department and laboratory.
7. Add areas for employee services; lavatories, locker rooms, dining facilities, first aid facilities.

External area requirements.

1. Establish a general traffic pattern that links the plant to the existing traffic pattern of the area. Generally, vehicles circulate in a clockwise direction.
2. Devise detailed traffic patterns for incoming materials and for despatch. Allow sufficient areas for loading docks. In the case of heavy industries, consider depressing the loading dock apron or raising the shop floor to truck floor level.
3. Where applicable, allow vehicular parking facilities for employees. In the United States, an allowance of 1.2 to 2.5 employees per car is customary. In some countries areas for tents and outdoor bathing facilities are provided or dwellings are built for the workers.
4. Allow area for yard storage of scrap and for large stocks of key materials.
5. Allow area for fire lanes, security lanes around fences etc.

The estimates of covered and external areas should be prepared for at least three points in time: the present day; at the end of the useful life of the plant; and at interim dates, possibly every 3 to 5 years. These estimates will give a good guide to the site area required for a well organized and planned shop activity, in the present and the future.

Construction of the workshop building

In designing the structure of the workshop building, the fundamental considerations are strength, overhead space and light.

Without a suitable floor to the workshop no precision work can be done. A concrete floor with a carrying capacity of 200 to 500 pounds per square foot is common practice and to be recommended. Care should be exercised that the vertical impact loads, lateral thrusts and longitudinal shocks resulting from crane operation are properly provided for in proportioning the frame. The roof structure should be strong enough to suspend loads (allow at least 2,000 lb for each handling point). The rest of the shelter should be constructed to give adequate protection in the climate for which it is intended. Bays should be designed with adequate heights to allow material to be handled overhead.

Daylight is a valuable asset. Therefore, walls are usually constructed of brick only up to the sill of the windows, the glass being extended in height to the purlins. There is always some lose of light due to unclean glass. East or west exposure often causes a bothersome glare early or late in the day. Northern exposure is best.

Workshop layout

A plant layout may be as simple as a single row of machines, processing one part in successive steps from materials reception to despatch, located in a building consisting of a single machine bay and one aisle. At the other extreme, a complex plant layout may be evolved by rationalizing the arrangement of multi-purpose equipment in a job shop which processes small lots with varying priorities, process times and tooling requirements.

Fixed position layout is suitable in small shops where a part is essentially completed at one location, such as a bench or machine. We are mainly concerned here with how to plan process layouts where a part moves through several successive steps. The primary benefit of appropriate plant layout is that it gives management a realistic guarantee of efficient production and, therefore, of low production costs. All the objectives listed below apply specifically to small or medium-sized shops, but not all of them apply in every case. It is evident that there is greater flexibility when planning a new workshop than when modifying an existing one.

Preliminary considerations

The total covered area should be organized, process by process, into a system in accordance with the following principles:

1. The flow of materials must conform to the requirements of the manufacturing process.
2. The flow of the product should be continuous, preferably in a straight line and with no back tracking.
3. Operations that will need an expanded area should be located adjacent to property reserved for future use.
4. Major process equipment should be so located that no relocation will be necessary during the useful life of the workshop, while not impairing efficiency of production.

Possible alternative production methods, by pass routes, the effects of technological change, must be kept in mind when planning the layout. Manufacturing processes essential to the production of the most profitable items, currently and prospectively, should be given priority in assigning areas and routes within the workshop.

The grouping of production facilities into a press department, a cutting-off department, etc., is a useful approach to economical metalworking. It should be a key objective to minimize materials handling. This is the main reason for advocating the use of straight line production paths. The discharge point of one operation should be logically linked to the next point of usage by combining handling with processing. In batch-type operations in-process storage facilities should not block the flow of materials.

Attention must be paid to employee comfort and safety. Well lit, well ventilated factories, with adequate work space per employee and clear access to work areas, are conducive to high productivity. All safety and health hazards must be carefully examined and corrective measures taken.

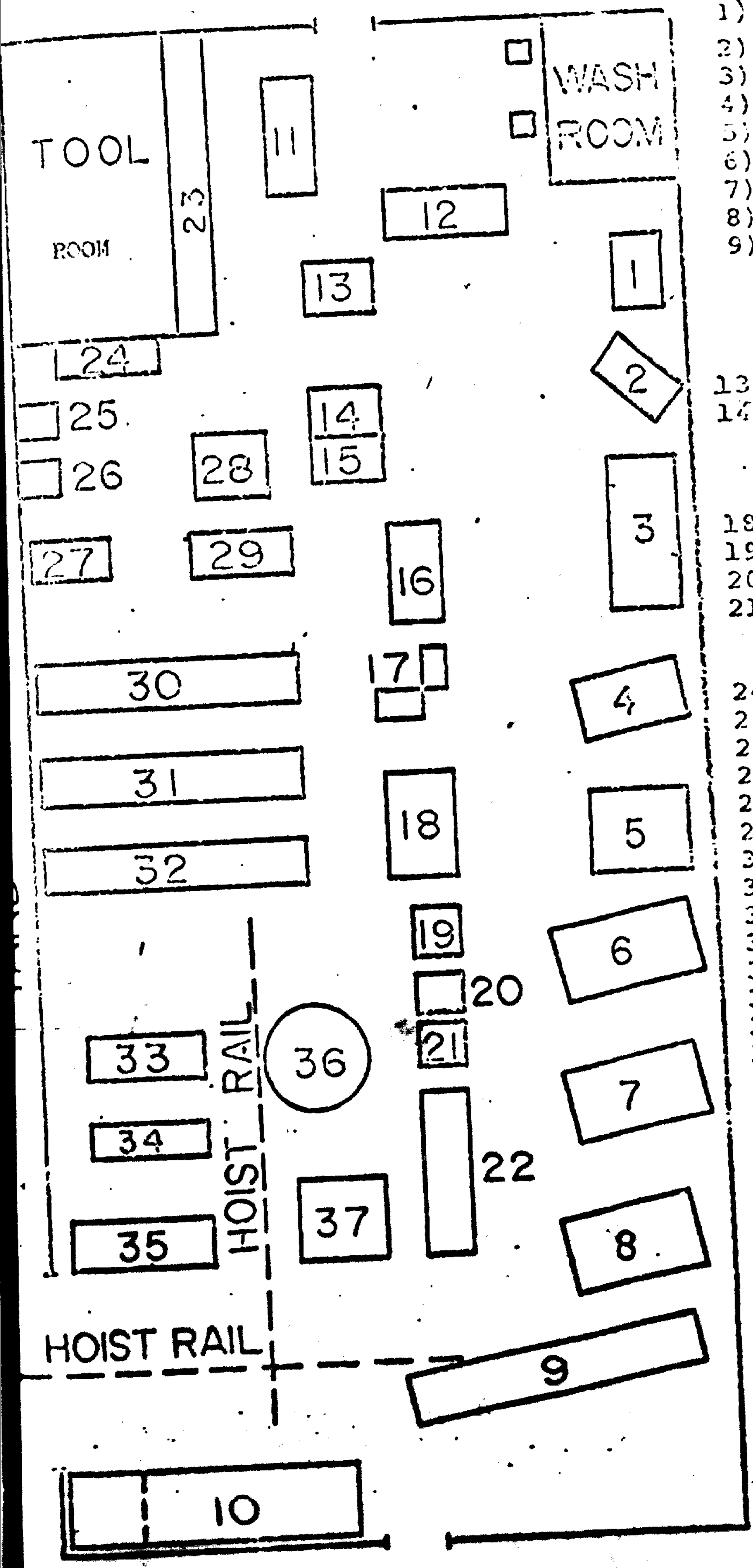
The classical approach to layout in small metalworking plants

In preparing the detailed layout, the first essential is comprehensive planning. Survey and plan the operation to give a high rate of turnover of work in process without raising costs. In job-shop operations, the sum of all machining time on a workpiece is rarely as high as 10 per cent of the total elapsed time in the shop and is often 1 per cent or less.

Straight line flow can rarely be followed completely and hairpin flow is a very practical approximation, because receiving and despatch operations can be adjacent or combined. Figure 3 illustrates a layout for a plant employing about 20 people, such as may be commonly encountered. The layout after rearranging the equipment for better material flow and handling might be as shown in figure 4.

Figure X 3

Small plant layout as commonly encountered

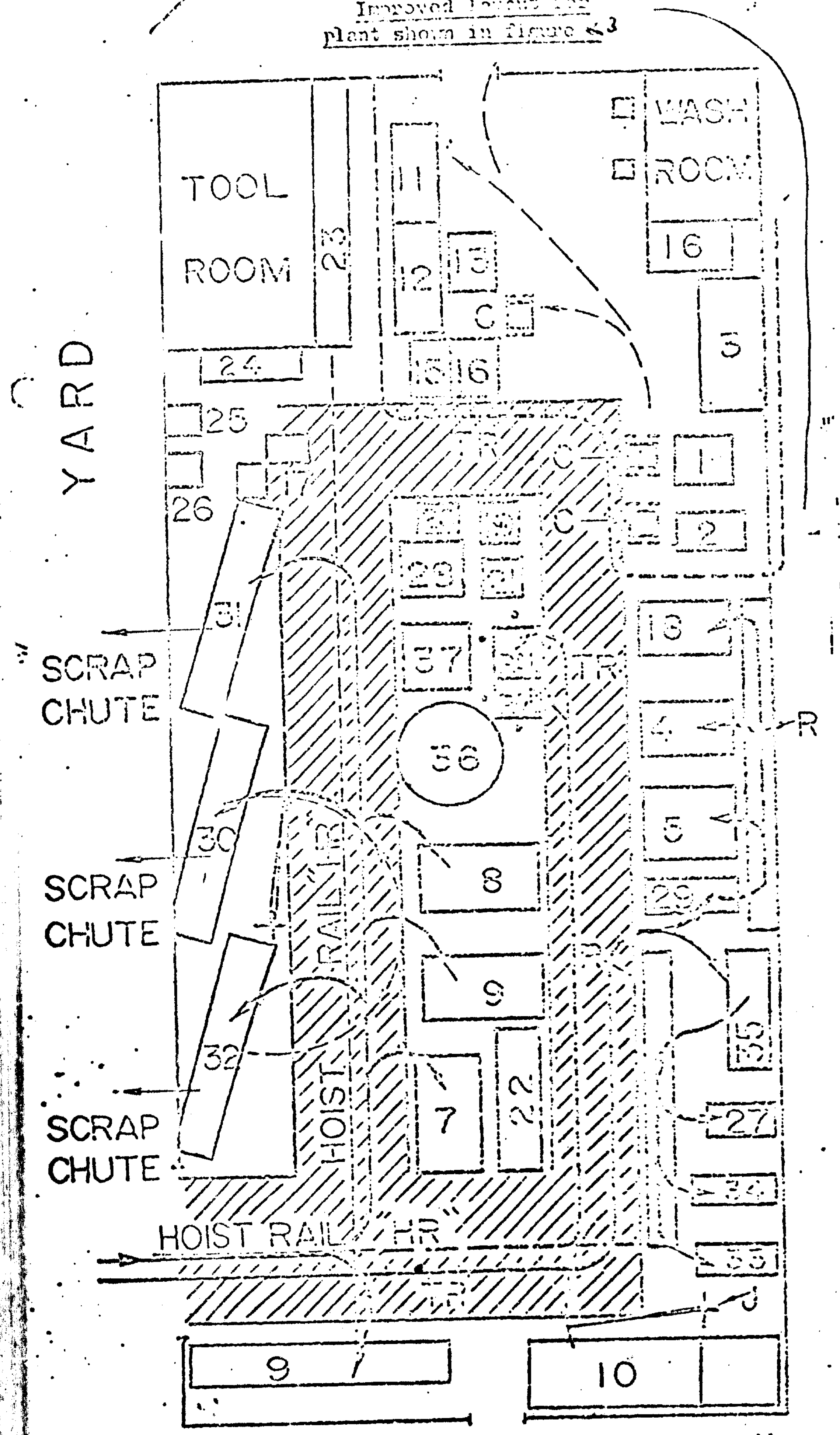


LEGEND

1) 2 HORIZONTAL GRINDERS
2) LATHE
3) CYLINDRICAL GRINDER
4) MILLING MACHINE
5) MILLING MACHINE
6) MILLING MACHINE
7) MILLING MACHINE
8) DRILL
9) JIG BORER
10) STEEL STORAGE RACK & CUTTING-OFF
11) LAYOUT BENCH
12) LAYOUT BENCH
13) SPARK EROSION MACHINE
14) SPARK EROSION MACHINE
15) TOOL BENCH
16) TOOL BENCH
17) TOOL GRINDERS
18) MILLING MACHINE
19) DRILL
20) DRILL
21) DRILL
22) TOOL BENCH
23) INSPECTION BENCH
24) BENCH DRILL
25) DRILL
26) DRILL
27) SHAPER
28) VERTICAL MILL
29) LATHE
30) LATHE
31) LATHE
32) LATHE
33) SHAPER
34) SHAPER
35) LATHE
36) VERTICAL BORING MILL
37) LATHE

Figure 4

Improved layout for plant shown in figure 3



LEGEND

C	WHEELED CA
R	GRAVITY RO CONVEYORS W TOTE BOXES
J	FLOOR-MOUNT CRANE WITH OPERATED HO
HR	OVERHEAD HO RAIL WITH OPERATED HO
PAL	PALLETIZED MATE ON RACKS
TR	TRUCKING AISLE UNMOTORIZED FL TRUCKS AND FOR TRUCKS

NUMBER REFEREN
MACHINES AS IN
FIGURE 3

When preparing layout proposals, the plant and machines should be drawn to the same scale. If no three-dimensional models of the machines are available, two-dimensional cutouts should be used.

Aisle locations and department locations should be considered simultaneously. Every group of equipment should be readily accessible in a jobbing shop, because parts will not always flow through all departments. Some departments have to be in fixed locations because they are not easily moved (solid foundations, duct work, etc.). Try to plan for the possible expansion of each department by at least 25 per cent. There is a tendency to plan for 40-60 per cent expansion, but this is not to be recommended unless good, detailed forecasts can be made and planning skills of a high order are available.

Main aisles should permit two-way traffic, but access aisles should have one-way flow. Handling equipment should be specified to move workpieces between machines or between departments; if necessary, special items should be devised.

Scrap should be removed from machines and collected on a plant-wide basis.

Consideration should be given to where bottlenecks may possibly develop, for example, when tool or machine failure occurs, and provision should be made for an alternative routing or by pass.

The efficiency of the manufacturing cycle must be calculated carefully in the course of planning. Space utilization should be calculated in advance and checked. Figures are needed for the construction cost per square foot of plant. Aisle space potential for materials movement should be looked into. The efficiency of the materials handling operation is measured by comparing total manpower to that engaged on materials handling, or operator's total hours to time taken up in handling chores. Finally the all-important machine utilization ratio which the plan implies must be calculated; in some job shops the ratio is below 40 per cent in the absence of planning.

Materials handling

The simplest example of materials handling is the transport of a single item by one man within one workshop bay. On the other hand, it may be so complex that it comprises 50 handling movements in the course of manufacturing a single part. It may account for as much as 80 per cent of the cost of production in a large machine shop. There should be three distinct areas of materials movement in the machine shop:

- Receiving and storage at reception point;
- In-process handling, including handling at the work station;
- Despatch, including boxing or crating and storage at despatch bay.

Materials handling is a necessary, wholly indirect cost. The objectives of a good materials handling system may be classified as follows, starting with the simplest objective and proceeding towards the more sophisticated ones:

- Extension of the productive capacity of the few skilled workmen, by removing the fatiguing burden of moving and lifting things. Production is increased because effort is reduced and more of the available time is spent on machining the workpiece;

- Reduction of scrap and waste. Product damage is kept to a minimum by correct handling, and scarce materials can be conserved. In the finishing stages, particularly, mechanical handling ensures uniformity and repeatability, and reduces scrap;

- General improvement of working conditions, removing unduly hard burdens from the whole work force and reducing health hazards;
- Reduction of costs. Since the cost of material, labour and fixed overheads may be taken as roughly equal, the reduction of the materials handling cost offers a large economic advantage. In highly developed metalworking plants, if materials handling labour represents 10 per cent of total labour, that is an unusually good ratio, whereas a ratio of 40 per cent is badly out of line. In general, factory space is at a premium and modern materials handling improves the utilization of available space. In addition, by controlling and reducing inventories of work in process it can free additional funds for more productive purposes.

Applying the above general principles to fit a particular shop, the nature of the materials to be handled must first be defined. There are the material inputs. In addition, there are at least three kinds of output that every metalworking shop generates: the product itself, scrap and rejects. At the receiving bay, depending on the size of operation, the materials might be bar stock, ingots, castings, etc., while at the despatch bay they might be crates, totes, skids, etc. containing finished products.

Secondly, optimizing the plant layout should have determined the best location (or relocation) for production and handling equipment. Production planning and scheduling should have established the best machine loading and routing of materials. Without these analyses, the installation of conveying equipment could simply result in production bottlenecks, machine idle time and lengthy rehandling times.

Thirdly, the following guidelines may prove useful:

- If possible, gather parts into groups; if size permits, handle them in totes or boxes.
- Operatives should move one item at a time.
- It should be easy to remove items from the flow of materials, preferably without lifting, by simple loading and unloading.
- Exploit the space available for storage by using racks, shelves, self-stacking totes etc.
- Observe first-in, first-out (FIFO) procedures unless specifically not desired.
- Seek to reduce inventory, particularly of finished parts (because of the money tied up in labour costs). Leave no unmarked lots in storage.
- As materials handling and transport are always a financial burden, try to perform operations on material while it is in motion. (This is easy in continuous-process industries, but more difficult in a metalworking shop.) Possibilities include pre-heating, cooling and finishing processes such as washing, bonderizing, painting, porcelainising and baking.
- It is important to plan scrap handling. Steel containers will suffice in small shops; drag lines or vibrating conveyors in larger shops; and crushers, slat and harpoon conveyors in high-production shops.
- At every inspection station provide facilities for storage and removal of rejects.

Selection of equipment

The fourth stage, selection of equipment, can then begin. The range of equipment, in increasing order of complexity, is as follows:

Equipment powered only by gravity or man's muscles

- Roller conveyors, wheel conveyors
- Ball transfers
- Hand-powered monorail systems
- Chutes, racks, shelves
- Chain hoists on a variety of hand-powered cranes (jib, gantry and bridge)
- Hand trucks in large variety

Simple mechanized and electrically powered equipment without interlocks or automatic controls

- Powered roller conveyors
- Metal or wood slat conveyors
- Belt conveyors (metal belt, canvas belt, etc.)
- Overhead trolley conveyors
- Powered hoists on a variety of hand-powered cranes
- Fork lift trucks.

Other mechanized equipment driven by electricity and/or compressed air, embodying some controls and interlocks

- All types of conveyor already mentioned
- Vibrating conveyors
- Powered transfers
- Powered lifting equipment
- Powered hoists on powered cranes
- Fork lift trucks.

It is immediately apparent that the same essential task can be carried out by different types of equipment. Appendix 1 describes a method of assigning weights to their various attributes in order to help make a rational choice between the available alternatives.

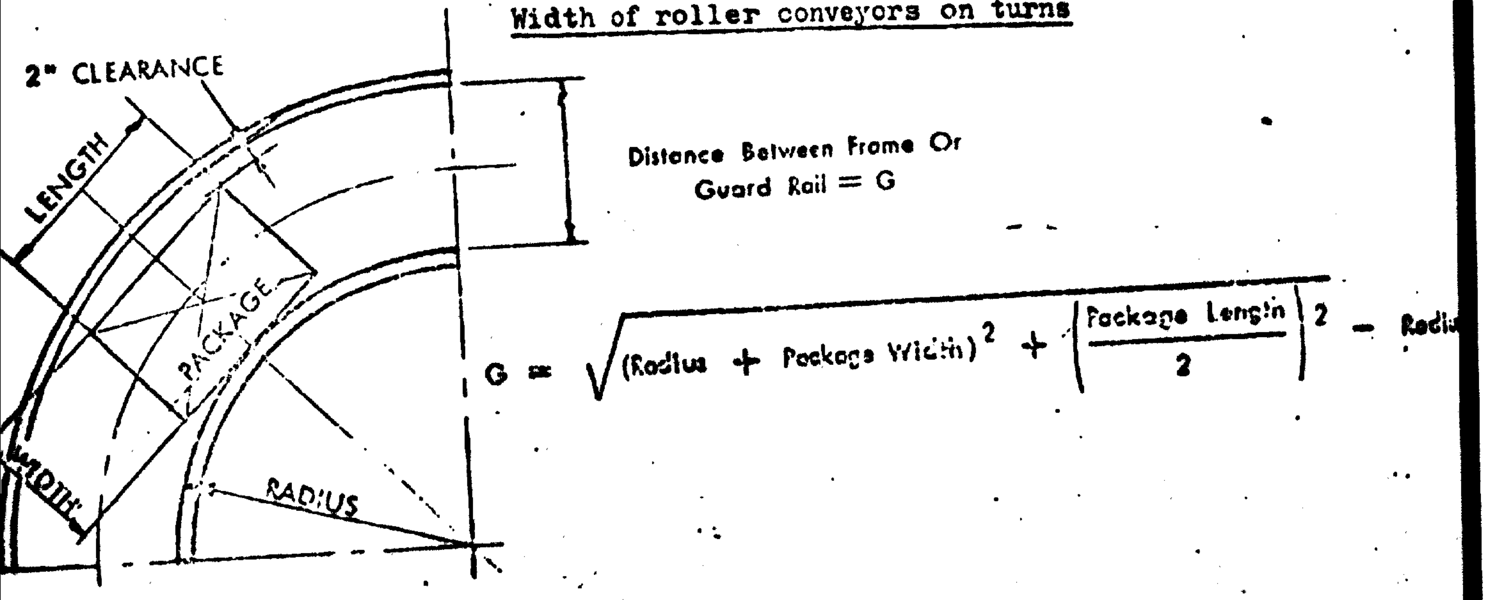
Some basic illustrations and information now follow which will facilitate the selection of equipment. The physical capability of workers has to be brought into consideration, as well as the characteristic of the equipment. We begin with our first group - equipment powered by gravity or man's muscles.

Roller conveyors

The width of a roller conveyor is determined by adding 2 in (5 cm) clearance to the width of the largest object it is expected to move. This applies to straight sections: on turns the width should be sized as illustrated in figure 5 below.[4]

Figure 5

Width of roller conveyors on turns



$$G = \sqrt{(\text{Radius} + \text{Package Width})^2 + \left(\frac{\text{Package Length}}{2}\right)^2} - \text{Radi}$$

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[4] Conveyor Equipment Manufacturers Association Standards 401-1962.

Gravity-propelled roller conveyors will be much lower at the discharge than at the starting end if they are long. The slope required to ensure self-starting depends on the item to be conveyed. See table 2.

Table 2

Minimum slopes for roller conveyors

Item on roller conveyor	Inches drop in 10 ft.	cm drop per metre
Metal tote boxes	1½	1.25
Tote pans	2-5	1.7-4.2
Empty oil drums	5	4.2
Drums over 150 lb/70kg	3½	3.0
Full oil drums up to 250 lb/115 kg	1½	1.3
Cartons up to 15 lb/7 kg	5	4.2
Cartons of 15 to 50 lb (7 to 25 kg)	4	3.3
Wood cases up to 50 lb/25 kg	4½	3.8
Wood cases over 50 lb/25 kg	3½	3.0
Wirebound and steel strapped cases	6	5.0
Crates up to 125 lb/55 kg	4	3.2

Average values for roller conveyor capacities are shown in table 3 below.[5]

Table 3

Roller weight and carrying capacity
(in pounds)

NOMINAL ROLLER LENGTH	1.9" DIA.				2½" DIA.		2½" DIA.	
	16-Gauge		13-Gauge		12-Gauge		14-Gauge	
	CAP.	WT.	CAP.	WT.	CAP.	WT.	CAP.	WT.
6"	–	–	–	–	350	1.9	250	1.7
9"	150	1.9*	250	2.3*	350	2.6	250	2.3
12"	150	2.2	250	2.9	350	3.4	250	3.0
15"	150	2.6	250	3.5	350	4.4	250	3.7
18"	150	3.0	250	4.1	350	4.9	250	4.4
21"	150	3.5	250	4.7	350	5.7	250	5.0
24"	150	3.9	250	5.3	350	6.4	250	5.7
27"	150	4.3	250	5.8	350	7.2	250	6.4
30"	150	4.7	250	6.4	350	8.0	250	7.1
33"	150	5.2	250	7.0	350	8.7	250	7.7
36"	150	5.6	250	7.6	330	9.5	250	8.4
39"	150	6.0	250	8.2	300	10.3	250	9.1
42"	150	6.4	250	8.8	[illegible]	11.0	250	9.8
45"	150	6.8	250	9.4	260	11.8	250	10.4
48"	150	7.3	250	10.0	250	12.5	250	11.1
51"	150	7.7	250	10.6	[illegible]	13.3	[illegible]	11.8

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[5] Rapistan, Inc., Grand Rapids, Michigan, Data Book 51.5, September 1966.

Monorails

Hand-pushed containers suspended from monorails are very practical, because they can use the traffic aisles and do not occupy any of the floor areas.

Selection of the proper track for a monorail system is dependent on such factors as (a) maximum weight likely to be concentrated between suspension points, (b) maximum distance between available suspension points, (c) frequency of traffic, and (d) speed at which containers are moved. These factors, together with the structural strength of the building, determine the types of fittings used to suspend the track system. Normally these fittings can be hung from the structure of the building itself. However, if the structure is too weak it will first be necessary to install a special superstructure.

For installations with long spans and high capacity, beam or girder type track is often used. This consists of a hardenod "inverted T" track welded to and supported by a specially-designed structural beam with wide, mild steel upper flanges and web.

Track and suspension are illustrated in figures 6a and 6b below.[b]

Figure 6a

Wheels on typical monorail track

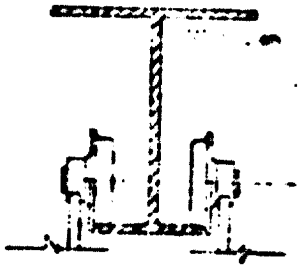
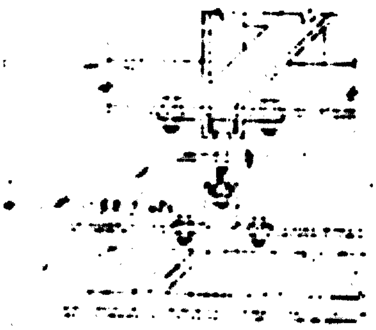


Figure 6b

Method of monorail suspension



As a general guide, hand-pushed loads can be assumed to travel at 150 feet/45 metres a minute and not to exceed 3 tons in weight.

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[b] Reproduced from Material Handling with Monorail, Monorail Manufacturers Association, Pittsburgh, Pennsylvania.

Cranes and chain hoists

Among hand-operated cranes, the underhung models are especially practical and use many of the components of the monorail system. (Beam-type sections are also used for crane girders.) The simplest underhung crane is the light, hand-pushed bridge for loads up to 3 tons. Equipped with a hoist, it provides inexpensive hoisting service over the entire area between the crane ways. It also can be used, with interlocks, to transfer loads from one track to another.

The bridge crane is the commonest design in hoisting machinery, consisting mainly of a girder riding on an elevated rail. A double leg gantry crane consists of a bridge supported by two legs that ride on rails, laid in a foundation at ground level. A single leg gantry crane consists of a bridge supported at one side by a leg riding on a rail at ground level and at the other side by a craneway along a wall of the building.

A jib crane consists of a bridge supported either from a vertical mast or from a wall. The bridge of mast-supported jib cranes can rotate through 360 degrees. Wall-supported jib cranes are often designed to swing out of the way when not in use.

Hand trucks

Hand trucks in great variety provide one of the most common means of handling. They may be classified according to load-carrying capacity and the effort required to move the truck.

The force that is necessary to push a truck is a function of its weight, the weight of the load and the coefficient of rolling friction between the wheels and the floor, the last factor being related to the wheel diameter.

In determining the tons per man-hour that can be handled with manually operated trucks, the walking speed of the operator should be taken as between 2 and 2½ mph - between 176 and 220 feet or approximately 53 and 66 metres a minute. The lower figure is recommended from the standpoint of limiting operator fatigue. Horizontal resistance when pushing a truck on a level plane is 40 lb (18 kg) or less. An appreciable increase over this figure lowers efficiency of the worker to a marked extent. Seldom is a value as high as 50 lb (23 kg) recommended, except for intermittent and infrequent movement, for example, up a ramp or grade. The optimum resistance for an average male operative is set at 32 lb (14.5 kg).

Table 4 below shows the average rolling resistance of trucks with moulded-on tires over various surfaces.[7]

Table 4

Truck rolling resistance on level surfaces

Surface	Coefficient of friction	Resistance (lbs per ton)
Concrete	0.010 - 0.020	20 to 40
Asphalt	0.010 - 0.025	20 to 50
Stone pavement	0.015 - 0.035	30 to 70
Wood block	0.015 - 0.025	30 to 50
Loose sand	0.015 - 0.030	30 to 60
Pneu. tire on smooth pavement	0.020 - 0.030	40 to 60

The efficiency of equipment operated by muscle power and of manual material handling is limited by human anatomy and physiology. It is important that working personnel should not be taxed beyond normal endurance. It is therefore useful to know the limits of human performance, to be able to determine where power-operated devices must be utilised, regardless of manpower availability and cost.

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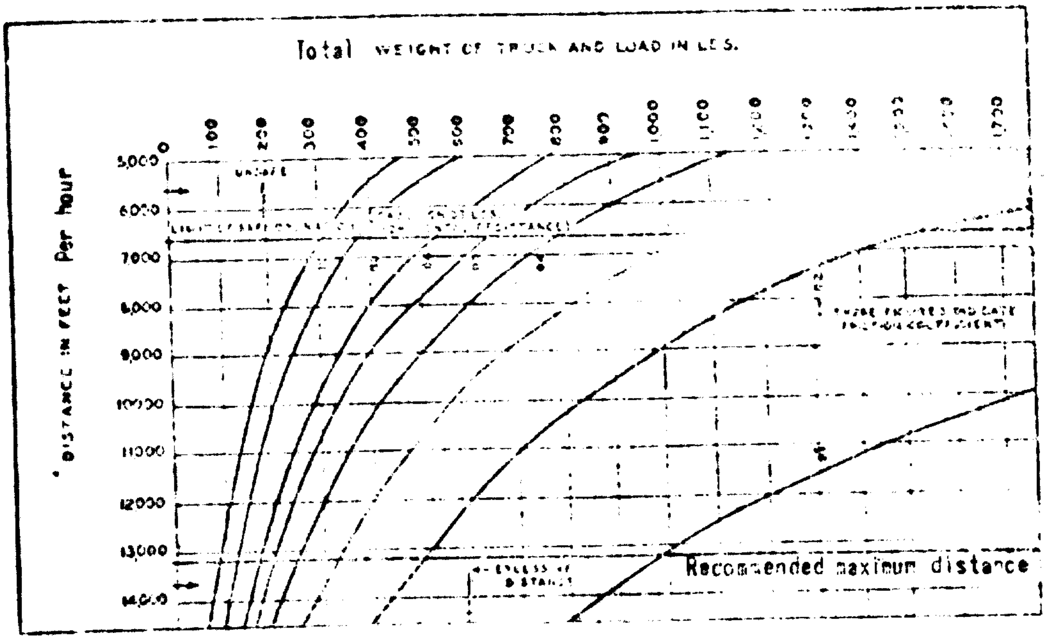
[7] Liberty Mutual Insurance Company, Hopkinton, Massachusetts.

Figure 7 below shows the relationship between weight and distance for hand-pushed truck operations.8/

Figure 7

Relationship between hourly hand-pushed truck movement, weight and coefficient of rolling friction



A truck of 1,000 pounds (total weight - truck plus load) can be pushed 7,000 feet per hour when the rolling friction coefficient is approximately 0.03. A rolling friction coefficient of 0.04, however, reduces this distance to 5,700 feet; this is the unsafe zone on the graph, indicating that the horizontal pushing resistance exceeds the recommended 32 pounds (limit of safe operation). The second horizontal line indicates the recommended maximum distance that a trucker should cover in one hour.

Tables 5 and 6 show the acceptable weight limits for manual lifting and lowering. 8/

Table 5

Maximum Weights (Lb) of Lift and Lower Acceptable to Various Percentages of Industrial Male Workers

		90%	75%	50%	25%	10%
Floor level to knuckle height	Lift	37.3	45.1	55.8	67.5	79.3
	Lower	36.2	48.4	64.9	75.4	87.8
Knuckle height to shoulder height	Lift	34.4	41.8	50.7	62.3	70.9
	Lower	30.0	44.4	54.6	65.3	76.3
Shoulder height to arm reach	Lift	30.4	36.6	40.8	50.1	60.3
	Lower	30.7	38.1	44.3	52.3	58.6

Table 6

Maximum Work Loads (Ft Lb/Min) for Lifting and Lowering Tasks Acceptable to Various Percentages of Industrial Male Workers

		90%	75%	50%	25%	10%
Floor level to knuckle height	Lift	229	262	323	381	434
	Lower	311	419	539	658	766
Knuckle height to shoulder height	Lift	333	397	468	540	604
	Lower	431	542	667	791	903
Shoulder height to arm reach	Lift	234	283	370	452	522
	Lower	255	357	471	564	666

8/ Liberty Mutual Insurance Co.

Figures 8a and 8b show corresponding information to that given in tables 3 and 4 for carrying.[9]

Maximum weight of carry acceptable to various percentages of industrial male workers

Figure 8a

Knuckle height

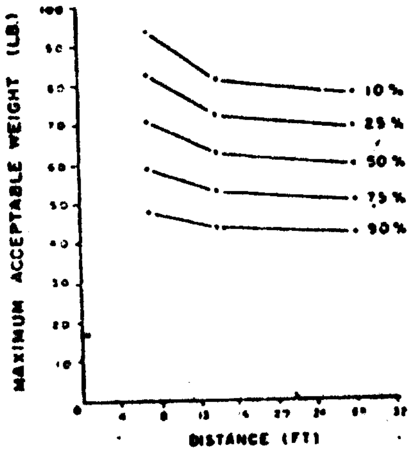
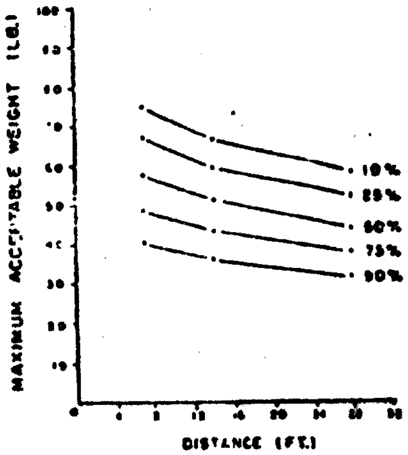


Figure 8b

Elbow height



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[9] Liberty Mutual Insurance Co., Snook, Irvine, Mass.

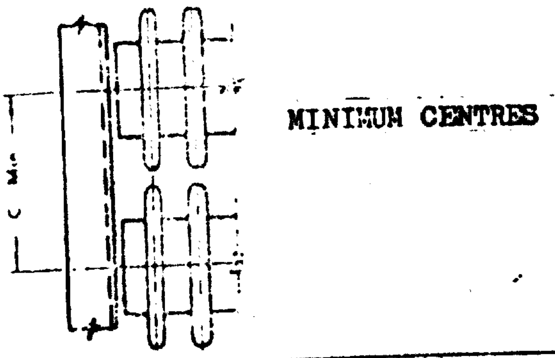
We turn to the remaining, non-manually powered materials handling equipment.

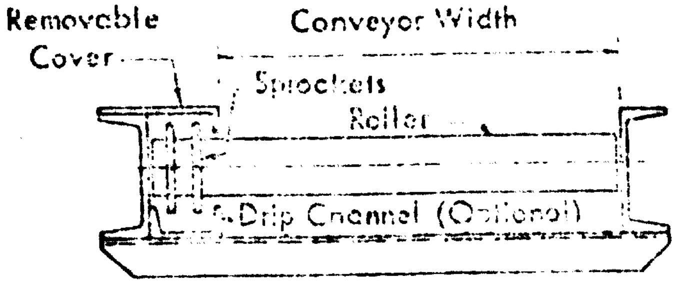
Power-driven roller conveyors

The same rule for determination of width applies to power-driven as to gravity roller conveyors, except that additional distance must be provided for a power transmission chain. Belt-driven powered roller conveyors are not practical in a machine shop environment where oil, cutting fluid, etc. can reduce the effectiveness of friction-operated devices. The capacity data in table 2 apply equally to powered rollers. Figure 9 below shows minimum distance between roller centres, which in turn limits the size of the smallest article handled.[10]

Figure 9

Some design characteristics of powered roller conveyors





A.S.A. Chain Size	MINIMUM CENTRES "C" (In Inches)							
	Number of teeth							
	13	15	16	17	19	21	23	25
40			3 1/4"	3 1/2"	3 3/4"	4"		5 1/4"
50		4 1/16"		4 11/16"			5 5/16"	
60	4 1/8"	4 1/2"			5 5/8"	6 3/8"		
80	5 1/2"		6 1/2"					
100	6 7/8"							

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[10] Conveyor Equipment Manufacturers Association Standards 404-1965.

Slat conveyors and belt conveyors

Slat conveyors are generally used where belts could not function because of the high temperature and the presence of chips and lubricants.

Woven wire belts or steel belts may be used for certain special applications. The small range and the high cost of steel and woven wire belts for conveyors limit their use.

Overhead trolley conveyors

Powered monorail installations and other overhead trolley conveyors are most efficient and economical materials handling devices, strongly to be recommended where the shop technology and layout are suitable. They occupy overhead space which would otherwise remain unused and offer low maintenance costs, high reliability and low power consumption. Such trolleys without power chains are often used as substitutes for monorail installations.

The trolley wheel is a large ball bearing with a high load capacity. The track on which it runs is an I-beam with lower load capacity and therefore its size sets the trolley load limits. The load ratings generally recommended are as follows:

Size of I-beam		Maximum allowable trolley load	
(inches)	(approx. equivalent in cm)	(pounds)	(approx. equivalent in kg)
2 5/8	6.7	75	35
3	7.6	250	115
4	10.2	400	180
6	15.2	1,000	455

Powered hoists and powered cranes

There is a service classification for specifying cranes. We are concerned here with cranes for moderate and heavy duties. The former classification applies in machine shops, assembly floors, foundries and fabricating shops where service requirements are medium. The latter applies in heavy machine shops, certain foundries, fabricating plants, stamping plants and steel warehouses.

Table 7 below shows typical operating speeds of commercially available equipment.[11]

Table 7

Operating speeds of powered cranes in feet per minute

acity In Tons	HOIST			TROLLEY			BRIDGE		
	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast
3	20	35	70	125	150	200	200	300	400
5	20	35	70	125	150	200	200	300	400
7½	20	35	70	125	150	200	200	300	400
10	20	30	60	125	150	200	200	300	400
15	15	30	50	125	150	200	200	300	400
20	15	25	40	125	150	200	200	300	400

The building should be constructed to accommodate a specific type of crane installation; it is not always economically feasible to modify its structure subsequently. Besides the static loads, there will be dynamic loads imparted to the structure.

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[11] Electric Overhead Crane Institute Specification #61.

The minimum clearance between the highest point of the crane and the lowest point of the roof, allowing for sag, should be 6 inches. Clearance between the ends of the crane and the nearest obstruction must not be less than 2 inches. Knee braces must not prevent approach with the hook.

Fork lift trucks

Because of their great flexibility, fork lift trucks are widely used as lifting, transporting and positioning devices. The simplest of them have their controls on the handles, the operator walking alongside. They are operated by electricity or gas and models are generally available up to 4,000 to 6,000 lb capacity.

Fork lift trucks on which the operator rides range in capacity from 2,000 to 60,000 lb, come in a great variety of shapes and may be powered by gasoline, gas or electricity. Vehicle speeds range up to 15 mph, but safe operating speed indoors is not more than 5 mph. Gasoline-powered trucks are suitable for indoor operation only if ventilation is adequate. Electrically powered trucks are divided into three groups: those for dusty and hazardous locations; those with explosion-proof motors; and general-purpose trucks.

In order to make effective use of fork lift trucks, the workshop aisles must be wide enough to permit right-angle stacking. Figure 10 below and the accompanying text[12] show how to calculate the minimum aisle width. Two cases are distinguished, depending on the relationship of the width of loads to truck width and inside turning radius.

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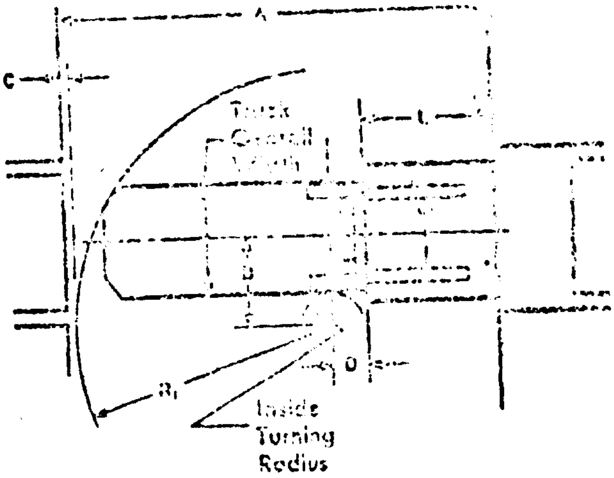
[12] Taken from *Mill and Factory*, May 1966.

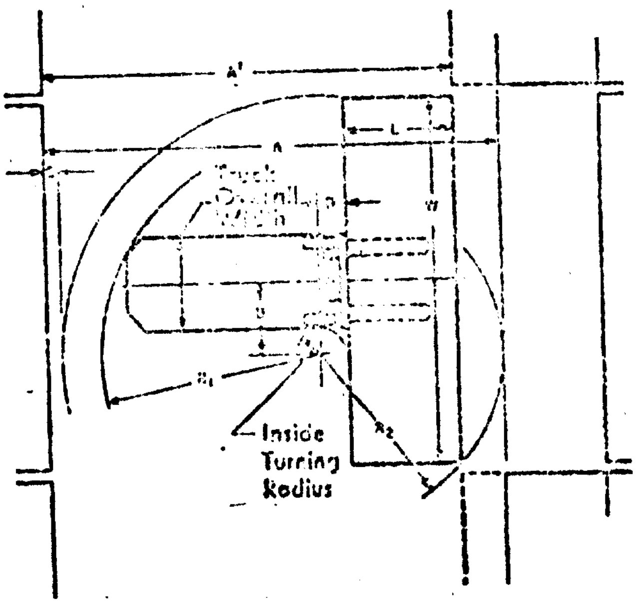
Figure 10

Minimum aisle width for fork lift trucks



= Minimum Aisle Width for Right Angle Stacking.
= ½ Truck Overall Width Plus Inside Turning Radius.
= Operating Clearance Best Suited for Individual Application and Steer Wheel Creep. (Consult Manufacturer)
= Distance from Face of Load to Centerline of Drive or Load Axle.
= Outside Turning Radius. (Empty Truck Under Power at Slow Speed.)
= Length of Load.
= Width of Load.
hen "W" is not greater than 2B use:

$$A = R_1 + D + L + C$$



= Minimum Aisle Width for Right Angle Stacking.
= ½ Truck Overall Width Plus Inside Turning Radius.
= Operating Clearance Best Suited for Individual Application and Steer Wheel Creep.
(Consult Manufacturer)
= Distance from Face of Load to Centerline of Drive or Load Axle.
R_1= Outside Turning Radius. (Empty Truck Under Power at Slow Speed.)
R_2= Distance from Center of Turn to Indicated Load Corner

$$= \sqrt{(D + L)^2 + \left(\frac{W}{2} - B\right)^2}$$

= Length of Load.
W = Width of Load.
When "W" is greater than 2B but not over $2(R_1 - B)$ use:

$$A = R_1 + R_2 + C$$

If swing indicated by R_2 need not clear line of stack as shown dotted, then use:

$$A^1 = R_1 + D + L + C$$

Materials handling at the work station

Work handling at the machine is often inefficient in general machine-shop practice. Improvements and mechanisation at the work station are a source of savings, of increasing importance as labour costs rise.

It is difficult to put a figure on the over-all efficiency of machining operations, but in many cases the time actually spent processing metal does not exceed 25 per cent of the floor-to-floor time at a given machine. (There are obvious exceptions - long and heavy cuts, operations on turret lathes.)

The effectiveness of the skilled craftsman should be extended by removing as many lifting, moving and positioning operations from his manual routine as practicable. This will increase output and safety, while reducing fatigue and spoilage. A money value can be put on all these benefits, which will generally exceed the recurring costs and depreciation of the additional equipment needed.

Materials handling at the work station is effected by devices for parts feeding, parts removal, work holding and positioning. There are also automatic and semi-automatic transfer machines for assembly, inspection, etc.

Parts feeding devices include the following: vibratory feeders; feeder and orientator combinations; feeder, orientator and counter combinations; sheet lifters and stackers.

Parts feeding through consecutive operations (for example, on presses) and parts removal often require special devices; but such standard pieces of equipment as orientators, magnetic belts, stackers and palletizers can sometimes be employed.

Work holding and positioning is effected in a number of ways, depending on the shape of the workpiece. There are standard reciprocating devices to advance and position one piece at a time on demand. There is a great variety of commercially available positioners, turning rolls, up-enders and similar equipment to position and hold the workpiece in a desired position during fabrication. There are manipulators which hold any workpiece in any position, serving as a third hand while the operation is performed upon it. When handling heavy dies, die holding and elevating devices should be used.

By ensuring that feeder stations are all at the same height, one can greatly reduce the manual effort, since raising and lowering each piece between operations are thereby eliminated.

Automatic and semi-automatic transfer equipment can be devised with various degrees of sophistication. A rotary turntable with assembly stations is a simple case. The production line can be mechanized to the point where each worker has his own "free float" time to turn, raise, lift, lower the workpiece by mechanical means, independently of the line speed but conforming to an hourly or daily schedule. The employment of transfer machinery that eliminates manual operations altogether is only a matter of economic justification, since the present state of the art enables equipment to be devised and manufactured to cope with any workshop need.

Table 8 shows how many minutes must be saved per day by an operator in order that the savings in labour cost alone may justify installing automation equipment.

The calculations are based on salary levels in the United States and assume 2,000 hours work per year; annual charges for the equipment are taken to be 10 per cent of its initial cost. Though over-simplified, this presentation has the merit of enabling a quick estimate to be made of the orders of magnitude involved. It is a simple matter to make alternative calculations, using assumptions which reflect more closely the conditions in any given developing country.

Table 8

Relationship of daily time savings to cost of materials handling equipment at the work station

Weekly Salary	$38	$48	$58	$67	$77	$87	$96	$106
Annual Salary	$2000	$2500	$3000	$3500	$4000	$4500	$5000	$5500
Equipment Cost	NECESSARY MINUTES PER DAY SAVING TO JUSTIFY EXPENSE							
$100	2	2	2	1	1	1	1	1
$200	5	4	3	3	2	2	2	2
$300	7	6	5	4	4	3	3	3
$400	10	8	6	5	5	4	4	4
$500	12	10	8	7	6	5	5	4
$600	14	12	10	8	7	6	6	5
$700	17	13	11	10	8	7	7	6
$800	19	15	13	11	10	9	8	7
$900	22	17	14	12	11	10	9	8
$1000	24	19	16	14	12	11	10	9
$1100	26	21	18	15	13	12	11	10
$1200	29	23	19	16	14	13	12	11
$1300	31	25	21	18	16	14	13	11
$1400	34	27	22	19	17	15	14	12
$1500	36	29	24	21	18	16	14	13
$1600	38	31	26	22	19	17	15	14
$1700	41	33	27	23	20	18	16	15
$1800	43	34	29	25	22	19	17	16
$1900	45	35	30	26	23	20	18	17
$2000	48	38	32	27	24	21	19	18

Source: **Extension of a chart prepared by O. B. Lovell, Controller, First National Bank, Madison, Wisc. and published in the Auditgram by the National Assn. of Bank Auditors and Controllers.**

Scrap handling practice

One of the most difficult housekeeping tasks in the machine shop and one of the least efficient in practice is the handling and disposal of scrap. The task is twofold: first, the removal of scrap from the machines and the shop; secondly, its processing, storing and disposal.

Removal of scrap from small shops is generally done by raking the chips from around and under machine tools and packing them into bins, barrels or tote boxes, which are then collected into powered or hand-pushed vehicles and transported to a collecting area. Such a system requires good plant layout to facilitate the raking and removal activities. Larger shops can be so arranged that chip removal is mechanized. This is in any case advisable when new facilities are planned.

The following types of in-plant scrap-handling conveyors are available:

- Apron conveyors
- Belt conveyors
- Flight, drag or chain conveyors
- Harpoon conveyors
- Chutes and self-dumping hoppers
- Pneumatic conveyors.

Despite the simplicity of a pneumatic vacuum system, it is with extreme caution that such apparatus should be used instead of mechanical scrap collecting equipment.

When collecting scrap in the shop, the first rule is to segregate it into at least the following groups:

- Machine shop turnings of clean steel, free of cast iron or non-ferrous metals, scale or excessive oil. No very rusty material should be included in this group.
- Mixed borings and turnings. Steel and cast iron should be free of scale, excessive oil and non-ferrous metals. This group should not contain badly rusted stock.

- Clean cast-iron scrap
- Non-ferrous metals, stainless steel.

Once scrap has been collected from the machine tools to a central area, usually in the yard, it must be processed and stored. For a small machine shop, the processing may consist simply of removing the cutting fluid by drainage. For a larger plant, the processing may consist of crushing, removal of cutting fluid and drying.

Overhead storage of scrap is most advantageous. Care should be taken not to store more than 60-70 tons in any one compartment, lest compacting occurs. The slope and gate sizes provided should be such as will prevent bridging.

Production planning

In production planning for a future plant, the various business parameters and the level of technology which are forecast will be the deciding factors. This case is not discussed here.

Production planning for an existing shop is determined to a considerable extent by the production facilities already installed. This is the most frequently encountered industrial situation in developing countries. The objectives of production planning in this case are:

- To utilise profitably and effectively the resources of men, machinery and material;
- To provide management with timely feedback information, so that it can maintain an orderly and continuous flow of production through the plant;
- To minimise the time required from receipt of order to

despatch of the finished product;
- To take account of changes in the business climate, technology, material resources, manpower resources etc.

Whether one man or a management team assumes the production planning functions, documentation of actual output is the essential starting data which, when compared with feedback information from the shop, provides the self-correcting mechanism for soundly based supplementary decisions.

In analysing profitability, the main factors for consideration are: the capacity of the shop; whether a given job can be done without working overtime or deferring jobs for other important customers; and whether it is necessary and possible to employ subcontractors.

In jobbing shops making small lots, orders should be pooled for better processing and released in the most economical batches, in order to keep machines fully and continuously loaded as far as possible. Subcontractors should be included in the total production capacity of the system. Delivery promises should be based on knowledge of the queueing situation at the various machines. Crash programmes should be avoided because they are costly.

Hand-written reports of activity at each work station can provide a constant flow of information to management on the workload and progress of work throughout the shop. Management should always be alert for signs of possible late delivery, in order to take corrective action while there is still a choice of less costly methods than last-minute overtime working.

It is also a mistake to release lots for production too early or to plan that an operation should finish long before the next one starts, for material held in inventory ties up capital and increases the possibility of damage, corrosion, pilfering and loss.

Cost reduction and a more competitive position in the market should be the constant goals of production planning. Small shops with little capital may best adopt the following approach:

- Promote general savings by rearranging equipment, reducing the materials handling effort and shortening the manufacturing cycle;
- Invest the savings in simple hand-powered materials handling devices (conveyors and the like), either made in the shop - this point is stressed for a metalworking shop - or purchased. Appreciable cost reductions should result. If not, the planning should be re-checked;
- The profit generated by cost reductions should be accumulated towards purchase of more sophisticated materials handling and process equipment or ultimately, perhaps, new production facilities, when further improvement of the existing facilities is impractical.

Production scheduling

Proper scheduling of production ensures a controlled flow of material through the shop. It can be instituted equally in a one-man shop or a large, multi-factory enterprise, for the logical process remains the same. All stages of production should be documented since, by definition, the scheduling process is the simulation on paper of the manufacturing activity.

Some of the steps described here may be abridged or combined with other steps in a small shop.

Scheduling begins with the receipt of the order from a customer, or the release of pooled orders by a planning group, and ends with the despatch of the goods. Typical scheduling operations in a medium-sized shop with an engineering department are as follows:

1. Receipt of customer (or pooled) order.
2. a. Process the order to the engineering department for analysis.
   b. Pass the request for all major components, materials or sub-assemblie to the purchasing department.
3. a. Engineering design and detailing is completed and returned to the manufacturing department.
   b. Final materials requisitions are drawn up.
4. a. Materials requisitions are passed to purchasing department.
   b. Materials control checks inventories, materials are ordered to maintain inventory levels.
5. Issue product or part details to production control for scheduling.
6. Production control applies time standards, determines the machine loading and the tooling required.

7. The order is inserted into the factory production programme, at a time which postdates the arrival of material and any special tooling. In the case of a lengthy job, the start will be deferred until sufficient material has been accumulated to permit continuous operation.

8. Progress through all successive stages of production prior to final assembly is scheduled along the same lines as 7.

9. a. Manufactured components move to assembly area.

   b. Purchased items are scheduled to be made available for assembly.

10. Assemble, test, inspect.

11. a. Transport to despatch department, pack.

    b. Notify accounting department.

    c. Notify customer.

12. Despatch.

Determination of material and labour cost

A majority of the factories in most developing countries employ less than 50 people. These factories have usually been built up from small shops by the exceptional working capacity and technical knowledge of the owner or manager, who is at the same time designer, craftsman, businessman, salesman and often also the accountant. This latter function may not be too burdensome as long as the business employs less than 12 people, but beyond this number the recording of financial transactions should be handled by a trained accountant.

Accounting is a staff service needed to show the company's financial condition, including the sums receivable and payable at a given time and a detailed analysis of expenses. The manager needs complete and detailed records to draft a budget or plan the co-ordination of sales, advertising, purchasing, labour costs, production volume, engineering and research activities, and replacement of machinery and equipment. When supervisors and foremen begin to understand the implications of a detailed budget for their own work, they will act to better purpose.

The various shop departments usually prepare their own budgets, to show general production expenses, purchase of materials, machinery and equipment, maintenance costs, production wages and salaries. Budgets improve in accuracy with good planning and can help to stabilize production costs during slack times.

Wages paid in a factory are usually classified into those for direct and those for indirect labour. Machine operators are always direct labour, while tool room, maintenance, and janitorial services are usually considered indirect labour costs. All expenditures which cannot be charged directly to a product, including indirect labour, are generally included in factory overheads (the burden). The same type of distinction is made in regard to materials. Those directly used in the manufacture of the parts, including special tooling, are considered direct material, while other materials such as lubricants, general-purpose tools, vices and clamps, are classified as indirect and included in overhead costs.

Machine tools, in common with other items of capital equipment, must figure in the production costs in regard to their insurance, deterioration, obsolescence and maintenance costs. In this way, funds are accumulated to replace a worn-out machine after a specified time or for investing in a new process and its equipment.

The production budget is based on a planned volume of output, which is based in turn on sales estimates. Correctly prepared to cover a year in advance, the budget prevents costly fluctuations in manpower. The estimation of the cost of purchases will be facilitated if proper inventory records are kept and used by management. Moreover, purchase contracts can then be placed in good time, so that materials, machinery and equipment are delivered to match production needs.

When production facilities are to be expanded or replaced, many other cost factors will have to be ascertained, which are applicable to a longer time period than annual operating costs and therefore will appear in the budgets for several financial years.

The inclusion of a good preventive maintenance plan in the budget provides for the repair and servicing of machinery and buildings at regular intervals, prolonging their use and maintaining asset values.

The accounting service establishes the basis for determining not only manufacturing costs but also administration and sales expenses. The latter two categories of expenditure should also be recorded accurately, since an appropriate share of them must be charged to each component part or product that goes out of the shop door.

Production efficiency measures

Labour productivity

Production efficiency depends on the skilful utilization of human resources as well as machinery. These two facets of productivity are to some extent interdependent and it is one of the essential functions of management to pay careful attention to the interaction between them. We begin by discussing some aspects of productivity which specifically relate to labour utilization.

Standard times have often to be estimated by the supervisor of a job shop before the first batch of workpieces is finished or even started. It is therefore more difficult to set costs and time rates in a job shop than in one engaged on series production. The latter usually has production records and may employ time study men to establish periodically the performance of machine operators and assemblers.

The most common apprcach to a new machining job is to give it to a skilled operator who has had previous experience with similar workpieces. Often a period of trial and error has to be allowed, under the close supervision of the foreman, before setting the job routine. The foreman and the operator should be encouraged to devise special tools, fixtures and materials handling procedures to increase output. When a new job is to be started by less experienced workers, an improvement in skill can be achieved over a period of time provided the operators are carefully selected. This requires from the operator an ability to improve co-ordination between eyes and head, on the one hand, and hands or feet, on the other.

To obtain the maximum improvement in operator skill on a particular job, certain conditions have to be met, including the following:

- Dimensions and tolerances should not be altered significantly during the production run.
- Materials supply and handling should be efficiently planned for continuous operation, thus eliminating any waiting time for operators or assemblers.
- Tool sharpening and reconditioning should take place at regular intervals, specified in advance.
- Machines should be checked and serviced according to schedule.
- Scrap and chips should be removed regularly and never be allowed to accumulate around machine tools, because they interfere with operating efficiency.
- The composition and physical properties of workpiece materials should not change, save in exceptional circumstances. Such changes may necessitate changes in speeds and feeds as well as in tooling or even in the type of machine tools used. It remains, however, the manager's duty always to look for materials with improved machining properties or greater durability in service.

To achieve a high level of performance and efficiency in any kind of repetitive shop operation, operator training will always be required, particularly for new and unskilled workers. The training period depends on the soundness of the instruction methods used. Depending on the job, the learning time may vary between a modest number of days and a period of years. With the more difficult jobs requiring higher worker skills, training programmes must include in their scope educational matter for mental development, and measures to increase manual aptitude.

The following factors determine the length of training required for jobs in a machine shop:

- A certain degree of accuracy will invariably be required. Most toolroom operations need a learning period of 3 to 4 years, owing to the high precision which must be achieved.
- The level of education needed for any particular job must be instilled if it is not present. Even operators of simple lathes and drill presses, not only tool grinders, should be made familiar with the reading of scales, micrometers and dial gauges. Training a man just to copy a part with the help of calipers is usually not sufficient.
- Instruction should not only be verbal but also in printed form and all operators should be proficient in reading blue prints.

- -

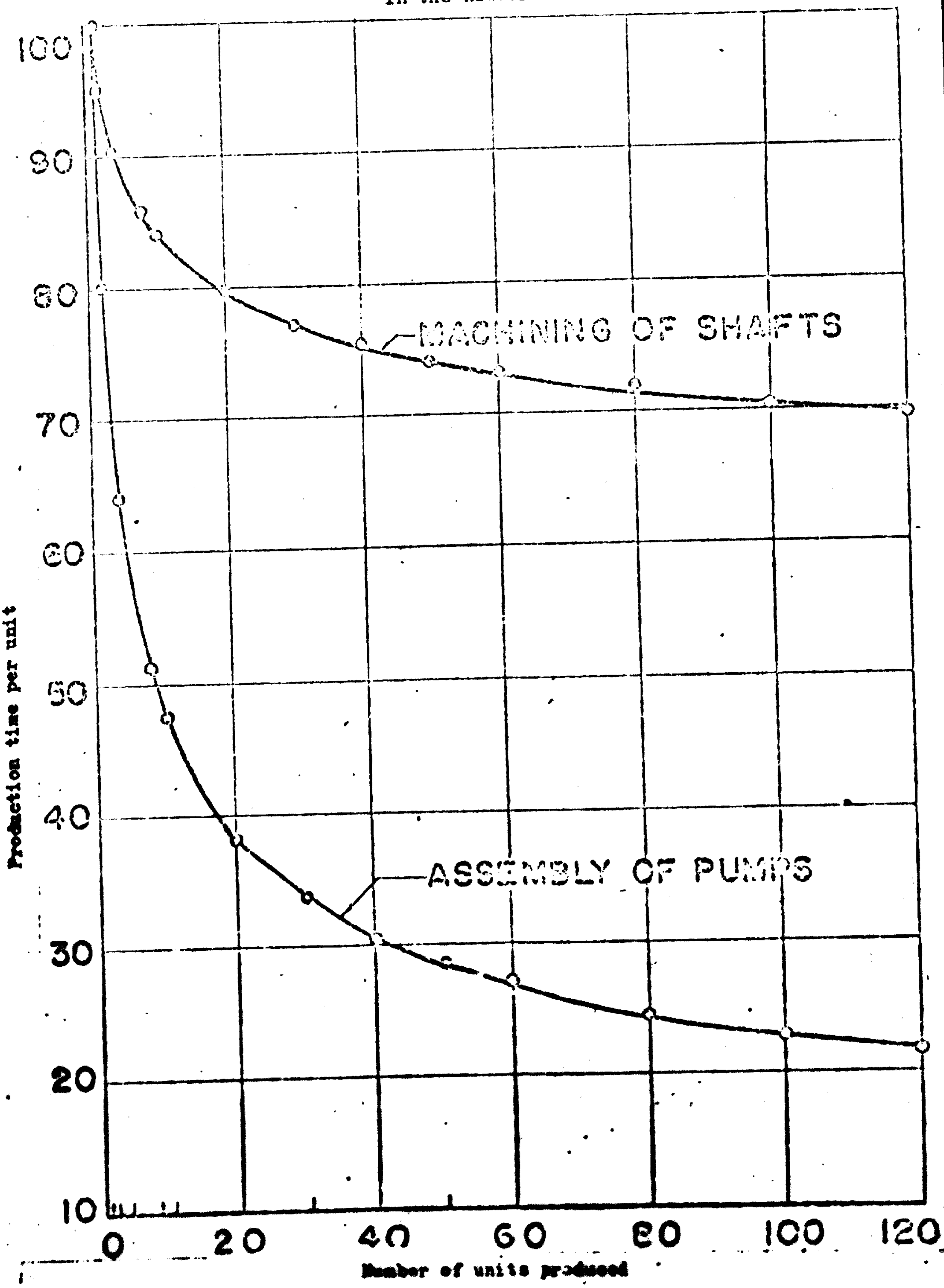
- Handling machine tools, loading and unloading workpieces requires manual dexterity at levels ranging from simple hand and arm movements to those requiring co-ordination and rhythm between the instrument-reading eye and the hand to alter the position of a tool.
- Some automatic machine tools call for a lower degree of manual skill than other machine tools, but often the need is for a higher mental dexterity as well as acute hearing, a keen sense of smell and sharp eyesight. A particular sound emanating from the tools may indicate abnormal wear or breakage; the smell of burning oil may signal an overloaded bearing; and the vibration of a tool or workpiece can cause a serious breakdown if not notioed in time.
- Physical stamina is one of the major qualities demanded of workmen in most developing countries. It should be the first factor to be considered where lifting and positioning of heavy workpieces is involved. Suitable materials handling procedures and equipment will not only shorten the learning period but will also improve the over-all performance of men and machines.

New employees, even when skilled, will rarely achieve their maximum output on the first day. However, their performance will improve steadily until it reaches the required level, provided that the shop organization is efficient. If the shop is disorganized by frequent supervisory and operator changes, the opposite result may occur. Profitable operation of a machine shop is above all a management function and by no means simple.

When any given job is repeated frequently, higher efficiency in the operation should result, but this happens only in well run shops. The phenomenon has been documented in numerous publications and the results have been generalized in the learning curve theorem: whenever the production quantity is doubled, the average production time per unit is reduced in a ratio which is constant for the given operation or set of operations. This ratio, expressed as a percentage, is known as the learning curve and typical values have been established over the years by industrial engineers. It has been found that the highest learning benefit occurs in assembly work, where the learning curve may be 75 to 80 per cent. These figures indicate, for example, that if 10 large structural units have been assembled in 10 days (average one day per unit), 20 units should require 15 or 16 days (average 0.75 or 0.80 days per unit). For welding, the learning curves have been determined as 80 to 90 per cent and for machining as 90 to 95 per cent.

Figure 11a shows a 95 per cent learning curve for the turning of pump shafts and 80 per cent curve for the assembly of pumps. It can be seen that these curves flatten as the number of units produced increases. This means that beyond a certain point there will be a negligible reduction in production time per unit.

Fig.11a. Improvement in productivity with increase in the number of units produced.



• The time scale could represent minutes for machining and hours for assembly of pumps.

Several learning curves are plotted in figure 11b, employing double logarithmic scales. This transforms the curves into straight lines, which makes them somewhat easier to use. Their common application is in estimating the costs of repeat orders after an initial trial run. If the expected improvement in performance is not obtained, the causes should be ascertained and the necessary corrective measures be taken. (Sometimes, it is the initial times which were not typical.) The setting of arbitrary job times based on vague guesses will usually do more harm than good and destroys the confidence of workers in management.

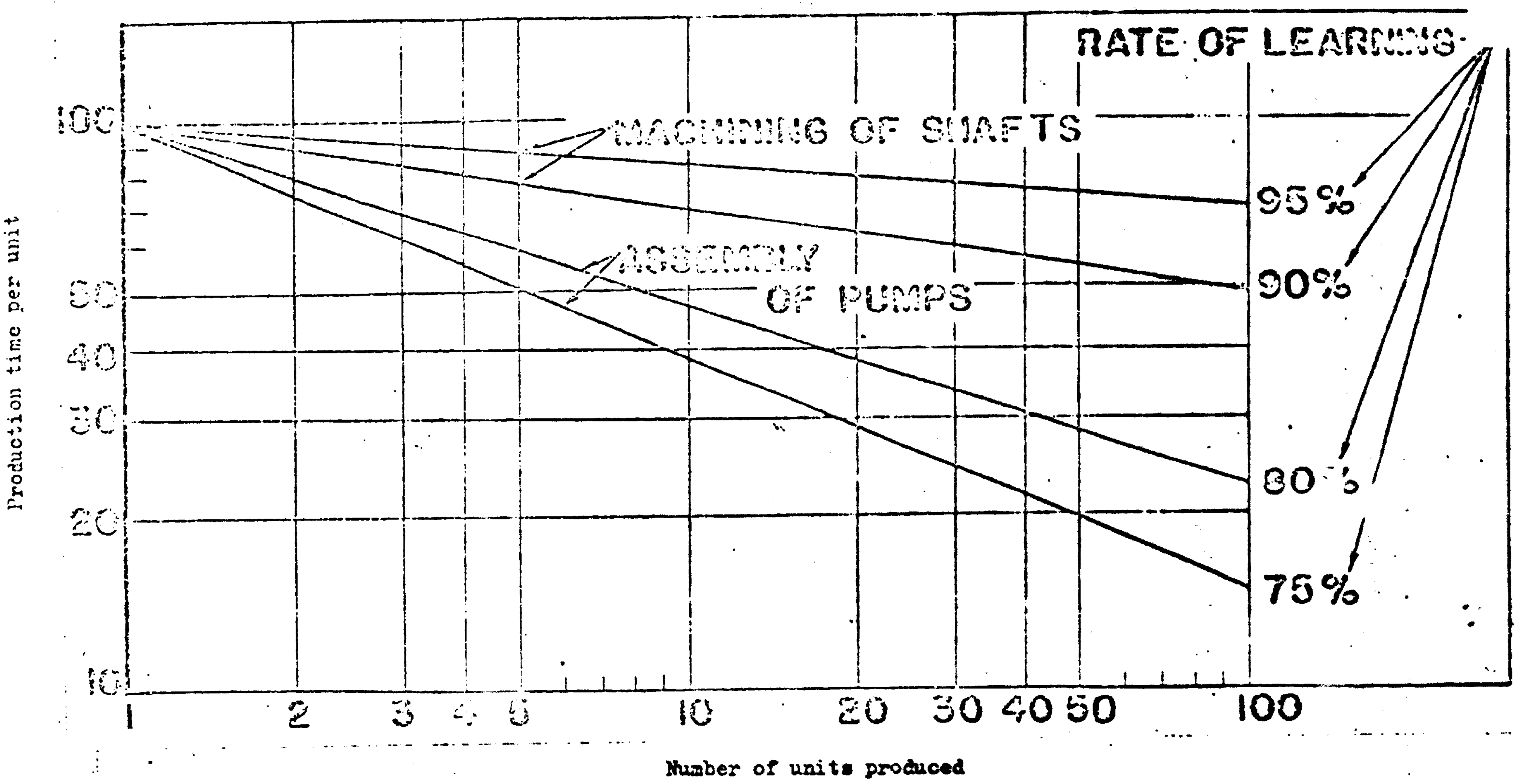
A general algebraic treatment of the learning curve theorem is given in Appendix 2.

Productivity of machinery

A cost analysis of manufacturing operations enables management to decide the number of workpieces that constitute the most economic lot size under given shop conditions. As lot size increases the unit cost decreases at first, partly (as we have seen) because labour costs may decrease and partly because setup time can be spread over a greater number of workpieces. When, however, the production of large batches leads to higher inventories, financial charges and other inventory costs increase. As the lot size further increases, the point is reached where storage space or working capital becomes a limiting factor. Possible changes of market demand, due to seasonal or other causes, introduce a further risk in maintaining higher inventories.

As a general rule, machine tool operations are fully analysed by managements. As far as the total machining times or floor-to-floor times are concerned it is assumed that the cutting times have already been measured by time

Fig. 11b. Straight line presentation of learning curves



studies for the particular workpieces, tool materials and tool geometry. These studies lead to definite values for cutting speed, depth of cut and feed rate which should change little during the course of production. The cutting time can therefore be shortened only by changing to tools made of a material that allows higher cutting speeds, greater depth of cut or faster feed, but still gives the desired surface finish and accuracy. Such a change also requires more horsepower and may therefore mean using a more powerful machine tool as well. If greater efficiency leads to repeat orders, the handling and set-up times should decrease by 10 to 20 per cent in accordance with a learning curve, provided the individual lot size is sufficiently large. The learning rate may not be as high as this, however, if a long time elapses between the repeat orders or a new operator is put on the machine.

Worker participation

Training and participation of workers in improving production efficiency cannot be effected simply by giving orders. As in all enterprises the best results are obtained by management creating favourable attitudes at all levels in the work force. When mutual trust and confidence permeate the organization, there is a good chance of the workers learning, including learning from their mistakes without being penalized. The shop supervisor's attitude should make clear his support of the work force and he should be interested in teaching and showing individual workers better ways of doing their jobs. When the members of an organization truly identify themselves with it and its objectives, thay are motivated to eliminate waste of time and materials and to improve processes and products. The atmosphere of the shop must be such that each individual feels that he has the possibility of demonstrating his personal and professional worth by the work he does day after day. This feeling, together with stability of employment and income, will make it rewarding to the worker to increase his output and, if the lines of communication between management and the work force transmit all the information he needs in this connexion, production efficiency will be increased. Labour turnover and absenteeism will fall to low levels, scrap and waste will decrease, costs will be reduced and a sense of loyalty will develop. It pays even a small shop to organize special training for employees to improve their skills. Many progressive companies give every member of the work force a chance to be involved in decisions about the organization of his particular job. They have seen that this leads to greater production efficiency than the old way of policing operations and punishing workers for their mistakes.

Group technology

Group technology is another powerful tool for improving production efficiency. This technique consists of the systematic analysis of every variety of workpiece machined by a firm, in order to establish which of them are sufficiently similar in shape and processing requirements to make it possible to schedule them together in a single, larger batch without difficulties. The first step, therefore, is to classify the workpieces according to the principal machining processes to be used. The second step is to group operations together, where feasible - for example, turning, drilling, cylindrical grinding, boring and related milling operations. On this basis, several different component parts can be grouped together for scheduling as one lot, to be processed with the same basic machine setup.

Although this is not a new idea, group technology ensures that complete and full advantage is taken of it, by extensive and careful analysis of components, supplemented by planned and uniform design simplification.

Parts of different configuration but requiring similar machining operations are also grouped for finishing in a common machine set-up. This is a selective process which can yield large savings. Designers and production engineers co-operate from the start of the planning process, grouping component parts and deleting or routing differently operations that conflict with this pattern. Jigs and fixtures can be designed to take into consideration variations in size and dimensions of component parts, thus enabling them to be grouped in the same job order. The result of all this is that group technology permits quicker scheduling of orders and the quotation of shorter delivery times.

Inspection methods

The inspection instruments and procedures in production workshops serve to check the precision of the parts produced by measuring one or several dimensions which must fall within definite tolerances. The greater the agreement between the actual values and those specified, the higher the accuracy of the inspected part. It must not be overlooked that the measured values can differ from the actual values due to errors of measurement. To minimize these errors, inspection methods and instruments have to be constantly maintained and subjected to critical examination during use, with the approval and active co-operation of the engineering department.

It would be very expensive to machine component parts to a standard of accuracy beyond what is functionally necessary. Assembly is possible only if parts do vary beyond stated limits and tolerances. Limits are usually set for the various types of fit (sliding, clearance, transition, interference and shrink fits).[13]

The type of part to be produced will largely determine the system of inspection required. Where the operator is highly skilled and has a clear understanding of the service requirements, no further inspection may be required. At the other extreme, even 100 per cent inspection after every operation may not necessarily guarantee that the specified quality has been obtained. Production in most metalworking shops is in batches of twenty workpieces or less, for which statistical sampling techniques cannot be readily used. (In series production on a large-scale, statistical sampling methods can ensure steady

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[13] Tolerances and fits are discussed in chapter 4.

product quality. For example, machine screws can be checked by inspecting the first piece and statistical sampling at intervals thereafter.) A part subject to several operations may go to a central inspection area prior to assembly or storage. Inspection assures management that the parts produced comply with the specifications and later provides the customer with evidence that the product he has acquired is as warranted.

Most shops have three sets of gauges on hand. The operator uses one set at his work station, another set is used for inspection and a third set is kept in store, often in a room with controlled temperature, for reference as master gauges.

The four principal means of measurement with graduations are the scale, the vernier, the micrometer and the indicator gauge. There are general-purpose and special-purpose versions of these instruments. Microscopes and instruments employing light of a specific wave length are used for high-precision measurements. Optical measuring instruments and comparators, and pneumatic and electronic gauges of various designs, enable comparisons to be made with selected standards of accuracy. For checking or setting various types of shop gauges, a set of master gauge blocks is the most useful reference to use in machine shops.

Special instruments are used to measure surface roughness. Most models have a diamond stylus which follows the surface irregularities, the instrument giving an average numerical value for the height of peaks and depth of valleys encountered by the stylus in traversing a certain distance over the workpiece surface. If roughness, waviness and form have to be maintained within specified limits, the machine operator should have a model or sample which shows all critical values for visual comparison.

CHAPTER 4 COMMERCIAL AND ENGINEERING ASPECTS OF MANAGEMENT

The special problems in developing countries

At the heart of the problem of increasing profitability in the metalworking industry in developing countries we find five key facts.

1. In comparison with the United States and Europe, production methods in developing countries in this industry generally have more labour content and are less efficient.

2. The limited size of the domestic market and lack of strong organizing power often make it difficult to achieve production economies through regional agglomerations of industry.

Industry in developing countries consists mainly of small plants, many of which are geographically separated. There are very few large enterprises which could help to organize the productive capabilities of smaller plants and serve as the principal market for their output. Some Governments encourage industry to locate in undeveloped areas of the country as a matter of policy, which militates against the development of regional complexes of related industries.

3. There is widespread evidence of difficulty in financing new production equipment and tooling to launch new product designs.

Most methods of depreciation (for example, 10-year straight line depreciation) do not encourage regular modernization of plant and equipment. In addition, high interest rates discourage replacement of fixed assets and new product ventures.

4. There are few people in most developing countries capable of original product design. The widespread practice of manufacturing new products by copying, with or without licensing and a know-how agreement from a foreign firm, has allowed no opportunities for product design talent to develop. The domestic market often provides little incentive to improve present products or to develop new products

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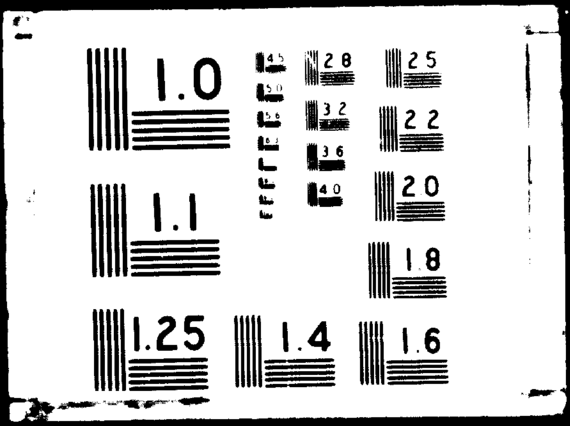

while entry into foreign markets seems virtually impossible, so that no attempt is made to design products for export.

5. In general, there appears to be little understanding among industrialists in developing countries of the role of marketing in a competitive economy. Serving a protected domestic market, they have not usually had to give much attention to marketing functions which are of great importance elsewhere. Thus, there has been little need for market research to identify requirements and estimate demand for new products, little pressure to determine the most suitable methods of marketing products and to develop distribution channels, little incentive to train salesmen and to conduct test marketing before launching full-scale production of new products.

Pricing policy, a key marketing variable, has usually been restricted by governmental policies.

There has been little need to discover a proper marketing mix for the domestic market: choice of distribution channels, promotion schemes, product design, and pricing policies.

Any long-term solution to the basic problem of expanding the metalworking industry in developing countries must give proper consideration to all the dimensions of the problem outlined above. In order to compete effectively in home and foreign markets, the industry must (1) modernize its equipment and methods of production; (2) develop new products and market them effectively; (3) organize supporting industry; and (4) acquire adequate financial resources for these tasks.

The role of product development in commercial strategy

The critically important part played by new products and technological innovation in generating industrial growth in developing as well as developed countries is generally accepted. The creation of new factories and the continued existence and expansion of established firms are closely dependent on product development and a rising level of technology. Before anything can be achieved, however, the need for innovation and the particular problems that arise in connexion with innovation must be recognized by the managements of individual firms, which alone can decide what type of product is to be made. It may be an item that has hitherto been imported or some specialized requirements of an industry already established in the country. Other possibilities are: a small product for which there is a relatively large demand if attractively packaged and sold through general distributors; and relatively large, complicated machines which will involve the firm in recruiting technical staff for its sales force and probably also for a service organization.

Whatever type of product is chosen, a number of steps have to be taken by the management in order to develop it:

- Organize the idea and determine the market analysis, exploratory market testing and engineering work necessary to give it concrete form;

- Carry out engineering development, including prototype design and testing;
- Arrange financing for new product lines, the income from which may in due course provide funds for further product development;
- Work out the production planning, which may demand new machine tools, special tooling, new jigs, fixtures and dies;
- Complete the marketing arrangements in the light of the market testing results, selecting the best method of distribution and giving distributors continuous support by advertising and promotion.

Top management should therefore have a plan for product development, growth objectives and cost controls, which is regularly updated. We are including in the term product development new products, new processes and new uses for existing products.

The first step - organizing the idea - involves examining the various possible ways of developing the product range.

Under the heading of new products, the simplest innovation may do little more than change the price of the existing product (the simplest way of changing a product's economic characteristics). The change may be associated with the use of more attractive colours or some other means of drawing more attention to the product. Further innovation, still based on the existing product, may consist of design modification or extension of the product range by making additional sizes. Finally, there is the adoption of a new product in a line new to the firm, which might be called a strategy of diversification.

Under the heading of process development, the alternatives are:

- Modification of an existing process to obtain lower production costs;
- Adoption of backward, or upstream integration of production: for example, if the quality of locally produced castings has necessitated importing, setting up one's own foundry to produce castings of acceptable quality;
- Adoption of forward, or downstream integration: for example, by setting up sales and service offices where existing distribution arrangements are unsatisfactory.

Under the heading of new uses (or new markets) it is necessary to consider new geographical market areas, sales to a new industry, export to neighbouring countries etc.

This kind of review of the possibilities can be carried out successfully by a company of any size, but implementation is never easy, particularly for a small firm.

Marketing includes advertising and other promotional activities which stimulate sales and acquaint potential customers with the current or new products of a company. Market research, which must often be coupled with technological forecasting, may lead to the modification of existing products as well as the design of new ones.

To investigate the need for product change in a particular company, the first necessity is to establish company objectives regarding the present and future magnitude of sales and profits. The present products' strengths and weaknesses should be compared with those of competitors' products. The next step is to analyse sales according to industry, location, volume, end-use, channels of distribution and expansion potential, as well as to tabulate production costs, the percentage of value added and the profit margin for each product. Armed with this information, the product strategy can be determined which will meet the competitive situation in regard to any given product and contribute towards attaining the company's growth objectives. Furthermore, specific characteristics can be defined which new products must satisfy in order to fall within the company's range of manufacture and match the market needs. This will narrow the search for new or improved products, which specialized staff must then undertake, and for which search and evaluation procedures need to be established.

It may be asked how smaller firms in developing countries can afford such market research activities. A number of measures can be adopted to implement the above recommendations.

1. Use secondary sources, such as technical publications, to identify and monitor basic environmental and technical forces causing changes in the market you supply.
2. Allocate some resources on a regular basis to evaluate technical and marketing trends that may influence your programme of technical development.
3. Use a technically qualified panel of part-time consultants to augment the company's technical and managerial resources.
4. Make a thorough evaluation of the technical methods used or proposed for use on existing and new products.
5. Set up a wide variety of channels of information about technological threats to existing products and growth possibilities.
6. Pin-point technical requirements within the firm, and seek out human resources and machinery to satisfy needs not met by your own staff and equipment.

To summarize, we give a list of DONTs and DOs, valid for both large and small firms.

DONT

1. Don't expect to find a ready-made solution for your new products needs.
2. Don't think you are too small to keep abreast of technical development in your field.
3. Don't think you cannot get a government contract.
4. Don't look at research and development as a gamble; consider it an opportunity to learn about new technical developments.
5. Don't overlook university facilities; their technical and scientific staff should be willing to help you individually.
6. Don't expect miracles.
7. Don't wait until you have only six months to find a new product or else close shop.

DO

1. Do - attempt to look three to five years ahead regarding
   a. Demand for your present products;
   b. Technological developments likely to affect your present products;
   c. Areas of potential demand consistent with your basic interests and capabilities;
   d. The sustained planning activity required for product development to meet growth objectives.
2. Do - get one extremely well qualified technical man on your staff, at least as a consultant, but as part of your permanent staff if possible.

3. Do - get to know the personnel in your technical field at all universities or institutes near you and discover from them the sort of research being done.
4. Do - search out products which the Government purchases, manufacture of which is consistent with your basic interests and objectives for the future. To this end, enlist the help of a consultant and, if necessary, of university research departments. In addition, read current commercial and technical literature, including well illustrated foreign technical journals.
5. Do - start planning while good business conditions provide the time to develop new products.

Export markets

In the short run, it is unrealistic to expect that more than a few, relatively large firms in developing countries could directly compete effectively in world markets, even if they modernized their production methods. It is observable that most metalworking enterprises in developing countries, if they try to export at all, look for markets for their existing products, which are very unlikely to meet requirements in industrially advanced countries without modification or redesign. In any case, continuing export sales depend on repeated analyses of foreign markets, leading to the design and development of products to meet their specific requirements. Small firms simply cannot afford to do themselves the requisite product development and marketing. The key question then is, "How can small firms gain access to such facilities in order to penetrate international markets?"

In the immediate future, the alternatives available to most small firms appear to be very limited. The most promising is to find other firms with the ability to undertake product development and marketing in relation to international markets, but deficient in manufacturing capacity and therefore willing to make use of the small firms as subcontractors.

Bearing in mind the production methods used in developing countries, there are two situations in which certain enterprises might reasonably hope for success when seeking production orders from United States or western European firms:

- Where the product requires labour-intensive methods of manufacture and assembly; and
- Where small production lots are required.

For example, a small firm in a developing country might manufacture or assemble one or two items in a foreign firm's product line for which there is a limited demand, the marketing to be effected by the foreign firm. Such an arrangement might provide both stable and profitable business for the small firm.

There is probably no single way for small firms to find such business opportunities. Firms wishing to find such business in foreign markets ought to make greater efforts than are presently apparent. It would seem appropriate for the Governments of developing countries to encourage the needed increase in such market-search activities. For example, they might provide financial incentives for industrialists to travel abroad for this purpose.

Secondly, since several small firms might be capable of executing production orders from foreign enterprises, it would be opportune for the Government of a developing country to provide an improved marketing intelligence service, especially in Europe and the United States, in order to put firms in touch with appropriate foreign enterprises and vice versa. The nucleus for such a service may already exist in the Ministry of Foreign Affairs and embassies and consulates in the industrially advanced countries; or in a market research office of the Ministry of Commerce and Industry; or in export and marketing institutes, whose efforts might usefully be augmented by foreign market research and consulting engineering firms.

Apart from such activities, increased effort by the Government might properly be channelled in two main directions:

- An active and continuous search, through personal contacts within the principal countries concerned, with the object of identifying products which could be manufactured under subcontract by interested national firms, instead of attempting to find markets for existing products of national firms in in those countries.
- An analysis of the national image projected in major potential export markets and the development of appropriate institutional advertising programmes to help individual manufacturers obtain business in neighbouring countries.

To summarize, the additional measures proposed consist of:

- Greater emphasis on active, personal seeking of opportunities - not just order taking;

- Substantial increase in the effort made by the foreign service and in the technical sophistication with which it is deployed;
- Increased use of domestic or foreign engineering and market research consultants to locate product opportunities; and
- Increased personal contact between industrial managers and potential foreign buyers.

These measures must be viewed only as an interim programme to deal with the short-term problem. If they are successful, local firms obtain valuable experience manufacturing for foreign markets and also some funds for modernisation of their plant and equipment.

The desirable long-range national objective is usually to develop a full capability among metalworking firms to design, develop and manufacture new products for export and to market them. In this way, the firms and the nation would reap the benefit of value added in all stages of the value-creation process: design, manufacture, and marketing. Of particular importance for small firms is the potential development of their domestic sales to related and supporting industries which becomes possible if they have acquired original design capability.

It is, however, pertinent to ask how a developing country, with its many small firms, limited home markets, little over-all organization of industry, and scarcity of product design and marketing facilities, can develop export-oriented firms with the characteristics outlined. One strategy would be to concentrate the national effort, as regards research and related manufacturing facilities, in a few major branches of metalworking and to foster regional agglomerations of supporting industry for these branches, concurrently modernizing them and improving their productivity. By such a concentrated effort a country might become, within a decade, a major force in world markets in one (or perhaps several) major branches of metalworking, much as the Swiss have done in precision instruments and machine tools. In other words, the strategy might conceivably bring about the necessary internal organization of industry, with the associated economic benefits from agglomeration, and might engender the necessary external economies of scale to support the required export marketing functions.

A major national techno-economic market research effort would be required in order to identify the most promising products of the metalworking industry to which the strategy could be applied. Such items are characterized by the high value added by design and manufacture, and low transportation costs as a proportion of the gross value of production. Export markets are subject to the fluctuations of the trade cycle, but are of fairly stable structure. The underlying trend in volume is one of rapid growth.

Dimensional accuracy and tolerances

The variety of products that are manufactured in small workshops of the metalworking industry is so great that it is impossible to discuss product engineering comprehensively in this paper. We confine our attention in this section to a few general principles which are always applicable when designing products. These concern dimensional accuracy and tolerances and their relationship to performance, interchangeability and production cost.

What is accuracy? One definition is - the exact quantification of a dimension in terms of the units of the measuring instruments employed. When the measurement of a dimension is repeated on a series of like products and the values obtained are nearly identical then we have precision. Since it is impossible to obtain absolute accuracy, industrial dimensions are given tolerances, which are the permissible variations from the stated design dimension. When variations in dimension are allowed in only one direction, owing to the design requirements, they are called unilateral tolerances. Commonly, however, tolerances are bilateral, permitting equal variations in a plus and minus direction from the prescribed value of a dimension.

It is now customary in metal processing to specify size tolerances and standards for them have been established in all industrialized countries. When mating parts must operate trouble free and are intended to be replaced only after a definite service time or when worn out, it is particularly important to have standards which specify their tolerances.

In engineering and other manufacturing operations, tolerances can be specified in regard to geometry, position, surface condition, hardness, composition and microstructure, in addition to size.

Development of standardization

Control of accuracy of machined workpieces has been a problem in all countries from the beginning of industrial metalworking. Gradually, as factories became larger, they began introducing their own standards for dimensions and fits in order to facilitate interchangeability of parts produced in various locations. Subcontract work, which becomes necessary during boom periods and in time of war, reinforced the need for national standards of tolerances and fits. In due course, an international unification of the various national systems was sought, chiefly by those nations of continental Europe which used the metric system of measurement and had interdependent economies. Unification, if implemented, makes doubts and misunderstanding impossible regarding the way two pieces are mated, no matter how far apart the shops where they are made and regardless of the language spoken. Negotiations led in 1935 to the creation by the International Federation of National Standardizing Associations (ISA) of the "ISA System of Tolerances", which was later approved as their national standards by many nations, including the USSR, Japan and China.

The United States and United Kingdom, although members of ISA, did not at first adopt the ISA system, primarily because it used the metre rather than the inch as the basic unit of length. During the Second World War it became apparent, however, that international standardization of tolerances and fits was urgently needed, despite the co-existence of metric and inch systems.

War-time experience was reflected in American Standard "Limits and Fits for Engineering and Manufacturing (Part I), ASA B4.1-1947".14/ In the preface to that document it was stated that the ABC meetings - joint meetings between America, Britain and Canada - had resulted in agreement on five basic principles. Since the first four of these principles, with certain minor and obvious variations, was embodied in the American Standard it may be useful to repeat them here. First, there must be a common language (definitions) through which analyses may be recorded and conveyed. Secondly, a table of preferred basic

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14/ The latest revision of this standard, prepared by the American Society of Mechanical Engineers, was issued by the USA Standards Institute under the reference USAS B4.1-1967.

sizes should be laid down, which helps to reduce the number of different diameters commonly used in a given size range. Thirdly, preferred tolerances and allowances are a logical complement to preferred sizes and should encourage the designer to select standard tolerances. Fourthly, uniformity of method in applying the tolerances is essential.

The lack of standard specifications for fits in many countries in the past and the restricted flexibility of the recommended systems of tolerances, are undoubtedly the main reasons why the establishment of national standards in this field has met with only limited success. Visits to hundreds of engineering shops in developing countries make it apparent that no single system has any widespread use. In most cases tolerances and allowances are indicated on drawings in arbitrary figures, from thousandths of a millimeter to thousandths of an inch. On the other hand, most people familiar with the question accept the desirability of standardization in this field and metric dimensions are generally preferred.

The ISO system of tolerances

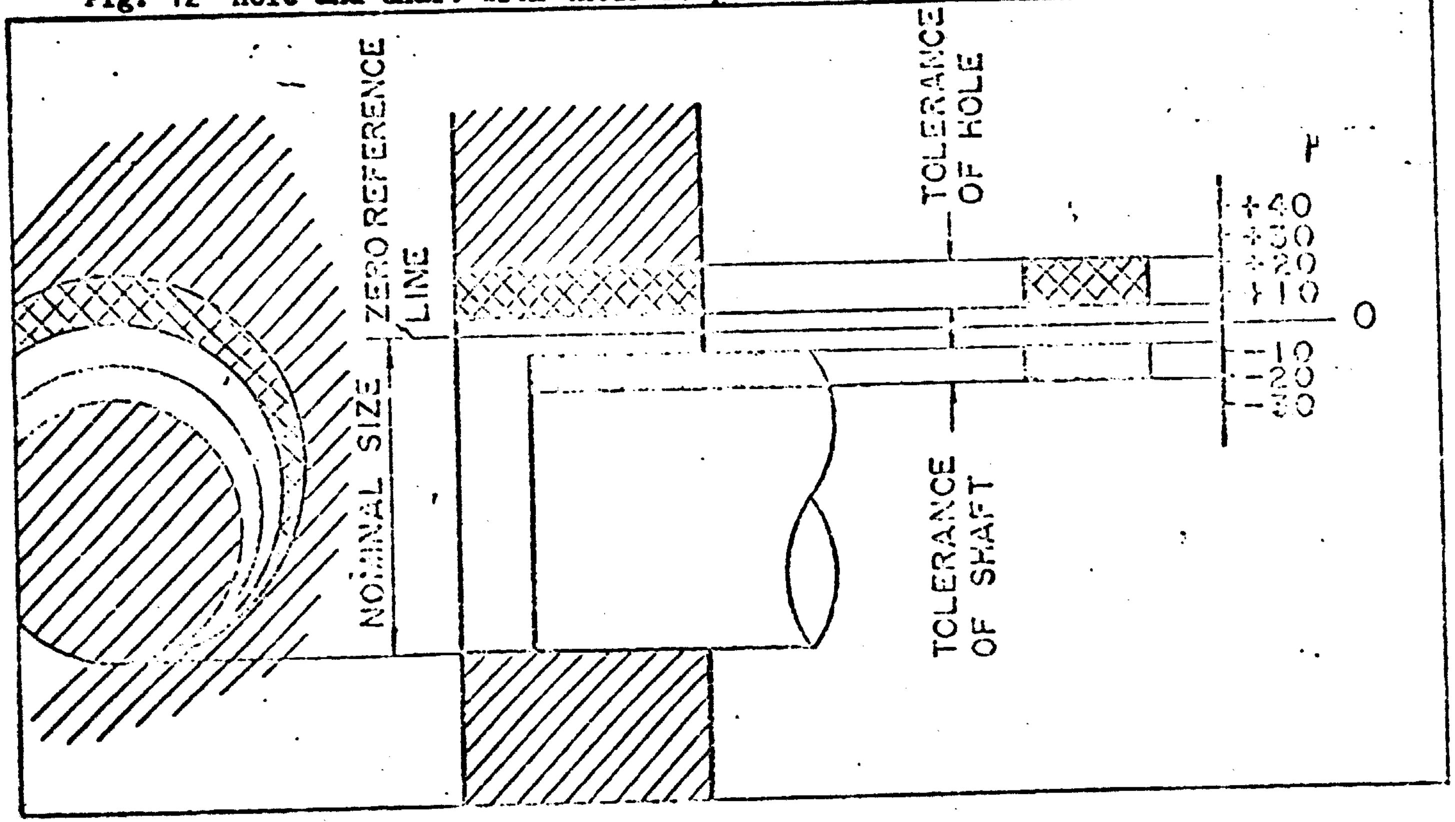
The negotiation of international standards has been continued by the successor body to ISA, the International Organization for Standardization (ISO). Its recommendations are embodied in the ISO system of tolerances, which applies particularly to fits between cylindrical parts, briefly designated as "holes" and "shafts", but can just as well be used between non-cylindrical mating parts, e.g., ways and keyways.

The reference temperature in the ISO system is 20 deg C or 68 deg F - the same as in the standards of the United States and many other industrialized countries.

The general requirements which must be considered when a fit has to be selected are illustrated in figure 12 below.

The quality grades of the ISO system define the accuracy to which a dimension is held, i.e., the tolerance which is allowed for the particular dimension in manufacture. The ISO system provides for 16 "grades of quality", or just "qualities" designated IT 1 to IT 16, IT 1 being the highest quality with the smallest tolerances. The qualities IT 1 to IT 4 are applicable almost exclusively to gauges and are not further discussed here. Starting with the quality IT 5, the basic tolerances of each quality are rounded multiples of the unit of tolerance i, which is in turn defined as a fraction of the nominal size D of the workpiece.

Fig. 12 Hole and shaft with their respective tolerances.



Note: μ, a micron, is 0.001 mm or approximately 0.00004 in.

Fits

Although, according to the ISO system, a free association of the different shafts and holes is permitted and no strict adherence to any special system is demanded, a basic hole system and a basic shaft system were taken into account when it was constructed. Both systems are used concurrently and no special preference should be given to either one of them. It has to be decided in each application which of the two systems allows easier manufacturing conditions.

As shown in figure 13, fundamentally the same setup can serve at one time for a basic hole, and at another time for a basic shaft tolerance, merely depending on details of construction. Drawings (a) and (b) show the wheel in outside position. In the basic hole system (a), the shaft must have a step in diameter in order to be inserted in the bushing. In the basic shaft system (b), it is possible to use a straight shaft, because removal from the wheel is feasible without damage.

Drawings (c) and (d) show the wheel in inside position. In the basic hole system (c), the shaft can be straight; in the basic shaft system (d) it needs a step to pass through the wheel without damage.

The system of fits provides for three groups of fits:

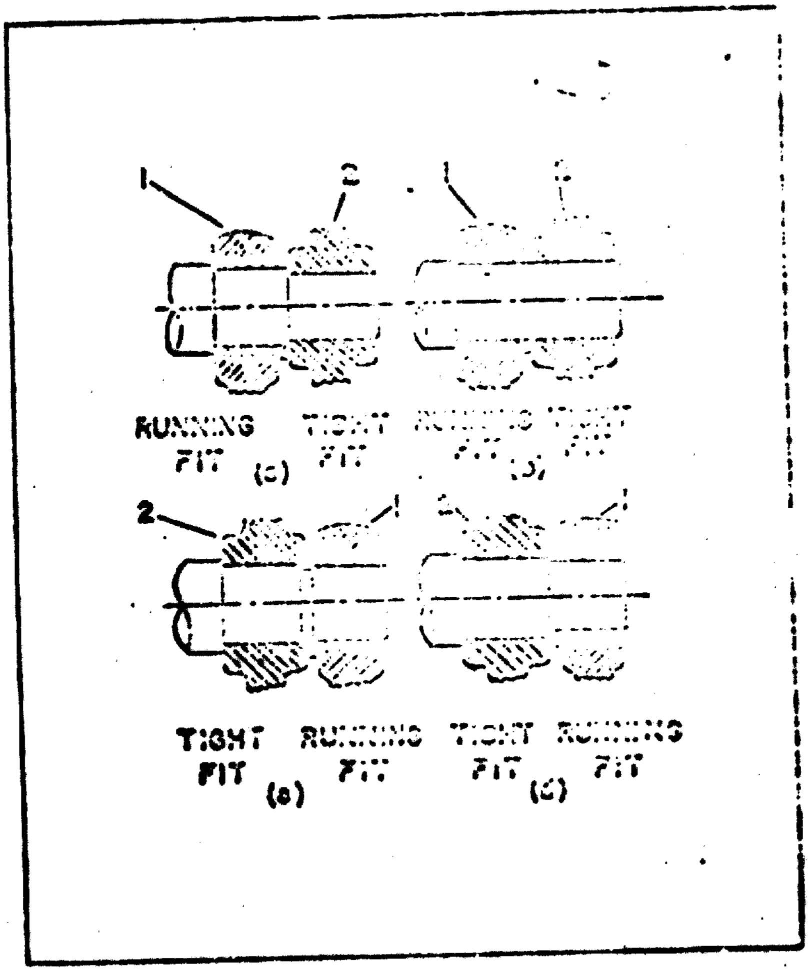
I. Clearance fits (running fits), in which the assemblies of parts always have a certain amount of clearance and are free relative to one another.

II. Transition fits, which according to their character are intermediate between clearance and interference fits and may have either clearance or interference.

III. Interference fits, in which the components, before assembly, always overlap in size to some extent and after assembly remain more or less fixed together.

Figure 13

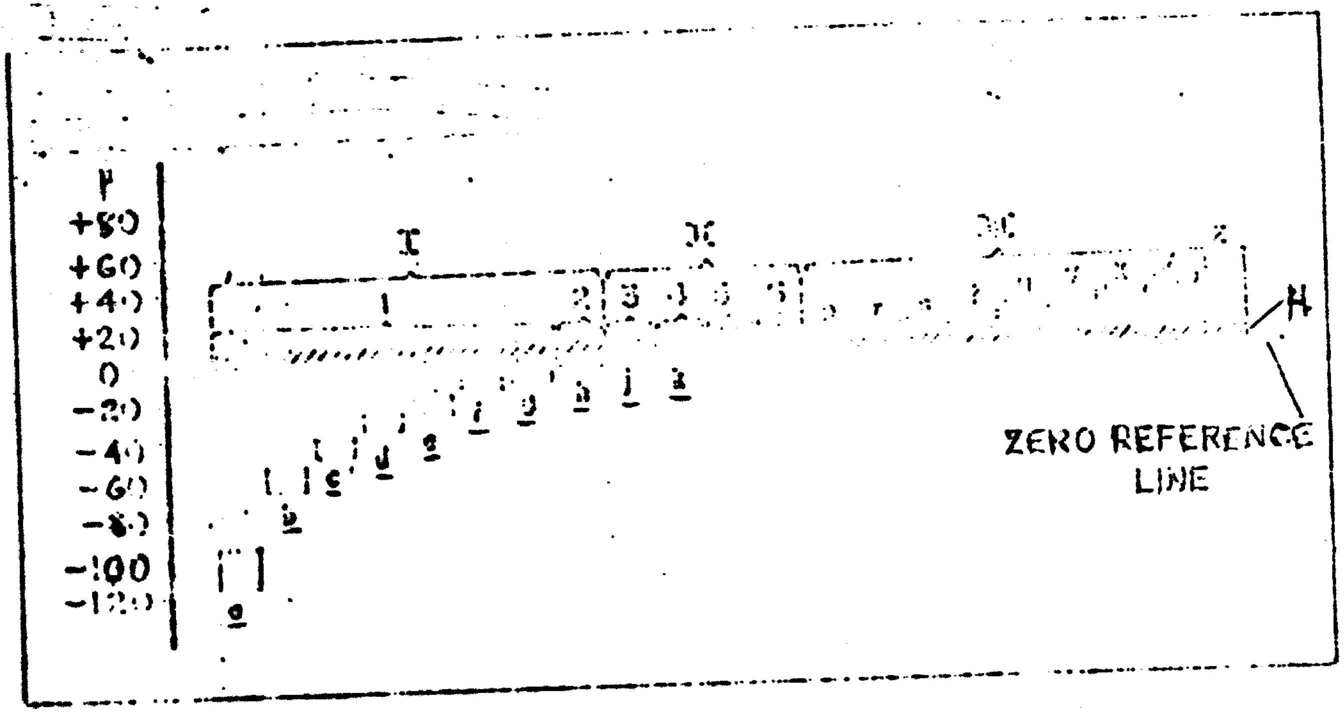
Comparison of a basic hole system with a basic shaft system



Shaft running in the bushing (1) is a press fit in the wheel (2). Drawings (a) and (c) illustrate the basic hole system, (b) and (d) the basic shaft system.

Figure 14 shows the designation of fits for the more commonly used basic hole system. The letters a to h apply to the tolerance zones below the reference line, a corresponding to the largest distance; the letters k to z apply to tolerance zones above the reference line, z corresponding to the largest distance. This gives a series of steps, from the maximum position below to the maximum position above the reference line. Independently of the grade of quality, these letters always indicate the smallest possible distance of the tolerance zone from the reference line and thus prescribe the minimum clearance or minimum interference between mating parts. This applies to shafts as well as to holes with few exceptions.

Fig. 14. Designation of fits for the basic hole system.



Notes: Hatched zone H is tolerance of basic hole; a to z are tolerances of corresponding shafts.

μ, a micron, is 0.001 mm or approximately 0.00004 in.

The designer of a product may be free to prescribe any degree of accuracy, any grade of quality contained in the tolerance system, that he considers necessary. Anxious that his design will really work, he may choose too good a quality and so increase manufacturing costs considerably, in most cases without realizing it.

Thorough investigations have shown that, within limits, once the equipment of the shop and the training of the personnel has been suitably adjusted, a desired accuracy can be achieved with relatively little extra effort. Nevertheless, the production of a certain quality will be least costly in a shop which has been equipped specifically for that quality, not better or worse equipped, and has a work force which is accustomed to that degree of accuracy, not more or less accuracy. In absolute terms, high precision work is definitely more expensive, because it requires more expensive machinery and more highly trained men. If pieces of low accuracy have to be made in a shop which is equipped for high precision work, they will be comparatively expensive. The rates of pay are higher on expensive machinery and the operators are not used to producing lower quality work. There is a close relationship between accuracy, production cost, machinery available and the skill of workers. If we ask for a greater accuracy than necessary, we not only make the piece in question more expensive, but may also increase the production costs for pieces with a lower specified accuracy, which have to be made on the same machines by the same workers. A good designer, therefore, never specifies a higher accuracy than is absolutely necessary. In terms of tolerances, he should select a quality of fit such that the next greater tolerance would make the workpiece unsatisfactory.

Many factories have found that it is often easier, in human terms, to reduce than to increase tolerances. When management decides to make a product less expensive by increasing the tolerances, the engineers and production people tend to object, because the change may mean "lower accomplishment", a reduction in skill content of their work.

Accuracy versus cost investigations are usually regarded as company secrets, but some results have been published. One series of tests in a precision machine shop consisted of grinding ten workpieces to each of six ISO grades of quality. By limiting the number off to ten, the influence of routine on the results obtained was likely to be reduced. All other conditions were kept as similar as possible; identical material was used, and the same operator employed. The design of test piece and the results are shown in figure 15. A sequence of operations was established in which test pieces were ground to the qualities IT 6, 10, 8, 5, 12 and 7 in turn. In such grinding operations the human factor can be responsible for large fluctuations in the time required. A regular and especially reliable operator was therefore chosen to do the work.

Figure 15

Relationship of grinding time to accuracy of workpiece

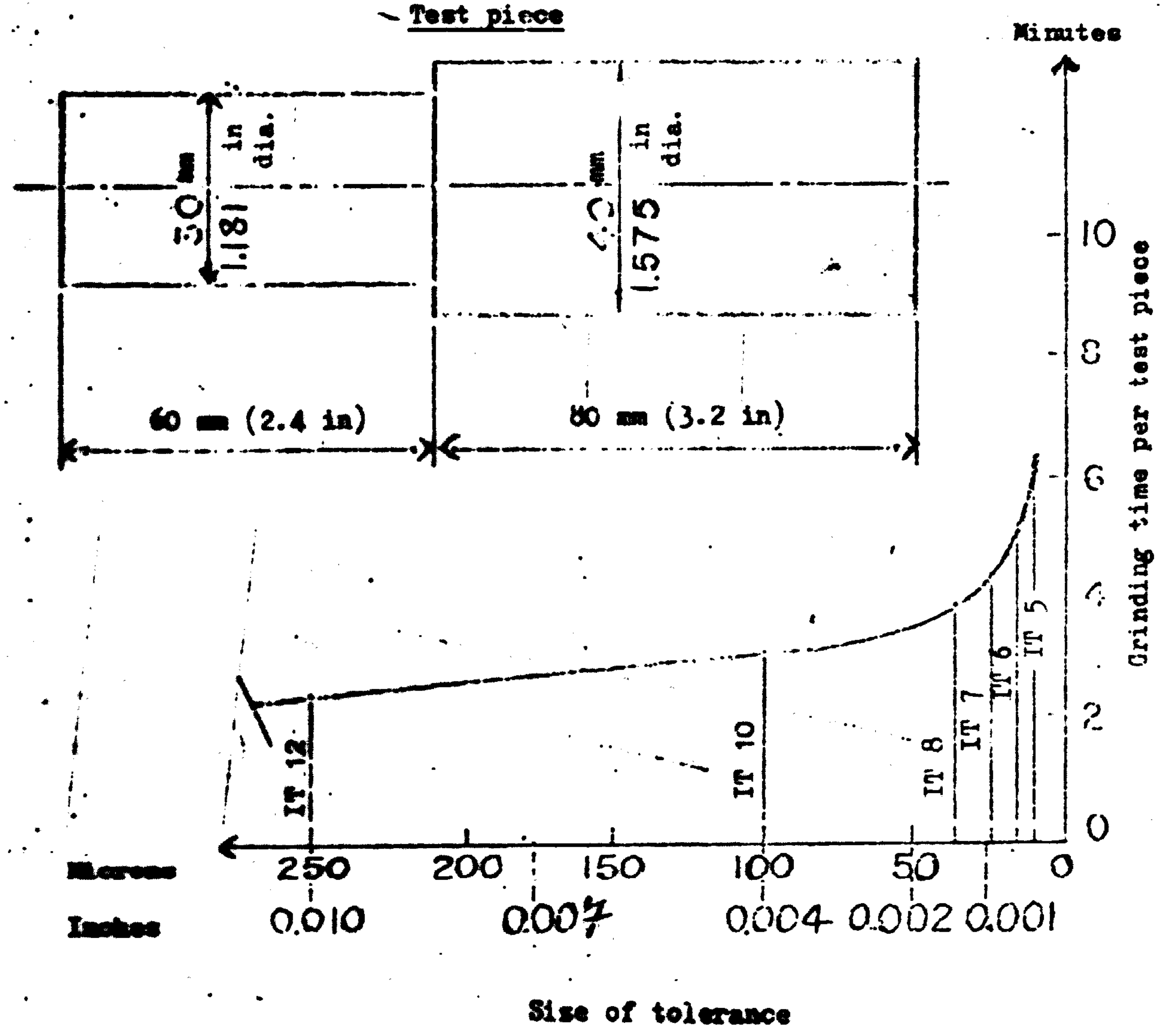


Figure 16 shows similar information, but expressed in terms of relative cost instead of time, for machining, shearing and stamping to various tolerances. As regards the machining range, it refers to average size workpieces. With a modern squaring shear and accessories, even large sheets can be sheared to size within plus or minus 0.005 in with little increase in cost. Carbide dies and presses in good condition will produce stampings with tolerances of plus or minus 0.001 in.

These are matters with which factories in the developing countries should concern themselves sooner rather than later. If they want to become a part of the industrial world, their factory and national standards should be compatible in their main features with the ISO recommendations, whose value is freely recognized by the industrialized nations.

There is a general tendency towards adopting the metric system in the UK and United States, despite the host of difficult issues raised by a changeover. The UK has already taken the decision in principle to "go metric". The United States Congress passed legislation setting up a study group to

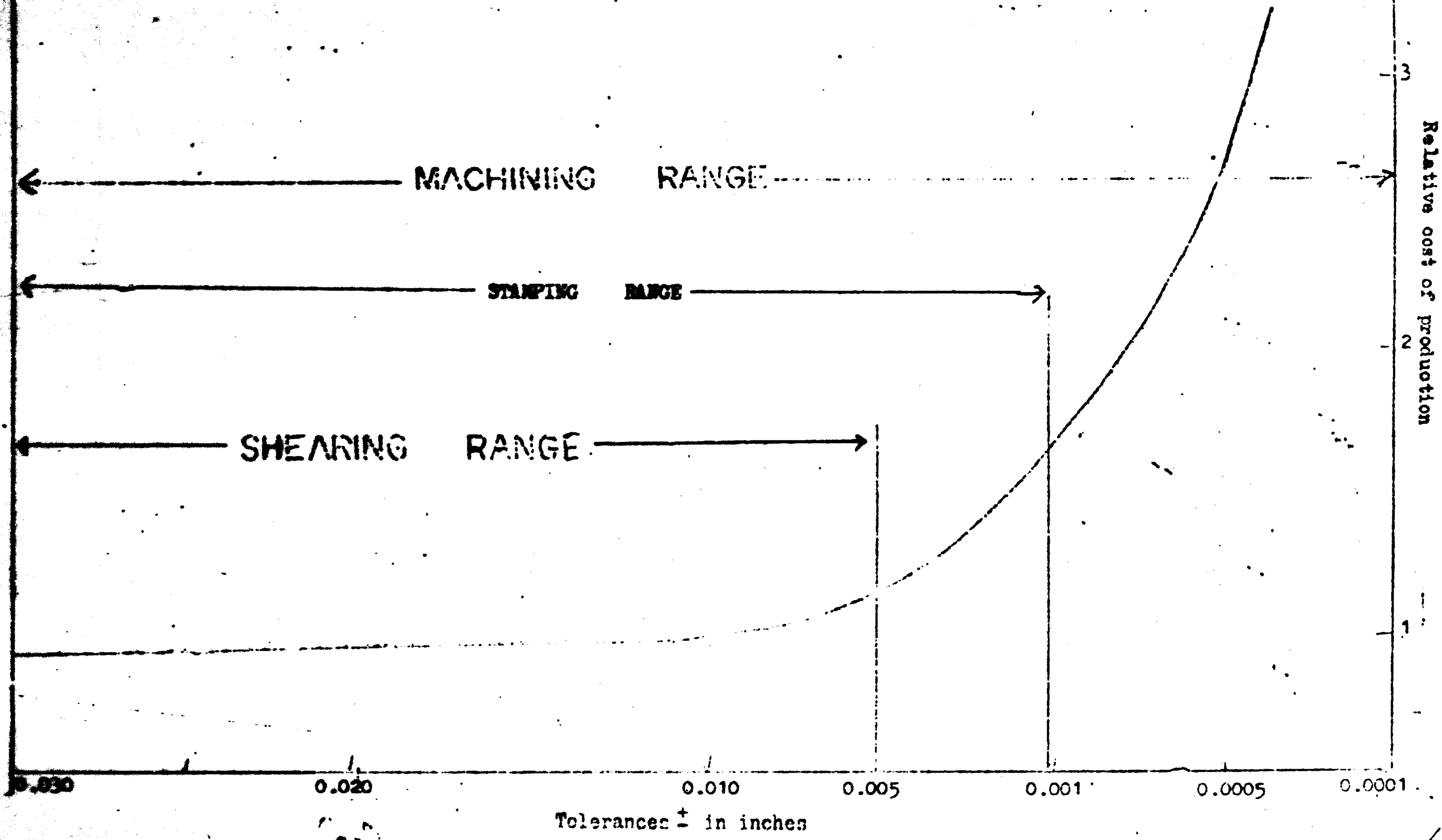
> "... investigate and appraise the advantages and disadvantages to the United States in international trade and commerce... of an internationally standardized system of weights and measures"

and received a detailed report in August 1971 which is under consideration.

There are a number of products defined in the inch system that have found wide acceptance in countries with metric measurements. →

Figure 16

Relationship of cost to accuracy in machining, shearing and stamping



The most important example is the Unified System for screw threads. The ABC meetings to which reference has been made led in 1948 to a Declaration of Accord in setting up this system, which is the most sophisticated and completely engineered set of screw thread standards ever developed. It has been adopted by the ISO as an alternative to the ISO metric series of threads. There is extensive production of screws to these inch standards, not only in the ABC countries but throughout the world. Their use predominates in one very popular foreign car imported into the USA from a country using the metric system. Unified System fastening devices are used in the Concorde, the Anglo-French supersonic air transport, because of their engineering superiority. This could well be another instance where inch-based sizes will continue to be used in the United States even if that country increasingly adopts the metric system.

There are many other standards in the machine tool field, with metric or inch dimensions, that are long-established and have found international acceptance, for example, standards relating to spindle noses and taper shanks. To disregard these and use an original but different design is a sure and expensive way to limit the market acceptance of one's product. It should be pointed out that the adoption of larger tolerances than the international practice may well result in a great deal of selective assembly and fitting work, adding significantly to production costs; moreover parts with larger tolerances may have a shorter service life.

Enough has been said to illustrate the complexity of the problems that have to be solved in implementing the universal adoption of an internationally recommended standard, in cases where several standards have been widely used in the past.

Selected Bibliography

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (1967) *American Standard Preferred Limits and Fits for Cylindrical Parts*, USA Standard No.B4.1, New York.

AMERICAN SOCIETY OF TOOL AND MANUFACTURING ENGINEERS (ASTME) (1968) *Cutting Machining Processes*, *Manufacturing Data Series*, Dearborn, Michigan.

AMERICAN SOCIETY OF TOOL AND MANUFACTURING ENGINEERS (ASTME) (1967) *Non-traditional Machining Processes*, *Manufacturing Data Series*, Dearborn, Michigan.

BACON, FRANK R., Jr. (1963) *Growth through New Product Development*, The University of Michigan, Industrial Development Research Program, Ann Arbor, Michigan.

BACON, FRANK R., Jr. and REMPP, KATHERINE A. (1967) *Electronics in Michigan*, The University of Michigan, Institute of Science and Technology, Ann Arbor, Michigan.

BACON, FRANK R., Jr. and SPARROW, FREDERICK T. (1962) *Research on Product Development Capabilities of Michigan Firms*, The University of Michigan, Industrial Development Research Program, Ann Arbor, Michigan.

BHATTACHARYYA, AMITABHA and HAM, INYONG (1969) *Design of Cutting Tools*, *Manufacturing Data Series*, American Society of Tool and Manufacturing Engineers (ASTME), Dearborn, Michigan.

FULLERTON, BAXTER T. (1961) "Machine replacement for the shop manager", *Tooling and Production*, March issue, pp.49-54.

GOSLIN, LEWIS N. (1967) *The Product Planning System*, Richard D. Irwin, Inc., Homewood, Ill.

GREVE, JOHN W. (Ed.) (1967) *Handbook of Industrial Metrology*, *ASTME [American Society of Tool and Manufacturing Engineers] Manufacturing Engineering Series*, Prentice-Hall, New York.

KHOL, RONALD (1970) "Chemical fabrication processes", *Machine Design*, 12 February issue.

MITROFANOW, S. P. (1960) *Wissenschaftliche Grundlagen der Gruppentechnologie*, VEB Verlag Technik, Berlin, German Democratic Republic.

NEWBROUGH, E. TRUETT (1967) *Effective Maintenance Management*, McGraw-Hill, New York.

NIEBEL, BENJAMIN W. (1967) *Motion and Time Study*, Richard D. Irwin, Inc., Homewood, Ill.

NISSLEY, HAROLD R. (1949) "The importance of learning curves in setting job shop standards", *Mill and Factory*, May issue, pp.119-122.

ODOM, J. V. (1969) "Problems of metric conversion", *ASTME [American Society of Tool and Manufacturing Engineers] Vectors*, No. 4, Dearborn, Michigan, pp.17-19.

PENTLAND, WILLIAM (1968) "Economic machining optimizes profit", *The Tool and Manufacturing Engineer*, Vol.61, No.4 (October issue), pp.36-40.

TARASOV, LEO (1969) "Role of wheel speed in grinding operations", *Machinery* (New York), May issue, pp.153-155.

UNITED NATIONS, CENTRE FOR INDUSTRIAL DEVELOPMENT (1967) *Report of the Group of Experts on Maintenance and Repair of Industrial Equipment in Developing Countries*, New York, December 1966, United Nations Industrial Development Organization, Vienna (UNIDO Doc. No.ID/1) (mimeo.).

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION (1971) Selection and Acceptance Testing of Metal-Cutting Machine Tools: A Practical Guide for Developing Countries (Sales No.: E.71.II.B.3).

VOGEL, TOM H. (1950) "Accuracy in machining - its standardization and cost", The Tool Engineer, November and December issues.

Appendix I

A RATIONAL METHOD OF SELECTION AMONG VARIOUS TYPES OF MATERIALS HANDLING EQUIPMENT

Materials handling equipment includes many dissimilar products that function differently yet perform essentially the same task. The following method may be used to make a rational choice among the available products.

Make a tabulation containing two columns for each piece of equipment to be compared, preceded by two columns in which must be entered:

1) All the attributes (performance, safety, first cost etc.) to be considered in selecting the piece of equipment; and
2) The weights, ranging from 1 to 10, which you assign to each attribute to indicate its importance; performance, reliability, safety and first cost are usually the most heavily weighted attributes.

In the first column for each piece of equipment is indicated its ranking with regard to a particular attribute. Rank 1 applies to the least suitable piece for that attribute, rank 2 to the second least suitable, and so on.

The second column for each piece of equipment is completed by multiplying the rank shown in the first column by the weight assigned, then summing these products.

The piece of equipment which shows the highest second-column total is the rational choice for the application.

An example may help to illustrate the procedure.

A new pump factory is erected. The building is of light steel with columns at a 40-ft. spacing, truss spacing at 20 ft., and panel points carrying 1500 lb each. Soil conditions are poor, the floor slab has a capacity of 500 lb per square foot. The process is essentially metal working in batches of various size and maximum flexibility is required. The loads range in size up to 600 lb. The incidence of loads is approximately 30 per hour. No expansion is planned for a number of years, but if expansion comes it will be orderly and the building will be lengthened by erecting additional bays. The manpower in the area is mostly unskilled, maintenance skills are rare, and spare parts are not locally available for machinery and similar equipment. The product line might conceivably be changed in the course of years. Equipment should be adaptable in handling machined parts. There are good aisles in the building, wide and straight, and area generally is not crowded.

A rational choice is desired among the following possibilities: bridge crane, hand-pushed overhead conveyor, forklift truck or floor mounted transfer machinery. Table A-1 shows the calculations, from which it appears that the conveyor is the most suitable installation in this instance, followed by the crane.

Table A-1

Calculations for choice of equipment

Attribute	Weight	Crane		Forklift		Conveyor		Transfer Machinery	
		Rank	Product	Rank	Product	Rank	Product	Rank	Product
Performance	10	4	40	3	30	2	20	1	10
Flexibility	7	4	28	3	21	2	14	1	7
[illegible]ptability	3	2	6	1	3	4	12	3	9
[illegible]ansion of operations	5	3	15	4	20	2	10	1	5
Effect on structure	5	3	15	1	5	2	10	4	20
Effect on building	7	2	14	1	7	3	21	4	28
Effect on site area	3	4	12	2	6	3	9	1	3
Reliability	10	3	30	2	20	4	40	1	10
Ease of maintenance	9	3	27	2	18	4	36	1	9
Spare parts availability	8	2	16	3	27	4	32	1	8
First cost	10	4	40	2	20	3	30	1	10
Useful life	5	3	15	2	10	4	20	1	5
Salvage value	3	4	12	3	9	2	6	1	3
Savings obtainable	9	2	18	1	9	4	32	3	27
Operating costs	3	2	6	1	3	4	12	3	9
Maintenance costs	2	3	6	2	4	4	8	1	2
Manpower required	10	2	20	3	30	4	40	1	10
Skills required	8	2	16	3	24	4	32	1	8
Safety	10	1	10	3	30	4	40	2	20
Po[illegible]ution	8	4	32	1	8	2	16	3	24
[illegible]l	..	..	378	..	304	..	440	..	227

Appendix 2

NOTE ON THE COMPUTATION OF LEARNING CURVES

Let $t(n)$ be the average man-hours per unit when n units are produced. Let L be the learning curve.

If we assume $t(n) = kn^d$, where k and d are constants for any given operation of production or assembly, we find that:

$$L = \frac{t(2N)}{t(N)} = 2^d \qquad (1)$$

$$t(1) = k \qquad (2)$$

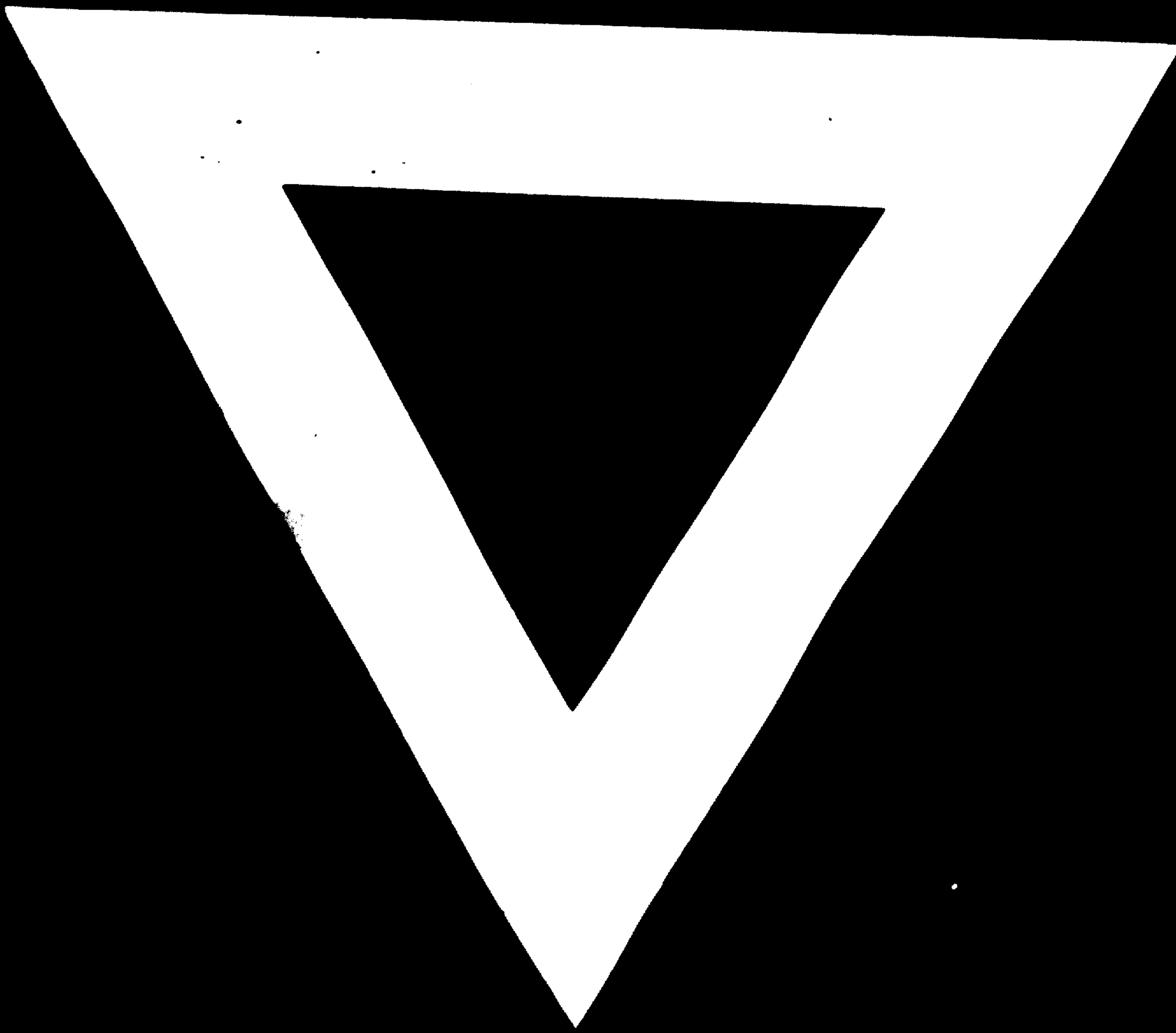
When the learning curve is presented on double logarithmic graph paper, the equation is

$$\begin{aligned} \log t(n) &= \log k + d \log n \\ &= \log t(1) + d \log n \qquad (3) \end{aligned}$$

Equation (3) is a straight line; if $\log n$ is plotted along the horizontal axis, its slope is $-d$ and the intercept on the vertical axis is $\log t(1)$.

If the average man-hours per unit are established for two (or preferably more) values of n, a straight line may be drawn and the value of d calculated from it. Since $d \log 2 = \log L$ from equation (1), it is a simple matter to arrive at the learning curve.

Alternatively, if the learning curve L and the man-hours required to produce the first unit $t(1)$ are known, we calculate $d = \log L/\log 2$ and draw the straight line of equation (3), from which we can read off the average man-hours per unit for any production quantity.



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