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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

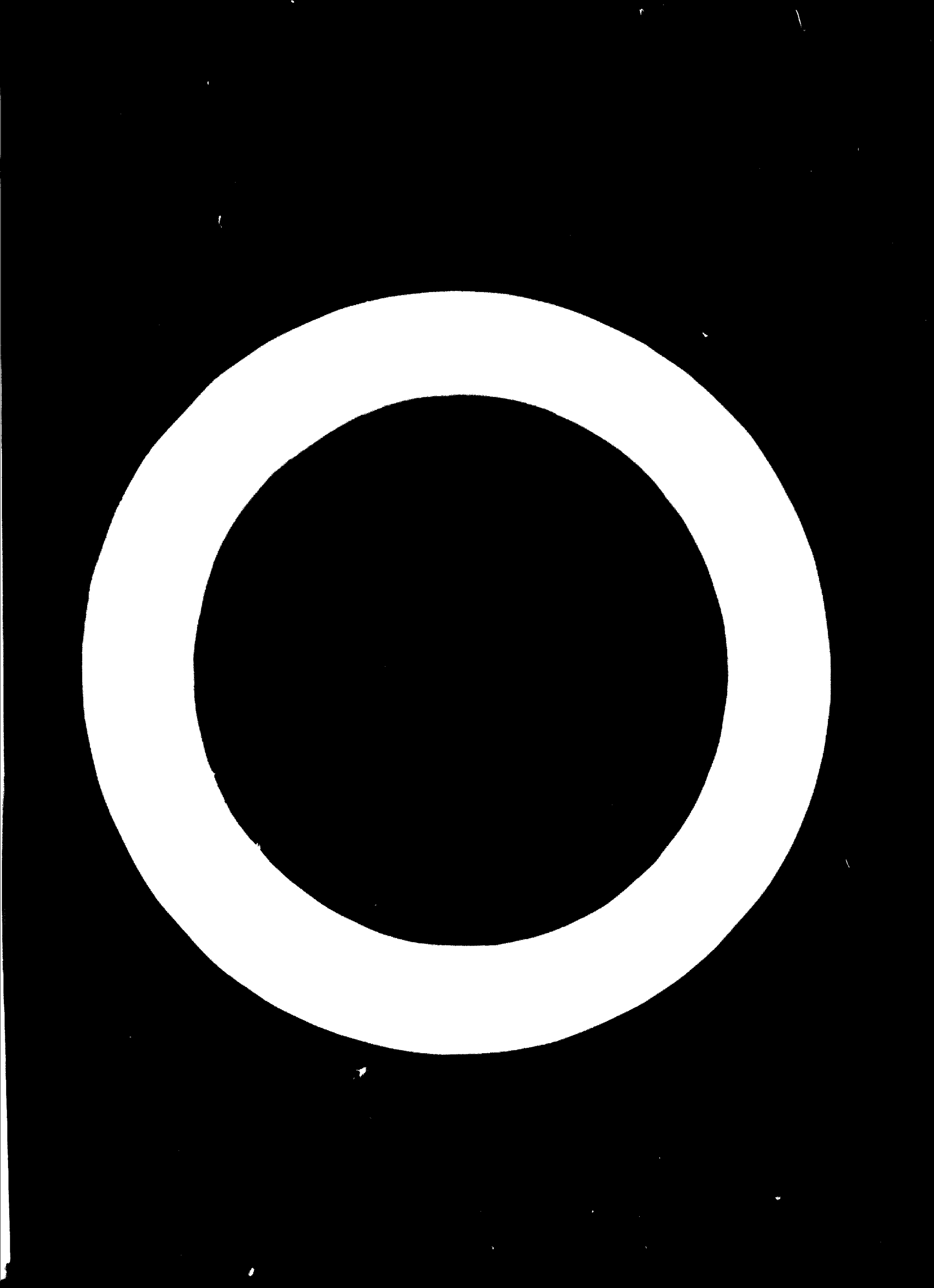
01401

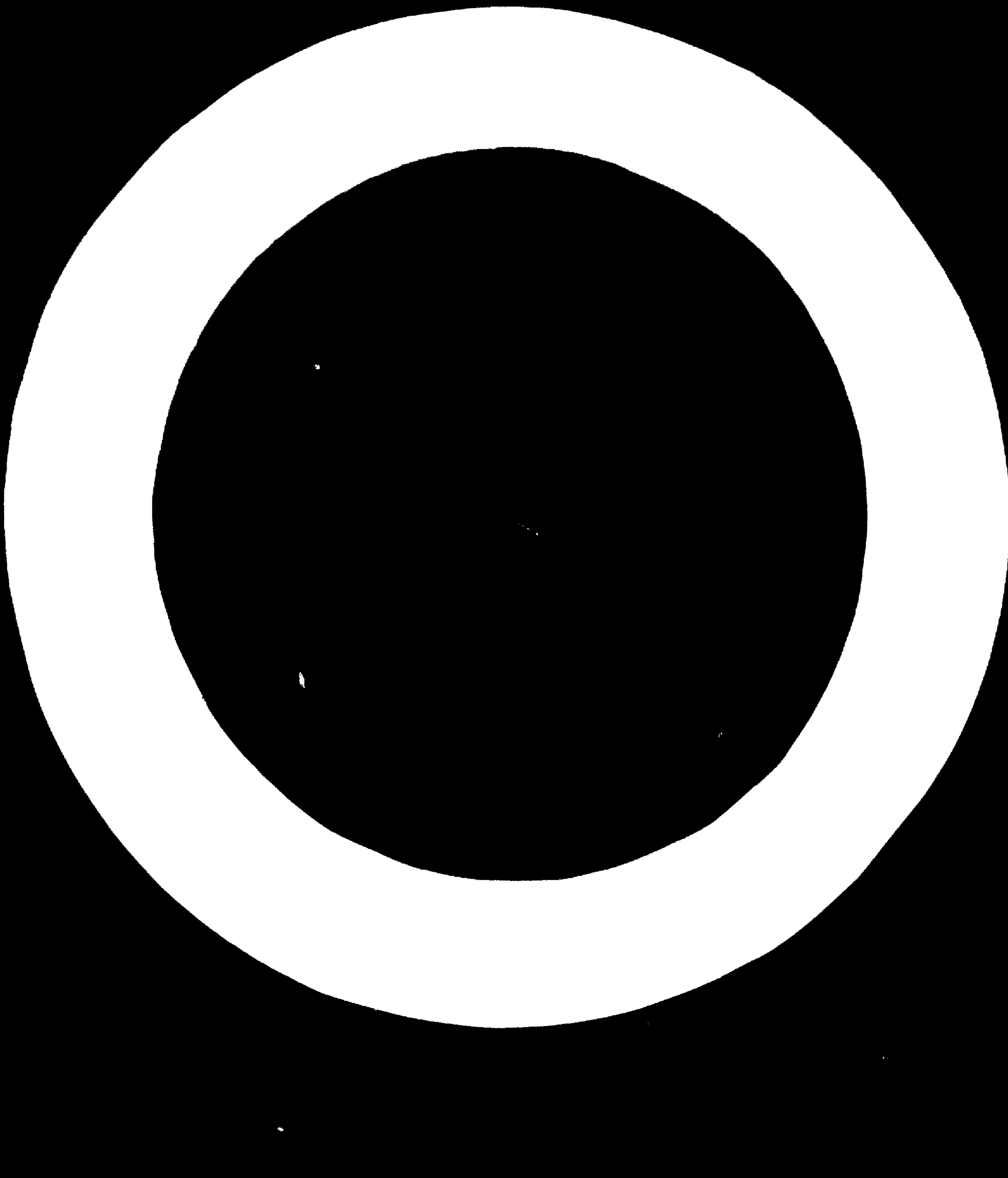
Development of Metalworking Industries in Developing Countries

Reports presented at the United Nations Interregional Symposium, Moscow
7 September—6 October 1966

Sales No.: E.69.II.B.2
ID/6

UNITED NATIONS
New York, 1969





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PRODUCTION MANAGEMENT FOR DEVELOPING COUNTRIES

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INTRODUCTION

"The highest efficiency in production is obtained by manufacturing the required quantity of product, of the required quality, at the required time, by the best and cheapest method." This is the way L. P. Alford and J. R. Bangs defined efficiency in production systems in their *Production Handbook*,[1] and this definition was subsequently adopted in later editions. It summarizes in a sentence the major problems that production managers have had to contend with during the past century, and it defines the prevalent parameters that a control mechanism in a production system must incorporate. And in spite of the vast development in production and control techniques in the past two decades, the formulation of the new analytical tools which managers have now at their disposal, the advent of computers and the sophisticated data-processing systems and the penetration of automation to the shop floor, the basic objectives of a production system remain unchanged. In fact, it can be argued that all these developments have come about in order to provide better means of achieving the objectives which are defined in terms of quantity, quality, time and cost.

It is interesting to note that the first three factors are defined as constraints, not as objective functions which one wishes to optimize. There is no advantage in producing more than is required (in fact, it can cause an embarrassment if it leads to excessive carrying costs or too severe a reduction in price); there is no virtue in producing too high a quality if such a high standard is not required (this will merely increase production costs); there is no need to complete the task too early in time (as this will just lead to unnecessary storage costs before the good are due for delivery). On the other hand, the constraints do set a "minimum" standard of performance, which it would not be in the interest of the firm to violate, as the penalties involved could be quite severe and could obviously lead to loss of future business. Certain margins of safety can, therefore, be built into the production framework—margins that will safeguard with a reasonable probability level the attainment of given specifications for quantity, quality and time.

Within these constraints, efficiency in production is achieved by using "the best and cheapest method". What does this phrase mean? It implies that, in many cases, several alternative methods can be designed to attain an objective and that these alternatives have to be evaluated before a final choice is made. The statement also seems to imply that there is a "best" method of performing a task, and this implication was generally accepted during the earlier days of industrial engineering, particularly by work study practitioners.

Curiously enough, this search for the "one best way" (as coined by F. B. Gilbreth, the pioneer of work study over forty years ago) was again revived after the Second World War, when operational-research techniques began to develop and when mathematical models were devised with the view of optimizing some objective function, whether it be the minimization of costs, the maximization of profit or any other predetermined objective. There is a difference, however, between the two movements. In the first, the selection of "the best method" was based on comparing a limited number of alternatives, and although one could state with some conviction that the selected method was better than some others, one could not assert that all the possible alternatives were really exhausted in this way. Some operational-research models, however, do exhaust all the alternatives, so that for any given model and a given set of data it is possible to state that a certain solution is truly the best.

There are many models, however, in which an exhaustive search is either too lengthy or too expensive, or sometimes just impossible, by the very nature of the problem or the limitations of the model. An obsession with optimization under these circumstances is clearly a waste of time, and a conscious effort must be made to relate the cost of finding a solution to a given problem to the expected benefit to be derived from such a solution. It is essential to bear this point in mind in applying modern management techniques to the control of production operations.

Production consists of a sequence of operations designed to transform materials from a given to a desired form. The transformation may be accomplished in one, or in a combination, of the following ways:

(*a*) Transformation by distintegration, i.e., by having essentially one ingredient as input and producing several outputs. This type of transformation is almost invariably accompanied by changes in the physical shape of the input, such as changes in the physical state or in the geometrical form. Examples: producing lumber in a sawmill; rolling steel bars from cast ingots; making components from standardized materials on machine tools; oil-cracking which yields several products; etc.;

(*b*) Transformation by integration or assembly, using several components as inputs and obtaining essentially

[1] L. P. Alford and J. R. Bangs, *Production Handbook* (New York, Ronald Press, 1952).

one product as output. Examples: producing machines, furniture, household appliances, motor-cars, radio and television receivers, alloys, sulphuric acid, concrete etc.;

(*c*) Transformation by service, where virtually no change in the object under consideration is perceptible, but where certain operations are performed to change one of the parameters which define the object. This may include: operations for improving the tensile strength, density, crystallographic structure, wear or other mechanical properties of the object; operations that change its locality or state by transportation or handling means; maintenance operations. Examples: sizing and coining in presswork; servicing and light repairs of motor-cars; loading and unloading of lorries; etc. Many purely service operations are not considered to be part of industry, but the planning and control of such operations is basically similar to those of industrial operations. By analogy, one could say that "the highest efficiency in servicing is obtained by processing through the service station the required volume, offering the required quality, at the required time, by the best and cheapest method".

The analogy between the third category and the first two emphasizes the fact that management methods are equally applicable to manufacturing and non-manufacturing operations. Thus, the techniques used in work study or in studies of plant layout or materials handling have had a wide appeal and have been applied to the study of warehouses, transportation systems, office blocks, ports or even farms. Operational-research techniques are widely based also, with no specific industry or manufacturing activity in mind. This means that methods and concepts of production control can be usefully applied to situations where no "production", in the conventional sense, takes place; and, similarly, that one can learn from experience in areas other than one's own in designing better control methods for "production" systems.

I. Utilization of Resources

The purpose of production management, therefore, is to make effective use of the resources available to the enterprise. These resources may be classified under five categories (*a*) manpower; (*b*) materials; (*c*) machines; (*d*) money; and (*e*) methods. These categories generally relate to the way in which the production costs can be accounted for: first, labour costs, direct and indirect, including, of course, any allocation of overheads; secondly, the cost of materials from which the product is made; thirdly, the cost of using machines and processes; and so on.

The effective utilization of manpower is an obviously desirable objective. With the increase in standards of living in industrialized countries and the inevitable resulting increase in labour costs, more and more attention must be paid to increasing the level of productivity, that is, the amount of ouput per man than can be obtained. This has been the greatest impetus to the development of work study techniques in the United States of America, under the name "time and motion study", and this title well signifies the detail in which particularly manual tasks have been studied, down to the recording and investigation of every element of motion of the operator's hands, with a particular emphasis on the time element. The more one can reduce the labour content of any given task, the more there is a chance of keeping prices down when labour wages increase, and this has been the central theme in most productivity drives in many European countries in recent years.

Raw materials constitute a tangible part of the cost of the product, and any effort to reduce this cost will evidently make the product more competitive. Studies on the use of raw materials can take several forms, such as investigations of causes for waste and scrap or assessing the possible use of alternative materials in the production process.

Similarly, the effectiveness of machines is often a central point in a productivity study, involving such typical problems as:

(*a*) Is the machine suitable for the job in question? What are the alternatives?

(*b*) Is the machine working at its optimum running conditions?

(*c*) What is the utilization (in percentage of the total machine time available) of the equipment and how can it be improved?

(*d*) Is it better to have special-purpose machines or general-purpose ones (the latter having more flexibility in being adaptable to a wider variety of jobs, but generally operating at a lower performance level than a special-purpose machine)?

(*e*) Should machines and mechanical devices take over manual tasks? The problem of mechanization and automation presents important economic and organizational considerations for the firm, in relation to both the type of tasks that should or could be mechanized and the capital outlay involved in the installation of such devices.

The cost of using financial resources is generally regarded as being outside the responsibility of production management, particularly when it comes to considering the allocation of these resources, the evaluation of alternative investment schemes or the method of raising money. But there are many decisions which affect the use of financial resources and in which production management is closely involved: the selection of processes; replacement and installation of plant and equipment; holding of stocks of raw materials or semi perishable goods; or decisions about "what to make and what to buy".

The fifth resource mentioned above is "methods", and although it is not a resource in the conventional sense of the word, it does represent the body of knowledge, the "know-how" (both technical and administrative) that the firm can employ in order to make good use of the other resources and, like the others, it costs money to acquire and develop.

An historical review of the industrial development in technological innovation and design the effective utilization of resources has played a prominent role in accelerating the rate of industrial progress. Every phase of this development obviously had its own problems and attention was focused on specific techniques to solve these problems. But they all had this in common—that resources which were costly or in rare supply should not be wasted. This history and past experience of highly industrialized countries can be a salutary lesson for developing countries, not with the view of blindly copying all the techniques and methods that have emerged over the years, but with the intention of trying to relate these techniques to the problems they are designed to solve and of determining their relevance to the problems which those countries have to face. There is little point in imitating a particular procedure or recipe, irrespective of how elegant or fashionable it happens to be, if its application will make only a marginal contribution, when there are perhaps more effective methods that can be employed. And one must also remember that, to a certain extent, manufacturing and control techniques must be a function of the social environment in which they have to operate.

II. The facets of production management

The next items to be considered are the planning and control of production operations. In discussing planning activities, one must first distinguish between short-term and long-term planning. The first relates to a framework of resources which are already defined, the planning function is then confined to designing and evaluating alternative schemes for achieving the production goals set by top management. Long-term planning, however, is concerned with the resources not as they are but as they should be, that is, with the acquisition of resources to fit future goals of the enterprise. Although production management is mainly associated with the first, there are many problems in long-term planning in which it must be involved, such as the replacement of machines and equipment due to wear and high maintenance costs or due to the technical innovaton incorporated in new designs, the rate at which the production activities should be mechanized or the kind of skills which will be required of operators in the future.

The main activities and methods of production management, particularly in relation to short-term planning and control, can be conveniently grouped under two categories, the first called "production planning and control", the second, "method engineering". These categories are briefly summarized in table 1.

A. *The production-consumption cycle*

The way in which all these activities are interrelated becomes clear when one considers the production procedure described in figure 1, where the main flow-channels of instructions, information and materials are shown. The production-consumption cycle begins and ends with the customer, as may be seen from the following sequence of operations:

(*a*) The sales department studies the reception of products in the market and consumer reactions to new modifications and designs. Market research is also carried out regarding proposed new products;

(*b*) The collected data are analysed by the sales department, which prepares a sales forecast with a breakdown of products and models as a function of time periods. The detailed forecast is submitted to management;

(*c*) A production budget is prepared by the financial department, in consultation with the manufacturing

Table 1

INDUSTRIAL ENGINEERING FUNCTIONS IN AN INDUSTRIAL ENTERPRISE

Production planning and control	*Methods engineering*
Materials: records, availability, procurement, storage, issue, control	Work study: method study (including workplace layout), work measurement
Methods: choice from available facilities for manufacture; tool and jig design	Process evaluation: comparison of processes, new processes
Machines: specifications, availability, loading	Machines: equipment policy, maintenance, renewal
Routing: sequence of operations, work flow, machine assignment	Layout: flow of work, location of machines and departments, material-handling systems, effect of expansion plans
Estimating: operation times	Quality control: inspection procedures, testing laboratories, cost of quality
Scheduling: time-table of production activities	Standardization and simplification of products, methods, auxiliary equipment, recording systems, procedures
Dispatching: releasing of production orders	Safety: instructions for handling materials and machines
Expediting: recording of progress, corrective action	Incentive schemes: wage and other incentives
Inspection: concerned with inspection results and their effect on the schedules	Suggestion schemes: feedback and new ideas from operators
Evaluation: effective even on a short-term basis, particularly for future routing, scheduling and stock control	

Source: Adapted from Samuel Eilon, *Elements of Production Planning and Control* (New York, Macmillan, 1962), chapter 4.

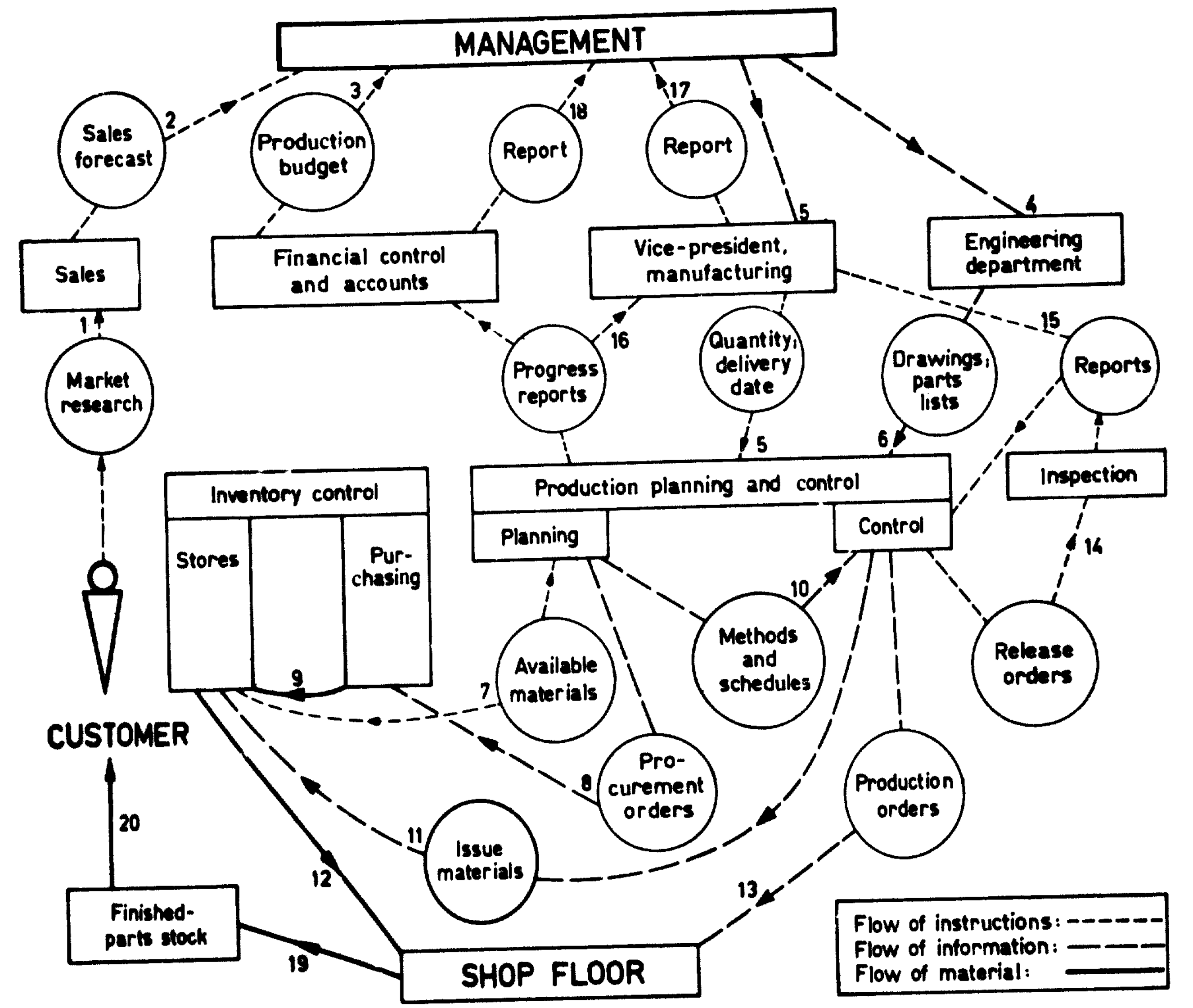

Figure 1

THE PRODUCTION-CONSUMPTION CYCLE

department. The proposed budget and the sales forecasts are closely scrutinized by management, and a decision is taken regarding the annual or semi-annual quantity to be produced;

(*d*) The engineering department is instructed to prepare drawings, parts lists and specifications, or to check and modify existing ones. The manufacturing budget is then adjusted accordingly;

(*e*) The vice-president or the head of the department responsible for manufacturing is authorized to begin production, and instructions are issued to the production planning and control department, specifying quantities, delivery schedules etc.;

(*f*) The technical information is obtained from the engineering department (including drawings, parts lists, specifications, standards etc.) and is passed on to the planning section;

(*g*) One of the first functions of the production planning and control department is to be well-informed about the availability of materials and expected delivery dates of materials already ordered. Production planning is carried out and detailed schedules are prepared;

(*h*) The inventory levels are checked to determine the orders for procurement of materials and standard parts that have to be issued. Parts and assemblies that are subcontracted are also ordered by the purchasing department;

(*i*) The purchased materials and parts are inspected prior to acceptance and are stored until instructions are obtained to release them to the shops;

(*j*) The production planning section supplies complete data on methods, machine loading and utilization, as well as on production schedules, to the control section for dispatching;

(*k*) The control section releases orders for materials, tools, fixtures etc;

(*l*) Orders are issued to the shop;

(*m*) Detailed production orders are dispatched to the shop by the production control section, specifying what, how, when and where operations should be performed. The control functions are carried out throughout the manufacturing period, and progress is constantly compared with the planned schedules so that suitable modifications may be considered and incorporated when required. This necessitates a close and permanent contact between the control section and manufacturing departments, to facilitate a constant flow of information and instructions;

(*n*) Inspection orders are released. The purpose of quality control during the production processes is to ensure that the specifications as laid down are conformed with. Final inspection of the parts is carried out before the product leaves the shop and moves to the finished-parts or products store;

(*o*) Evaluation of the prodution operations is the main pillar of the control function and has to be carried out both during and after these operations. Inspection reports are one facet of evaluation, and they form the basis for corrective actions in the processes or methods, and sometimes even for modifications in the specifications of raw materials;

(*p*) The production planning and control department reports on the progress of the work to the vice-president responsible for manufacturing. These reports are also studied by the financial control department. The control section also evaluates data obtained from the shops about operation times, idle time of men and machines, causes and effects of breakdowns, trends in the fluctuations of output etc. Action initiated by the control section as a result of such reports has to be followed up, and its evaluation should also be reported to the vice-president;

(*q*) Management receives interim and final reports from the vice-president of manufacturing;

(*r*) Management also receives a report from the financial department, after which a final evaluation can be made;

(*s*) The finished product is transferred (after inspection) to stock;

(*t*) Finally, the product is sold to the customer, who, after comparing the product characteristics with those of its competitors and with his expectations, is ready to contribute his views and reactions to market researchers.

It is evident from this outline that the production procedure involves the co-operative and co-ordinated effort of all the departments of the enterprise. Even when the functions of each department are clearly specified and well understood, the departments cannot operate independently. They have to perform as parts of an integrated body, and the purpose of the procedure described above is to specify where and in what form their efforts are required, and what kind of flow information should be constantly maintained.

B. *The control function*

After the potential capabilities of resources have been critically evaluated, a programme can be set up to include production target and the way in which the organization will utilize its resources to attain these targets. This is, in fact, what the planning function is supposed to do.

The control activity begins as soon as the proonducti operations begin. Control has two main functions: the first is to ensure that operations are performed to plan, by taking corrective action, by adjusting the plan and by "chasing" tools or materials (this is why the name "progress chasers" is often given to production controllers on the shop floor); the second is to evaluate the production plan and to determine if a better one could not be devised in the light of the experience gained (this exercise is particularly valuable as feedback to future planning activities).

Thus, control consists of four stages:

(*a*) Observation and recording of progress;

(*b*) Analysis of data and comparison with plans and objectives;

(*c*) Immediate corrective action to modify plans and redirect activities;

(*d*) Evaluation of the planning function and the effectiveness of the control procedures for future reference.

These states apply equally to the control of processes, to the control of inventory, to inspection and to cost control, as summarized in table 2.

Table 2

CONTROL OF PROCESSES, INVENTORY, INSPECTION AND COST

	Processes	*Inventory*	*Inspection*	*Cost*
Observation	Active processes: output *versus* time Idle processes: machine idle time; breakdowns	Records of stock level	Process control Control charts	Collect cost data
Analysis	Compare progress with plan	Distribution of demand Trends Seasonal fluctuations	Process capabilities Trends	Compute costs and compare with estimates
Immediate action	Expedite	Issue production and procurement orders	Initiate 100-per cent inspection Adjust processes	Adjust sales price (if possible)
Evaluation	Process capacity: maintenance schedules	Replenishment policies Inventory systems	Reassessment of specifications Process improvement Inspection procedures	Economic evaluation of processes Preparing better data for future estimates

Source. Adapted from Samuel Eilon, *Elements of Production Planning and Control* (New York, Macmillan, 1962), chapter 15.

III. The tools of production management

This is not the place to review the various tools of production management in detail. One can postulate in general terms about their potential usefulness for developing countries, but conditions in different countries vary so greatly that it would be foolhardy to suggest universal procedures.

Of the vast spectrum of tools, those which have been selected for discussion in the paper are (A) work study, (B) problems of machine capacity, (C) machine capacity for multiple-product plants, (D) control of product variety and (E) operational research. This is not because the author regards other tools as being unimportant. Production scheduling, design for production, selection of materials, standardization, tooling, selection and evaluation of processes, maintenance of plant, quality control and even packing and dispatching are all important facets of production; and, indeed, one could widen the brief to include problems of organization and industrial relations. But first, all these would be even more difficult to generalize about, and, secondly, to do justice to these issues a book of considerable length would be needed. The topics which have been selected for further discussion here perhaps serve to illustrate most poignantly that what production management is concerned with is the effective use of resources, but it is certainly not the intention to convey the impression that other tools have no contribution to make to this end.

A. *Work study*

Work study has long been recognized as one of the primary tools used by industrial engineers to increase the level of productivity in their plants. As the term implies, the purpose of work study is to investigate the factors that determine the effectiveness of executing tasks and to suggest alternative methods which will improve the performance of the operators and the equipment engaged on the task.

This term, which is widely used in the United Kingdom of Great Britain and Northern Ireland, is probably better than the conventional name "time and motion study", because it does not confine investigations to the study of times or motions associated with the task, but takes a broader view of the problems which are likely to be encountered.

Work study consists of two main areas: method study, which aims at improving the methods used in the operator machine system; and work measurement, which attempts to determine the times tasks take or should take. Although the measurement of time can be helpful in method study in that, in some cases, it provides a yardstick for the effectiveness of certain methods or for assessing the improvement suggested by new methods, there are numerous work study projects which can be carried out successfully without any time measurement, particularly when problems of work flow or the right sequence of operations are involved. The objectives of method study and work measurement are summarized in table 3 at the foot of the page.

The work-measurement area is often associated with rate fixing and wage-incentive schemes, and this is unfortunate. Admittedly, in firms which have piece-rates or other wage incentives which are closely linked with the output of individual operators, rate fixing is inevitable, but it should be realized that this is by no means the only purpose of work measurement. Even in firms which have no wage-incentive schemes, there is sometimes a need to determine the times of operations for planning and scheduling purposes.

How much of all these is relevant to developing countries? Generally, work study (and in particular method study) has a lot to offer, as it reveals the main interactions between such activities as operation, transportation (or handling) and inspection, it identifies delays and determines where they occur, and it highlights breakdowns and traces their causes and effects. In short, it helps to present the domain of the industrial tasks in an orderly and rational fashion, and, as such, it provides valuable information for those who attempt to control these tasks and to ensure that work proceeds along its pre-ordained course.

But this does not mean that all the techniques are equally useful. The very detailed study of work through various means e.g., micromotion analysis, observation of elemental motions through the use of films and operation charts which identify and record the distribution of motions to the two hands or even to various fingers—is justified only when such studies are concerned with highly repetitive tasks involving comparatively short cycle times and when the cost of labour is a significant component

Table 3

Objectives of method study and work measurement

Method study	*Work measurement*
Define the operations and their relationships	Provide information for method study
Determine whether operations can be eliminated or modified	Provide data for scheduling
Explore alternative processing methods	Assist production control in checking to determine if activities run according to plan
Eliminate or minimize delays	Provide a basis for wage-incentive schemes
Improve work-place and plant layout to simplify handling	
Allocate jobs to men with appropriate levels of skill	
Provide information useful for product design	

in the total cost structure. Under such conditions, even a marginal decrease in the cycle time can have a noticeable effect on the rate of output and on costs. Indeed, it is for this reason that micromotion has been used in numerous mass production or large-batch production lines in highly industrialized countries, with tangible contributions to the improvement of productivity. In many developing countries, such conditions are not widely encountered and it is a mistake to allow uncurbed enthusiasm for work study to employ such tools indiscriminately. Not only can these techniques be expensive and time-consuming, and the potential benefit minute, but the detailed analysis may cloud the issue; it may divert the attention of the investigator from the basic problems which the firm has to face. Management techniques, like the artisan's tools, must be suitable for the job and they must, therefore, be selected with care.

B. *Problems of machine capacity*

Machine output is inversely proportional to the cycle time, that is, the time required to complete a set of activities associated with the manufacture of one unit of product. In order to utilize the machine capacity to the maximum, it is often useful to study in detail some of the components that make up this cycle time.

A typical sequence of activities in a man-machine system employed on repetitive operations may consist of:

Operator	*Machine*
Unloading the machine	Being unloaded
Inspecting the workpiece	Being started
Loading the machine	Performing operations on the workpiece
Starting the machine	Being unloaded
Transporting work to and from the machine	

All these activities may be grouped under two categories:

(*a*) *Concurrent activities*: these are tasks that require the simultaneous "attention" of both operator and machine (such as loading and unloading; let the total length of these tasks per cycle be *a*);

(*b*) *Independent activities*: these are tasks which the operator and the machine can perform independently of each other (the operator: inspecting and handling, totalling *b* per cycle; the machine: running automatically for a time *t* without supervision).

In addition, one may have idle times incurred by both the operator (i_o) and the machine (i_m) during the cycle, so that the cycle time T for the operator is

$$T = a + b + i_o$$

and for the machine

$$T = a + t + i_m$$

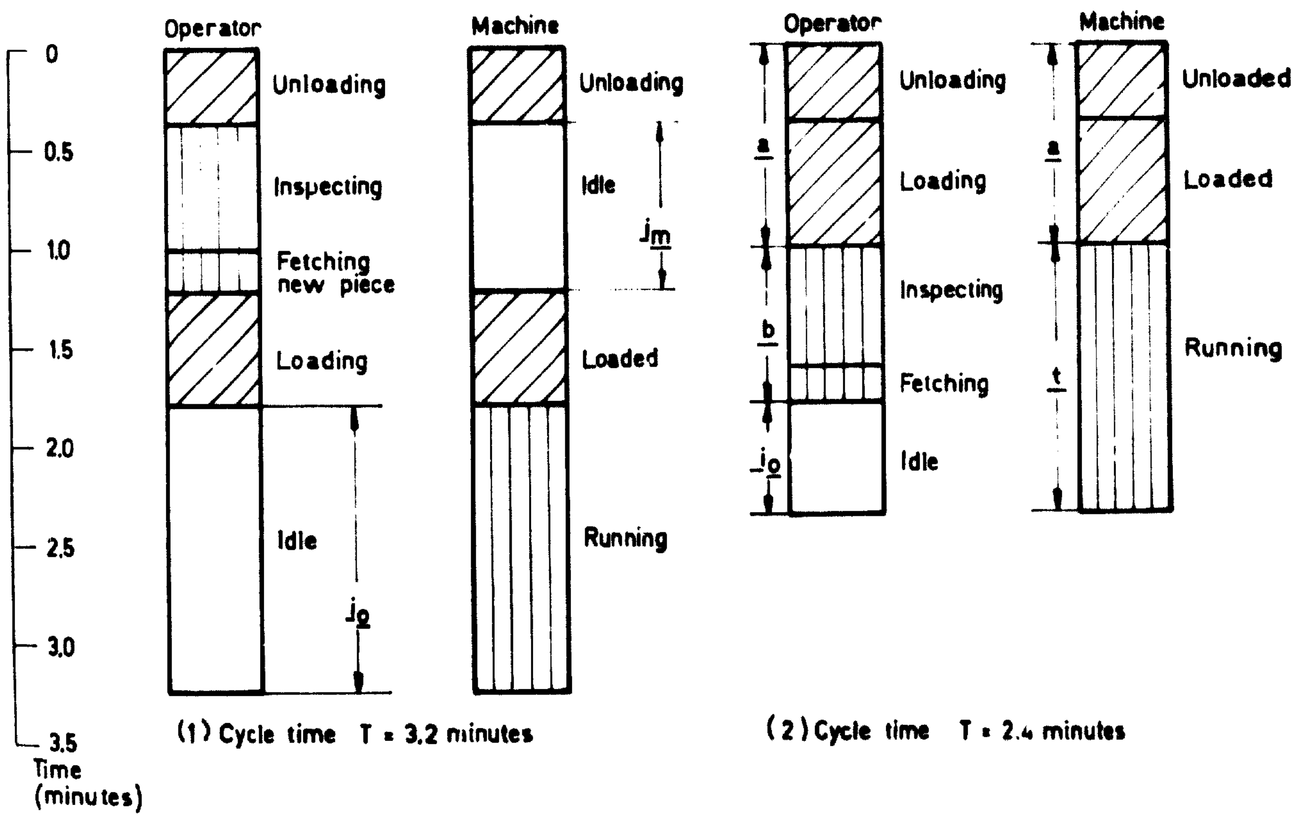

Figure 2

REDUCING THE CYCLE TIME

An example is shown in figure 2, from which it may be seen that:

- a unloading + loading = 1.0 minute;
- b inspecting + fetching = 0.8 minute;
- t machine running unattended = 1.4 minutes;
- i_o operator idle time = 1.4 minutes;
- i_m machine idle time = 0.8 minute.

The sequence of operations as shown in arrangement (1) in figure 2 is 3.2 minutes, but if this sequence is rearranged as in (2), machine idle time is eliminated and the cycle time is reduced to 2.4 minutes, leading, in this case, to an increased output of the machine by one-third. The secret is simply to ensure that idle time is not incurred by both

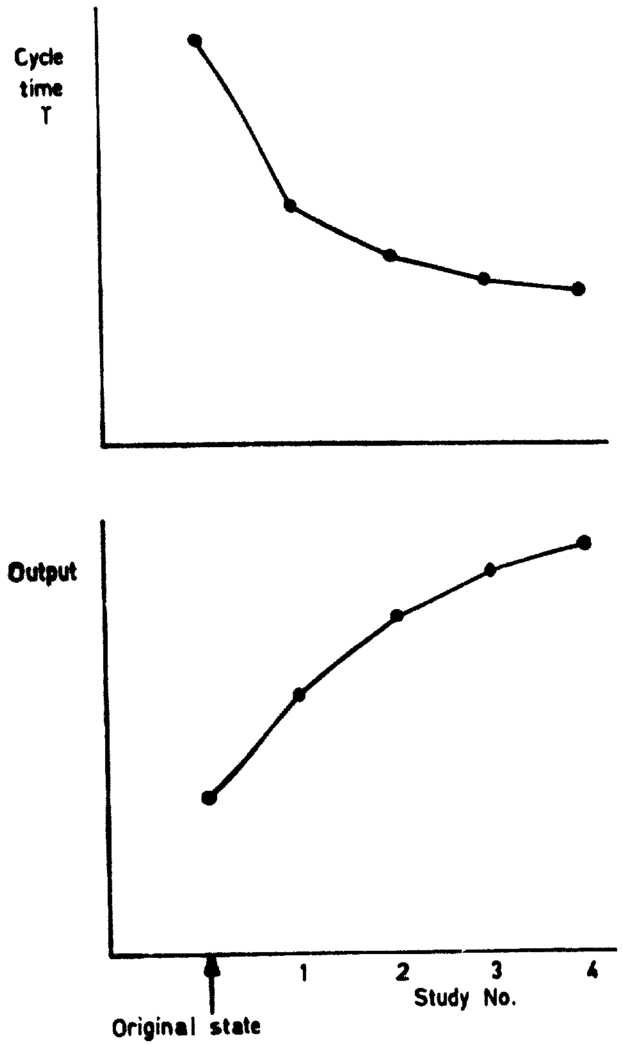

Figure 3

DIMINISHING RETURNS ON SEQUENTIAL STUDIES

man and machine. One may then turn to the constituents of the new cycle and see whether further reductions can be made, mainly through work study methods, and naturally attention will then be focused on the activities of the "busy partner", namely, the one which has no idle time (in case (2) in figure 2 the busy partner is the machine). To summarize, reduction in cycle time may be achieved by

(*a*) Eliminating idle time for one partner in the man-machine system by rearranging the sequence of operations and by avoiding delays at the beginning and at the end of the cycle;

(*b*) Reducing the independent activity time of the "busy partner";

(*c*) Reducing the concurrent activity time by devising more efficient methods for loading and unloading the workpiece.

The effect of such sequential studies often follows the law of diminishing returns, as is shown in figure 3. At first, the improvement is substantial, but as more and more studies are conducted, the level of sophistication and, with it, the cost of the study rise rapidly; and as the work becomes more rationalized, there is less room for manoeuvre and the resultant benefit shrinks further and further. It is, therefore, important not only to know when to begin an investigation into an industrial activity, but also when to stop and divert the investigators and their resources to new problems, or to devise new approaches to the old ones.

C. *Machine capacity for multiple-product plants*

One of the major problems with which production management is constantly faced is whether the manufacturing capacity is adequate and to what extent it is affected by the product-mix in multiple-product schedule. As an illustration of the way in which this problem can be analysed, one may examine the following example: a plant produces two products, A and B, and five machines are involved in the production process. The rates of production are given below:

	Rates of production (units per day)	
	Product A	*Product B*
Machine		
1	300	300
2	400	200
3	150	—
4		350
5	200	300

Thus, machine 1 can produce either 300 units of product A or 300 units of product B, but, of course, it is possible also to produce a mixture of A and B. The various combinations are represented in figure 4 by the line PQ. Point P indicates the production of 300 units of A and none of B, whereas point Q indicates the production of product B only. Any point on the line gives us a possible combination, for example, point R signifies 200 of A and 100 of B, and S stands for 50 of A and 250 of B.

The line PQ therefore represents the full capacity of this machine; any point below the line also signifies a feasible product-mix, although in the region below the line the machine is no longer being utilized to its full capacity. Point T, for example, stands for 150 units of A and 50 of B, but for this level of production of A, one can increase the output of B to 150 units before reaching the full capacity line.

Similarly, any point above the line PQ is not a feasible product-mix, because it requires more capacity than is available. Point U, for example, represents an output of 250 units of A and 150 of B, whereas the full-capacity

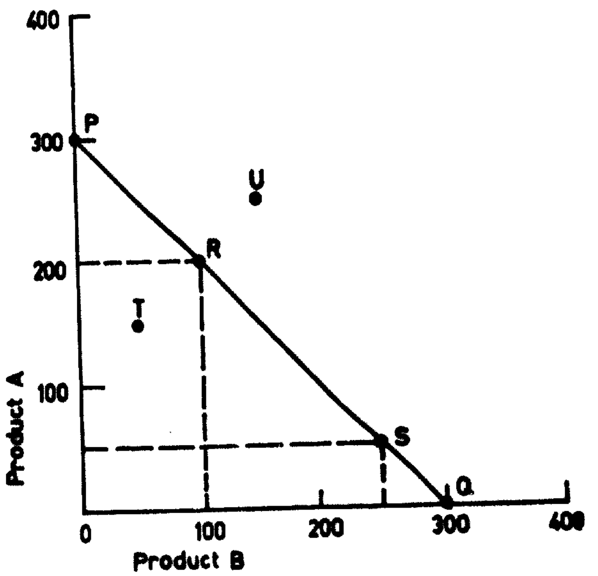

Figure 4

MAXIMUM CAPACITY LINE FOR A TWO-PRODUCT SYSTEM

line indicates that for 250 units of A only 50 units of B can be produced.

One may then turn to machine 2 (see fig. 5) and represent its full capacity line in the same way as that for machine 1. There are now two lines, one for each machine and they intersect at point R. To the left of R, line 2 is above line 1; this implies that any product-mix which involves using machine 2 to its full capacity is above the capacity of machine 1 and is therefore unacceptable. Any feasible product-mix for machine 1, however, is also feasible for machine 2, although it will result in machine 2 not being fully utilized. To the right of point R, the position is reversed: line 2 is below line 1, so that line 2

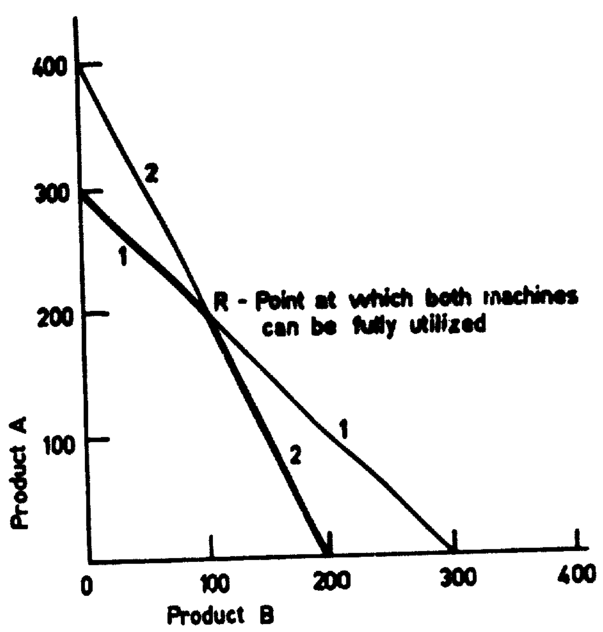

Figure 5

MAXIMUM CAPACITY OF TWO MACHINES

represents the limiting capacity available, whereas machine 1 will not be fully utilized. The heavy line, therefore, gives the full capacity for the two-machine system; any point below this line is feasible, any point above it implies that at least one of the two machines does not have adequate capacity. And only at one point, namely R, can both machines be fully utilized.

One may then superimpose capacity-restriction lines for the other machines, as shown in figure 6. Line 3 is horizontal, since machine 3 is used for product A only and it does not restrict the output of product B in any way; similarly line 4 is vertical because machine 4 is used for product B only.

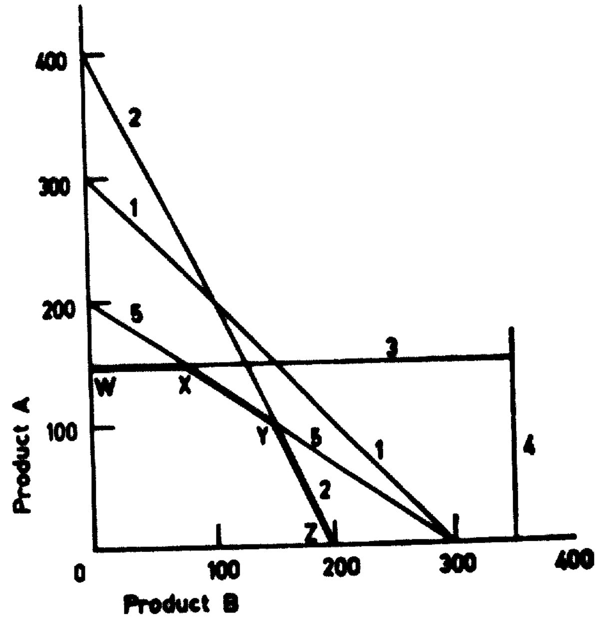

Figure 6

FEASIBLE PRODUCT-MIX

Following earlier arguments, the lowest line represents the global capacity restriction of the plant, because on that line one machine is fully utilized, and that machine can be described as the "bottle-neck". Other machines may be capable of a higher output, but the output of the plant as a whole is always determined by the bottle-neck.

The capacity restriction in this case is given by the broken line WXYZ. The portion WX represents product mixes for which machine 3 is fully utilized and all the others are underutilized. At point X machine 5 is used to its limit and along the portion XY this machine becomes the bottle-neck. As one moves along XY towards point Y, increasing the output of product B and decreasing the output of A, one gets further and further from line 3, which simply implies that increasingly more idle time on machine 3 is incurred. And at point Y, both machines 2 and 5 are fully utilized, whereas along the portion YZ, the capacity restriction of machine 2 is the significant one.

The polygon OWXYZ is the space within which product-mixes are feasible, although any point below WXYZ means that all the machines are under-utilized.

This is obviously a very useful analysis. One finds, for example, that in this case a product-mix is preferable to producing only product A. The maximum output of A is given at point W as 150 units, but on can produce up to 75 units of product B without having to reduce the output of A (at point X); and, provided product B is at all profitable, it is certainly better to operate at X than at W. One also gets useful data in considering such problems as:

(*a*) Is it worth while increasing the capacity of certain machines, and, if so, which?

(*b*) When the bottle-neck is removed (the capacity of the limiting process is increased), where is the new bottle-neck? (a bottle-neck will always exist, if one wishes to maximize output; however, it may shift to another machine);

(*c*) Should the product-mix remain the same for the new capacity restrictions?

Those familiar with linear programming will recognize it in the foregoing discussion, and it goes without saying that when a product-mix of more than two products is considered, graphical presentation becomes difficult – if not impossible – and one must then resort to formulation of the various restrictions in an algebraic form. But this does not detract from the value that may be gained from such an analysis, which can be and often is very useful even for small plants.

D. *Control of product variety*

One of the major problems with which production management is constantly faced is the control of the variety of products, materials and methods. The variety of products is stimulated by the whims of customers and by the natural desire of the salesman to satisfy them. Variety is like entropy in thermodynamics; it has a tendency to grow unless a conscious effort is made to put it under control. The advantages and disadvantages of having a wide variety of products are summarized in table 4 at the foot of the page.

There is little doubt that a small range of products enhances the efficiency of production methods, as well as the planning and control procedures of production activities and inventories, but there is a limited number of products for which demand is high enough to justify exclusive production lines working on a continuous or mass-production basis. Even in highly industrialized countries with well-established markets, the development of production processes has generally more than kept pace with increasing demand; the desire to keep production facilities busy, and the fact that customers increasingly prefer some variations of the basic product to the standard model always lead to a diversification of products. In addition, financial managers and salesmen are often very unhappy about over-specialization. It makes the company too vulnerable, they argue. First, it commits the company to a narrow and often rigid set of specifications, thus allowing ample opportunities for competitors to consolidate their position in the market; secondly, by utilizing its resources for a single product, the company can be seriously challenged by new products which threaten to replace or make obsolete the current one. The balance between the convincing technical and administrative advantages of specialization and the philosophy of risk spreading by diversification is obviously a delicate one, and it is probably one of the major factors in determining the productivity of the plant.

The growth of variety is often effectively demonstrated in a distribution of sales income curve, as is shown in figure 7. The products are arranged in a descending order of their sales income, and the cumulative income is then plotted against the percentage of the products offered by the firm. In this curve, it may be seen that some 25 per cent of the products account for 75 per cent of the total income, and this is by no means uncommon in firms which tend to diversify their product range. In fact, cases in which 10 to 20 per cent of the products are

Table 4

ADVANTAGES AND DISADVANTAGES OF PRODUCING WIDE VARIETY OF PRODUCTS

Pro variety	*Against variety*
Satisfy a wide range of demand	Reduce stocks of materials and finished goods
Closer contact with the market	Reduce investment in plant and equipment
Avoid losing orders for more profitable goods, if customer directs all his orders to other suppliers	Save storage space
Create new demand	Simplify production planning and control procedures
	Simplify inspection methods
	Reduce range of required skills
	Simplify training methods
	Reduce sales price as a result of higher productivity
	Simplify dispatching to customers, reduce waiting times of orders

Source. Samuel Eilon, *Elements of Production Planning and Control* (New York, Macmillan, 1962), Chapter 5.

responsible for more than 80 per cent of the sales income have been recorded. Figure 8 also shows this point in a histogram form, and the level of profit or loss accorded to each product is also indicated. In the case described in figure 8, one finds that some of the popular products (Nos. 2, 5 and 6) are not very profitable, and one must immediately suspect that the costs of production are unduly high or that there is something wrong in the pricing policy. It is not difficult to see that when the distribution of sales and profits take this form, an elimination of the tail-end of the product range (involving more than 25 per cent of the products) will reduce the

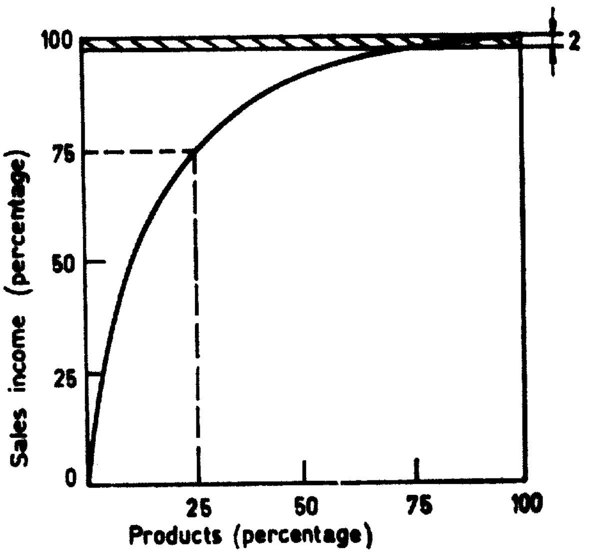

Figure 7

CUMULATIVE SALES-INCOME DISTRIBUTION

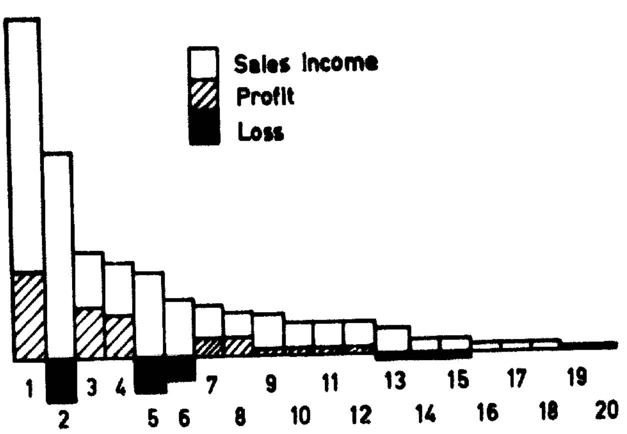

Figure 8

SALES AND PROFITS HISTOGRAMS

total sales income by little more than 2 per cent, and this is an obvious course of action that, under these conditions, must be further investigated.

Many readers will be familiar with the break-even chart method shown in figure 9. This is a useful analysis in studying the profitability of any particular product. The total costs are assumed to consist of two major components: fixed costs (F) and varible cost (*a*Q). The fixed costs are assumed to be unaffected by the volume of production, the direct or variable cost (*a*) is the cost of materials, machines and direct labour associated with the production of one unit of the product, so that the direct cost of Q units is *a*Q. If the sales price, or income, is *b* per unit, one obtains a break-even point at the intersection of the line F + *a*Q with the sales-income line *b*Q. Activity below this break-even point incurs a loss to the firm; activity above this point yields a profit. It follows, therefore, that the greater the production volume, the greater will this profit be.

This analysis is, of course, a gross over-simplification of what happens in real life, and there are many assumptions that could be challenged:

(*a*) The direct costs (*a*) may well depend on the level of activity (Q). If Q is high, there is more incentive to introduce labour-saving devices; furthermore, operators have a better opportunity to become proficient at their job and thereby reduce the labour content per unit of product;

(*b*) The sales price (*b*) is not necessarily constant and the introduction of quantity discounts to customers will make the sales-income line of a somewhat different shape than that shown in figure 9;

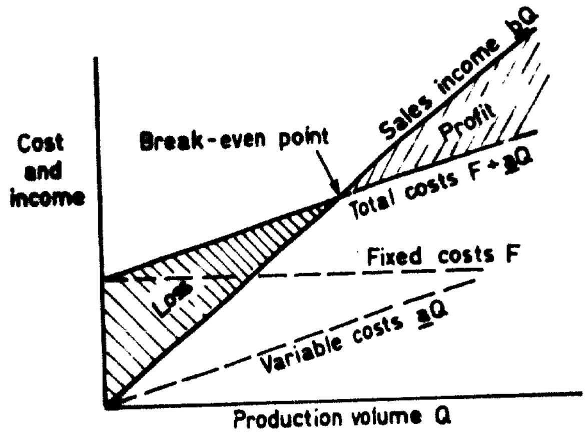

Figure 9

A CONVENTIONAL BREAK-EVEN CHART

(*c*) The fixed costs (F) may well depend on the level of activity of the firm and could, in fact, assume a step-wise function when plotted against the activity (Q);

(*d*) While it is generally not difficult to determine the level of the fixed costs when the firm is engaged on producing a single product, there is some uncertainty about the way the fixed costs of the whole plant should be allocated to several products. One popular method is to perform this allocation according to the relative proportions of sales incomes of the various products, but this raises the problem of reallocation when production volumes are adjusted or when some products are eliminated.

All these appear to be serious objections, but, in fact, the break-even analysis can be easily modified to take account of the first three.[2] The fourth difficulty can be overcome also by using a multiple-product break-even chart and by comparing the marginal benefits (*b a*), which can be regarded as a profitability index: the higher it is, the larger the production volume of this product at which one should aim. One can see that the products can be arranged in order of preference, according to their profitability indexes, and a sales policy can then be formulated to discourage the sales of products with a low index and to encourage the sales of those with a high index.

Another problem that needs to be looked into is that of "interdependence of products". A customer may require a range of products which he generally purchases from one supplier, and these products may include some "bread-and-butter" lines which have a high profitability index and some which are less profitable from the manufacturer's point of view. If the manufacturer were to eliminate his less profitable lines, the customer might well decide to change his supplier altogether, so that the sales of the profitable products could be adversely affected. If this effect were to be significant, the manufacturer might well find that he must continue to offer products in the tail-end of his sales-income distribution in order to enhance the sales of the products that he is primarily interested in promoting.

However, once the interdependence factor is properly identified and quantified, it is possible to proceed with a detailed analysis of the likely effects of a variety reduction programme, as well as with the possibility of introducing a pricing policy which would increase the relative profitability index of the less popular products. If such a policy actively discourages the sales of these products in favour of the others, then variety reduction is achieved by an evolutionary process, which is perhaps more palatable to suppliers and customers; if, on the other hand, the sales of the less popular products persist, at least their profitability index and their sales-income contribution have been improved.

One of the main problems in variety control in developing countries, particularly in the consumer goods field, is that with relatively small governmental encouragement (in the form of excessive duty on imports to protect local industry, or of subsidies and other benefits to local manufacturers) a comparatively large number of manufacturers may emerge, all competing in a relatively small market. In one country with about 2 million inhabitants, well over twenty manufacturers of washing machines were recorded a few years ago, some producing more than one model. Similar instances can be cited for other domestic appliances, material-handling equipment, machine tools, components for the building industry, electric motors and switch gears etc. The proliferation of competitors in a relatively small market does not give any of them a chance to rationalize their production methods and attempt to export their goods, and the customer does not benefit either because production of small quantities tends to keep prices high. Variety control in small markets is, therefore, of paramount importance, probably even more so in the developing countries.

E. *Operational research*

"Operational research is the attack of modern science on complex problems arising in the direction and management of large systems of men, machines, materials, and money in industry, business, government and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcome of alternative decisions, strategies or control. The purpose is to help management determine its policy and actions scientifically."[3]

The theme is again that of effective use of resources, and some of the problems which were discussed earlier can be legitimately regarded as being within the operational-research orbit. The evaluation of plant capacity and the allocation of machines to various jobs or products, or the analysis of the profit function for different product-mixes, can be treated as linear-programming problems, in which mathematical models are set up with linear constraints describing maximum machine capacities, limitations on the supply or use of certain materials, maximum or minimum production volumes which must be observed for certain products etc.

Problems of congestion in production departments — for example, semi-finished products piling in front of machines or inspection stations, long delays in tool-rooms or in getting materials and tools from stores, delays in the dispatch area — are problems in which the theory of queues can be of some help.

In the queuing model, one visualizes a stream of customers arriving at a service-point and demanding service. A customer can be served if one of the servers in the system is free; and when the service is completed, the customer is discharged from the system and a new customer can be attended to. If customers arrive and none of the servers is free, the customers have to wait in a queue. In the production environment, the components waiting to be processed are the "customer"; the machines are the "servers". The operators waiting to be served in the store are "customers"; the storekeepers are "servers"; and so on. The type of problems in which operational researchers are interested when faced with congestion situations are:

(*a*) How long does a customer expect to wait before he obtains service?

(*b*) What is the probability of his having to wait longer than a given time period?

(*c*) What is the average length of the queue?

(*d*) What is the probability of the queue exceeding a given length?

(*e*) What are the expected utilization and idle time of the server?

(*f*) How many servers should there be to attain a

[2] L. P. Alford and J. R. Bangs, *Production Handbook* (New York, Ronald Press, 1962), chapters 5 and 20.

[3] Definition suggested in 1962 by the Operation Research Society of the United Kingdom.

desirable level of service (which can be defined in terms of queue length and waiting time)?

(*g*) How can arrivals and service time be regulated to reduce congestion?

(*h*) Should priorities be given to certain customers, and, if so, what will the effects be?

Operational research has also contributed to a more effective control of inventories. The main problem here is to determine a sound replenishment policy, so that stocks of materials, components or finished goods are available when required, yet the stock level is not so high as to incur excessive holding costs. This is a typical problem of conflict of interests. If demand for the commodity in question is variable, probability of running out of stock can only be attained if a comparatively high safety stock margin is maintained, and it is this balance between having a reasonable stock level and an acceptable incidence or risk of run-out that an inventory control policy attempts to formulate.

Another important area in which some useful models have been developed is that of plant maintenance and replacement. Numerous maintenance policies can be formulated, ranging from one extreme, which specifies maintenance only when plant breakdown occurs, to the other, which calls for scheduled preventative maintenance at very short time intervals. The purpose of preventative maintenance is to reduce breakdowns, but the more frequent it is, the more costly it is and the less the potential plant capacity which is available. Maintenance costs are also an increasing function with plant age, and this raises the problem of deciding when is the best time to replace the plant with a new one.

Scheduling is another theme on which numerous operational-research studies have been carried out. Scheduling is the projecting of activities and their sequences, generally on a time scale. In production scheduling, one is not only interested in stating the allocation of jobs to machines or men, but also in the sequence in which these jobs should be carried out. The complexity of the scheduling activity naturally depends upon the type of production (whether it is continuous, batch or job production), upon the number of operations or machines involved in the production sequence and upon the degree of variability in the demand or in the pattern of incoming orders.

In the case of continuous production, the problem is to control the production level in relation to fluctuating demand, particularly when the demand has a seasonal pattern. Two extreme alternatives can be adopted: the first is to have a constant level of production and a large enough inventory to serve as a cushion between the factory and the market. The fluctuating demand is then absorbed by this inventory, which is replenished at a constant rate. The second is to reduce inventory to a minimum and to transmit the demand fluctuations to the production line, so that production levels will also fluctuate. The advantages of the first method are that with a stable production level, resources can be more effectively utilized, i.e., machines can be kept running at a high performance level, and, what is more important, the labour force can be maintained at a constant level without fear of redundancy at short notice. But if carrying high inventories during a slack season is very costly, the firm may be forced to allow some of the market fluctuations to be reflected in the production programe, and the problem of finding a compromise solution can then be solved by using suitable linear-programming models.

Batch production presents problems of a somewhat different character. When the rate of production is higher than the rate of demand, the stock level will increase at a rate which is equivalent to the difference between the rate of production and the rate at which stock is withdrawn from the store to meet the demand. Therefore, one has to resort to batch production: the store is replenished with a batch, then the stock is depleted at a relatively low rate, until it is time to produce another batch to replenish the store. Between the two batches, the equipment is available to produce other products; the purpose of the scheduling activity under these conditions is to produce a programme in which the batches of the various products are dovetailed in such a manner that the stock level for each fluctuates between acceptable levels and that the equipment is effectively used with as little idle time as possible. In other words, it is necessary to determine a production cycle, in which the appropriate quantities for each product are manufactured in turn.

In batch production, therefore, some regularity in the production schedule can be perceived, even if the production cycle is subject to variations in order to accommodate fluctuations in demand. In job production there are no such regular patterns. Jobs differ in their characteristics and specifications; they often arrive at random and the amount of processing and the machines required may vary with the job. In addition to the obvious objective of keeping the machines as fully employed as possible, one may have to bear in mind the delivery dates which have been promised to the customer. Job shop-scheduling is a vast and intricate queueing problem, and simulation exercises can be of tremendous help to the scheduler in pointing out the vital parameters in the system and in suggesting what priority rules can be adopted when the schedule is constructed.

Another important scheduling problem occurs in project planning. Large-scale projects—such as the building of dams, bridges, industrial or residential estates, airports, harbours, ships, motorways etc.—involve large commitments of finance, machinery and manpower. A project can be broken down into individual jobs which may well depend upon each other (certain activities can begin only when others have already been completed), so that the successful management of a project largely depends upon co-ordinating the various activities and upon using the resources effectively. Here, network analysis has made a major contribution in providing indispensable aids to management for evaluating progress and controlling the execution of project work.

Conclusion

Modern management is becoming increasingly conscious of the need for analytical tools, reliable data and purposeful control. Can new techniques, such as those of operational research, be of use to developing countries? The evidence so far indicates that they definitely can. On the national scale, every Government is concerned about the allocation of financial resources, about the relative merits of various development schemes and about the rate of industrialization; these are areas in which analytical tools can make a significant contribution. Certainly at the level of undertaking large-scale projects, and even for production management in factories, modern scheduling methods can be very helpful.

The secret is not to copy blindly management practices from highly industrialized countries. Control tools must be related to the industrial and economic needs of the country and they must fit into the social environment in which they have to operate; and the selection and adaptation of these tools is an art of no mean complexity.

5. 4. 74