Quantitative Production Management

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Preface

This volume contains a discussion of some of the quantitative methods available to persons engaged in that peculiar art, 'production management'. Over the last three or four decades a number of mathematical techniques have been developed, each of which allows particular problems to be solved in a routine fashion. These techniques permit the manager to delegate routine problems to a computer or to a subordinate, and thus free him for the vastly more important task of resolving problems for which routines are not available. Even when a complete solution cannot be produced, a quantitative treatment may give an insight into the structure of a problem and thus increase the effectiveness and stature of the production manager.

The present work is structured in the same way as Lockyer's *Factory and Production Management*, although it must be emphasized that both works are self-contained. The work of the production manager is taken to be the amalgam of five 'areas of interest'—product, plant, processes, programmes and people—and the treatments are grouped accordingly. Problems suitable for quantitative treatment in each area are briefly outlined and appropriate techniques are then described. Since mathematics has no boundaries, some selection on the part of the authors has been necessary. Two tests have been applied:

(i) *Utility* Has the particular method been used or observed in use by one or other of the authors?

(ii) *Insight* Does the quantitative analysis provide some insight which helps the manager to carry out his job?

These somewhat arbitrary methods of selection may have resulted in omissions which some readers may deplore. For this no apology is offered: the alternative is a very much longer, and more costly, text. In particular, the approach is concerned with problems rather than techniques, and those treatments which serve only to produce 'good examination questions' have been avoided like the plague. The operational research worker is frequently a person with a solution looking for a problem. The production manager is always a person with a problem looking for a solution, and it is some of these solutions which we hope to provide here.

The level of mathematics needed to appreciate the vast majority of the discussion is substantially that possessed by an intelligent 17-year-old still studying mathematics. In the very rare cases where knowledge beyond this is required, adequate treatment is provided in the text. It is assumed that the reader is familiar with elementary statistical concepts and methods. The text is thus useful to those studying for first and second degrees and diplomas in 'Management' which are generally regarded as quantitatively based, and which include a substantial study of the wealth-producing function, 'Production'. Its essentially practical approach will also make it useful for practising Production Managers, Industrial Engineers, O.R. workers and Management Services personnel.

In general, each chapter is self-contained and can be read without reference to any other chapter. However, adequate cross-referencing has been made so that should there be need to refer back, the reader will be so directed. Many of the quantitative methods described are solvable in useful time only if a computer is employed. No discussion of computer programming is included, since many good texts are already available, and no particular programs are described or recommended since computer and program development is so rapid that any such program would be likely to be out-of-date very quickly: indeed a program which does *not* change is likely to be a program which is not used and the authors hope to exclude this sort of work.

'Suggestions for Further Reading' sets out those textbooks and papers which the authors have found of value both in their academic and consulting lives. It is not intended that this should be a comprehensive bibliography. Here again the tests of utility and insight were applied.

Sets of illustrative examples will be found at the end of all chapters, except Chapter 1. These have been carefully graded in order to illuminate each part of the chapter as it occurs. For a reader to understand fully the treatments in the chapters it is strongly recommended that the questions should be worked through. Almost all the solutions can be derived using a hand-held programmable computer. Where graph paper is required the authors have found the Chartwell series published by H. W. Peel & Co., Ltd., in particular C7018 is useful for Gantt charts, C6572 is useful for reliability and C5575 is useful where log-normal plots are required. Furthermore, the serious student will find that study of the catalogue from Pitman will be extremely useful. All the questions are fully worked out, with some comments, in the authors' companion volume *Quantitative Production Management: Solutions Manual.*

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Section I Introduction

1 Production Management—Art or Science?

1.1 Introduction

Organizations, of whatever kind, are viable only if they provide satisfaction to the consumer, and this simple criterion is the only general condition for their existence.

Such a statement, of course, raises as many questions as it produces solutions and it is not appropriate here to try to investigate all of these. Two things, however, do need to be clarified: (i) the satisfaction may be in terms of a physical product, a service or a system; (ii) the consumer may be either outside or inside the organization, i.e. he may be a customer for the product or a user of the system. Broadly, therefore, all organizations can—for the purposes of discussion—be considered to be made up from two subsystems, one of which determines need and transfers that which satisfies it to the customer, the other of which produces that which is to be transferred. Within commercial organizations these two subsystems are commonly referred to as the 'marketing' and the 'production' or 'operations' functions, and it is here asserted that these two functions can be identified in *all* organizations.

For simplicity, in the present text the term *production* will be used synonymously with *operations*, and the word *product* will be taken to subsume a physical item, a service, or a system. All the so-called 'service' industries have a 'production' function and their problems are conceptually identical to those in the more obvious 'production' industries. Thus the booking of squash courts in a leisure centre is analogous to the loading of jobs on to a machine; the assessment of the number of hotel rooms which a tour operator should book for the next year is identical to the production manager's assessment of the capacity required in the next budget period and so on.

The success of any organization must, therefore, depend significantly upon the effectiveness of the production (or operations) management function, yet it is this function which is least well understood and which is certainly extremely difficult to carry out. Unlike, say, the accounting function, production management is under-codified: there is neither an agreed definition of its scope nor any authoritative statement concerning 'good practice'. The present chapter attempts to describe some of the areas of interest of the production manager, outlines the characteristics of the task, indicates the problems which may be found within it and suggests some ways in which a practising production manager can deal with his job to the best effect.

1.2 The production manager's areas of interest

The production manager is particularly interested in five areas of organizational activity, although in practice problems can overlap several or all of these areas.

(i) *The product* The production manager is, or more accurately should be, involved in questions concerning quantity, quality, reliability, selection, forecast, selling price and delivery of the product.

(ii) *Plant* The design and layout of the buildings, and the design, performance, reliability, maintainability and cost of using equipment, involve the production manager just as much as the technical performance of the piece of processing equipment.

(iii) *Processes* Obviously, the way in which processes are carried out are the concern of the production manager. He must consider not merely how things are carried out, but where and by whom. He must consider how long a process will take, whether it is safe, and whether it is acceptable to the culture of the workforce at his disposal. The choice of the appropriate process is rarely unique, rarely only technical, and seldom simple. It is unfortunate that much of the so-called 'research' into 'productivity' concerns itself with the technical problems of carrying out a process rather than with the managerial problem of trying to organize that process within the operating unit as a whole.

(iv) *Programming* The statement of a delivery requirement should be the start of enormous programming activity by the production manager. He must programme not merely the delivery of finished goods but all the activities which lead up to this: the obtaining of raw materials, of components or intermediates, of tools, of equipment, of packing and frequently of transport. Indeed, no delivery promise should ever be made until the producers have carried out, at least in skeletal form, an exercise concerning the above programmes to discover whether a delivery date can be met. The intellectual challenge of this is high and until recently little help was available to the production manager except that of sheer intuition. Quantitative tools are now becoming available, some of considerable power and elegance. The strength of these tools, however, is no greater than that of the people who wield them, and the behaviour of people, both within and without the organization, can disrupt the most elegant solution in an entirely unpredictable way. Conflict will inevitably arise between the need for discipline to achieve an effective solution and the need for freedom to meet the personal expectations of employees and consumers.

(v) *People* The bulk of the staff of any operating organization will be directly or indirectly under the control of the production manager. Like all other products of man, man is variable: variable in intellect, in skill, in expectations. The work of the social scientists is continually enlarging our understanding of man and organization and bringing home the fact that the 'simple' panaceas—better communications, small groups, worker participation, industrial democracy—are rarely simple, usually involving fundamental rethinking of the whole organizational purpose. Unlike the social scientist, the production manager has to live with his mistakes, and he should, therefore, be closely involved in all matters concerning payment, both of basic wages and financial incentives: safety, working conditions, trade unions, negotiations, motivation and learning.

1.2 Special characteristics of the production management function

There are probably five special characteristics of the production management function which are worthy of consideration.

(i) *Measurement* Unlike most other managerial activities, almost every act of the production manager results in something which can be measured. Output, scrap, lateness, idle-time, breakdowns, work-in-progress, stock in stores, etc., are all easily measured and compared with some budget or other criterion.

(ii) *Range* Because of the five areas of interest in the previous section, the production manager is presented with a very wide range of problems, few of which are self-contained. A decision concerning a new piece of equipment, for example, may very well involve other decisions concerning plant location, safety, incentive schemes, schedules, work-in-progress and so on. This complexity of decision-making spreads across the whole of the work of the production manager.

(iii) *Volume* Again, because the production manager controls so many of the personnel and such a high proportion of the physical and financial resources of any organization, and because most of his work is fast moving, he is presented with a large volume of problems which may very well range over a number of different activities.

(iv) *Speed* Decisions need to be taken rapidly. When a piece of processing equipment breaks down, resulting in a number of employees standing idle, time is rarely available for 'in depth' studies. Similarly, a delivery promise generates a train of dependent subsidiary decisions and a delay at any one point may very well cascade down the train and change delivery dates enormously. It is usual, therefore, to find that the production manager needs to make decisions rapidly.

(v) *Imperfection of data* Despite the ability to measure the work of the production manager, it is regrettable to discover that many of the measurements, and the criteria against which they are made, are often grossly imperfect. A 'standard time' may well be in error by 20 per cent. The capacity of a work centre may not be known at all—it may be taken to be the volume of work which has previously been produced by the work centre, something as remarkable as measuring the volume of a bucket by the last quantity of water carried in that bucket. Even worse, of course, the 'bucket' itself is not of a constant capacity: it can be stretched by changing techniques, working overtime, subcontracting and so on. Maintenance times are often set down 'by guess and by God'. Activities such as emergency overhauls, which occur—by their very nature—extremely infrequently, are extremely difficult to forecast. Even an apparently simple item like the volume of stock in stores is often known with very poor accuracy. It is a well-tried experiment in any teaching group to pass a quantity of small items, say screws, around the group and ask each member to count the number of items. It is not uncommon to find that if there are N members of the group then there will be N different answers to the number of items. Of course, technical devices such as computing scales have been improved recently so that their technical abilities are extremely high. However, 'wastage' in stores is as real as 'wastage' in the supermarket. The production manager thus has to work with data which are likely to be grossly in error.

1.4 Art or science?

Faced then, with a multiplicity of problems, all of which involve imperfect data, the production manager finds himself required to make sensible decisions. How can this be done? Two approaches are possible. One is to try to build up a comprehensive all-embracing 'system' from which a model is derived, and, when a problem arises, to insert it into the model and see what answer emerges. A second approach, and that favoured by the authors, is to break the task down into smaller parts around which the production manager 'can get his arms'. In practice most organizations can be considered as a collection of 'areas of responsibility', and the need is for the net behaviour of these areas to conform to some previously agreed aggregate programmes. To assist in doing this, it is useful to associate, from experience, a 'time span of action' with each area. This span will identify the period over which production plans can reasonably be expected to be achieved and held stable. Beyond this time span any such expectation will be unrealistic. Detailed planning and control within these areas of responsibility will potentially produce substantial benefits.

Broadly, problems can be considered to be of two kinds. *Programmable* problems are those problems for which a routine can be set down which will produce an answer; usually these may be considered to be the contribution of 'science' to production management. *Non-programmable* problems are those which must be dealt with using personal skills, experience, judgement and enterprise, and these qualities contribute to the 'art' of production management. One of the purposes of the suceeding chapters is to increase the production manager's ability to identify and solve programmable problems, thus releasing time for the solving of the often vital and more difficult non-programmable problems.

Section II The Product

2 Product Conformance–Statistical Quality Control 1

Process Control

2.1 Introduction

Statistical quality control (SQC) techniques are used to measure the degree of conformance of components and processes to previously agreed design specifications and their application can show considerable advantages over 100 per cent inspection, both in time saved and in improved reliability of the quality control procedures. In statistical quality control, 'quality' is taken to be the percentage of items which conform to the agreed design specification, a high quality batch being synonymous with a low percentage of rejected items.

In essence, SQC techniques select a representative probability sample, usually a simple random sample, from the population, which is the batch of parts ('product control') or the output of a processor ('process control'). By analysing this sample, it is possible to deduce the quality of the total batch or the current performance of a processor. Furthermore, if the acceptable risks are specified before sampling, the consequences of the possible outcomes of the sampling procedure are calculable in advance. However, neither SQC nor 100 per cent inspection can guarantee the quality after inspection.

SQC can be broadly divided into two groups, as in Fig. 2.1.

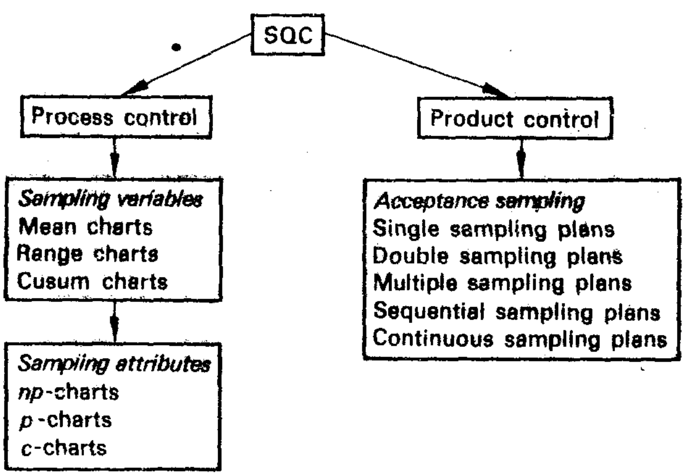

Fig. 2.1 Organization of SQC.

2.2 Process control

2.2.1 Process variability and design tolerance

In sampling variables, e.g. the dimension of a shaft or the weight of a bag of sugar, it is important to realize that the main assumption, on which the statistical analysis is based, is that the process variable is *normally* distributed about a known mean μ, with a known variance σ^2, whence:

(i) approximately 67 per cent of the values of the variable will lie between $\mu+\sigma$ and $\mu-\sigma$;
(ii) approximately 95 per cent of the values of the variable will lie between $\mu+2\sigma$ and $\mu-2\sigma$;
(iii) approximately 99.7 per cent of the values of the variable will lie between $\mu+3\sigma$ and $\mu-3\sigma$.

or alternatively:

(i) there is a probability of 25 in 1000 of a value lying beyond $\mu+1.96\sigma$;
(ii) there is a probability of 25 in 1000 of a value lying below $\mu-1.96\sigma$;
(iii) there is a probability of 1 in 1000 of a value lying beyond $\mu+3.09\sigma$;
(iv) there is a probability of 1 in 1000 of a value lying below $\mu-3.09\sigma$.

Some other values of the standardized normal deviate are:

Value of z in the normal standard deviate $z\sigma$	3.09	3.00	2.00	1.96	1.28	1.00
Area of the normal curve lying to the right of the normal standard deviate $z\sigma$	0.0010	0.0013	0.0228	0.0250	0.1000	0.1587

The design tolerance $2T$ is the difference between the upper and lower design limits. If $2T>6\sigma$, very few items will be outside the design tolerance and scrapped or rejected items are avoided. Conversely, as $T\rightarrow 0$ there will be an inevitable increase in the number of scrapped or rejected items (Fig. 2.2). Furthermore, if $2T>6\sigma$, the process mean can vary without affecting the percentage of items rejected whilst if $2T<6\sigma$, the process must be controlled very closely, since any variation in the process mean will produce more than a proportionate increase in the percentage of rejected items.

The standard deviation of a distribution is usually employed as a measure of variation. In SQC of variables, the sample size n is usually