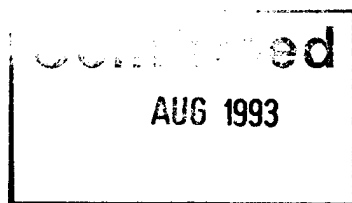


BRITISH STANDARD 6000 : 1972

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GUIDE TO THE USE OF BS 6001, SAMPLING PROCEDURES AND TABLES FOR INSPECTION BY ATTRIBUTES



**GUIDE TO
THE USE OF BS 6001,
SAMPLING PROCEDURES AND
TABLES FOR INSPECTION
BY ATTRIBUTES**

BS 6000 : 1972

BRITISH STANDARDS INSTITUTION

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This standard makes reference to the following British Standards:

BS 600 Application of statistical methods to industrial standardization and quality control.

BS 1313. Fraction-defective charts for quality control.

BS 2564. Control chart technique when manufacturing to a specification, with special reference to articles machined to dimensional tolerances.

BS 2635. Drafting specifications based on limiting the number of defectives permitted in small samples.

BS 2846. The reduction and presentation of experimental results.

BS 6001. Sampling procedures and tables for inspection by attributes.

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The following BSI references relate to the work on this standard:
Committee reference OC/8 Draft for comment 71/61260

CO-OPERATING ORGANIZATIONS

THIS BRITISH STANDARD was prepared under the supervision of BSI Technical Committee OC/8, 'Statistical methods', on which the following are represented:

British Iron and Steel Research Association
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Printing and Packaging Industries
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BRITISH STANDARD GUIDE TO THE USE OF BS 6001, SAMPLING PROCEDURES AND TABLES FOR INSPECTION BY ATTRIBUTES

FOREWORD

In 1967 BSI published BS 9001 with identical technical content to Defence Specification DEF-131-A, 'Sampling procedures and tables for inspection by attributes'. The title of BS 9001 was supplemented by the words ' for electronic parts of assessed quality ', as that British Standard was initially published to satisfy a particular requirement at that time for sampling procedures and tables for use in assessing the quality of electronic parts (known as the Burghard scheme), which is covered by the BS 9000 series of standards.

Following the publication of BS 9001 representations were made to BSI concerning the specific references to electronic parts in the title of BS 9001, as it was stressed that these particular sampling tables are used in several sectors of British industry for a multiplicity of purposes. Consequently BSI published a short note on this problem in the February, 1968, edition of BSI News to solicit comments on the proposal that a parallel standard to BS 9001 be published in the general purpose series of standards. Reaction to this proposal was generally favourable, although qualified in some respects by references to other types of scheme which might alternatively be used.

Recently both ISO and IEC have been considering the adoption of these sampling procedures and tables and it seems likely that they will be published as International Standards some time in the future, although with the qualification that they are not exclusive, since several other types of schemes are operating quite reasonably in other sectors to suit particular purposes. Consequently it has been decided to republish the same technical content in the general purpose series of standards, with the number BS 6001 and the title, ' Sampling procedures and tables for inspection by attributes '. BS 6001 and BS 9001 will exist side by side for the present but ultimately BS 9001 will be withdrawn. These sampling procedures were developed following the work of an American, British and Canadian Working Group which led to an ' ABC ' agreement in 1962 to standardize the military sampling inspection tables of the three countries. As a consequence of this agreement the following military standards were published: MIL-STD-105D (USA), DEF-131-A (UK), CA-G115 (Canada), and with the exception of an appendix on sequential sampling, which is peculiar to the British document, they are identical in technical content. Since that time these military standards have been incorporated into the national standards of many countries, for example DEF-131-A is identical with BS 6001 and MIL-STD-105D is identical with American National Standard ANSI Z1.4. The plans were developed primarily for the inspection of continuing series of batches. However, with very little adaptation to the procedure the tables in BS 6001 are suitable for use by the manufacturer for his own production inspection, also for many other purposes, such as the inspection of complete equipments, product in storage, servicing and administrative procedures, and other functions.

At the time of publishing BS 9001 it was intended to publish later (as Appendix B) Defence Guide DG-7-A, 'A guide to the use of Defence Specification DEF-131-A'; however, in view of these developments it has been decided to publish this Guide separately as BS 6000 because of the importance of explaining the consequences of using these sampling procedures and tables for their successful operation. The Guide advises both those who perform the inspection and those whose task it is to lay down the requirements for the inspection to be performed.

BS 6000 has been based on the 1969 reprint, incorporating Amendment No. 1, of Defence Guide DG-7-A, which was prepared by the Engineering Standards Co-ordinating Committee on the authority of the Defence Administration Committee, Ministry of Defence, in 1966. Acknowledgement is made to the Ministry of Defence and to Mr. I. D. Hill, who was responsible for much of the development work in this sphere and assisted the BSI committee in preparing this Guide.

In the light of industry comments submitted several minor editorial modifications were made throughout the text and in particular Clause 42 and Table 9 of DG-7-A were omitted and replaced by an explanation of the nomograms included at the end of the standard. Also the random sampling numbers (Table 7) given in this Guide are different from those given in DG-7-A. It was felt that the more different sets of random numbers that exist the better, so this opportunity has been taken to provide a new set.

NOTE. The British Standards referred to in this standard are listed on page 2.

GUIDE

1. INTRODUCTION

1.1 British Standard 6001 has an introductory text giving instructions for the use of the tables that it contains, but this text is kept as short as possible and gives only the essential minimum. The aim of the present Guide is to expand these instructions and, by giving a detailed commentary and a number of examples, to clarify the method of sampling inspection given by BS 6001.

Numbers in square brackets in this guide are references to the relevant clause numbers in BS 6001.

1.2 The discussion in this Guide assumes a manufacturer to be presenting batches to an inspector who accepts or rejects them on behalf of a customer, in the light of requirements laid down by the customer. It is not suggested that this pattern is universal—for instance, the manufacturer may sometimes be required to do the inspection himself, the inspector may sometimes lay down the requirements without reference to the customer, and so on. The pattern adopted here has been taken simply as a basis for discussion, and where some other pattern is in force the Guide will need interpreting in this light.

The text of BS 6001 specifies that certain functions will be performed by the 'responsible authority', who may be designated in the specification, contract, inspection instructions or other documents. It is important to understand that BS 6001 has been issued primarily for use in a system where inspection of the product by sampling is the method of acceptance and where detailed specifications prescribe the quality conditions which have to be met.

The plans in BS 6001 are intended for the inspection of continuing series of batches. They may also be used for the inspection of isolated batches provided that the risk involved is understood. See 36 [1.2].

This Guide aims to advise both those who perform inspection and those whose task it is to lay down the requirements for the inspection to be performed. The latter will find their main requirements given in 1 to 16, 23 to 28 and 32 to 42.

1.3 The tables in BS 6001 are designated by Roman numerals, with subdivisions denoted by capital letters, e.g. Table I, Table II-A, Table II-B, etc. The tables in this Guide are designated Table 1, Table 2, Table 3, etc. In this Guide, tables will be referred to without specifying each time which document is the appropriate one, since this will be clear from the table numbers themselves. Reading the Guide is unlikely to be rewarding unless a copy of BS 6001 is available for reference.

2. THE AIM OF THE SAMPLING METHOD

The main aim of any acceptance inspection must be to see that the customer gets the quality required, while remembering that financial resources are not unlimited, and that the cost of the article must reflect the cost of inspection as well as the cost of production.

2.1 There are three methods sometimes used in performing the task of inspection:

(1) 100 % inspection, in which every item produced is examined;

(2) sampling methods based on the mathematical theory of probability;

(3) *ad hoc* sampling, not based on the theory of probability, e.g. the inspection of a fixed percentage, or spot checking.

Method (1) can be a formidable task. It is expensive and, unless special care is taken, not always completely successful. It can sometimes degenerate into lip-service to 100 % inspection while in fact sufficient money, time and staff are not available.

Probably the most serious criticism of this method is that it appears to divert the responsibility for quality from the producer to the inspector. There is a feeling that the inspector is there to sort things out, so that, within limits, what happens in production is not of such vital importance. It need hardly be said that this feeling is completely misplaced. The inspector has no means of inserting quality into a product if the producer has not done so. The result of this system may therefore be found to be hard work, high cost and poor quality for the customer.

However, it should be understood that 100 % inspection may form an important part of the inspection process for both the customer and the producer, because there are many situations when it cannot be avoided, as will be clear from a study of this Guide. But it has often been shown that 100 % inspection is not always synonymous with 100 % certainty. Very special care must be taken if it is necessary to be sure that a batch is completely free from defectives: inspectors must be thoroughly trained, have proper equipment and be given adequate time for their work. Even then important items may need more than one inspection.

Some items are so important that every one must be examined. Where this is so a real effort should be made to ensure that a system is devised that clearly places responsibility for quality with the producer. One method of doing this is to treat the inspection as if it were a sampling operation in which the sample is the entire batch, as distinct from 100 % sorting into good and bad items. This idea is explained in more detail in 24 of this Guide.

Method (2) has the disadvantage, compared with 100 % inspection, that some of the items produced will not be inspected. But the risks involved can be precisely calculated, and a plan chosen to allow no more risk than can be afforded.

This method has the merit of putting the responsibility for quality fairly and squarely where it belongs—with the producer. The inspector can no longer be regarded as the man who sorts things out. The producer must see that the quality of his production is right, otherwise he will be put to much trouble and expense, with rejected batches on his hands. The result is that this method can often lead to less inspection work, lower costs and good quality for the customer.

The producer whose product is in accordance with the requirements of the specification need not fear the system. In designing the BS 6001 tables, the point of view

was always kept firmly in the foreground that it is to everyone's advantage that the method should make things as easy and smooth as possible whenever the quality is as required.

Method (3) is not to be recommended since it leads to uncalculated risks, and often to unjustifiably high risks; further, there is no logical basis for either acceptance or rejection of the product.

2.2 The main purpose of the procedure of BS 6001 is to control the acceptance of products at a quality level which is equal to or better than the acceptable quality level (AQL) [4.2]. However, the designation of an AQL does not imply that the manufacturer has the right knowingly to supply any defective product.

One way, therefore, of regarding the AQL is as an index to the calculated risks that the inspector is prepared to accept in order to obtain the economic benefit of sampling inspection. If, however, the sampling risk cannot be accepted, or a suitable plan is not available, then the product must be inspected 100 %. When sampling inspection is being used and the manufacturer is producing at a quality that is worse than the AQL, a sampling plan that has been well chosen should reject sufficient batches to make it worthwhile for an improvement in quality to be made with the minimum delay. It follows that when production is under control a quality better than the AQL can be expected.

It should also be understood that it is often difficult and expensive to be sure that a machine, a process or a production line is producing no defectives. In practice some percentage of defectives is usually acceptable but this does not necessarily mean that all of them will find their way into the final product: some will be detected at later inspection stages and others may fail to assemble or function on test. The allowance of defectives that is acceptable is dealt with in 3.8. It is largely governed by economic considerations, as the customer may be faced with the choice between a good article that he can afford or a better one that is beyond his means. The important factor is that acceptance, and therefore production, must be kept under control—this is what BS 6001 is for.

3. THE WORDS 'LOT' AND 'BATCH'

It is of the essence of the sampling system adopted in BS 6001 that items for inspection should be offered, not singly, but in groups. Such a group of items is normally termed a 'lot' in American industry. In British industry the term 'batch' is more common, although certain industries (notably electronics and ammunition) use the American terminology.

ISO Recommendation R 645, 'Statistical vocabulary and symbols', gives equal recognition to these terms and for simplicity the word 'batch' is used in this Guide, without wishing to deny anyone the right of reading it as 'lot' if it is so desired.

4. UNIT OF PRODUCT

4.1 In using BS 6001 it is necessary to count such things as batch size, sample size, number of defectives, etc.

This counting is done in terms of the unit of product [1.5]. Usually the unit of product will be a single article (of the type being inspected) and when this is so the word 'article' may be used if desired instead of 'unit of product'.

4.2 The reason for introducing the term 'unit of product' is that it is sometimes desired to perform sampling inspection of a product which does not consist of individual articles, or in which the basic entity being inspected consists of a number of articles.

4.2.1 Example (1). Chopped polyester fibre, produced in 50 kg batches, is to be examined for aggregates of over-size material. Each batch is to be inspected but it is not practicable to inspect the whole of each batch. The unit of product here may be defined as 25 g of fibre. A batch of 50 kg would then be considered to give a batch size of 2000, and the appropriate number of 25 g specimens to make up the sample size would be selected at random from the batch for inspection.

4.2.2 Example (2). An electronic equipment contains in its circuit two similar electronic tubes, and it is important for correct functioning that the electrical characteristics of these tubes should be closely matched. In this case the unit of product might be defined as a matched pair of tubes; 500 matched pairs, a total of 1000 tubes, would then give 500 units of product, and the batch size would be 500.

If the sample size necessary, as derived from the tables, were, say, 50 this would mean 50 pairs, i.e. a total of 100 tubes. It would, of course, be necessary in this situation for the pairs to be defined before the sample was drawn, and for them to be kept intact right up to the time of use.

In the case of electronic tubes consisting of two similar electrode structures within the same envelope, the entire article would be a unit of product although it would be necessary to test each section individually.

5. INSPECTION BY ATTRIBUTES

Inspection by attributes means that each unit of product inspected is classified as acceptable or defective; that is, each unit is considered to have either the attribute of acceptability or the attribute of defectiveness, and the inspection system does not depend upon the degree of acceptability or the degree of defectiveness [1.4].

The alternative system, known as inspection by variables, does take the degree into account, and works by considering measurements made on the inspected articles.

Sometimes a feature for inspection must be considered as an attribute where no measurement is possible. This occurs in, for example, inspection for the presence or absence of a particular component in an assembly. Either the component is there, or it is not. Measurement on a continuous scale is impossible. This is, therefore, essentially an attribute.

Where measurements are possible, however, either approach may be used. Measurements may be taken and used in a variables approach; or measurements may be taken and then be used as attributes by classifying each article, on the basis of its measurements, as acceptable or defective; or thirdly, 'go, no-go' gauging may be used.

instead of measuring, in which case the information is in the attributes form immediately without passing through the measurement stage, although there is a continuous scale that could have been used for taking measurements.

BS 6001 is concerned only with attributes inspection, either where attributes must be used, or where attributes are used although variables could be. It is not relevant if it is desired to use variables as such, but MIL-STD-414, 'Sampling procedures and tables for inspection by variables', may be useful in such a situation (see also 43).

6. PRESENTATION OF PRODUCT

For the purpose of sampling inspection it is necessary to distinguish three different ways in which a product may come forward for inspection:

(1) The product may be presented by the manufacturer, at the time of manufacture, made up into batches, where a sequence of batches is to be presented in a logical order. In this situation it is possible to watch the series of sampling results from successive batches, to change the sampling plan when the quality being offered makes a change desirable, and to use the inspection in such a way as to give the manufacturer an incentive to keep his production up to the required quality.

(2) The product may be presented by the manufacturer as a continuous sequence, where batching is either impossible or undesirable. In a sense, this may be considered as a special case of category (1), in which the batch size is equal to one. Since it is impossible to sample from a batch size of one, this calls for quite a different technique.

(3) The product for inspection may be a single isolated batch, or just a few isolated batches, as distinct from a sequence. This may occasionally happen at the time of manufacture but is more likely to arise when inspection of the product in store is to be performed at a later date. In this case there is no question of using the evidence of recent batches to change the sampling plan and the inspection cannot be used as an incentive to anyone. Different techniques are again necessary.

The system of BS 6001 is designed primarily for the situation of category (1) but, as explained in 36, it may also be used for category (3). BS 6001 is not relevant to category (2), for which a plan of the type known as 'continuous sampling' is required; MIL-STD-1235 may be useful for this purpose (see 43.4).

7. DESCRIPTION OF SPECIFICATION

BS 6001 may be considered as consisting of three parts, namely the procedure (pages 4 to 8), the master tables (Tables I to IX, pages 9 to 29) and the extended tables (Tables X-A to X-S, pages 30 to 62). Appendix A, page 63, extends the text of pages 4 to 8 and pages 64 to 65 extend the master tables on pages 9 to 29.

The procedure defines the terms used and gives rules for the operation of sampling inspection.

The right-hand pages of the extended tables repeat information already given in the master tables. It proves useful in practice to have this information available in two different forms of layout; sometimes one layout is the more useful, sometimes the other.

8. DRAWING A SAMPLING PLAN FROM THE TABLES

8.1 Before drawing a sampling plan from the tables it is necessary to know five things, as follows:

(1) The acceptable quality level (or AQL).

(2) The inspection level.

These two terms are explained later (11, 12, 13, 38 and 39). In general they will be laid down for a particular product at the beginning of a contract and will remain constant throughout the run of that contract. For the moment, they will be considered simply as two symbols that are required to be known in order to find the correct place in the tables.

(3) Whether normal, tightened or reduced inspection is to be used.

This is decided by studying the sampling results of the last few batches, and is explained in detail later (17, 18, 19, and 21); for the moment it will be assumed that normal inspection is being used.

(4) Whether single, double, multiple or sequential sampling is to be used.

How to decide this is also explained later (28). Usually the same form of sampling will be used for all the successive batches in a production run, but this is not essential—a change may be made when desired. For the moment we shall assume single sampling.

(5) The batch size.

8.1.1 *Example (3).* Suppose the AQL is 1.0, the inspection level is II and the batch size is 2500.

The first requirement is the sample size code letter (usually called simply the code letter, for short). This is merely an indexing device to enable reference to be made from one part of the tables to another. For a batch size of 2500 and inspection level II, Table I gives the code letter as K.

In Table X-K-2 on page 49 it is found that the sample size for single sampling is 125.

AQLs for normal inspection are given along the top of the table, and under the value 1.0 we find the numbers 3 and 4 given under the headings Ac and Re.

The sampling plan required is:

sample size 125

acceptance number 3

rejection number 4

Alternatively, the appropriate master table, Table II-A on page 10, SINGLE NORMAL, could be used. Against code letter K is found sample size 125; and in the column for AQL 1.0 are found the acceptance and rejection numbers 3 and 4 as before.

8.1.2 *Example (4).* Suppose the AQL is 0.40, the inspection level is I and the batch size is 230. Table I gives the code letter as E.

The letter E is found on page 39, but this page has no column for AQL 0.40. Instead, the symbol of an inverted triangle appears for AQLs less than 1.0. This triangle refers to the footnote 'Use next subsequent sample size code letter for which acceptance and rejection numbers are available'. If the triangle is thought of as an arrowhead, it is pointing towards the edge of the page to be turned. This leads to letter F where again AQL 0.40 is not given, and in

to letter G where the required plan is:

sample size 32
acceptance number 0
rejection number 1

Had the master table on page 10 been used, it would similarly have been found that there was no plan for letter E and AQL 0.40, but a downward-pointing arrow would have directed us to letter G instead.

8.2 It is very important to remember that if a triangle or series of triangles directs you from one page to another of the extended tables, or an arrow directs you from one row to another of the master tables, the sample size to be used is the one given for the new page or the new row arrived at and not the one given for the original page or row [9.4].

Where upward-pointing arrows or triangles are found the meaning is precisely similar. The triangles again point to the edge of the page to be turned.

8.2.1 Example (5). Suppose the AQL is 0.015, the inspection level is III and the batch size is 120. Table I gives the code letter as G, but referring to the tables a series of triangles leads to letter P before a plan is found. The required plan has a sample size of 800 which exceeds the batch size.

In this case the entire batch of 120 has to be taken as the sample. The acceptance and rejection numbers remain 0 and 1.

9. DEFECTS AND DEFECTIVES

9.1 It is possible to use sampling plans to control either the number of defects or the number of defectives. A defect is a deviation from requirements, whereas a defective is a unit of product that contains one or more defects.

For example, suppose that a ball-point pen fails to write. The failure to write is a defect; the pen is a defective.

The distinction is of no importance if an article has no more than one defect, but as soon as multiple defects arise the distinction is essential. If one article has three things wrong with it, there are three defects but only one defective.

9.2 The quality of any given quantity of product is expressed either as the per cent defective or as the number of defects per hundred units.

9.2.1 Example (6). Suppose there is a batch of 500 articles. Of these 480 are acceptable, 15 have one defect each, 4 have two defects each, and one has three defects.

The per cent defective is given by the formula:

$$100 \times \frac{\text{number of defectives}}{\text{number of units of product}} \\ 100 \times \frac{20}{500} = 4$$

That is, the batch is 4 % defective.

The number of defects per hundred units is given by the formula:

$$100 \times \frac{\text{number of defects}}{\text{number of units of product}} \\ 100 \times \frac{26}{500} = 5.2$$

That is, the batch has 5.2 defects per hundred units.

9.3 BS 6001 states that AQL values of 10 or less may be expressed either in per cent defective or in defects per hundred units, whereas values over 10 may be expressed only in defects per hundred units [4.5]. Which is to be used is a matter for individual consideration in each particular case. The important thing is that it must be considered and specified beforehand—not left until a sample has been inspected. Factors to be taken into account in making the decision are as follows:

(1) Inspection for per cent defective assumes that if an article is at all defective, then the number of defects it contains is of no further importance. An article with one defect is bad; an article with three defects is also bad, and no distinction need be made between them.

Inspection for defects per hundred units, on the other hand, assumes that finding an article with three defects should worry us to the same degree as finding three articles with only one defect each.

(2) Inspection for defects per hundred units assumes that the possible defects are independent of each other. Suppose that there are two possible defects, say, incorrect length and incorrect diameter. If these two defects are independent, it means that if all the units produced were taken and divided into two groups according to whether the length was defective or not, then the per cent defective for diameter would be found to be the same in each of these two groups; or, alternatively, if they were divided into two groups according to whether the diameter was defective or not, then the per cent defective for length would be the same in the two groups. It can be shown mathematically that these two procedures are equivalent.

If two defects are not independent then they are said to be correlated. If the diameter is more often defective among the units defective for length than among those correct for length, then the length and diameter defects are positively correlated. Conversely, if the diameter is less often defective among the units defective for length, then the two defects are negatively correlated.

Negative correlation of defects is not common. It is rare for the existence of one defect to reduce the chance of another. Positive correlations are more common, and may arise either because one defect directly causes another, or because some common cause acts to produce both of them.

If inspection for defects per hundred units is to be used, it is desirable to consider possible correlations and decide whether any pairs of defects are likely to be highly correlated, in which case it should be laid down that the occurrence of both is to count as only one defect. Inspection for per cent defective avoids this difficulty.

(3) If the AQL is small, say less than 2.5, then the decision may be made largely on grounds of administrative convenience, since the effects of plans specified either way will be almost identical. In the AQL range 2.5 to 10 some difference will be apparent, a defects per hundred units plan being rather more severe than the equivalent per cent defective plan.

(4) It would be better for an inspection station to use a constant method rather than change from one to the other. If, for instance, a high proportion of the AQLs in a particular field had values greater than 10 then it is better to use defects per hundred units.

hundred units must be used, then that method should be used throughout.

(5) From the point of view of keeping records which will be useful later as giving a complete quality history, defects per hundred units may be preferred, as the records will then contain information on all defects, whereas some defects may escape the record if the per cent defective approach is adopted.

(6) The per cent defective approach may sometimes save work by allowing inspection of a particular unit of product to be curtailed as soon as a defect has been found. There are not many situations, however, where the saving is likely to be substantial, and curtailment is not recommended when the sampling procedure is being used to control the process average (33) of the production.

9.4 Once the decision has been taken, the AQL should be defined in terms of that decision. For this reason Examples (3), (4) and (5) are incomplete, for the AQL values are there taken as pure numbers, and the acceptance and rejection numbers are in consequence taken as pure numbers also. The examples are for demonstrating how to draw a sampling plan from the tables but would be meaningless in practice.

9.4.1 Example (7). In Example (3) the AQL is 1.0 and the sampling plan is:

sample size 125
acceptance number 3
rejection number 4

The AQL must be defined, however, in terms of defectives, or of defects.

If the AQL were 1.0 % defective, the sampling plan would be:

sample size 125
acceptance number 3 defectives
rejection number 4 defectives

If the AQL were 1.0 defect per hundred units, the sampling plan would be:

sample size 125
acceptance number 3 defects
rejection number 4 defects

The tables, it will be seen, are used in precisely the same manner in either case.

9.5 The discussion in the remainder of this Guide will be in terms of inspection for defectives (except where AQL values are specifically greater than 10). When desired it may be read in terms of inspection for defects, by replacing 'defective' by 'defect' and 'per cent defective' by 'defects per hundred units'.

10. SINGLE SAMPLING

10.1 Each single sampling plan, such as those described in the previous clauses, consists of three numbers—the sample size, the acceptance number and the rejection number. The way to operate the plan is to draw from the batch, at random, a sufficient number of units of product to make up the sample size. The units of product drawn are then known individually as 'sample units', and collectively as 'a sample'.

The sample is inspected and the number of defectives discovered is counted. If the number of defectives is less than, or equal to, the acceptance number, the entire batch is to be accepted, with the exception of any sample units that are found to be defective, which should be rejected.

If, on the other hand, the number of defectives is greater than, or equal to, the rejection number, the entire batch is to be rejected and returned to the manufacturer (unless otherwise agreed) [10.1.1].

Since, in a single sampling plan, the rejection number is always one unit greater than the acceptance number (with the exception of reduced inspection which will be dealt with later—21), a positive decision to accept or reject must always be reached by this procedure.

10.1.1 Example (8). Gudgeon pins are to be inspected for their high and low diameter. We have the following details:

AQL 1.5 % defective
inspection level II
normal inspection
single sampling
batch size 1400

The tables give the sampling plan as:

sample size 125
acceptance number 5 defectives
rejection number 6 defectives

A sample of 125 pins is drawn at random from the batch of 1400 and inspected. 122 pins are found to have diameters within the specified limits, 2 have diameters which are above the upper limit, and one below the lower limit. There are thus 3 defectives in the sample. These 3 are rejected, but since 3 is less than the acceptance number—5—the rest of the batch is accepted.

11. MEANING OF ACCEPTABLE QUALITY LEVEL

11.1 The AQL is the 'only just acceptable' quality; it is the poorest quality that can be considered acceptable as the process average, that is the average quality level of the production [4.2 and 4.3].

It would be preferred, of course, that every batch produced should be better than the AQL, but the AQL is defined in terms of the average. If the average quality being produced (that is the average per cent defective over a number of batches) is at least as good as the AQL, then the product can be regarded as satisfactory.

If there were some way of knowing the precise per cent defective of each batch presented, all those would be accepted which were better than the AQL, and all those rejected which were worse. In practice the batches are sentenced on the best knowledge available, but it is well to bear in mind that the AQL is the border line that would be used if it could be, and for which the sampling plans are a substitute.

11.2 The fact that an AQL is specified should not be taken to imply that a proportion of defectives up to the specified value is completely acceptable. It is always better to have *no* defectives than any proportion whatever, and the more the proportion can be reduced below the AQL the better. The manufacturer does not have the right knowingly to supply any defective product [4.4 and 4.5].

find it to his advantage in the smooth operation of the scheme to control his manufacturing processes so that the percentage of defectives in the submitted batches is better than the AQL. If he can make it much better, rather than only marginally better, this will be to his own advantage as well as to the customer's.

11.3 It should be noted that the AQL is related to the quality required in the product—it is not a description of the sampling plan. Thus statements sometimes heard, such as 'this sampling plan has an AQL of 4 % defective', are meaningless and misleading.

On the other hand, there would be nothing wrong with 'we are using this sampling plan because the AQL for this product is 4 % defective'.

12. PREFERRED AQLs

12.1 The tables give 26 values of AQLs ranging from 0.010 (i.e. 1 defective per 10 000 units of product) to 1000 (i.e. 1000 defects per 100 units of product, or an average of 10 defects per unit). These 26 values are chosen so that each is approximately one and a half times as large as the previous one (the average ratio is in fact the fifth root of 10, or 1.585).

When the specified AQL for inspecting any given product is one of these preferred AQLs the tables may be used. If, however, a specified AQL is not a preferred AQL the tables are not applicable [4.6].

In these circumstances reference should be made to whoever specified the AQL, with a request to have it examined to see whether a preferred value would be satisfactory. If not, then a sampling plan must be designed specially for the particular AQL required. (See 40.)

The very high values of AQL, 100 and above, are not likely to be used often, since they imply that a product in which every unit contains defects may be considered satisfactory. Clearly this could be so only if the defects being sought were of a minor nature, and the unit of product was something fairly complex, such as a complete vehicle.

12.1.1 Example (9). In the inspection of cloth, to be made up later into clothing, the unit of product might be a

considerable area of cloth. In the inspection for minor weaving faults, an average of 4 faults per square metre might well be acceptable, in which case an AQL of 400 defects per hundred square metres could be specified.

13. MEANING OF INSPECTION LEVEL

13.1 The inspection level defines a relationship between batch size and sample size. The tables are planned so that when the batch size is large the sample is, in general, larger than when the batch size is small. It does not, however, get larger in proportion—for a large batch the sample is a smaller proportion than for a small batch.

Table I gives three general inspection levels numbered I, II and III, and four special inspection levels, numbered S-1, S-2, S-3 and S-4. The general levels will be the most often used, and it is laid down that Level II will be used unless one of the other levels is specified [9.2].

Level I gives rather less than half the sample size of Level II, whereas Level III gives about one and a half times the sample size of Level II.

13.1.1 Example (10). For a batch size of 600, the inspection levels are:

Inspection level	Code letter	Sample size (single sampling)
I	G	32
II	J	80
III	K	125

It should be remembered, however, that for certain AQLs the arrows in the table will lead to sample sizes different from these.

13.2 A complete table of sample size as a proportion of batch size would need to take into account the AQL also, because of the arrows. Even for a given value the relationship is not a smooth one, since only certain values of the sample size are available, whereas all possible batch sizes have to be allowed for. As a result such a table would tend to confuse rather than to enlighten.

In Table 1, however, may be found a useful summary of the position.

TABLE 1. RELATIONSHIP BETWEEN SAMPLE SIZE AND BATCH SIZE FOR THE THREE GENERAL INSPECTION LEVELS

Sample size as percentage of batch size (single sampling; normal inspection)	Level I	Level II	Level III
	batch size	batch size	batch size
Not more than 50%	at least 4	at least 4	at least 10
Not more than 30%	at least 7	at least 27	at least 167
Not more than 20%	at least 10	at least 160	at least 625
Not more than 10%	at least 50	at least 1 250	at least 2 000
Not more than 5%	at least 640	at least 4 000	at least 6 300
Not more than 1%	at least 12 500	at least 50 000	at least 80 000

NOTE: This table should be regarded as an indication only. The values of batch size quoted are such that all larger sizes meet the required condition. In most cases some smaller batch sizes also meet it, but in every case a batch size of one unit less than that quoted above fails to meet it.

The figures quoted assume that the AQL is not such as to necessitate a sample size that fails to meet the condition.

13.3 The special inspection levels are designed for situations where the sample size must be kept small. They should not be specified without carefully examining their implications, in terms of sampling risks, by a study of the O.C. curve (see 15).

There is a note in 9.2 of BS 6001 which says 'In the designation of inspection levels S-1 to S-4, care must be exercised to avoid AQLs inconsistent with these inspection levels'. The point is that the main purpose of the special inspection levels is to keep samples small where this is really necessary. For instance, the code letters under S-1 go no further than D, equivalent to a single sample of 8, but it is no use specifying S-1, in the hope of keeping the sample size down to 8 or less, if the AQL is 0.10 for which the minimum sample size is 125.

13.4 The amount of information gained from examining a sample depends upon the absolute size of the sample, *not* upon the percentage of the batch that is examined. It is sometimes asked, therefore, 'Why is the sample size made to depend upon the batch size?'.

There are three reasons:

(1) Correct random selection (see 31) is more difficult to ensure if the sample is too small a proportion of the batch.

(2) When there is more at stake, it is more important to take the right decision. Proper use of the tables leads to the result that good batches become more likely to be accepted as the batch size increases, whereas bad batches conversely become more likely to be rejected.

(3) With a large batch a sample size can be afforded that would be uneconomic for a small batch, e.g. a sample size of 80 from a batch of 1000 may be easy to justify economically, where a sample of 80 from a batch of 100 would be relatively expensive.

14. THE SAMPLE SIZES

The sample sizes given in BS 6001 for single sampling form a series (like the series of AQL values) in which each number is about 1.585 times the preceding one. This means that the multiplication, AQL times sample size, gives a result that is approximately constant on diagonals of Table II-A, which leads to a self-consistent table if acceptance numbers are also taken as constant on diagonals.

This feature was helpful in designing the tables rather than being directly helpful in using them, but the resulting pattern does mean that the tables lend themselves to the construction of convenient summaries and of special nomograms or slide-rules that could be convenient on occasions. See, for example, 42 and Figs. 12 and 13.

15. OPERATING CHARACTERISTIC CURVES

15.1 An operating characteristic curve (O.C. curve) is a graph showing what any particular sampling plan can be expected to do in terms of accepting and rejecting batches [11.1].

A specific sampling plan can be operated in ignorance of the properties of its O.C. curve. A clear understanding of the implications of the O.C. curve is, however, essential to the intelligent application of acceptance sampling and for such tasks as setting the inspection level, deciding whether to put limits (and, if so, what limits) to permitted batch sizes, etc.

An O.C. curve refers to a particular sampling plan. Each possible plan has its own unique curve, and it is the comparison of O.C. curves that enables one sampling plan to be compared with another. Each point on the curve for a particular sampling plan shows against the horizontal scale a value of percentage defective, and against the vertical scale the percentage of batches that may be expected to be accepted if batches from a process producing that percentage defective are offered for acceptance and the sampling plan in question is applied.

15.1.1 Example (11). For code letter L and AQL 1.5 % defective, the following plan (for single sampling and normal inspection) is found on page 51 of BS 6001:

sample size 200

acceptance number 7 defectives

rejection number 8 defectives

On the facing page (page 50 of BS 6001) is found the O.C. curve of this plan on Chart L. The curve is marked 1.5, the AQL value, to distinguish it from the curves for other AQLs on the same chart. This curve is reproduced in Fig. 1, which shows also the method of interpreting any particular point on the curve. Suppose it is wished to know what will happen if a manufacturer submits a large number of batches all from a process producing 3 % defective and this plan is applied to them.

A vertical line is raised on the graph at the 3 % defective point, and where it meets the O.C. curve a horizontal line is taken to see where it meets the vertical scale. In this case it does so at approximately the 75 % point, which shows that about three out of every four batches will be accepted under the given circumstances and about one out of every four rejected.

Each point on the curve can be interpreted in a similar way.

In addition to Chart L on page 50 there also appears Table X-L-1, which gives tabulated values from which the curves were drawn. From these certain points on the curve can be derived more accurately than by eye from the curves themselves. The left hand column in the table refers to the vertical scale of the charts while the figures given below each AQL value refer to the horizontal scale.

In the 1.5 column, for example, it is found that if batches from a process producing 1.99 % defective are offered, 95 % of them will be accepted if the given plan is used, whereas if batches from a process producing 5.89 % defective are offered, only 10 % of them will be accepted, and so on for the other points given.

Now, suppose that a manufacturer submits 50 batches and they are all inspected using this plan. Suppose, further, that of the 50 batches:

10 batches come from a process 0 % defective

10 batches come from a process 2.3 % defective

10 batches come from a process 3.5 % defective

10 batches come from a process 6 % defective

10 batches come from a process 10 % defective

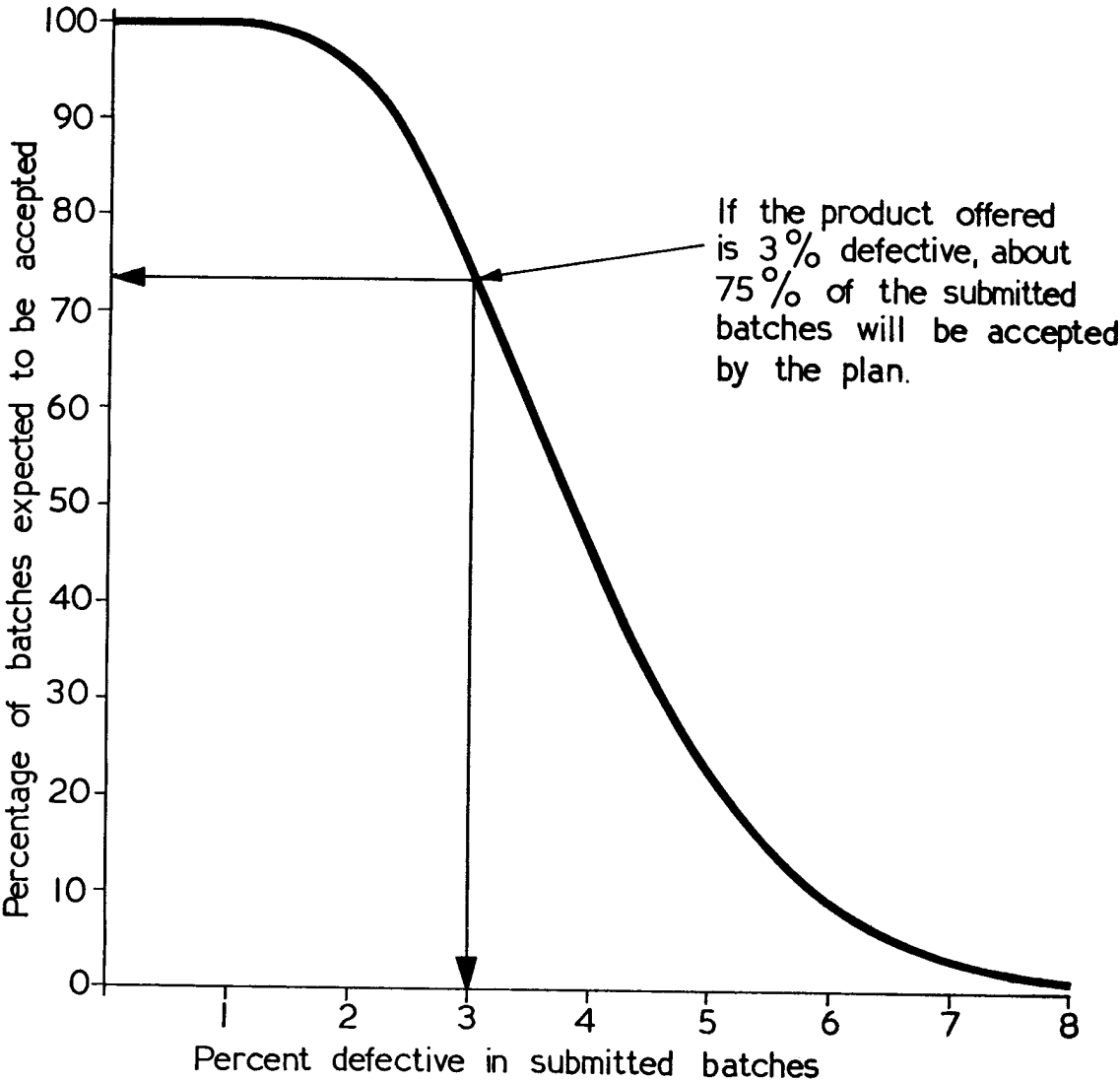
The expected result can be deduced from the O.C. curve in Fig. 1 and is shown in Fig. 2. After the inspection the following batches have been accepted:

10 batches of 0 % defective

9 batches of 2.3 % defective

6 batches of 3.5 % defective

1 batch of 6 % defective

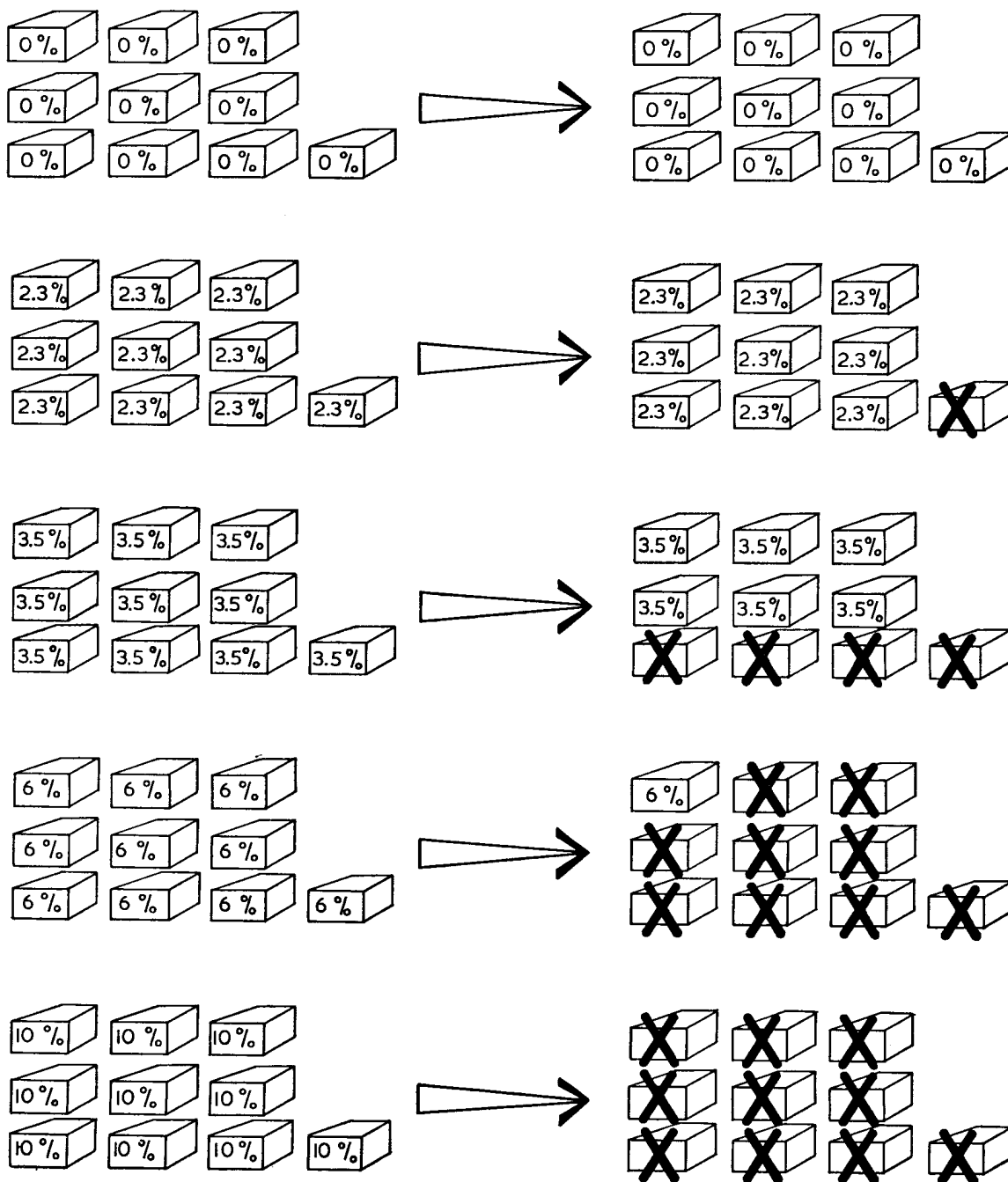


sample size 200
acceptance number 7
rejection number 8

Fig. 1. Operating characteristic curve of a single-sampling plan

BATCHES OFFERED FOR ACCEPTANCE

RESULT OF OPERATING SAMPLING PLAN



sample size 200
 acceptance number 7
 rejection number 8

Fig. 2. The effect of a single-sampling plan

and the following rejected:

- 1 batch of 2.3 % defective
- 4 batches of 3.5 % defective
- 9 batches of 6 % defective
- 10 batches of 10 % defective

Several points should be noted:

(1) The submitted batches had an average quality of 4.36 % defective. The accepted batches have an average quality of 1.83 % defective. The rejected batches have an average quality of 7.10 % defective. The sampling plan has, therefore, made a considerable difference to the accepted quality, although in this particular case it has not quite achieved the AQL.

(2) This difference cannot be expressed as an overall figure, since it depends upon the quality of submitted batches. A particular case of 50 batches has been examined, but if another 50 batches had, say, 25 batches from a process 0.5 % defective, and 25 batches from a process 2 % defective, a different picture would be obtained, although it could be derived from the O.C. curve in just the same way.

(3) The quality improvement has come from accepting and rejecting entire batches. The quality of each individual batch remains unchanged. The one batch of 6 % defective that was accepted, for instance, is still 6 % defective. (It is true that a few defectives may have been found in its sample and been individually rejected, but this difference is trivial.)

(4) The O.C. curve shows the percentage of batches 'expected to be' accepted, not the percentage 'that will be' accepted. This is because, in the short run, there is likely to be some deviation from the expected figures. The expected figures are averages that will be substantially true in the long run, but are unlikely to be realized precisely over only a short sequence of batches.

(5) The figures derived from an O.C. curve are valid, irrespective of the order in which the batches are presented. In Fig. 2 the batches are shown, for clarity, segregated into classes, but these batches could be mixed up and taken in any order whatever. The expected results, i.e. which batches were accepted and which rejected, would be unchanged. (This is always true when merely interpreting the O.C. curve of one particular sampling plan. If the sampling results are used to give an indication of when to change to another plan, the order of batches is important, as will be seen later.)

(6) Points on the O.C. curve are relevant in any particular case only in so far as batches of those qualities are offered. For instance, the O.C. curve shows that if batches from a 4 % defective process were offered, about 44 % of such batches would be accepted, but this is irrelevant to our particular case—no such batch was offered, so none could be accepted.

(7) Examination has shown what the sampling plan will do under particular circumstances. For this purpose a knowledge has been assumed of the true percentage defective in each batch. In practice this would not be known. If it were, the batches could be sentenced directly instead of using a sampling plan. It will not be known, therefore, that one of the accepted batches is 6 % defective, that ten are perfect, and so on—it will simply be known that they have been accepted.

(8) It is helpful to regard the horizontal scale of an O.C. curve as indicating the quality level of the production process. Individual batches will vary a little in quality around this quality level as an average. Under these circumstances, the O.C. curve is entirely independent of the batch size, which can be ignored in so far as the O.C. curve and its consequences are concerned.

15.2 A study of the O.C. curves given in the specification will show that when the acceptance number is zero the upper end of the curve is rather difficult to interpret accurately. There is, however, a simple approximate formula for this upper end when the acceptance number is zero, accurate enough for practical purposes whatever the sample size.

The formula is:

$$\begin{aligned} &\text{percentage of batches expected to be accepted} \\ &= 100 - (\text{sample size}) \times (\text{per cent defective in} \\ &\quad \text{submitted batches}). \end{aligned}$$

Note that this formula is valid only for acceptance number zero, and only for the upper end of the curve, i.e. percentage of batches expected to be accepted not less than 80.

15.2.1 Example (12). We have AQL 0.40 % defective, code letter G. The sampling plan is:

sample size 32
acceptance number 0 defective
rejection number 1 defective

What is the percentage of batches expected to be accepted at the AQL? The answer is $100 - (32 \times 0.40)$ % of batches = 87 % of batches.

15.2.2 Example (13). In the same circumstances what would have to be the per cent defective in submitted batches for 95 % of batches to be accepted? Turning the formula round:

$$\begin{aligned} &\text{per cent defective in submitted batches} = \\ &= \frac{100 - 95}{32} \% \text{ defective} \\ &= 0.156 \% \text{ defective} \end{aligned}$$

16. BATCHES

16.1 The responsible authority has the right to specify what is to be the batch size [5.4], but it clearly makes sense that where possible this should be done in consultation with the manufacturer, so that a figure that is mutually convenient may be chosen. Certainly the specification of the batch size (and other parameters of the sampling plan) should never be done in ignorance of the production process. It is not essential that an inviolable figure should be chosen, although it will nearly always be desirable that upper and lower limits to the batch size should be specified.

16.2 From the sampling inspection point of view there is an advantage in large batches, since from a large batch it is possible to take a large sample, thereby achieving better discrimination between good batches and bad ones. With large batches the sample is a smaller proportion of the batch than with small batches for the same AQL (see also 20).

This 'large batch' policy should not be overdone, however. If the making-up of a large batch necessitates the putting together of smaller batches which could have remained separate, then a large batch is advantageous only if the smaller batches are of a similar quality. If there is likely to be any substantial difference between the qualities of the smaller batches, then it is much better to keep them separate.

For this reason batches should consist of units of product produced under essentially the same conditions [5.2].

16.2.1 Example (14). A manufacturer is making articles which are inspected under the following conditions:

AQL 2.5 % defective

inspection level II

normal inspection

single sampling

He has two machines, say A and B. Each machine produces 900 articles an hour, and it is decided that one hour's production from one machine is to be a batch. Reference to the tables, for the conditions given above and a batch size of 900, gives the following sampling plan:

sample size 80

acceptance number 5 defectives

rejection number 6 defectives

A suggestion is made that it might be advantageous to change the basis of batching to one hour's production from the two machines taken together, thereby increasing the batch size from 900 to 1800. If this were done the tables show that the sampling plan becomes:

sample size 125

acceptance number 7 defectives

rejection number 8 defectives

Whether this would be advantageous depends upon whether machines A and B are producing to the same quality or not. As a demonstration consider the following three possible cases:

Case 1. Machines A and B are both producing to the same quality of 2.3 % defective. This quality is better than the AQL, so it is desirable that the sampling plan should accept as often as possible.

If the batch size is 900 and the sample size is 80, the O.C. curve shows that just under 99 % of batches will be accepted and just over 1 % rejected. The articles inspected will be 160 per hour.

If the batch size is 1800 and the sample size is 125, the O.C. curve shows that just over 99 % of batches will be accepted and just under 1 % rejected. Only 125 articles will be inspected per hour.

The larger batch size is clearly better.

Case 2. Machines A and B are both producing to the same quality of 10 % defective. This quality is worse than the AQL so it is desirable that the sampling plan should reject as often as possible.

If the batch size is 900 and the sample size is 80, the O.C. curve shows that 20 % of batches will be accepted and 80 % rejected. The articles inspected will be 160 per hour.

If the batch size is 1800 and the sample size is 125, the O.C. curve shows that 8 % of batches will be accepted and

92 % rejected. The articles inspected will be 125 per hour.

Again the larger batch size is clearly better.

Case 3. Machine A is producing a quality of 2.3 % defective, and machine B a quality of 10 % defective.

If the batch size is 900 and the sample size is 80, the O.C. curve shows that about 99 % will be accepted and 1 % rejected of the 'A' batches, while 20 % will be accepted and 80 % rejected of the 'B' batches.

As a whole, therefore,

$\frac{99\% + 20\%}{2}$ of batches will be accepted,

i.e. about 60 % of batches,

and $\frac{1\% + 80\%}{2}$ of batches will be rejected,

i.e. about 40 % of batches.

The accepted batches will have an average quality of:

$\frac{99}{99+20} \times 2.3\% \text{ defective} + \frac{20}{99+20} \times 10\% \text{ defective}$

i.e. 3.6 % defective.

The articles inspected will be 160 per hour.

If the batch size is 1800 and the sample size is 125, the quality of the batches will be $\frac{1}{2}$ (2.3 % defective + 10 % defective), i.e. 6.15 % defective. The O.C. curve shows that 50 % of batches will be accepted, and 50 % rejected. The articles inspected will be 125 per hour.

The larger batch size means less inspection, as in Cases 1 and 2, but there is a price to be paid. Instead of 60 % of batches accepted with an average quality of 3.6 % defective, 50 % of batches are accepted and these are 6.15 % defective.

In either case, of course, such a low acceptance rate would soon alert both the producer and the inspector to the fact that the production was not of the required quality and steps would be required to improve it. If the production from the two machines has been sentenced separately, it will be easy to see where the trouble is, but if the product has been mixed it may not be at all obvious that only one of the two machines is to blame.

This example is exaggerated, of course, in that the qualities from the two machines—2.3 % defective and 10 % defective—are so very different. If they were closer in quality the results of combining the batches would not be so serious, but the principle is the same.

16.3 In practice, a batch very often contains items originating from more than one source. The sources may produce at different levels of quality and each source may not contribute an equal share of the total number of items making up the batch. Typical examples are parts from a multi-cavity mould, from a multi-spindle automatic lathe or from several similar production lines. The production may be so arranged that it is not easy to identify their separate sources without making special arrangements which could be inconvenient and costly; further, it may be necessary to include the production from all such sources in order to make up batches of the required size.

The question may then be asked whether the O.C. curve for a sampling plan from BS 6001 is still valid.