BS ISO 7870-8:2017

BSI Standards Publication

Control charts

Part 8: Charting techniques for short runs and small mixed batches

bsi.

National foreword

This British Standard is the UK implementation of ISO 7870-8:2017.

The UK committee draws users' attention to Figures 8-12. The figure titles suggest they are computer generated when they have actually been drawn by a drawing office. Computer generated figures are preferred, to avoid the time consuming and unnecessary checking of these figures and to more realistically show the outputs that users will encounter.

The UK participation in its preparation was entrusted to Technical Committee SS/4, Statistical Process Management.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Control charts —

Part :
Charting techniques for short runs and small mixed batches

Cartes de contrôle —

Partie : Techniques de cartes pour petites séries et pour petits lots combinés

Reference number
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 69, *Applications of statistical methods*, Subcommittee SC 4, *Applications of statistical methods in product and process management.*

A list of parts in the ISO 7870 series can be found on the ISO website.

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Introduction

It is generally recommended that at least 25 subgroups of data be collected, and plotted, before any constructive analysis can take place to form the basis for establishing standard traditional variables control charts. This represents best practice for the application of *standard* statistical process control (SPC) charts to long production runs of a single product characteristic (for instance, a diameter) or a process parameter (for instance, temperature). However, it presents a problem in many potential applications of SPC.

In the business environment, there is an increasing need for versatility and flexibility in highly efficient systems. These support just-in-time inventories and create greater product variety, with smaller batches and shorter runs. The consequent ever-increasing resets, changeovers, die changes, and so on, bring new challenges to the meaningful application of SPC. These occur at a critical time when the pressure for continual performance improvement has never been greater.

Processes accommodate many part numbers, often of similar shape but different nominal sizes at best, and part configurations having multiple characteristics with different specified nominal values, units of measure and tolerances. For example, a bolt maker with short runs of various size bolts (diameter and length), or a tube extruder with tubes of different size outside diameter, inside diameter and wall thickness. The customary approach is to put a different standard control chart on each characteristic of each part number. The consequences of this administratively cumbersome, product-focused, procedure would include the generation of large numbers of run charts each containing data too sparse to be useful, either for control or improvement.

In the same way that other functions have responded to the challenge, for instance, the introduction of lean methods and single minute exchange of die (SMED) in production, so the SPC facilitating function responds. This situation presents both a problem and an opportunity.

The problem arises because, in many organizations, production runs are often too small to generate enough data to apply standard control charts. This can occur in two ways. Firstly, there is the case where the batch, or lot, size itself is very small. Secondly, there is the situation where the run is very short; for instance, the high speed stamping operation that may run only for a short period. It is frequently not practicable, in either case, to generate enough subgroups to make the control chart meaningful.

The opportunity arises because much current statistical *process* control is actually statistical *product* control, that is, SPC implementation is often product-focused rather than process-focused. Different products that are generated by a single or similar process are looked upon as dissimilar entities. Consequently, sources of process variation can be overlooked when analysing the product orientated control chart. Due to the sparseness of product information in short run, small batch situations, the focus has to be on the common element, the process. Short run SPC provides the means to transform a succession of short run product-related jobs into a long term process. An example is the “jobbing” shop that does not make many of the same part, but has a number of processes that are continually being employed. They turn many shafts, drill many holes, etc., continually. The grouping of drilling, turning, grinding processes and the like, or their corresponding facilities (for instance, machine tools) could make good candidates for the application of short run SPC.

Some basic statistical concepts, terminology and symbols are introduced in this document; however, these are kept to a minimum. The language chosen is that of the workplace rather than that of the statistician. The aim is to make this document readily comprehensible to the extensive range of prospective users and too facilitate widespread communication and understanding of the method.

It is advisable that those who are not familiar with the control chart technique read both ISO 7870-1 and ISO 7870-2 before reading this document.

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Control charts —

Part :
Charting techniques for short runs and small mixed batches

1 Scope

This document describes ways of applying regular variables control charts to short runs and small mixed batches where the sample size for monitoring is restricted to one. It provides a set of tools to facilitate the understanding of sources of variation in such processes so that the processes can be better managed.

The charts described are process-focused rather than product-focused. The user can plot, monitor and control similar characteristics on different items, or different characteristics on an item, on a single control chart.

NOTE 1 The terms short run and small batch size are not well defined. Here, short run and small batch size are taken to mean only a few items are manufactured before a different item is then produced.

NOTE 2 For situations where the subgroup size is larger than one, other standards apply.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3534-2 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.2 Symbols

C_{L} centre line of a control chart

L_{CL} L_{CL_x}, $L_{\mathrm{CL}_{\bar{x}}}$ and L_{CL_R} are the lower control limits for individuals, mean and range, respectively

T target (aim) value

n subgroup size

R the difference between the maximum and minimum of the values

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R_{exp} the expected value of the range of a particular characteristic

R_{moving} moving range, the difference between the maximum and minimum of the consecutive values

S process standard deviation

s realized value of the process standard deviation

u test statistic for set-up acceptance

U_{CL} U_{CL_x}, $U_{CL_{\bar{x}}}$ and U_{CL_R} are the upper control limits for individuals, mean and range, respectively

$\bar{X}$ general value of a quality characteristic of the process mean

$\bar{x}$ realized value of a quality characteristic of the process mean

4 How to select the correct type of Shewhart control chart for continuous variables data

4.1 General

The business aim of statistical process control (SPC) is to control and improve quality, increase productivity and reduce cost. The principal graphical tool of SPC is the control chart. There are three main classes of control charts: Shewhart, cumulative sum (cusum) and exponentially weighted moving average (EWMA).

NOTE Cusum control charts are dealt with in ISO 7870-4 and EWMA in ISO 7870-6.

The Shewhart control chart provides a graphical representation of a process showing plotted values of a representative statistic of a selected characteristic (for instance, the individual value, mean, range or standard deviation), a centre line, and one or more control lines. The control line(s) and centre line are used as a basis for judging the stability of the process, namely, whether or not the process is in a state of statistical control. Control lines are derived from the actual performance of the process and are not to be confused with specified limits or specified tolerances.

Shewhart control charts provide a common language for communicating technical information on the performance of a process. Control charts are effective tools in understanding process behaviour. They distinguish between special and common cause variation. When no special cause is present, the process is said to be in a state of statistical control.

When a process is in statistical control, its capability is predictable and can be assessed. Reducing common cause variation and improving process targeting can enhance process capability.

Potentially, the control chart has wide applicability throughout any organization.

4.2 How to select the correct type of Shewhart control chart for measured data generally

The procedure for selecting a Shewhart type measured data control chart is as follows.

a) If the characteristic to be monitored is ongoing with a targeted constant aim and process spread, refer to ISO 7870-2.

b) If the characteristics do not have a constant aim or process spread, and the sample size is limited to one, see 4.3.

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c) If the characteristics do not have a constant aim or process spread and the feasible sample size is greater than one, specialist guidance should be sought.

This selection procedure is illustrated in Figure 1.

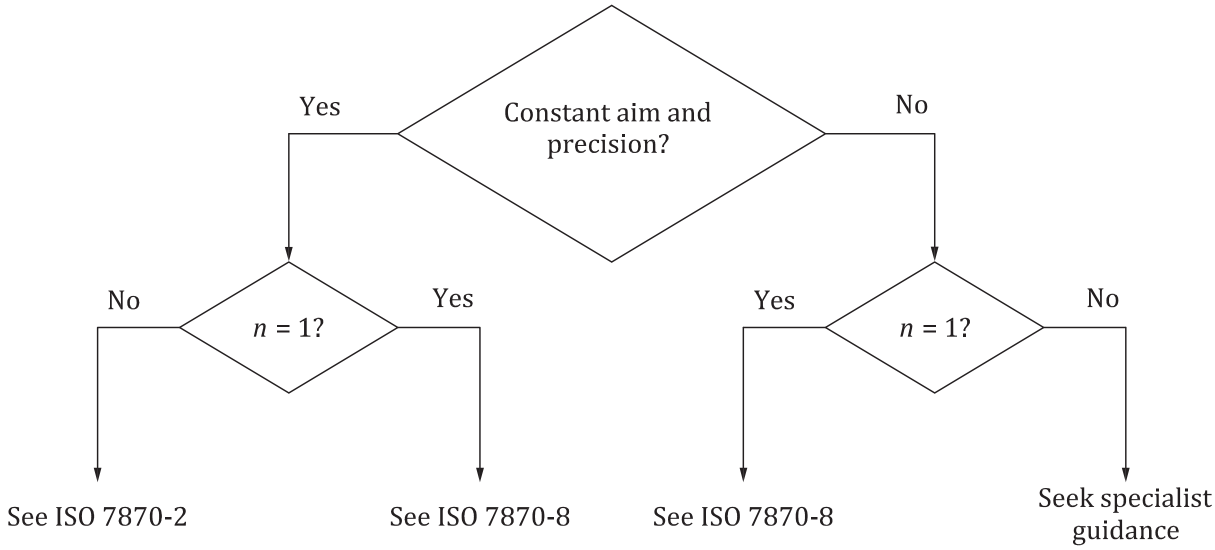

Figure 1 — Shewhart control chart selection flow chart for “measured” data

4.3 How to select the Shewhart control chart when the characteristic does not have a constant aim or process spread

There are a number of Shewhart type control charts available for handling short run and small batch situations where there are expected changes in aim or process spread. These include the following:

a) not constant aim, individual and moving range charts;

b) not constant aim, moving mean and moving range charts;

c) universal, moving mean and moving range charts;

d) universal, individual and moving range charts.

The procedure for selecting the appropriate control chart is illustrated in Figure 2.

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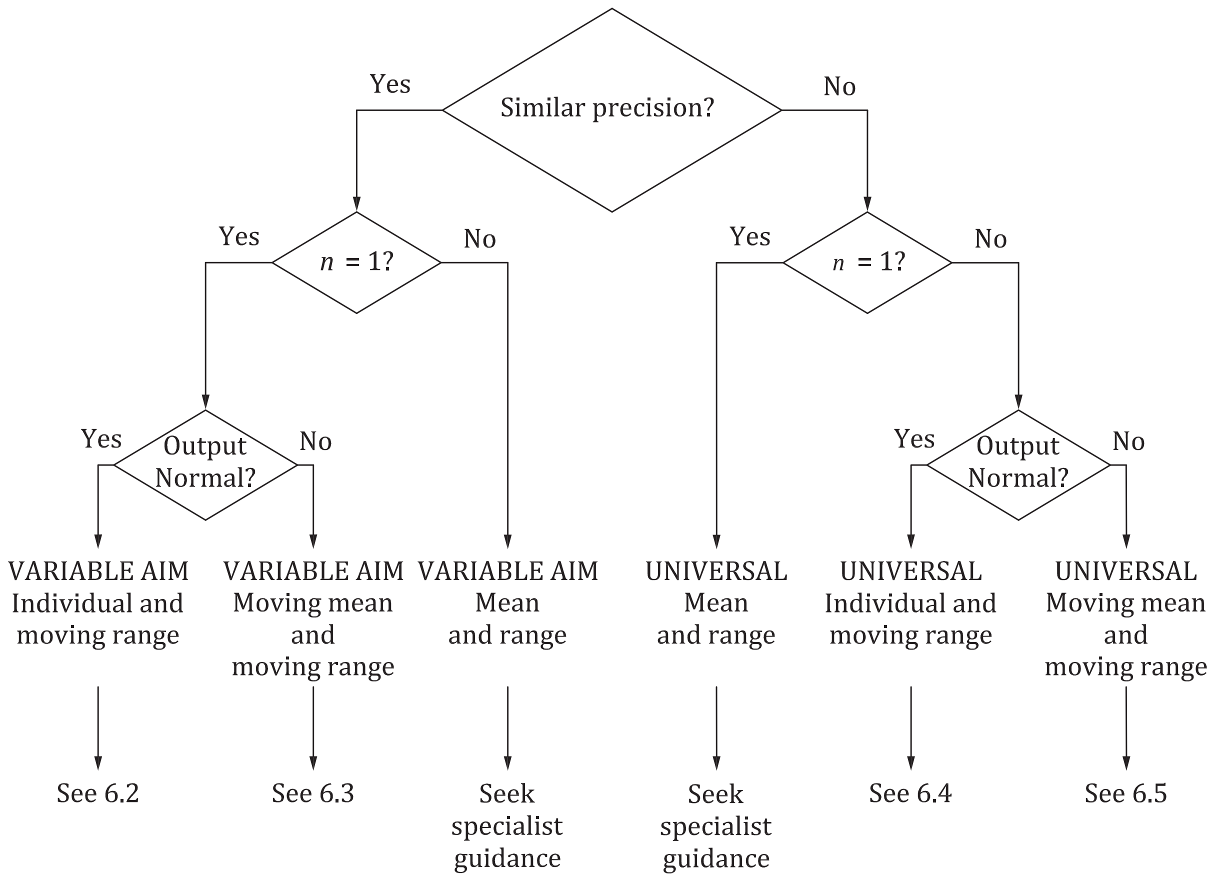

Figure 2 — Control chart selection flow chart for short runs and small batches

Table 1 assists in the interpretation of Figure 2.

Table 1 — Chart selection table for short runs and small batches (subgroup size, *n* = 1)

Parameter or characteristic	Process aim	Process spread	Output	Chart name	Clause reference	*Additional information: Result required*
Single	Dissimilar	Similar	Normal	Variable aim, individual and moving range	6.2	*Quick response to change*
Single	Dissimilar	Similar	Approximately normal	Variable aim, moving mean and moving range	6.3	*Detect trend; smooth data*
Multiple	Dissimilar	Dissimilar	Approximately normal	Universal, individual and moving range	6.4	*Quick response to change*
Multiple	Dissimilar	Dissimilar	Non-normal	Universal, moving mean and moving range	6.5	*Detect trend; smooth data*

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5 How to prepare for short run, small mixed batch control charting

5.1 Focus on the process

Shewhart-styled control charts are usually applied to high volume long run products. One of the consequences of this is that SPC often focuses on statistical product control rather than the indicated statistical process control. This is because process results that are after-the-event product characteristics are frequently monitored and concentrated on rather than the process parameters giving rise to them.

Short run and small batch processes typify the flexible strategy essential to meet world class levels of performance. The key to successful short run and small mixed batch statistical process control is to focus on the process rather than the product. While nominal product characteristics necessarily change in both type and size, the process generating the product frequently stays the same, for instance:

a) the same drilling process produces different diameter and depth holes where the nominal values are not the same;

b) the same heading machine produces bolts with various nominal size heads, lengths and diameters;

c) the same press produces stampings with various nominal slot widths;

d) the same mixing process produces different solutions with different chemical elements and target ratios;

e) the same extruder extrudes tubes with different nominal outer and inner diameters and wall thicknesses;

f) the same coiner produces blanks in multiple cavity dies;

g) the same soldering operation produces small batch size printed circuit board assemblies with different nominal solder strengths per board.

NOTE The examples given relate to engineering processes.

SPC techniques are applicable to any short run or small batch process that is in any way repetitive. Process knowledge transfer is feasible from one run or batch to another. SPC techniques provide the means to transform a succession of short run product data into meaningful information in terms of a single long term process. It achieves this by combining multiple product characteristics involving dissimilar nominal sizes and units of measure, unlike characteristics and of different process spread, into a single, process-based, Shewhart control chart.

Short run SPC usually provides a more informative, effective and efficient alternative to traditional methods, for example:

— 100 % final inspection that is an expensive and after-the-event activity;

— first-off inspection based on a single measurement that provides limited set-up information and does not take into account process changes over time;

— last-off inspection, that is a high-risk strategy, taken after the event, that provides too little information and, too late.

If a separate control chart is produced for each feature and nominal dimension, it is not cost effective and is administratively cumbersome to operate. This will lead to an excessive number of charts being produced and often with too few data points to properly interpret them with no benefit.

5.2 Procedure for grouping similar processes

To effectively group characteristics, a procedure is required that prevents that data coming from significantly different processes to be monitored by the same control chart. If the systematic influences

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are unknown and not compensated for, the unintended consequences are that two or more stable processes create frequent false alarms when monitored in the same chart.

A procedure that combines expert knowledge and data analysis to create groups and adjust them if needed is given in Figure 3.

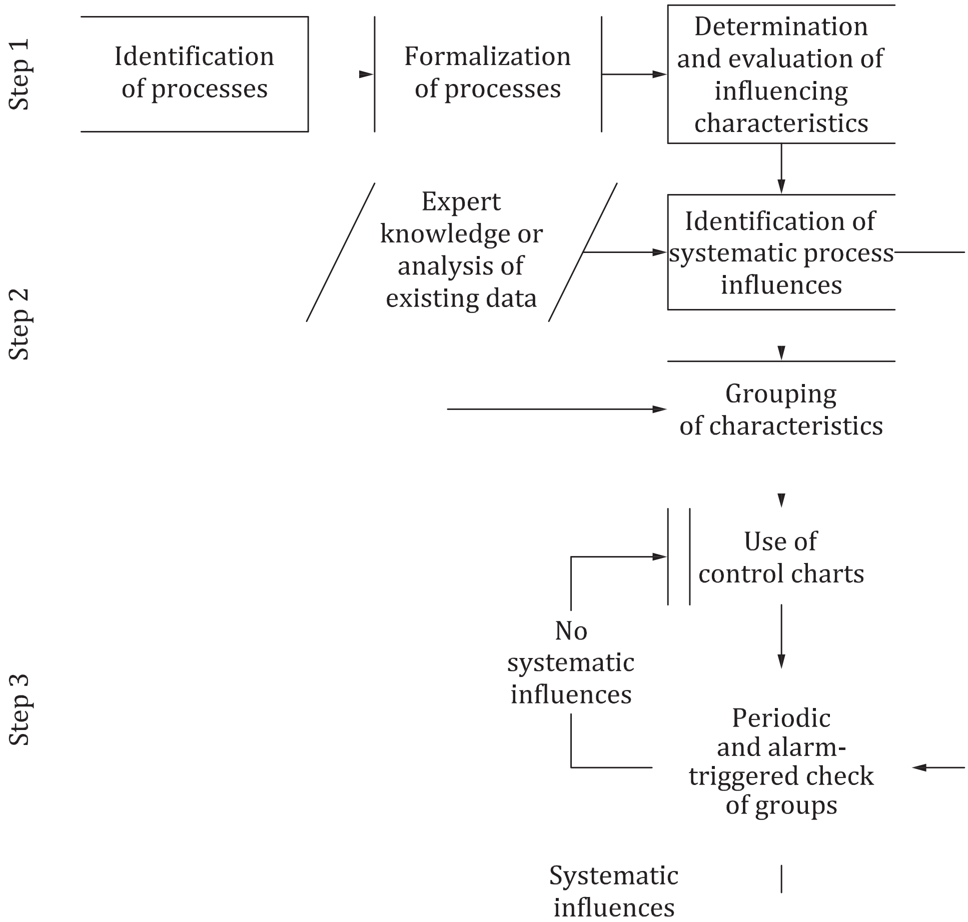

Figure 3 — Procedure for identifying and grouping similar characteristics

a) **Step 1**: First, processes that are potentially "groupable" need to be identified. This can be different processes that follow the same procedure but with varying characteristics, such as nominal/target value, tolerance, material, measurement process, production machine, tool, environmental conditions, etc. Characteristics that vary between processes are plotted in a cause-effect diagram along with their respective parameter space (Figure 4).

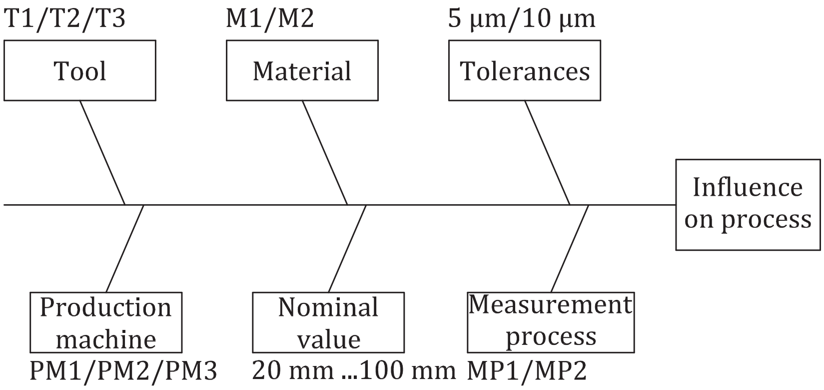

Figure 4 — Cause and effect diagram to establish differences between similar processes

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b) **Step 2**: The next step is to determine if a difference in certain characteristics causes two or more processes to behave significantly different. This information can be obtained, for example, by

   1) expert knowledge/workshops,

   2) simulation,

   3) preliminary experiments, and/or

   4) statistical analysis of existing data about the processes.

   If there are no significant differences or the differences are systematic and can be compensated by normalization and no other practical reasons stand against it, the characteristics can be grouped and joint control charts can be applied.

c) **Step 3**: In the course of the application of control charts, more data are collected and more knowledge is gained about the processes. Therefore, it is wise to periodically recheck that the grouping conditions are still valid. This is especially true if alarms are frequently raised where no assignable cause can be found. To be able to flexibly group and re-group processes, it is important to record the characteristics as metadata along with the measured data so that each measurement value is associable with a group of processes.

EXAMPLE In Table 2, the grouping is done for the characteristics given in Figure 4. Without grouping, 360 combinations have to be monitored. With grouping, the number of combinations to be monitored is reduced to 4. For this example, it is assumed that tools, tolerances and measurement process have no significant effect on the process, the difference in nominal value can be compensated by normalization and the material and production machine have a significant influence on the process which cannot be compensated.

Table 2 — Example of grouping of characteristics

Characteristic	**Tool No.**	**Significant material**	**Tolerance** µm	**Significant production machine**	**Normalized nominal value** mm	**Measurement process**
Group 1	T1/T2/T3	M1	5 to 10	PM1	20 to 100	MP1/MP2
Group 2	T1/T2/T3	M2	5 to 10	PM1	20 to 100	MP1/MP2
Group 3	T1/T2/T3	M1	5 to 10	PM2	20 to 100	MP1/MP2
Group 4	T1/T2/T3	M2	5 to 10	PM2	20 to 100	MP1/MP2

5.3 Typical applications

The short run chart can be applied to product characteristics or process parameters regardless of the type of feature or differences in units of measure and process spread; for instance, a single short run chart can be set up to monitor multiple characteristics such as taper, parallelism, ovality and hardness on a cylinder.

Another application is the small batch identification ticket that travels through the various processing stages of a job. A single short run chart is used to monitor quality performance at the various process stages of a job; for instance, at machining operations, heat treatment, anodizing and painting. At a milling machine, one short run chart can be set up to monitor different operations performed, such as drill, bore and ream in the X, Y and Z axes.

The principles embodied in short run charts can also be applied to situations other than short run, small batch situations; for instance, the gap between a motor vehicle door and body panels where the gap is measured at different locations, A, B, C and D on a single door/body combination. A single chart then obviates the use of four different standard SPC charts, one for each location measured.

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5.4 Preliminary process diagnosis

As with any SPC implementation, it is important to pre-establish the types of major potential sources of variation (dominance) in a process. This will determine not only the SPC approach to be adopted but whether SPC is the correct tool to be applied. As a once-only exercise, certain questions need to be posed and considered about the short run and small batch process. In a manufacturing situation, the most likely principal sources of process variation should be assessed, for instance:

a) source material dominance: where the incoming material or previous operation has a major influence;

b) set-up dominance: where the characteristic is highly reproducible once properly set up;

c) operator dominance: where the process is highly dependent on the skill, care and attention of operational personnel;

d) time dominance: where the process can drift (for instance, with tool wear and lack of replenishment of solution mix ratios);

e) fixture or pallet dominance: where the fixtures or pallets holding the parts are a large source of inconsistency;

f) process parameter dominance: where the output is dependent on process parameters (for instance, depth and speed of cut, temperature of oil);

g) environmental dominance: where the temperature and humidity of the manufacturing area change;

h) information dominance: where variation and nonconformities are caused by frequent job or specification changes or poor measurement information.

5.5 Procedure to establish the correct initial set-up of a process characteristic

5.5.1 Purpose

This procedure determines if the initial dimensional set-up of the mean of a process characteristic is acceptable when it is feasible to measure at least three items.

5.5.2 Scope and limitations

The test is accurate if the values of the process characteristic conform to a normal distribution. If the distribution is not normal, the test will only give an approximate guide.

5.5.3 Reasons for need of procedure

The practice of set-up in a process, based on a single measurement, without knowledge of inherent process or measurement system variability, can have serious consequences. A number of different scenarios can arise. Typical ones are illustrated in Figure 5 and Table 3.

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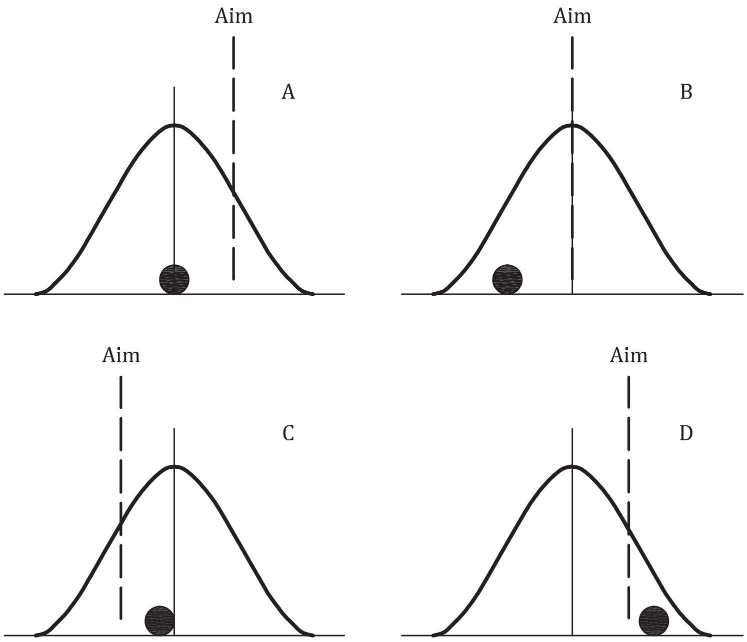

Key
a single setting observation

Figure 5 — Four different scenarios with a single observed measurement

Table 3 — Four scenarios when a single measurement is taken at set-up

	Actual process mean (unknown to setter)	**Set-up measurement reading**	**Adjustment by setter**	
			Set-up (X)	Consequence
A	Process is centred to left of aim	To left of aim (but, unknown to setter, on or near the mean of the distribution)	Right by amount of off-set of measurement to aim	Correct adjustment
B	Process is on target	To left of aim (but, unknown to setter, in lower tail of distribution)	Right by amount of off-set of measurement to aim	The process is moved away from target by the amount of the adjustment
C	Process is centred to right of aim	To right of aim (but, unknown to setter, below the mean of the distribution)	Left by amount of off-set of measurement to aim	The process is moved in the correct direction but by an insufficient amount
D	Process is centred to left of aim	To right of aim (but, unknown to setter, in top tail of distribution)	Left by extent of off-set of measurement to aim	The setter adjusts the process in the wrong direction

5.5.4 Method

a) Record the aim value of the characteristic to be processed.

b) Set up the process initially in the operationally prescribed manner.

c) Produce a sample of at least three items without changing the set-up.

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NOTE Maintaining an ongoing estimate of variability might be possible, and preferable, to relying solely on a tiny current sample. Even if the true variability is a little bit different from one run to another, the smoothing from pooling data will still provide a benefit.

d) Record the sample size (*n*). Measure the individual values (*X*) of the appropriate characteristic on each piece and record them in their production sequence.

e) Calculate the sample mean, $\bar{X}$, and the sample standard deviation, *S*.

f) Calculate the value of $u = \frac{\left(\bar{X} - T\right)}{S}$.

g) Compare *u* with the range of critical Student's *u* values given in Table 4, appropriate to the sample size, *n*, taken.

h) If the calculated *u* is within the range of the critical *u* values given in Table 4, accept the set-up.

i) If the calculated *u* is outside the range of the critical *u* values given in Table 4, readjust the set-up to bring it closer to the target value.

j) Repeat the procedure until the set-up is accepted.

Table 4 — Range of critical set-up acceptance values for *u*

Sample size, *n*	2	3	4	5	6	7	8	9	10
Critical *u*	±4,46	±1,69	±1,18	±0,95	±0,82	±0,73	±0,67	±0,62	±0,58
NOTE There is a 0,1 probability that a process on target can fail this test.									

5.5.5 Example

On a particular process, the aim, *T*, is 4,00, *n* is 3 and the set-up mechanism is graduated in 0,01 steps.

Measurements taken on the three pieces processed after initial set-up are 4,02, 4,00, and 4,02.

Mean is 4,013 3.

Standard deviation is 0,011 5.

Thus, $u = \frac{\left(\bar{x} - T\right)}{s} = \frac{\left(4,013\ 3 - 4,00\right)}{0,011\ 5} = 1,16$.

Table 4 is based on the standard Student's *t* distribution using the test statistic:

$$t = \frac{\bar{X} - T}{S/\sqrt{n}}$$

An estimate of the standard deviation can be made using:

$$S = \sqrt{\left[\frac{\sum\left(X - \bar{X}\right)^2}{n-1}\right]}$$

The calculated *u* = 1,16 is within the range of ±1,69 for *n* = 3, given in Table 4.

Therefore, the process set-up should be accepted without any adjustment.

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5.6 Procedure to pre-establish control limits for SPC charts for short run, small batch, processes

5.6.1 Purpose

This procedure provides information for determining centre lines and control limits for control charts in a small batch or short run situation when inadequate statistical information is available for the measure, or for surrogate product characteristics, items or process parameters.

Prior to using this procedure, it is essential that a preliminary process analysis is conducted in accordance with 5.4.

5.6.2 Scope of application

As with Shewhart-styled control charts, the control limits are based on an expectation of constancy of the mean and standard deviation throughout each small batch or short run. For processes with expected drift, or other peculiarities, specialist guidance should be sought.

5.6.3 Reasons for need of procedure

Meaningful statistical control of short run and small mixed batch processes require rapid establishment of control charts. Consequently, the general recommendation to establish control limits using at least 25 subgroups of data (with a minimum of 10 preliminary subgroups), cannot be followed. To establish appropriate control limits for control charts, it is necessary to have reasonable estimates of the process mean and standard deviation together with knowledge of the distribution. Control limits based, of necessity, on restricted sample sizes are readily estimated using normal probability plots.

5.6.4 Method

After the set-up is judged acceptable, run, measure, and record in production sequence the number of items considered practicable, as a basis for establishing control charts.

a) Plot the individual values, on standard graph paper, in production sequence. If there are obvious abnormalities, seek out the reasons. When there is no obvious abnormality present, proceed with this method.

b) Additional to the manual plotting of values, software programs can be used instead to perform this and other functions.

c) Tabulate the values in ascending order against the percentage plotting positions for the appropriate sample size given in Table 5.

d) Plot the results on a normal probability plot (an example of which is shown in Figure A.5).

e) If it appears reasonable to do so, fit the best straight line through the data points. Extend the lines to the boundaries of the probability paper. Read the centre line of the control chart, for the individual or the mean, from the measurement value corresponding to the 50 % point on the probability scale. Estimate the standard deviation of individuals by dividing the vertical distance represented by the distance between the plotted line intersection with the 50 % point and the 4s scale position, by four. From these estimates of mean, and standard deviation of individuals, a control chart appropriate to the situation is constructed.

f) If it is more appropriate to draw a smooth curve through the data points, a skewed distribution is indicated. See ISO/TR 18532 for further analysis and its interpretation.

g) If it is not reasonable to draw a straight or smooth curve through the plotted points on the probability worksheet, on the basis of the number of measurements initially taken, increase the sample size. Continue until this is achievable or a decision is taken to stop and diagnose the reasons for the situation.

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Table 5 — % probability plotting positions for sample sizes of 3 to 20

	Sample size, *n*																	
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	21	16	13	11	9	8	7	7	6	6	5	5	5	4	4	4	4	3
	50	39	31	26	23	20	18	16	15	14	13	12	11	10	10	9	9	8
	79	61	50	42	36	32	29	26	24	22	20	19	17	16	15	15	14	13
		84	69	58	50	44	39	36	32	30	28	26	24	22	21	20	19	18
			87	74	64	56	50	45	41	38	35	33	30	29	27	25	24	23
				89	77	68	61	55	50	46	43	40	37	35	33	31	29	28
					91	80	71	64	59	54	50	47	43	41	38	36	34	33
						92	82	74	68	62	57	53	50	47	44	42	40	38
							93	84	76	70	65	60	57	53	50	47	45	43
a)								93	85	78	72	67	63	59	56	53	50	48
									94	86	80	74	70	65	62	58	55	52
										94	87	81	76	71	67	64	60	57
											95	88	83	78	73	69	66	62
												95	89	84	79	75	71	67
													95	90	85	80	76	72
														96	90	85	81	77
															96	91	86	82
																96	91	87
																	96	92
																		97

Table 5 is based on plotting positions 100 (i - 3/8)/(n + 1/4), for i = 1, 2, ..., n.

5.6.5 Example

Following acceptance of a set-up based on three measurements, three further items were measured. The six results in production sequence were:

49,94; 50,00; 49,98; 50,11; 49,88; 50,04.

a) Establish a preliminary small batch statistical process control chart.

b) Check for process stability.

A plot of the six results in sequence in Figure 6 does not reveal any obvious peculiarity relating to process stability.

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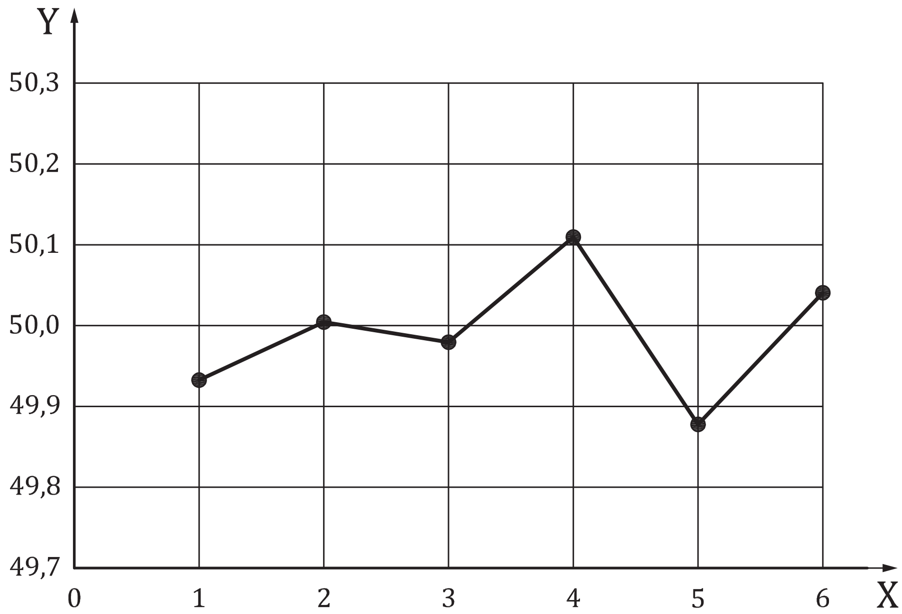

Key

X subgroup number

Y measurement value

Figure 6 — Preliminary process stability check

c) Check for process normality.

The results are now arranged in ascending order and tabulated against % plotting positions in Table 6 appropriate to the sample size in Table 5.

Table 6 — Data for normal probability plot

Measurement	% plotting position
49,88	11
49,94	26
49,98	42
50,00	58
50,04	74
50,11	89

These are plotted on a normal probability worksheet in Figure 7 (see Annex A for reproducible copies of normal probability worksheets).

A straight line is plotted through the data points. The good fit of this line to the data points gives a statistical indication of normality. This, together with prior technical knowledge of the expected behaviour of the process, indicates that the underlying pattern of variation appears to be reasonably normal.

Additionally, with today's software, it is easy to perform statistical tests, such as the ANDERSON-DARLING test to assess for normality of the data.

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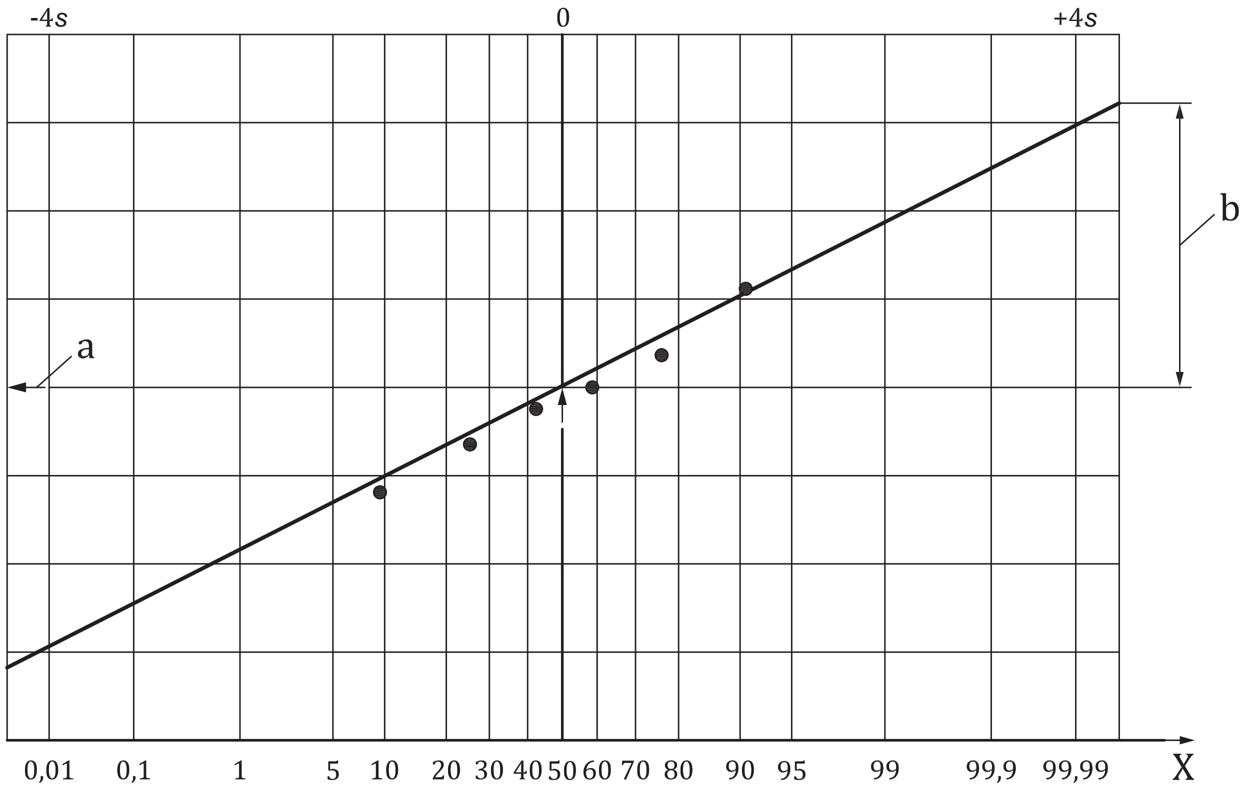

Key

a mean

b 4 standard deviation

X below (%)

NOTE Additional to probability plots, etc., use the target values as the centre line and a historically derived standard deviation to generate control limits.

Figure 7 — Normal probability worksheet

d) Estimate the process mean and standard deviation.

The process mean and standard deviation are estimated from the normal probability worksheet, thus:

Mean: 50,00 (the measurement value corresponding with the intercept of the plotted line and the 50 % probability value).

Standard deviation: 0,08 (a quarter of the distance marked 4 standard deviations in Figure 7).

The same data entered, i.e. mean 49,99, standard deviation 0,0796 0, n = 6, AD = 0,129, p-value 0,959, into a software program gives the following probability plot (Figure 8):

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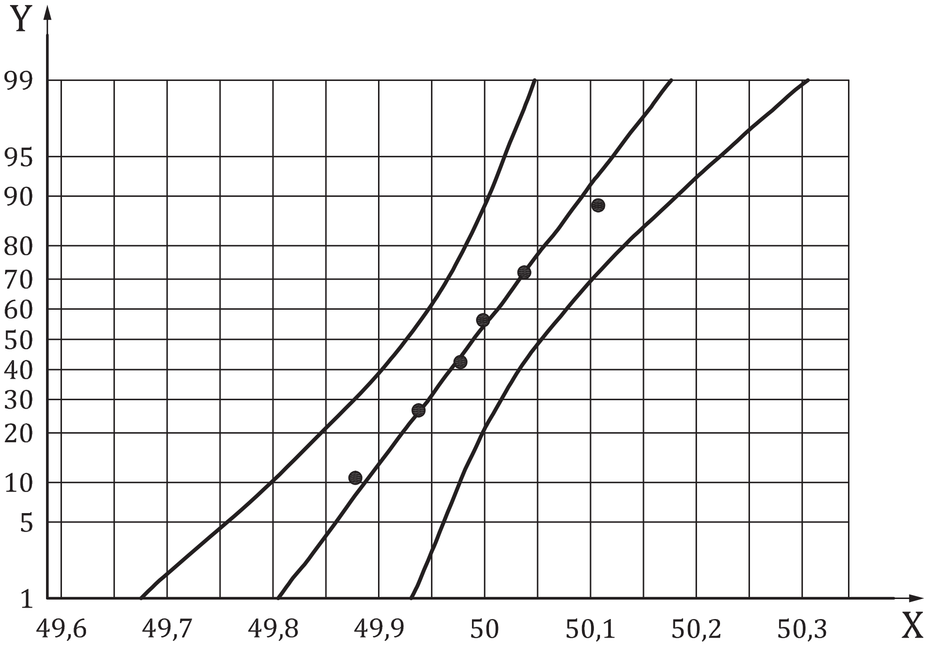

Key

X measurement

Y per cent

Figure 8 — Software created probability plot

These values of mean and standard deviation can now be used to construct the centre line(s) and control limits for an appropriate preliminary statistical process control chart for this small batch, short run process.

6 How to establish and apply short run, small mixed batch, control charts

6.1 General

Methods to establish and deploy the four kinds of short run and small batch control charts referred to in 4.3 and Figure 2 are described. These are all based on the understanding that reliable information is available on the aim and variability (for instance, standard deviation) of the characteristic being monitored.

6.2 Variable aim, individual and moving range chart

6.2.1 Purpose

This procedure describes the set-up and use of an SPC chart applicable if the following conditions are met:

a) the sample size is one;

b) a process, running items of various size or dissimilar characteristics with different aims, or nominal values, is to be monitored;

c) the extent of the variation of the characteristics is expected to be constant throughout;

d) a timely response is required to any sudden change in the characteristics monitored.

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6.2.2 Scope of application

Applications for this method include situations where:

a) the sample size is restricted to one;

b) it is necessary to reduce the number of control charts when a number of different characteristics are being monitored at the same work station;

c) the process parameter or product characteristic is repeatedly changing of nominal value, for example, as with short runs on generically similar items of different sizes processed at the same work station;

d) the process variation of the characteristics is expected to be constant throughout;

e) a timely response is required to any change in process level;

f) the pattern of variation of the characteristics plotted is approximately normal.

6.2.3 Method

Set up the variable aim individual and moving range chart portrayed in Figure A.1. Use the method as described in ISO 7870-2, with the following exceptions.

a) Establish an aim value for each item or characteristic. This is usually the nominal value, the desired value, or the overall average value experienced.

b) In the individuals plot, each plot point is based on a single measurement. Plot deviations from the relevant aim value (for example, X minus nominal or X minus overall average value) as applicable.

c) As each individual measurement becomes available, progressively construct a tally chart of $(X - T)$ in the section marked "distribution". Check that the distribution shape is approximately normal (symmetrical and "bell"-shaped).

d) In the moving range chart, plot the absolute value of the difference between each two consecutive $(X - T)$ plot points.

e) Calculate centre lines and control limits using Table 7. Continue and monitor for process control as in ISO 7870-2.

Table 7 — Key data for constructing a not constant aim, individual and moving range chart

	Individual	Range
Plot point	$X - T$	R_{moving}
C_L	0	R_{exp}[a]
U_{CL}	$+2{,}66R_{exp}$	$3{,}27R_{exp}$
L_{CL}	$-2{,}66R_{exp}$	0

[a] R_{exp} = (1,128 × expected standard deviation) for a moving range of two.

6.2.4 Example

On a continuous, short run, extrusion process, one sample is taken every 10 min. The length of the extrusion is measured on each sample. Four sizes of product are produced at this workstation, small, standard, large and extra-large. The process is set up to produce nominal lengths of 17,0; 20,0; 30,0 and 36,0, respectively. The specified tolerance for all sizes of product is nominal ±5,0.

Historically, on this process, the R_{exp} is approximately constant for all sizes of extrusion, at a value of 2,0. This is based on moving ranges of two.

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Summarizing:

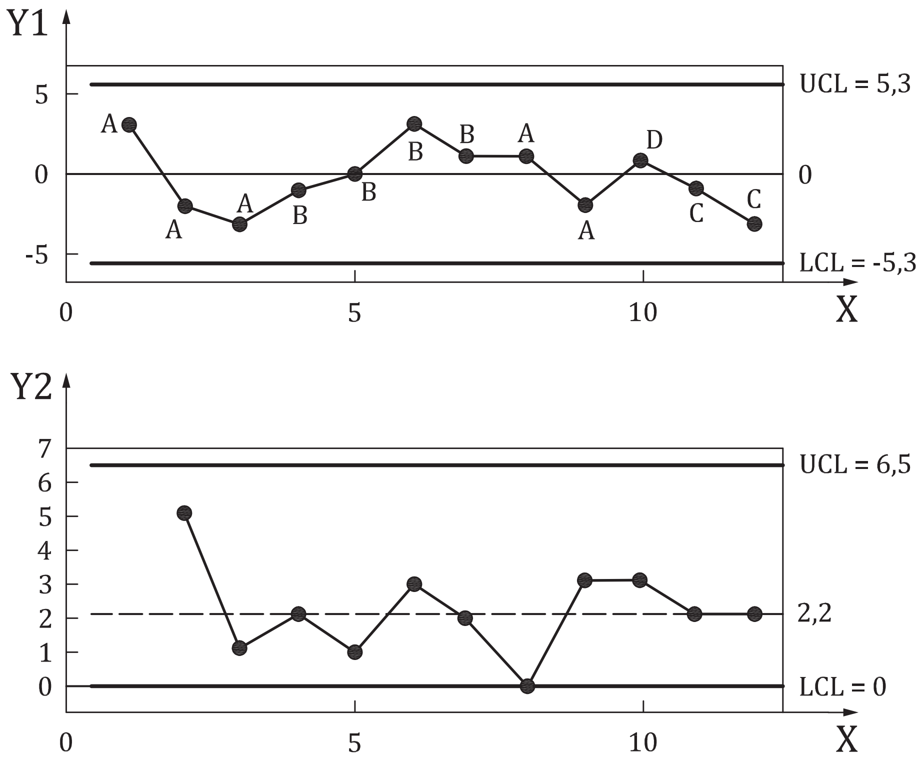
Item	A	B	C	D
T	20	30	17	36
R_{exp}	2,0	2,0	2,0	2,0

Table 8 shows the results of 12 consecutive samples taken at this workstation. A control chart for this extrusion process has been constructed.

Table 8 — Data and calculations for not constant aim, individual and moving range chart

Item	A	A	A	B	B	B	B	A	A	D	C	C
X	23	18	17	29	30	33	31	21	18	37	16	14
T	20	20	20	30	30	30	30	20	20	36	17	17
$X - T$	3	−2	−3	−1	0	3	1	1	−2	1	−1	−3
R_{moving}	—	5	1	2	1	3	2	0	3	3	2	2

The resulting computer generated control chart is shown in Figure 9. A reproducible control chart for general manual use is given in Figure A.1.



Key

X subgroup number

Y1 individuals

Y2 moving range

Figure 9 — Variable aim, individual and moving range control chart

Interpretation of the individual and moving range chart for short runs is similar to that for Shewhart control charts as given in ISO 7870-2. The only principal difference is the desirability to provide an item reference on the individual chart as shown in Figure 9.

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6.3 Variable aim, moving mean and moving range chart

6.3.1 Purpose

This procedure describes the set-up and use of an SPC chart applicable when the following conditions are met:

a) the sample size is one;

b) a process, running items of various size or dissimilar characteristics with different aims, or nominal values, is to be monitored;

c) the extent of the variation of the characteristics is expected to be constant throughout;

d) the detection of trends is more important than response to sudden changes.

6.3.2 Scope of application

Applications for this method include situations where:

a) the sample size is restricted to one;

b) it is necessary to reduce the number of control charts when a number of different characteristics are being monitored at the same work station;

c) the process parameter or product characteristic is continually changing in nominal value, for example, as with short runs on generically similar items of different sizes processed at the same work station;

d) it is more important to determine trends than sudden changes.

6.3.3 Method

Set up the special moving mean and moving range chart portrayed in Figure A.2. Use the method as described in ISO 7870-2, with the following exceptions.

a) Establish an aim value for each item or characteristic. This is usually the nominal value, the desired value or the overall average value experienced.

b) In the moving mean plot, calculate and plot each point from two consecutive ($X - T$) values. Plot the moving mean of X minus nominal, or X minus overall average value, as applicable.

c) As each measurement becomes available, progressively construct a tally chart of ($X - T$) in the section marked "distribution". Take note of the distribution shape as described in ISO 7870-5.

d) In the moving range chart, plot the absolute value of the difference between each two consecutive ($X - T$) plot points.

e) Calculate centre lines and control limits using Table 9.

f) Continue and monitor for process control and capability as in ISO 7870-5.

Table 9 — Key data for constructing a not constant aim, moving mean and moving range control chart

	Moving mean	Moving range
Plot point	Moving mean of $X - T$	Moving range of $X - T$
C_L	0	R_{exp}[a]

[a] R_{exp} = (1,128 × expected standard deviation) for a moving range of two.

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	Moving mean	Moving range
U_{CL}	$+1{,}88R_{exp}$	$3{,}27R_{exp}$
L_{CL}	$-1{,}88R_{exp}$	0
[a] R_{exp} = (1,128 × expected standard deviation) for a moving range of two.		

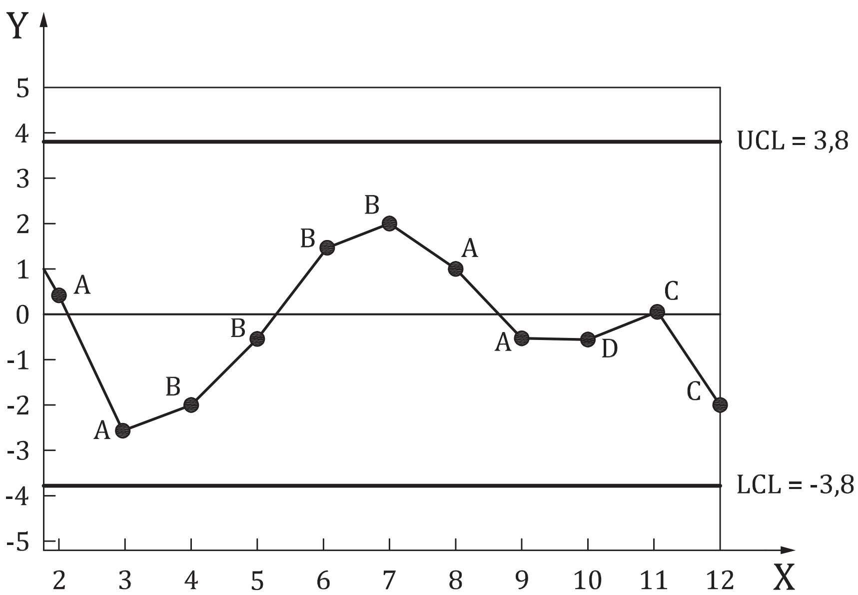
6.3.4 Example

The data in 6.2.4 are used to illustrate the construction of a moving mean, short run and control chart for items having a not constant aim but constant variability. Table 10 illustrates that just one extra row is required for Table 7 to calculate the moving mean.

Table 10 — Data and calculations for variable aim, moving mean and moving range chart

Item	A	A	A	B	B	B	B	A	A	D	C	C
X	23	18	17	29	30	33	31	21	18	37	16	14
T	20	20	20	30	30	30	30	20	20	36	17	17
$X - T$	3	−2	−3	−1	0	3	1	1	−2	1	−1	−3
$\bar{X}_{moving}$	—	0,5	−2,5	−2	−0,5	1,5	2	1	−0,5	−0,5	0	−2
R_{moving}	—	5	1	2	1	3	2	0	3	3	2	2

The subsequent computer-generated plot of the moving mean is shown in Figure 10. The moving range chart is identical to that in example 6.2.4. A reproducible control chart for general manual use is given in Figure A.2.



Key

X subgroup number

Y moving mean

Figure 10 — Variable aim, moving mean and moving range control chart

Interpretation of the moving mean chart is as given in ISO 7870-5. Interpretation of the moving mean chart for short runs is similar to that for standard charts as given in ISO 7870-5. The only principal difference is the desirability to provide an item reference on the moving mean chart as shown in Figure 10.

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6.4 Universal, individual and moving range chart

6.4.1 Purpose

This procedure describes the set-up and use of an SPC chart applicable when the following conditions are met:

a) the sample size is one;

b) a process, running items of various size or dissimilar characteristics with different aims is to be monitored;

c) there is a significant change in the value of the average range, or standard deviation, with differing characteristics or size of the aim or nominal;

d) a timely response is required to any sudden change in the characteristics monitored.

6.4.2 Scope of application

Applications for this method include situations where:

a) the sample size is restricted to one;

b) it is necessary to reduce the number of control charts when a number of different characteristics are being monitored at the same work station;

c) the process parameter or product characteristic is continually changing in aim value, for example, as with short runs on generically similar items of different sizes processed at the same work station;

d) the extent of the process variation changes with the type of characteristic and size of an item;

e) a timely response is required to any change in process level;

f) the pattern of variation of the individual values plotted is approximately normal (symmetrical and “bell” shaped).

6.4.3 Method

Set up the universal individual and moving range chart portrayed in Figure A.3. Use the method as described in ISO 7870-2 with the following exceptions.

a) Establish aim or reference values in the form of both the aim, desired or overall average value and measure of variation, R_{exp}, for each item or characteristic. Enter these target values for each characteristic, or item, in the appropriate A, B, C, D, E, column of the table below the charts.

b) In the individuals chart each plot point is based on a single measurement. Plot deviations from the relevant aim value, after standardizing for R_{exp}, namely, plot $(X - T)/R_{exp}$.

NOTE If is $(X - T)/R_{exp}$ plotted instead of $X - T$, the plot can lose the operator's intuition for how much of a difference matters. It is statistically equivalent to plot $X - T$ and incorporate R into the control limits

c) As each individual measurement becomes available, progressively construct a tally chart of $(X - T)/R_{exp}$ in the section marked “distribution”. Check that the distribution shape is approximately normal (symmetrically “bell” shaped).

d) In the moving range chart, plot the absolute value of the difference between each two consecutive $(X - T)/R_{exp}$ plot points.

e) Insert the centre lines for the individual and range chart at the values shown in Table 11, namely, at 0 and 1, respectively.

f) Calculate control limits using Table 11. Enter in graph.

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g) Continue and monitor for process control and capability as in ISO 7870-2 and ISO 22514.

Table 11 — Key data for constructing a universal, individual and moving range chart

	Individual	**Range**
Plot point	$(X-T)/R_{exp}$[a]	R_{moving}
C_L	0	1
U_{CL}	+2,66	3,27
L_{CL}	−2,66	0

NOTE The centre lines and control limits in Table 10 are independent of the aim and standard deviation of the measures plotted. Hence, the resulting control chart is termed a universal one.

[a] R_{exp} = (1,128 × expected standard deviation) for a moving range of two.

6.4.4 Example

A process is to be monitored where there are frequent changes in the item processed. The items vary both in size and in variability. Reliable information is available on the aim and expected standard deviation of each item loaded. These are as follows.

Item	A	B	C
T	10	40	30
$\boldsymbol{R}$ **exp**	1	3	2

Individual samples are taken at appropriate intervals with the results shown in chronological sequence.

Item	A	A	A	A	A	A	B	B	B	B	B	C	C	C
Sample value	10	9	11	10	10	9	40	37	39	43	40	32	30	29

A universal small batch, individual and moving range, control chart for this process has been created.

The results are shown in Table 12.

Table 12 — Data and calculations for universal, individual and moving range chart

Item	**A**	**A**	**A**	**A**	**A**	**A**	**B**	**B**	**B**	**B**	**B**	**C**	**C**	**C**
X	10	9	11	10	10	9	40	37	39	43	40	32	30	29
T	10	10	10	10	10	10	40	40	40	40	40	30	30	30
$X-T$	0	−1	1	0	0	−1	0	−3	−1	3	0	2	0	−1
R_{exp}	1	1	1	1	1	1	3	3	3	3	3	2	2	2
$(X-T)/R_{exp}$	0	−1	1	0	0	−1	0	−1	−0,3	1	0	1	0	−0,5
R_{moving}	—	1	2	1	0	1	1	1	0,7	1,3	1	1	1	0,5

The observed data, X, and R_{exp} are rounded here purely for clarity in understanding the approach. In practice, the resolution of measurement should desirably be no worse than one half of the expected standard deviation.

The resulting computer-generated control chart is shown in Figure 11. A reproducible control chart for general manual use is given in Figure A.3.

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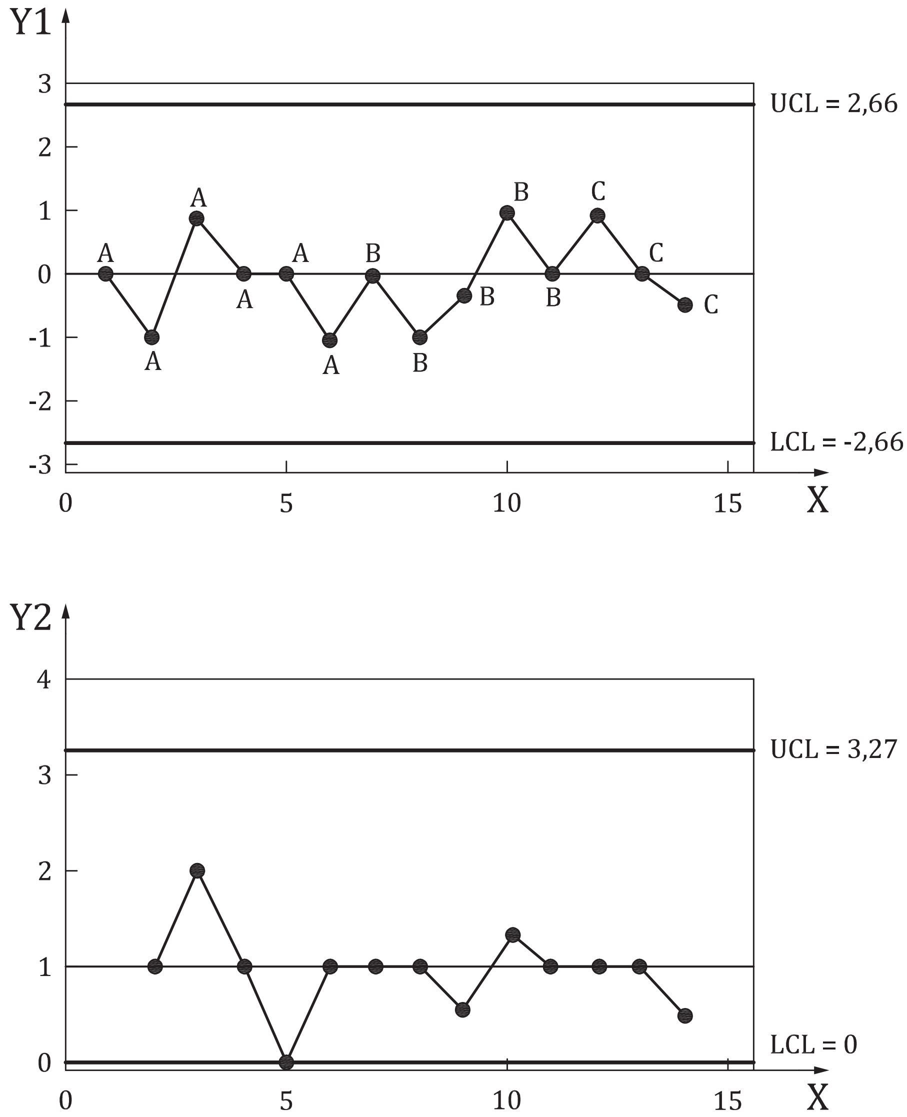

Key

X subgroup number

Y1 individuals

Y2 moving range

Figure 11 — Universal, individual and moving mean chart

6.5 Universal, moving mean and moving range chart

6.5.1 Purpose

This procedure describes the set-up and use of an SPC chart applicable when the following conditions are met:

a) the sample size is one;

b) a process, running items of various size or dissimilar characteristics with different aims is to be monitored;

c) there is a significant change in the value of the average range, or standard deviation, with differing characteristics or size of the aim;

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d) detection of trends is more important than response to sudden changes.

6.5.2 Scope of application

Applications for this method include situations where:

a) the sample size is restricted to one;

b) it is necessary to reduce the number of control charts when a number of different characteristics are being monitored at the same work station;

c) the process parameter or product characteristic is continually changing in nominal value, for example, as with short runs on generically similar items of different sizes processed at the same work station;

d) the extent of the process variation changes with the type of characteristic and/or size of an item;

e) it is more important to determine trends than sudden changes.

6.5.3 Method

Set up the universal moving mean and moving range chart portrayed in Figure A.4. Use the method as described in ISO 7870-5, with the following exceptions.

a) Establish aim or reference values in the form of both the nominal, desired or overall average value and the previously established measure of variation, R_{exp}, for each item or characteristic. Enter these target values for each characteristic, or item, in the appropriate A, B, C, D, E, column of the table below the charts.

b) In the moving mean plot, calculate and plot each point from the mean of each two consecutive $(X - T)/R_{exp}$ values.

c) As each individual measurement becomes available, progressively construct a tally chart of $(X - T)/R_{exp}$ in the section marked "Distribution of $X_{variable}$". Check that the distribution shape is approximately normal (symmetrically "bell" shaped).

d) In the moving range chart, plot the absolute value of the difference between each two consecutive $(X - T)/R_{exp}$ plot points.

e) Insert the centre lines for the moving mean and moving range chart at the values shown in Table 13, namely, at 0 and 1, respectively.

f) Calculate control limits using Table 12. Enter in graph.

Continue and monitor for process control and capability as in ISO 7870-5.

Table 13 — Key data for constructing a universal, moving mean and moving range control chart

	Moving mean	**Moving range**
Plot point	Mean of each two consecutive values of $(X - T)/R_{exp}$[a]	Absolute difference between each two consecutive values of $(X - T)/R_{exp}$
C_L	0	1
U_{CL}	+1,88	3,27
L_{CL}	−1,88	0

[a] R_{exp} = (1,128 × expected standard deviation) for a moving range of two.

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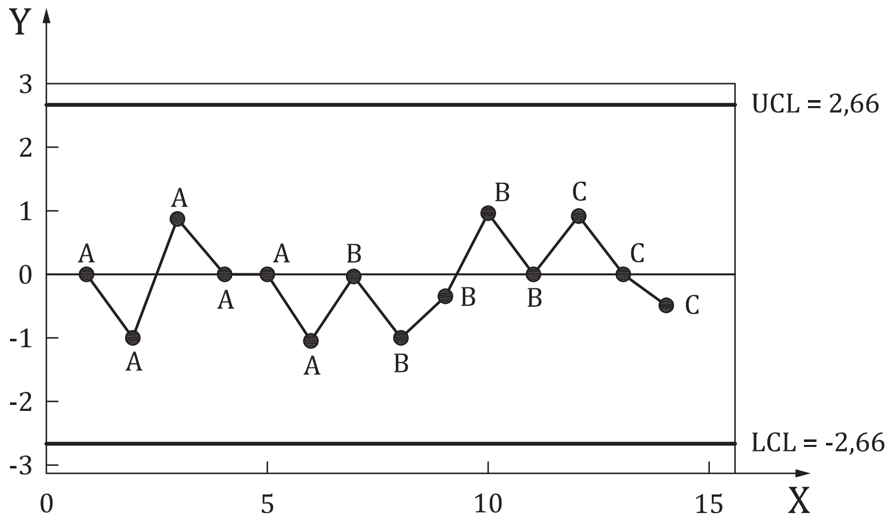
6.5.4 Example

The data in 6.4.4 are used to illustrate the construction of a moving mean, short run, control chart for items having a not constant aim and variability. Table 14 illustrates that just one extra row is required to Table 12 to calculate the moving mean.

Table 14 — Data and calculations for universal, moving mean and moving range chart

Item	A	A	A	A	A	A	B	B	B	B	B	C	C	C
X	10	9	11	10	10	9	40	37	39	43	40	32	30	29
T	10	10	10	10	10	10	40	40	40	40	40	30	30	30
X – T	0	−1	1	0	0	−1	0	−3	−1	3	0	2	0	−1
R_{exp}	1	1	1	1	1	1	3	3	3	3	3	2	2	2
$(X - T)/R_{exp}$	0	−1	1	0	0	−1	0	−1	−0,3	1	0	1	0	−0,5
$\overline{X}_{moving}$	—	−0,5	0	0,5	0	−0,5	−0,5	−0,5	−0,6	0,3	0,5	0,5	0,5	−0,2
R_{moving}	—	1	2	1	0	1	1	1	0,7	1,3	1	1	1	0,5

The subsequent computer-generated plot of the moving mean is shown in Figure 12. The moving range chart is identical to that in 6.4.4. A reproducible control chart for general manual use is given in Figure A.4.



Key

X subgroup number

Y individuals

Figure 12 — Universal, moving mean chart for short runs

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Annex A
(informative)

Reproducible copies of control charts forms and normal probability worksheet

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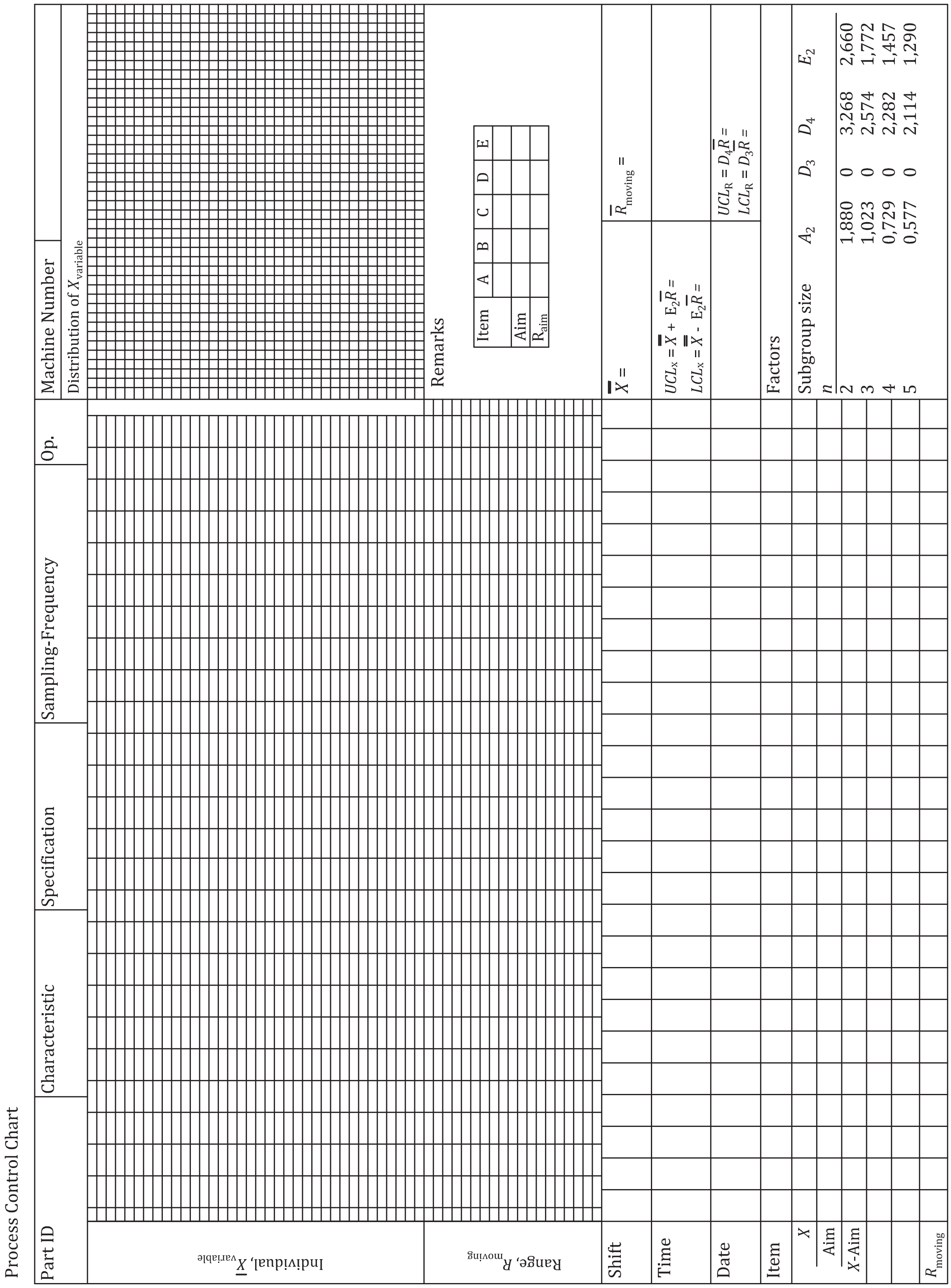

Figure A.1 — Not constant aim, individual and moving range chart

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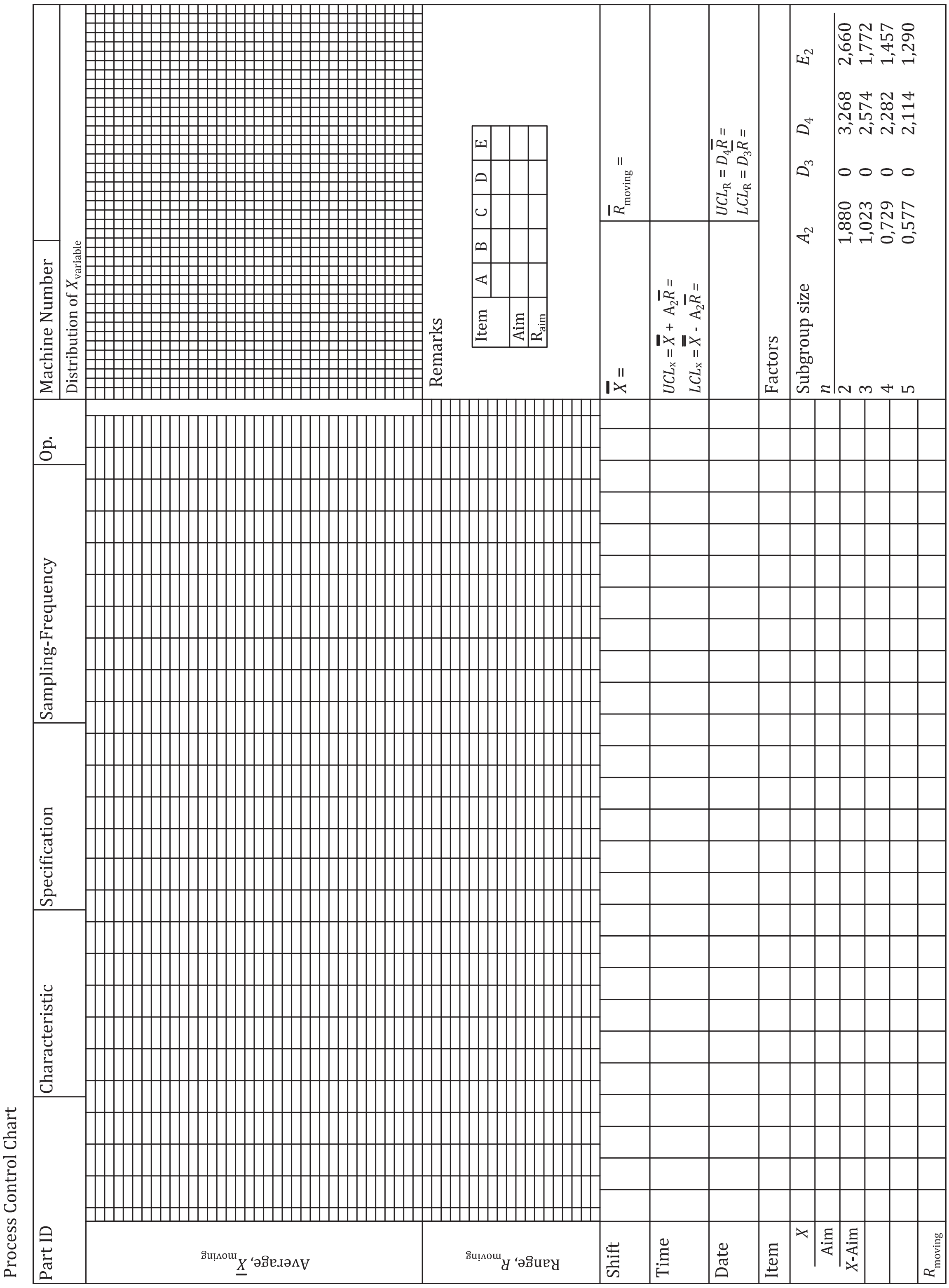

Figure A.2 — Not constant aim, moving mean and moving range control chart

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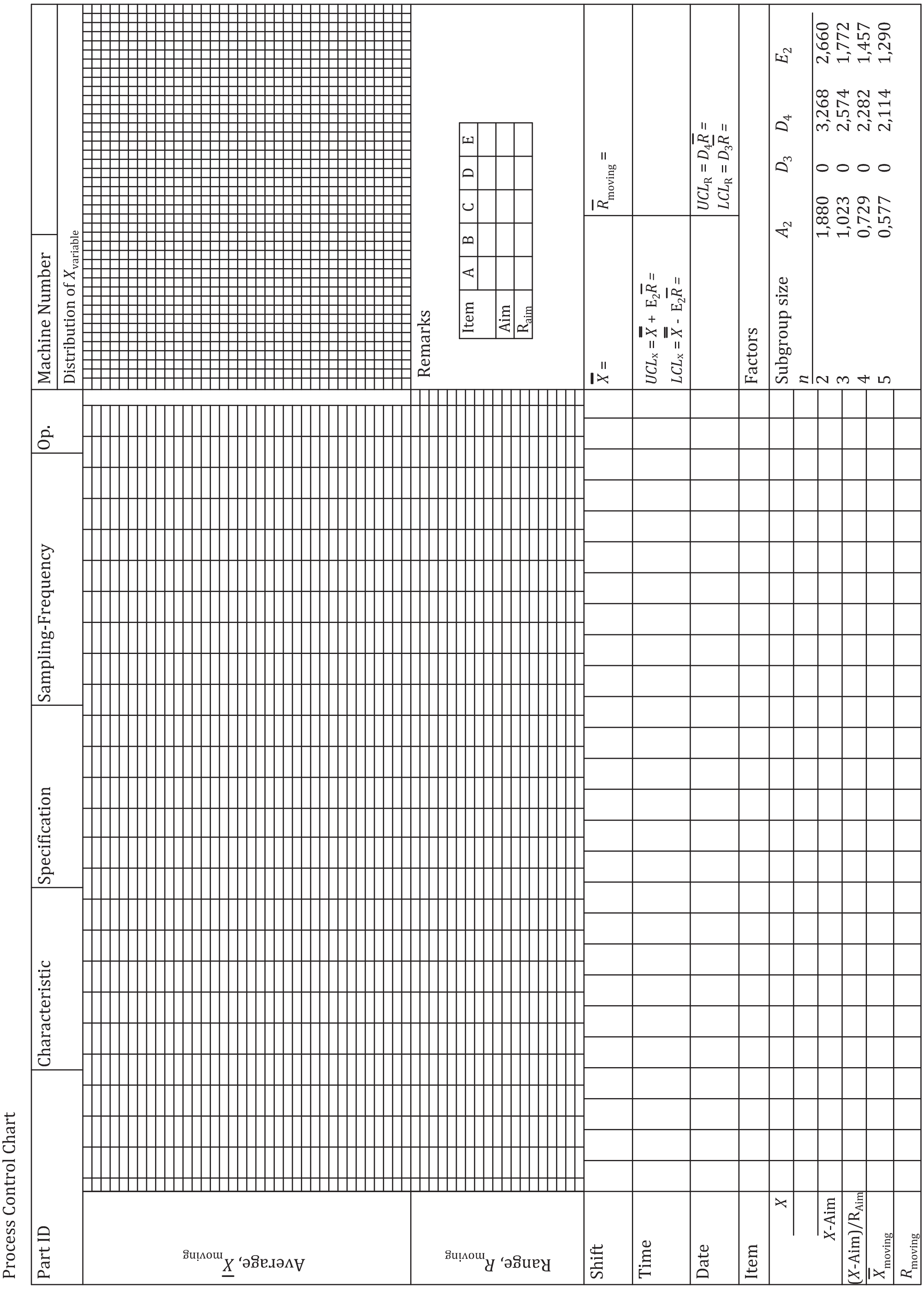

Figure A.3 — Universal, individual and moving range chart

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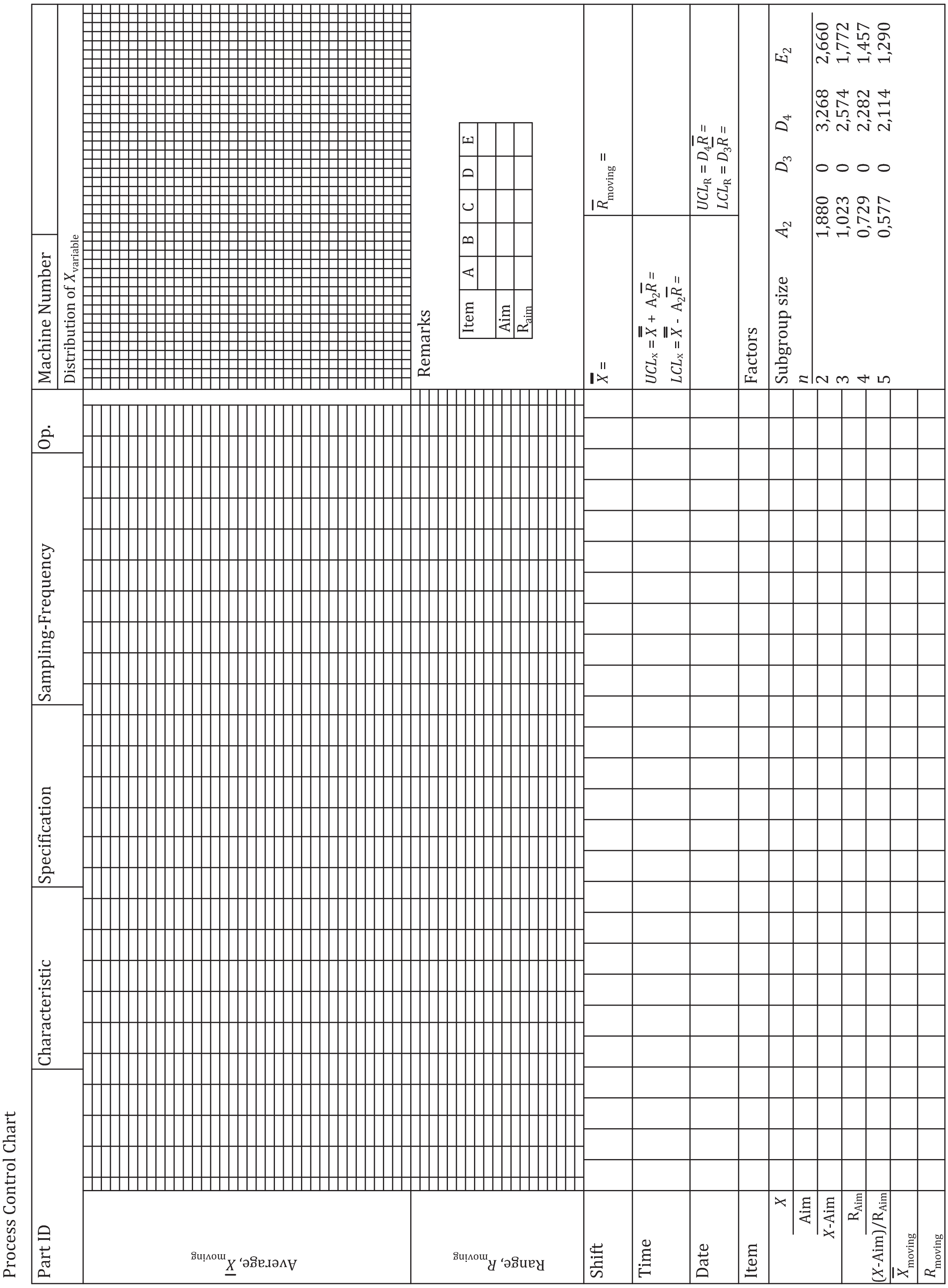

Figure A.4 — Universal, moving mean and moving range control chart

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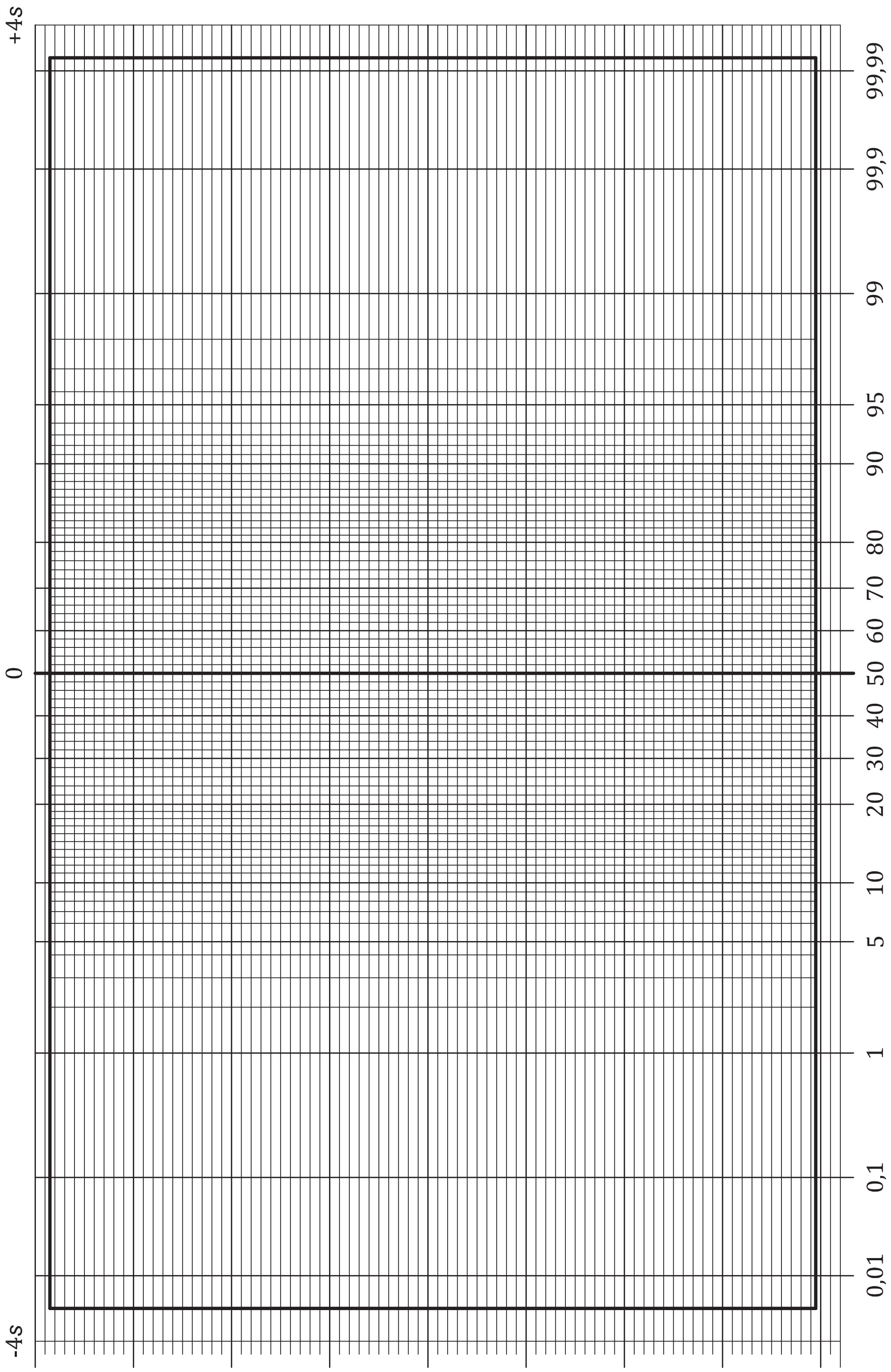

Figure A.5 — Example of normal probability worksheet

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