LUND UNIVERSITY
Campus Helsingborg

New method of control charts analysis

Adam HAMROL, Professor
Agnieszka KUJAWIŃSKA, PhD

Poznan University of Technology

adam.hamrol@put.poznan.pl
agnieszka.kujawinska@put.poznan.pl

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1. Introduction to quality concepts and statistical process control

Quality can mean different things to different people. Quality may be thought to have two main divisions: the quality of a manufactured product and the quality of services received. From the manufacturing standpoint the quality is simply conformance to specifications.

Total quality in an organization means simply the quality work that is expected in every job. There are no exemptions. When something is done, it should be done right in the first time. When a product is made, it should be defect-free. When a service is provided, the customer should be pleased with the result.

There is a variety of definitions of quality attributed to the historical leaders in the quality evaluation. Walter Shewhart, the author of quality control via control charts, described quality as having both an objective and a subjective side. The objective part of quality relates to measurement specifications with minimum of variation from target values. The subjective side relates to the commercial value (costs, use and esthetics). Joseph Juran described quality as “fitness to use”. Edwards Deming claimed that quality was in the eye of the beholder. For the consumer, quality represented satisfaction at a price that the consumer was willing to pay. Phil Crosby defined quality as “conformance to requirements” (Juran, 2000).

The various definitions aren’t contradictory in any way. They depend more on the focus of the definer. In a few words, quality is: fitness to use, conformance to specifications, producing the very best product, excellence in products and services, total customer satisfaction and exceeding customer’s expectations.

When a company produces a product or services, it utilizes many interrelated processes and each process includes several or many steps to accomplish a specific task. There may be several sources of data. All different processes are combined to yield the final product or service.

Statistical Process Control (SPC) is a procedure in which data is collected, organized, analyzed and interpreted so that a process can be maintained at its present level of quality or improved to a higher level of quality. SPC can be applied wherever work is being done. Initially, it was applied to production processes, but it has evolved to any work where data can be gathered. SPC involves the use of statistical signals to identify sources of variation, to improve performance and to maintain control of processes at higher quality level. SPC leads to a system of prevention which will replace the system of detection. Statistical signals are used to improve a process systematically so that production is maintained (Dietrich, 2000).

Statistical process control can improve quality by reducing product variability and can lead to improvements in production efficiency by decreasing scrap and rework. SPC is a trouble indicator. For each statistical application, such as control charts, histograms, there is an excepted form or pattern. When the actual form or pattern differs from the excepted, it is usually a signal that the problem exists. The potential problem must be investigated and eliminated. So the primary goals of SPC are: to minimize production costs – it can eliminate costs associated with making, finding and repairing or scrapping substandard products; it reduces product variability to the level that is well within specification; it leads to process predictability (Hamrol, 2005).

The basic tools for SPC are: flowchart, paretodiagram, checksheets, cause-and-effect-diagram, histogram and most important - control charts.

2. The variability and the control chart concept

It is important to understand that no two products or characteristics are exactly the same. Their differences may be large or not but they are always present. All processes (characteristics) have some variability. The variation of processes is the result of two types of causes. The first is called special-cause or assignable-cause. Some of the special-causes can be recognized and controlled, whereas others remain unrecognized. However, some of these causes might be an indispensable part of the process' nature and they can be shown in a systematic way and they cannot be eliminated. The second type of variation called common-cause variation (random-cause) is inherent in the process. When the special-causes are eliminated, the process can work as well as it worked if no modifications were introduced. Common causes' variation can not be eliminated because it is part of the process.

One of the main functions of control charts is to indicate when special-cause variation is present. SPC charts provide hints to the source of special-cause variation and show local action which should be has eliminated.

Control charts are the graphic presentation of the product's characteristic value or defined in advance statistical measures of chosen attributes that are presented in the form. The broken-line graph illustrates a process' behavior over time. The charts visualize the process' average and variation characteristics of the product, (according to the maxim that one picture is worth more than thousands of words, and one chart is worth more that thousands of numbers).

Samples are periodically taken, checked, or measured and the result plotted on the chart. The chart can show how the specific measurement changes, how the variation in measurement changes or how the proportion of the defective pieces changes over time. Control charts are used to find sources of special variation, to measure the extent of common-cause variation and to maintain control of a process.

When the process is in statistical control, the points on the control chart should follow a completely random pattern and measurements will have a normal distribution. The rational subgroup information, position and spread are plotted on a control chart over time. The pattern of points can be interpreted so that the advent of special causes' variation can be noted sometimes in one point or in up to several points on the chart. The chart is said to be out of statistical control when this happens, and the pattern of the points will provide hints to the source of the special-causes. When the process is fixed, the control chart will return to a random pattern (process is in statistical control) (Hamrol, 2001).

There have been many situations in which the setting of points indicated that the process lost the stability. The identification of the patterns is oftentimes restricted to 4 cases: the point beyond the control line, trend, run, and shifts (the several points above or under the central line) (Fig. 1). The written sources on the subject indicate many other patterns. Most of them are not easy to identify and it is difficult to expect from the operator to be capable of making a right decision.

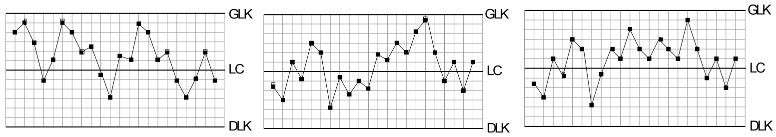


Fig. 1. The example of some symptoms: cycle, trend, shift

Application of the control charts is often associated with written presentation on paper and their interpretation by the operator. Decisions that the operator makes are the result of his experience and sometimes the decisions are intuitive. Weak side of such a solution is the necessity of constant observation of the pattern on the control charts and deciding on the stability process by the worker whose attention should be focused mainly on the machine's operation. Another weakness of such a solution is also insufficient knowledge of the operator on the sources of the special-cause variation and correcting actions. What is more, there is always a risk that an experienced worker resigns from his post. Then, the company loses his knowledge.

The solution of the above-mentioned problems, concerning the analysis of control charts, is application of automatic pattern recognition tools. The automatisation of chart's picture recognition is understood as limiting or even exclusion of the man's participation in the whole process. Thus, the man will no longer decide about the stability of the process and will no longer take up corrective actions to the process. It is, however, possible by designing and programming certain methods of pattern's classification on the charts. This solution leads to decrease in the wrong number of made decisions, which eventually leads to increase of process' stability.

The mentioned observations compelled to analysis the recognition of patterns' methods which can be used on the control charts.

The pioneer researchers in this area are Cheng and Hueble from Arizona State University, Hamrol and Kalka from Poznan University of Technology.

3. Software aided SPC

During the last decades there was a lot of software which aided statistical process control. The following table presents classification of well-known and available software that focuses on application of automatic "stable recognition module".

All the well-known and available software has its disadvantages. One of the disadvantages is the decision whether the process is unstable. It is still made by the operator of the machine. It is the result of the lack of efficient methods of pattern recognition on the charts.

Table 1. The composition of software capabilities which aid statistical process control

Software	Firm	Basic statistical analysis	Control charts - creating	Analysis of control charts	Mathod of analysis
Statistica CC	StatSoft	Y	Y	Y	3 zone
qs-STAT, procella	QDAS	Y	Y	---	---
Q-PAK	TQMsoft	Y	Y	---	---
STAT9000	OPTOSOFT	Y	Y	Y (3 pattern)	3 zone
ATEST	MARCEL	Y	Y	Y	lack of data
QI Analyst	Wonderware	Y	Y	Y	3 zone
ISOFT	TRY	Y	Y	---	---

There is the method which is used in the SPC software. It is the method of 3 zones. The method of 3 zones, strictly connected with assumed characteristics' distribution – normal distribution, imposes limitations concerning generating the unconventional signals (pattern).

The method is applied in well-known IT systems like Statistica, QDAS, and is based on standards that were designed for the technological processes AT&T described in the year 1959. The zones are defined for the normal distribution and are multiplicity of standard deviation (so called sigma) process. The above limitation makes defining of non-standard signals such as; cycles, groups of points, mixtures, impossible. The method enables the researcher to define and recognize the symptoms on the chart by calculating probability of points' occurrence in the following zones of control charts labeled as: A, B, C (Fig. 2).

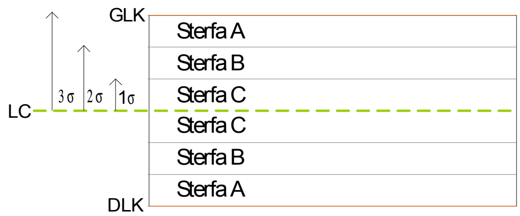


Fig. 2. The area's division on ABC zone

Analyses of available methods concerning the pattern recognition lead the authors to develop theoretical assumptions and implement software for new solutions. The new methods were called: One Two Three (OTT), Matrix Weight (MW). The authors have also tried to use artificial neuron network (ANN) to recognize the patterns on control charts.

The aim of the methods: OTT, MW and ANN is to classify the process as stable or unstable. In the first case, there is no need to undertake any actions in relation to the monitored process, whereas in the case of the latter, the special-cause variation should be found and then proper actions should be undertaken.

4. Authors' methods

4.1. OTT Methods

The idea of the method is based upon attributing of the sequence several points (for example seven) to their inclinations and comparing them to a model placed by the expert in the database (Fig. 3).

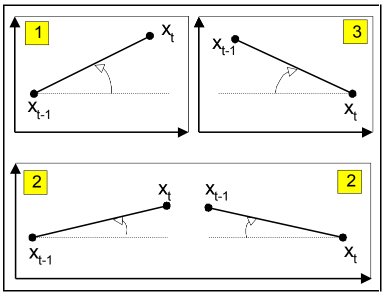


Fig. 3. Associating the segment with its inclination to the horizontal axis

The first step of the method deals with dividing the control chart into k-areas. The zones are assigned the weight from the range <1, k/2>. The areas around central line get the greatest weight. The number of areas as well as the arrangement of their importance on the card is determined by the variability distribution.
The pattern (several points) on the control chart is recorded as a vector $[O_i, M_i]$.
Oi - is a sequence of symbols reflecting the slope. The slope is described by numbers :

1(positive slope), if $(\bar{x}_t - \bar{x}_{t-1}) > \varphi$,

2 (without slope), if $|\bar{x}_t - \bar{x}_{t-1}| < \varphi$,

3 (negative slope), if $(\bar{x}_t - \bar{x}_{t-1}) < -\varphi$.

where φ is the boarder value (threshold) determined by an expert.
M_i - describes pattern's position on the chart's area. It is the product's of weight areas of the end and beginning: $M_i = w_i * w_{i+1}$.

The vector recorded in this way is compared in a row with the patterns P_i, defined earlier in the database. The next step is calculating the distance (d_i) between O_i and P_i:

$$d_i = \begin{cases} 0 & gdy \quad P_i - O_i = 0 \\ 0{,}5 * g_i & gdy \quad P_i - O_i = 1;-1 \\ g_i & gdy \quad P_i - O_i = 2;-2 \end{cases} \quad \text{where } g_i = \log M_i$$

Next the measure of similarity S is calculated: $S = 1 - \frac{\sum d_i}{L}$. When calculated S is greater then the limit value S_g and is close 1, then the analyzed pattern is strongly similar to the given pattern in the database. In order to assign the right class pattern to fluctuations and shifts inequality must be realized: $\sum_{i=1}^{n-1} M_i \leq (n-1)(w_l w_{l-1})$.

4.2. The MW method

The developed method is based on division of the chart into the matrix of [k x n] size (k-columns, n- lines), and each of them is assigned the weight $w_i \in <0, 1>$.

There is a separate matrix for every pattern created.

The location of matrixes is compatible with the stretches of the appearing pattern.

For every picture of the n length there is S measure fixed. The measure is comparable with the limit value defined by an expert.

The S measure is a sum of areas' weights in which there are points that belong to the analyzed row.

If S has a greater value or equals to the limit value then there is a signal produced indicating the appearance of the pattern.

The method's limitation is the necessity of matrix creation for each class of patterns as well as choosing the limit value S_g that determines the picture's recognition as a symptom (Fig. 4).

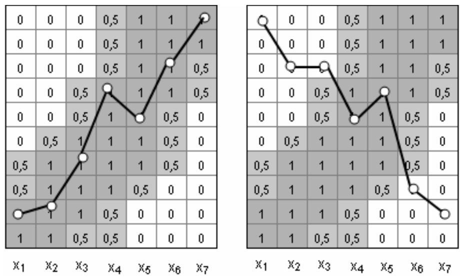


Fig. 4. The matrix of the growing trend

4.3. The verification of the developed methods

Verification of the developed methods was carried out on the set of data obtained from the grinding process (process 1) and from the second process (the superfinish of the surface of TV screen - process 2).

In order to verify the efficiency of the methods, they were programmed in DELPHI 7.0 language and the software was called CCAUS: Control Charts – Analysis Unnatural Symptoms.

The software enables: introduction of the measurement data, carrying out basic statistical analyses of the data, creating control charts, analysis charts and search for the symptoms by using OTT and MW methods, creating the database with the sources of process' instability, creating database that would undertake correction. The main aim of CCAUS is the analysis of control charts. The analysis is carried out by comparison of the pictures created on the chart with their defined patterns set by an expert in the database.

The verification was carried out according the following plan:

- defining k-element set of patterns for the process 1 and 2 (W_{sz}, W_{do}). The patterns were defined according to the instructions considering the use of the control chart that are obligatory in given companies and from which the information about the process was obtained. In both cases, there were 7-element patterns obtained
- collecting data from the processes (P_{sz}, P_{do}) as well as the results of picture recognition by the operator of the machine (OP)

– data class analysis P_{sz} P_{do}. Marking all the patterns indicating the changes in the stability of the process (the set: L_{sz}, L_{do}), according to the experts and the person who is responsible for the process.
– recognizing the symptoms in the classes P_{sz} and P_{do} by applying the OTT method, MW method as well as artificial neuron network SSN.

Comparing the effectiveness of recognition by set measures:

$$MP_r = \frac{n_r}{n} \qquad MB_r = \frac{nb_r}{N}$$

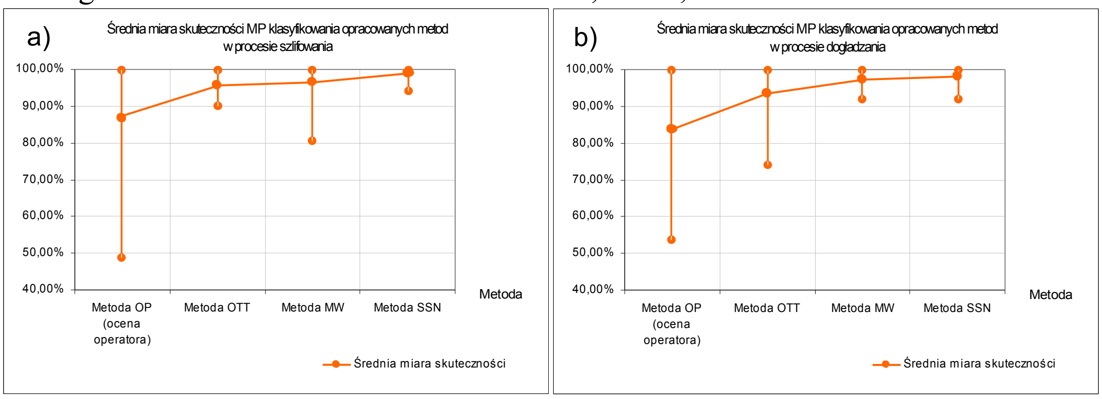
where MP_r – indicator of correct recognition, MB_r – indicator of incorrect recognition, n- the number of all the patterns, n_r – the number of patterns recognized by the r-method, N- the number of all the indications, nb_r – the number of incorrect indications of r-method

Table 2. The results of the methods' verification

	Methods/ Value of mesure MP_r [%]							
	Process 1				Process 2			
Paterrn	OP	OT	MW	SSN	OP	OTT	MW	SSN
Run + (RR)	100	100	100	100	100	100	100	100
Run – (RM)	100	100	100	100	100	100	100	100
Trend + (TR)	93	99	100	99	97	99	100	99
Trend - (TM)	91	98	100	98	92	97	99	98
Shift up – SU	90	90	100	99	90	89	98	99
Shift down – SD	85	92	96	100	87	92	98	100
Group 2from3 – GR	48	90	80	96	53	96	93	96
Mixture – MIX	-	-	-	-	51	74	91	92
Avarege	**86.71**	**95.5**	**96.5**	**98.86**	**83.75**	**93.38**	**97.38**	**98.00**

The values of MB measure were not presented because in all the cases they were less than 1%.

Fig. 5. The values of MP measure for OP-, OTT-, MW- and SSN-methods



The weakest of the methods is the traditional method (assessment of operators, OP) – the least value of MP measure (Fig. 5).

The percentages of correct recognition by the use of MW and SSN methods are almost approximating each other but there is a slight better performance of artificial neuron network (as well as for process 1 and 2).

The verification of the methods' efficiency confirmed that the operator is a weak element in the process' analysis of the control charts. The operator performs well when dealing with a trend, run or shift pattern but not with the mixture type pattern and 2 from 3 points in the warning area. Basing the classification on the OTT method provides the researchers with an average result and it is much better than the man's recognition. Similarly to the operator, the OTT method does not "like" the models called mixtures. The best results were obtained for artificial neuron networks and the matrix importance method.

5. Conclusions

The control charts are the pictures of process' stability. They let the authors use the techniques of picture recognition in the process of charts analysis. Developing the OTT and MW methods provided the author with good results of process' state's recognition. They proved to be more efficient than the operator - the man.

The developed methods let the experts create unconventional patterns of instability processes, which significantly widens the possibility of their application.

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