

Statistical Process Control (SPC) as an Instrument for Generating Competitive Advantages

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ABSTRACT:

Statistical Process Control (SPC) is a tool for quality and process control. On the one hand, it supports the pursuit of effort minimization, and on the other hand, the secure assessment of processes. Due to constantly increasing customer requirements and ever increasing competitive pressure, a corresponding continuous increase in quality is required. In order to be able to use SPC successfully, certain conditions must be met. In the planning phase of new products or services for example, it should already be recognized which characteristics need to be considered as quality-critical. This paper identifies, due to a qualitative research approach through problem-centered interviews in the technical organization of a leading international company in the flexible packaging industry, necessary preparations for a stepwise implementation of SPC in an organization. The selection of the respective characteristics and of the measuring and testing technology is discussed, as well as the execution of appropriate ability examinations and the representation in quality control charts. In addition, brief and concluding comments will be made on corresponding preparatory work for an efficient output of the measurement data in an operating data acquisition system.

KEYWORDS: SPC, Statistical Process Control, competitive advantages, quality

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Introduction

A high quality standard has always been an essential prerequisite for long-term market success. Produced products or offered services must be able to convince the customer to buy through quality. Quality, however, no longer means the exclusive consideration of high production standards, but rather the attitude of a company to meet customer expectations. In a broader sense, quality can also help to reduce costs in a company, since troubleshooting is more expensive the later the error is discovered. Since this requires a comprehensive view of quality, it must be understood as a technique and mindset.

In the sense of Total Quality Management (TQM), quality needs to be understood as a management strategy that goes beyond traditional quality assurance and unites the entire company in the constant fulfillment of customer requirements. Furthermore, the fulfillment of quality requirements can make high demands on the organization and design of business processes. It uses powerful statistical methods for quality and process control, which require not only different ways of working, but also sufficient knowledge of statistical fundamentals. These effective methods also include the procedures of SPC. This tool of quality management supports the pursuit of effort minimization of all kinds, including testing and testing costs. SPC significantly reduces control efforts, supports secure process assessment, and provides important process optimization information from ongoing process monitoring. A modern and future-oriented company will therefore not renounce the application of SPC and the resulting increase in the quality of its products.

Objectives

The objective is the presentation of the necessary prerequisites and preparations for a stepwise implementation of SPC in an organization of the flexible packaging industry, based on conducted qualitative research through problem-centered interviews. The selection of the respective characteristics and of the measuring and testing technology should be treated as well as the execution of appropriate ability examinations and the representation in quality control charts. In addition, brief and concluding comments will be made on corresponding preparatory work for an efficient output of the measurement data in an operating data acquisition system.

Issue

The quality of products or services produced must always be in line with customer requirements. Even if their purchase is controlled by the price at first, customers ultimately identify the respective company with regards to quality. The fulfillment of customer requirements has replaced the fulfillment of technical parameters and product specifications. The discovery of defects in the finished product or the product as a result of processes is getting more and more in the background, rather, the process itself must be paid attention. The entire operational activity can be understood as the interaction of processes or process chains. The individual process steps must always be geared towards the customer. The fulfillment of requirements, however, can only work without problems, if it is already lived in-house within the business and production processes. In addition to a long-term business success the objectives of the management must therefore be the social benefits and benefits for all members of the company (Faes, 2009, p. 11). Many companies are through expansion and steady growth, as well as more complex enterprise structures, in a situation where statistical process control becomes indispensable. Furthermore, in highly competitive markets, companies can only survive by building and securing long-term competitive advantage, for example through SPC (Meffert, Pohlkamp, & Boeckermann, 2010, pp. 7-8).

Statistical Process Control in the Production Process

An ongoing production process must, in contrast to the previously often used habit of sorting out the defective products after every step of the process, be managed in such a way that products are constantly produced that meet the requirements. If a process control is based on a continuous 100% test, this is also referred to as a continuous process control. However, if this is done on the basis of a periodic sampling test then we talk about a statistical process control (Timischl, 2012, p. 177). In the area of production-accompanying testing (incoming goods inspection, production inspection, acceptance tests), the greatest direct saving potential is hidden, which can be utilized by a functioning quality management system, including Statistical Process Control. SPC reduces fluctuations in the production process, which, on the one hand, moves production more stably to the required specification limits, and on the other hand ensures to make quality control more dynamic.

In order to be able to use SPC successfully, certain conditions must be met. In the planning phase of new products or services, it should already be recognized which characteristics are to be regarded as quality-critical. Furthermore, the influence of several factors on the different stages of production have to be determined, since a process results from the interaction of employees, machines, methods, materials and the environment. Behind these are features that influence and determine the process state. Since the characteristics of the features are random and therefore subject to variance, all of these features just mentioned are potential candidates of SPC. Of course, in ongoing production, processes must continue to be monitored in order to be able to derive optimization measures from possible production errors.

The state of the process changes with the distribution and variance of the characteristic values. The process is under control when its feature variances move within certain limits. Often one speaks in this case also of the fact that the process is under statistical control or is capable. However, if the feature variances are clearly shifted, the process state also changes and one speaks of a disturbed, uncontrolled or not capable process. The aim is therefore to minimize the variance in the product life cycle as early as possible. The successful use of SPC also requires the definition of responsibilities and instructions in case of so-called out-of-control situations.

Fields of Application of Statistical Process Control

By applying SPC, a process is constantly monitored and by interpreting historical data with the help of a control chart, predictions can be made and process transparency can be increased. This is in turn a prerequisite for benchmarking. The measurements required to guide a control chart, including frequent duplicate or multiple measurements, are often performed in the field of quality assurance. If this is the case, the control chart can be created directly with the measurement results without having to carry out additional determinations. In most cases, the process result itself is evaluated by means of control charts in the processes to be controlled. As a result, all factors that could influence the process are taken into account in the observation. Subsequently, this means that changes to machines, systems, materials and employees can be detected as long as they have an influence on the process result. A process comparison between different competitors or within a company group is done by comparing the control charts, as they are extremely sensitive to process changes. This continuous comparison

requires no additional expenses. Through SPC, employees can be involved in the process of continuous improvement, thus facilitating the transfer of new processes from development to routine. SPC thus creates the basic prerequisites for increased quality and cost reduction. In summary, it can help to improve the quality of products or services, reduce waste, increase productivity, improve customer service and make processes more efficient (Sower, 2017).

SPC as a tool for process improvement and process monitoring with the aim of designing predictable processes that are subject to statistical regulation is used relatively little in German-speaking countries. Often, the fear of uncertainty and innovations or of a supposedly unfavorable cost-benefit ratio will be the reason for this. The quality tool of SPC, as the name suggests, is just a tool and therefore highly dependent on the skills of the people using the method. It is therefore essential to pay attention to appropriate training of employees. Furthermore, SPC requires some understanding of statistical methods and does not guarantee that no defective products will be delivered to customers. Often, companies only use SPC as an external marketing tool to meet customer expectations or to comply with company policy. This could result in employees becoming suspicious and viewing SPC as another meaningless slogan. Further difficulties in applying the tool would be a lack of understanding and awareness about its benefits, a lack of resources or negative reactions from employees or the management level. SPC should not only be reduced to the possibility of providing quality control charts to the management board in order to give customers the impression that measures for continuous quality improvement have been implemented (Blokdyk, 2018).

Cost-optimal Process Control

The development of quality control charts including cost parameters, such as inspection costs, costs for production interruptions and costs for wrong decisions, has progressed rapidly, especially in recent years (Blokdyk, 2018). In order to construct such cost-optimal control charts, one uses optimization methods in which a target function is minimized or maximized. Possible objective functions would be the total costs or the profit per piece or per time unit. In the case of cost-optimal control charts, in addition to the control limits, the sample size and the interval length between two samplings can be calculated. On the one hand, this procedure ensures high reliability in process control and, on the other hand, enables to make a general decision about the

expediency of the use of control charts. The disadvantage or the difficulty with the cost-optimal process control and its application in the industry is probably the fixation of the various cost parameters (Storm, 2007, pp. 359-360).

Industry 4.0 and Statistical Process Control

As in most other business areas, information technologies have also found its way into quality management. The term Computer-Aided Quality (CAQ) stands behind the automated monitoring of target specifications for a mass-produced product including statistical evaluation. In the meantime, IT-solutions are already being offered for all areas of quality management in which an SPC-module is most probably integrated. Of course, in addition to complete solutions, there are also providers who sell almost exclusively software solutions for SPC. The use of such systems opens up a considerable potential for rationalization. In the meantime, production lines with fully automated SPC are available through the use of fully automatic measurements on the workpiece, which are immediately processed and evaluated by the SPC-module (Ebel, 2000, p. 25). Advantages of the computer-aided SPC modules are e.g. the fact that all inputs can be graphically visualized in a variety of displays at the push of a button or that only original values must be entered into the module, all other statistical parameters are calculated by the system (mean, variance, standard deviation, etc.). However, IT-support should not be confused with the guarantee of high quality production. It is always the responsibility of the employees to make decisions and ultimately to execute them (Buechner, 2015).

Quality Control Chart Technology

The control chart technique is generally based on the central limit theorem. This states that the sum of independent variables with finite variance is *nor*-times distributed, that means that mean values are approximately normally distributed even if the associated individual values have a poor approximation to the normal distribution. The control chart is the central object of the statistical process control and an important tool of quality management. Basically, it is used for the graphical representation of statistical characteristics, wherein the abscissa of the diagram, the time course of the sampling and the ordinate, the statistical

characteristics of the observed feature are plotted. The quality control chart thus helps to illustrate the production process vividly in order to indicate faults and errors as early as possible. If the decision on a possible regulatory intervention in the production process is made only on the basis of the current sample, we speak about classic control cards. They are control cards without memory. So-called quality control charts with memory, on the other hand, also consider the results of earlier sampling for decision-making, which above all enables the early and faster detection of possible process disturbances (Oakland, 2018).

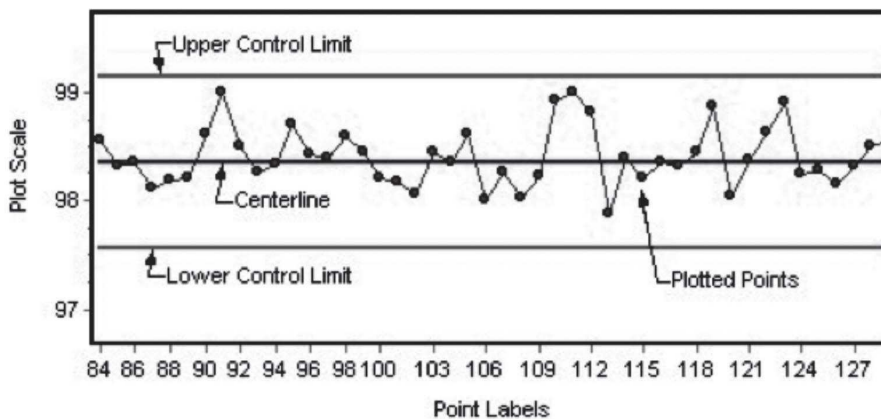


Figure 1: Example of a Quality Control Chart

Source: <http://acqnotes.com/acqnote/careerfields/control-chart> (25.09.2018)

Basically, there are numerous quality control charts that are used depending on the area of application and the type of characteristic recording. As with the characteristic types, a distinction is made between control charts for continuous (measuring) and discrete (counting) tests. Each control chart has its advantages and disadvantages and corresponding locations. Nowadays, increasing IT-support provides statistical programs that contain a variety of quality control charts (Stapenhurst, 2013).

The management of a control chart involves drawing samples at pre-determined times, determining the measured values, evaluating the sampling function of the measured values and finally the entry in the quality control chart. Of course, several features can be tested in parallel and monitored in further control charts. For variable (continuous) characteristic types, the sample size must always be constant. It should be noted that incomplete samples are not included in the consideration. From the original values statistical characteristic

values, such as, for example, average, median, span or the standard deviation, can be calculated.

Process-capability

A process is stable if its values are random and therefore within the limits of intervention. The proportion of rejects is higher, the wider the scattering is or the closer the process position is to a tolerance limit value. One speaks of a capable process if it adheres to the tolerance specifications with regards to the quality characteristic considered. Process capability investigations are indispensable measures for reducing errors before starting a production process. With the help of easily determinable key figures, a statistically well-founded statement about the expected error rate becomes possible (Timischl, 2012, p. 208).

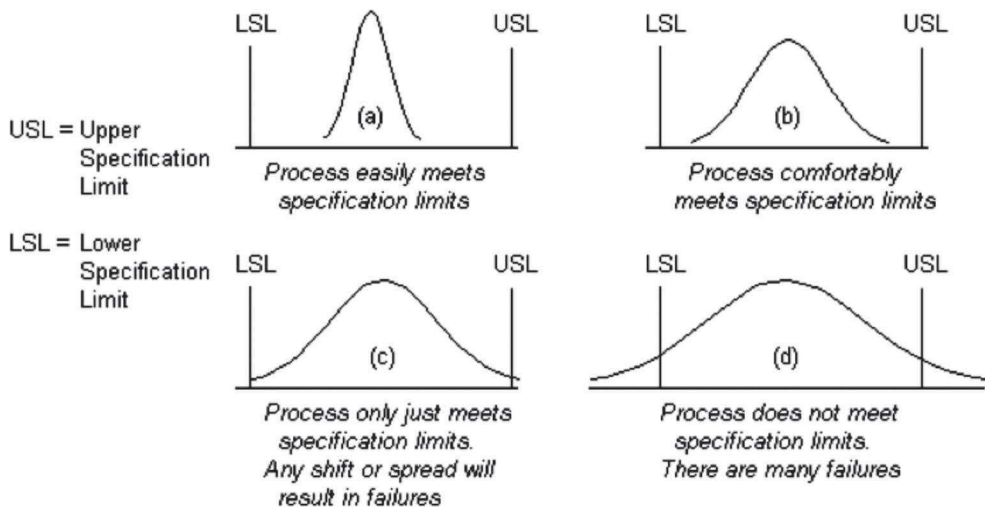


Figure 2: Natural distribution fit within defined specification limits

Source: http://www.syque.com/quality_tools/toolbook/Procap/how.htm (25.09.2018)

For a process to deliver a consistent result over time, it must be ensured that it is a controlled and capable process. The process capability study helps to investigate and analyze precisely these prerequisites in a process. In order to determine the process control and process capability, normally an already

existing and well-functioning control chart technique is an indispensable prerequisite.

The following steps are required to perform the process capability check (Brunner & Wagner, 2010, p. 192):

- Select features and measuring equipment
 - Carry out preliminary investigation
 - Switch off systematic or special influences
 - Test for normal distribution
 - Sample planning and sample execution
 - Determine process characteristics
 - Calculate process capability indices

This procedure is the same for all process capability studies, except for sample planning. Only the capability indices are labeled differently.

Sample size and confidence level

The literature recommends 50 consecutive parts for a short-term or machine capability study. A provisional process capability study shall require at least eight random samples of five parts drawn at regular intervals. By contrast, the long-term process capability study should cover an observation period of at least 20 production days and should include at least 25 samples of five parts each. They should be repeated regularly every one to two months. Data from running control charts can also be used to determine the process capability (Brunner & Wagner, 2012, p. 193).

Due to the fact that the mean and standard deviation of the process spread are only estimated values, it follows that the process capability indices also represent estimates. The actual values are subject to random scattering. For this reason, the confidence interval must be defined, which for example, with a confidence level of 99%, covers the true values of the process capability indices.

Principles and measures for SPC

In addition to the statistical and mathematical aspects of SPC, it also requires a change in the behavior of process owners. The following generally valid rules must be observed when using them correctly for the regulation and analysis of the respective process.

In principle, the time intervals between the individual samplings can range from a few minutes to several hours. They depend on the type of process and the experience with the respective process. If a process is stable over several hours, then the distances are correspondingly greater than in a frequently changing process. In the literature one often finds the generally valid rule, according to which one should take a sample at least seven times between two interventions. Experience has shown, however, that even with fewer samples a relatively good control is possible.

Any intervention in the process, either as a result of a violation of the intervention limits or for other reasons, must be documented accordingly in the control chart. In doing so, attention should be paid to the details of time and nature of the procedure and who made the intervention. This information is important for a later process analysis and the fundamental gathering of experiences. After each intervention, a sample must be taken and documented to ensure that the process intervention has resulted in the desired and intended change. If this is not the case, a new intervention must be made or the process must be stopped. This information must also be documented in order to analyze the process and to be able to derive corresponding corrective and improvement measures.

It is necessary to work with a constant sample size, because the calculation of the intervention limits starts from a certain extent. If a change in the sample size is required, the process control must be continued with a new control chart and newly calculated intervention limits. All entries must be made unadulterated by the process owner. Only in this way are reliable results guaranteed and guaranteed improvement measures possible. In addition to the date and time of the respective entry in the control card, the name of the entry must also be recorded. This allows traceability and the possibility of asking questions in case of ambiguity. In the form of a quality control chart, the company has at its disposal documentation of the experience that is indispensable for continuous improvement (Quentin, 2008, pp. 104-110).

Research Methodology

The data collection is carried out by means of guided and problem-centered interviews. The basis for the preparation of the interview guide and the related questions are the information and up-to-date knowledge base from the literature available on this topic. The interview guide consists of an introduction and a main part. Above all, the purpose of the introduction is to adapt to each other as well as briefly outline the meaning and usefulness of the survey. The main part then asks questions about necessary features and pre-requisites of and for the implementation of SPC to generate competitive advantages. When conducting the interviews, care is taken, as far as possible and appropriate, to ask open questions in order to gain as much information as possible from the interview partner and not to direct him in a particular direction.

The problem-centered interview chooses a linguistic approach to elucidate its questioning on the basis of subjective meanings. An attempt is made to build up a confidence situation between the individual parties. Although the interview partners are guided by the guideline to specific questions, they respond openly and without any defined answer options. This procedure has the advantages of being able to verify on the one hand whether one was understood by the interviewees, on the other hand the disclosure of subjective views and opinions as well as the discussion of specific conditions of the interview situation (Mayring, 2016, pp. 68-69).

The evaluation method is based on the summary approach of qualitative content analysis according to Mayring. At the beginning the interviews are transcribed. The entire material is viewed without specific considerations and the respective records of the conducted interviews are written. In a further step all utterances that do not change the content are removed since the main interest lies only in the content information. For the data analysis, a summary content analysis is used, the aim of which is to reduce the material in such a way that the essential contents are preserved and a manageable basic form is created, which is still an image of the basic material. Gained statements should be structured in order to then be able to draw appropriate conclusions (Mayring, 2016, p. 115-120).

The data collection was carried out in a specific, pre-defined period. The general willingness to interview and the subsequent evaluation of the information obtained was clarified in preliminary information by e-mail or by telephone. Subsequently, an appointment for an online interview was arranged at larger local distances or an appointment for a personal meeting at shorter distances. A readiness for any audio recording of the discussions has also been queried in

advance. In the course of a test run (preliminary study) of the interview at two selected interviewees, the general suitability of the created interview guide was checked, or whether it still needs to be modified and adapted. As no concrete problems and difficulties could be observed in the course of this analysis, the created guideline was not further changed and the results of the interviews of the preliminary study were used directly for the main study.

Data analysis and main findings

The continuous tightening of competition and the desired reduction of manufacturing costs make it almost impossible to detect any errors only after the completion of a product. Errors in the process may therefore not be permitted and should always be avoided. Statistical Process Control thus helps to improve the performance of the production process. In the course of the practical implementation of SPC, this tool must function as the basis for continuous quality improvement. In this case, quality is generally understood to mean compliance with tolerance limits. However, since this viewpoint hardly motivates the constant improvement of product quality, one should also consider fluctuations in tolerance within the scope of process improvement. During implementation, special attention must be paid to ensure that all participants and contributors endeavor to produce products with economical and feasible action that only slightly spreads the set point. This is necessary because the increasing demand for quality on the part of the customer forces a continuous quality improvement.

The objectives of SPC, based on statistical models, are to allow a largely realistic description of production and accompanying tests, as well as a reliable prediction of production status and test results. It is state of the art to work for the monitoring and control of manufacturing processes using statistical methods. Quality control charts are used if an existing, controlled process status needs to be maintained. Whether a corresponding intervention in the respective process is necessary can be seen not only at the current position of a measured value, but also at the course of the preceding measured values. If one recognizes certain trends, one should counteract these by a process intervention.

The use of SPC requires some preliminary work and a step-by-step approach. First, a selection of the features to be directed by SPC is required. The foundations for this were the conducted interviews, results of risk analyzes, brainstorming or existing tolerance requirements. Subsequently, the selection of the measuring and test technique as well as the methods and a proof of

the suitability of the test process were carried out. Following any optimization of the machine setting parameters, the performance of capability studies was followed by statistical methods. In the process capability study, it is determined whether a machine under real conditions is capable of producing a particular feature of a product in a consistent manner and within specification limits.

The following activities were performed at a leading international supplier in the flexible packaging industry. The implementation of SPC takes place on the one hand in the quality assurance, on the other hand at the machines directly in the production. For this reason, a basic understanding of the different measurement processes should be present. SPC must be seen as a helpful and supportive tool rather than an aggravation of the activity. An implemented system in the company supports the measurement data input, the process monitoring and simplifies the complaint handling. It also helps to more effectively ensure the traceability of quality data. Until the software was introduced, measurement data was manually entered into spreadsheet software.

For the selected characteristics, appropriate capability examinations and normal distribution tests have been carried out to determine whether the available data can be used. In some cases different methods and tests were used. Substantial extensive, but unavoidable, preparatory work for this step was the collection of the corresponding data. Tables and lists maintained by the quality assurance staff were filtered, collected, sorted and presented in a clearly arranged manner. These data formed the basis for further action. In the case of long-term studies (at least 20 production days), in this case in a specific period of exactly one year, at least 25 random samples of five parts were usually used for the analysis.

In addition to the histogram and the frequency sum function, including capability indices and characteristic values of the distribution, a probability network and a trend representation have also been developed, which are omitted in this paper for reasons of volume and readability. Furthermore, the respective intervals of the standard deviation of the features were cited to make a possible comparison to the already existing limits and tolerances.

In order to subsequently use those features for statistical analyzes which show a deviation from the normal distribution, the sample size was chosen larger. Instead of five values, 20 values were summarized and the mean value calculated from these characteristics. After repeated tests, no significant contradiction could be found regarding the assumption of the normal distribution.

Often the normal distribution is assumed to be the source distribution of the respective data. However, before this assumption can be made, the data must be examined to see if the normal distribution is an appropriate distribution at all.

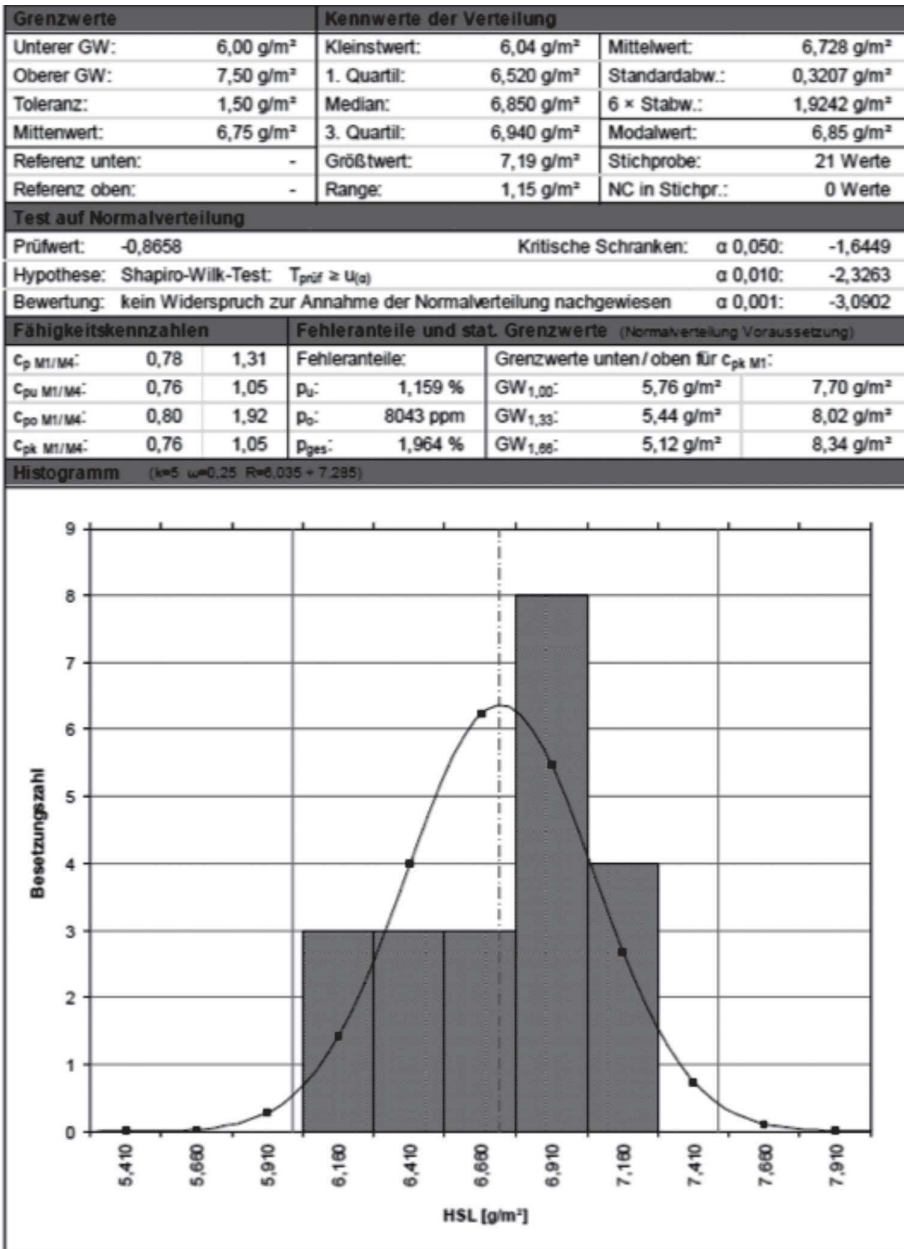


Figure 3: Example of conducted test for normal distribution

Source: Author's figure

Checking the distribution form solely by creating a histogram is not sufficient, since the appearance of the histogram strongly depends on the beam or class width and the limits of the classes, which are basically freely selectable.

The review of the normal distribution was carried out in several steps. First, a visual check was carried out by means of histogram, probability network and trend analysis. After a comparison of the key figures, the check on the normal distribution was finally concluded on the basis of the χ^2 -test. Since a single distribution is compared with the multitude of all other possible distributions, a purely visual or computational test is not sufficient.

Finally, it can be stated that all selected features, after extensive testing, such as the creation of histograms, frequency sum functions, probability meshes and trend plots, and sample size matching, can be considered as normally normal distributed and of further use nothing stands in the way of this statistical process regulation. In the implementation of statistical process control and the further work with this tool subsequently explained points are found to be particularly noteworthy and implementation-relevant.

For particularly critical characteristics or functions, the formation of cross-departmental teams is necessary to enable the required objective assessment through measurable variables and the targeted management of control charts. Overlaid systematic influences must be avoided or, if this does not seem possible, must be dealt with appropriately. Employees must be involved on-site to enable early detection of process deterioration trends and to intervene in good time before the error occurs. This is achieved by the continuous tracking of process sequences and the continuous monitoring of the most important parameters. The findings are used to monitor deviations in good time, which can subsequently lead to product defects. In this way countermeasures or corrective measures can be taken as quickly as possible.

Conclusions

Statistical Process Control (SPC) should basically protect the process against outside influences. The goal is to make sure that only unavoidable (random) errors occur in the respective process, which can be counteracted by appropriate machine corrections. Any influenceable (systematic) errors must already be detected in advance and avoided. Causes of systematic errors can have an instrumental impact (e.g. inaccurate adjustment or calibration), represent personal errors (e.g. reaction time), or may be due to environmental factors

(e.g. temperature variations). By contrast, random errors are unmanageable and provide an uncertain reading (e.g. random errors vary in magnitude and sign).

The practical explanation of SPC will first address the key material specifications of the markets and then, step-by-step, the procedure from the selection of features and measurement techniques to the conduct of capability studies as well as the creation of control charts from the system for production data acquisition.

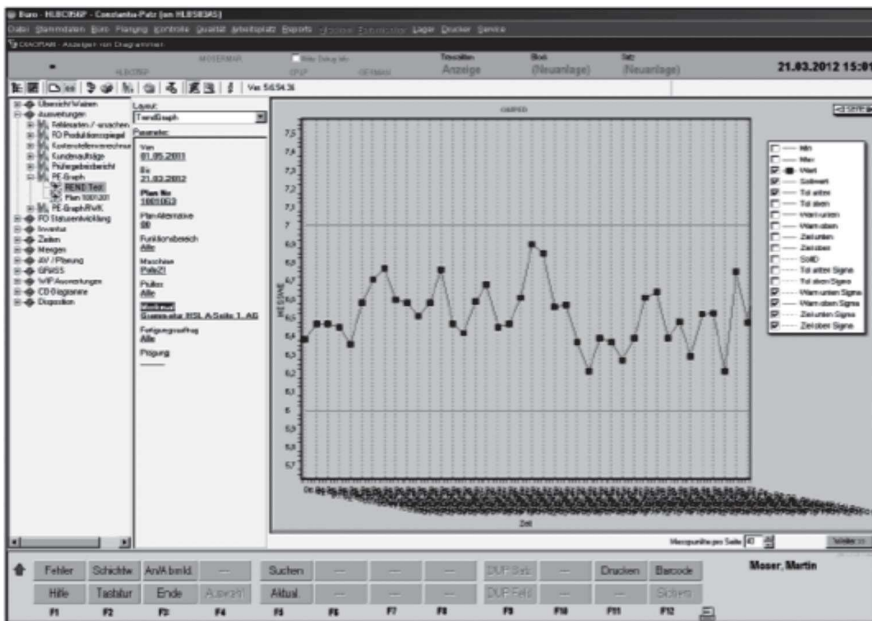


Figure 4: Example of SPC implementation in production data acquisition system

Source: Author's figure

All features identified as relevant in the run-up are identified as being normally distributed after extensive testing and validation, which is a prerequisite for working successfully with SPC. Some features have deviations from the normal distribution at first. However, after adjusting the sample size, this problem could be solved. In most IT-systems of companies, which are usually also used in quality assurance and quality management, the simple creation of test results and reports, which can then be exported for evaluation in spreadsheets,

and quality control charts is possible. In close cooperation with the company responsible for programming the IT-system, the respective input screens and options for visualizing the control charts must be adapted to current needs. During the planned changeover of the production test plan, the SPC-tool is to be introduced as an integral part of the testing and/or monitoring activities, including incorporation into the respective working documents.

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