A framework for implementation of statistical process control

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1. Introduction

Statistical process control, better known by its abbreviation SPC, has become an important part of quality control activities. In literature, however, hardly any descriptions of approaches used to implement SPC can be found. If descriptions are given they often focus on the methodological aspects, i.e. tools of SPC (Berger and Hart, 1986; Chaudry and Higbie, 1989) or the organizational aspects of implementation (Gaafar and Keats, 1992; Parks, 1983, 1984). Since both organizational and methodological aspects are important to implement SPC successfully, this paper discusses an approach which includes both aspects.

A second shortcoming of descriptions of SPC implementation is the definition of SPC. Often SPC is equated with control charts, but nowadays it is clearly recognized that control charts do not make an effective SPC system. On the other side there is the view that equates SPC with total quality management (TQM). Although it should be an important part of TQM, SPC should not be described in such general terms. In this way it is turned into a concept that is hard to translate to actual production situations.

Therefore we will present SPC as a hands-on approach based on a coherent set of activities to analyse, improve and monitor processes based on statistical thinking (Hoerl, 1996). The concept of SPC can be used for all processes (e.g. in designing processes and products), but it should start in the production department. Therefore the framework presented in this paper will be primarily directed towards production processes. In addition, we will describe how company-wide implementation of SPC sets the stage for TQM.

A third shortcoming, that can be the result of the wish to describe practical guidelines, is the limited flexibility of some guidelines. Especially methodological

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guidelines which are often directed to a specific situation. The QS 9000 standard, for example, a standard much broader than ISO 9000, is used by Chrysler, Ford, and General Motors, e.g. mass production and automotive industry in the QS 9000 standard. A standard used by Chrysler, Ford and General Motors for prescribing and auditing TQM systems (much broader than ISO 9000; see Chrysler, Ford and General Motors, 1994), concentrates on mass production and the automotive industry. This makes such guidelines difficult to use in other types of industry. Therefore in this paper not only the activities are described, but also the underlying goals or functions are discussed. Different situations may ask for different activities to execute these functions (Schippers, 1997). Based on experience in practice, these differences are described.

The practical experience of the authors was acquired through active involvement of the researchers in various projects where the presented approach was used to implement SPC. The companies involved were in mass production (DE/Sarah Lee (coffee and tea), Philips Semiconductors (diodes), and Philips Components (ceramic multilayer actuators)), small batch production (Signaal (printed circuit boards), Fokker Aviation (cable harnesses)), and also in low volume production of complex products (ASM Lithography (wafersteppers), and Fokker aircraft (aircraft)).

The organizational part of the approach consists of the use of four phases in the implementation as described in section 2, and an organization structure for SPC implementation described in section 3. The methodological part of the approach consists of a ten-step method. Section 4 describes this method and how it is used by teams to implement SPC for a process. In section 5 the experiences and lessons learned using the framework will be discussed.

2. Phases in the SPC implementation

In literature most reasons for the failing of implementation of SPC are in the field of organizational and social factors. Lack of management and operator commitment, lack of understanding and lack of training of SPC techniques, poor project control and fading attention after the first introduction of SPC, are found to be causing unsuccessful implementations or even roadblocks for implementation of SPC (Dale and Shaw, 1991; Gaafar and Keats, 1992; Lockyer *et al.*, 1984; Mann, 1995).

Based on our experience in SPC implementation projects (see section 1), we can add the following organizational problems in implementing SPC:

- It takes several years to implement SPC company wide; time and money have to be invested before SPC is fully effective through the whole organization.
- Constant attention and support of top management is necessary.
- SPC demands delegation of tasks, responsibilities and authority to the lowest possible level.

- Implementation of SPC has to be guided by an expert with thorough knowledge of the possibilities and problems with statistics (the so-called SPC consultant).
- The organization has to be familiar with tackling problems through the use of data.
- Teamwork and project management are essential.

These problems arise when the implementation is concentrated on the methodological aspects of SPC. They can be avoided by carefully planning the implementation phases as described in this section, and by forming an organizational structure as described in the next section. Only after these boundary conditions are fulfilled, does it make sense to start the methodological part using the ten-step method as described in section 4.

Before describing the four phases in which SPC is implemented we will pay some attention to the initiation of the SPC implementation. This can be started after top management is convinced that SPC can contribute to the company's bottom line. Besides this, the pressure of an industrial customer demanding SPC as a prerequisite before any deliveries can take place can be very stimulating. Philips started introducing SPC because Ford wanted them to, and Signaal and Fokker felt strong pressure from Lockheed.

After top management has been convinced to use SPC, the implementation is divided into the following four phases (as shown depicted in Figure 1):

- Phase 1: Awareness.
- Phase 2: Pilot projects.
- Phase 3: Integral implementation in production.
- Phase 4: Total quality.

Phase 1: Awareness

The first step in the awareness phase, that can be seen as the formal start of the implementation of SPC, is an awareness meeting for the staff of the company.

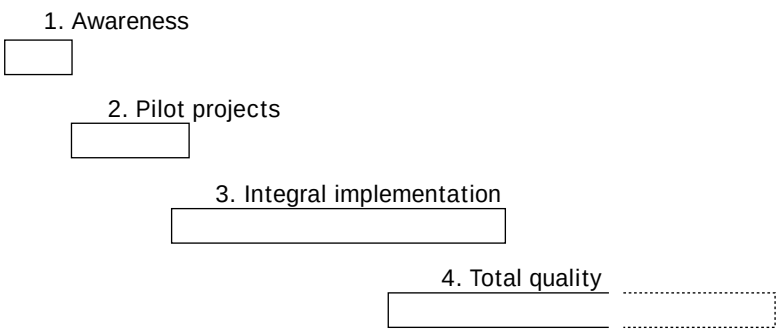

Figure 1.
Phases of SPC implementation

The goal is to let the staff become familiar with the fundamentals of SPC and its implementation. The awareness meeting addresses the following:

- SPC means a shift from detection to prevention.
- SPC is a new way of management in which tasks and responsibilities have to be delegated to the lowest level of the organization.
- SPC is a way to establish the capabilities of a process.
- All processes are subject to variation and dealing with variation is the goal of SPC.
- Recognizing, quantifying, controlling and reducing variation is necessary.
- Teamwork and project management are necessary to achieve this.

Also the benefits of SPC for the organization should be addressed, such as:

- Financial benefits through less scrap and rework lead to reduced production costs, shorter throughput times, and better product quality.
- Better communication with customers, development, and suppliers concerning productability, specifications and delivery performance.
- The organization will be statistical-oriented, i.e. decisions are made based on data instead of assumptions.
- Operators become more responsible and involved in the performance of production processes.

In order for the awareness meeting to be a success, good preparation is necessary and the assistance of an external consultant can be very useful.

After the awareness meeting a steering committee is formed and top management gives them the assignment to make a plan for the implementation. The plan is based on interviews with staff members from all departments involved and should include processes to be dealt with in the pilot projects. The processes used in the pilot phase should be known as problematic (but not too extensive and complex) so that real results can be achieved.

Phase 2: Pilot projects

From the start of this phase a project management approach should be used, guided by a steering committee as described in section 3. The steering committee installs a few teams that will work on the processes selected in the previous phase. The teams, called "process action teams" or PATs, are described in section 4. Each team receives the assignment to bring the process under control using the ten-step method described in section 4.

When the ten steps are executed and improvements are implemented, the process is called an operational SPC point. Depending on the complexity and size of the process, the throughput time varies from three months to more than a year. This is based on weekly meetings of two hours, if necessary with additional hours in the period when the process is thoroughly analysed.

To enlarge the commitment and to improve the knowledge of SPC, it can be useful to give SPC training for members of the steering committee, process engineers, quality engineers and development engineers. The team members receive training-on-the-job when using the ten-step method.

After approximately half a year, feedback about the results of the pilot projects will be given to the steering committee and top management. Based on the results a go/no go decision will be made. At this moment the organization may not yet expect enormous return on investment, because first, the organization needs to learn, and second, long-term effects cannot yet be seen. However, the organization should be confident that SPC can control processes and improve profits.

Phase 3: Integral implementation in production

In this phase more process action teams will be installed by the steering committee. The organization structure described in the next section has to become effective. Beginning with the weakest, other processes will be selected and PATs will be assigned to use the ten-step method to bring them under control. All important process steps have to be controlled in this way. It is likely to find around 20 to 30 processes to be covered by PATs. This implies that the throughput time of this phase is about 1.5 to 2.5 years.

From the beginning of this phase it is necessary to give one person within the company the task of SPC co-ordinator. Especially when external SPC consultants were hired to assist in the implementation, the knowledge and pulling force of these experts have to be taken over gradually by this SPC co-ordinator. The SPC co-ordinator should become familiar with all the ins and outs of SPC and become the driving force of SPC together with the delegated commitment of top management. In this phase the SPC co-ordinator (if necessary assisted by an SPC consultant), should give SPC training to all people involved.

Phase 4: Setting the stage for TQM

After a process is under control the PATs are dismissed and transformed into process improvement teams. They should be part of the regular organization and their task is to ensure the control of the process, tackling problems and searching for opportunities for continuous improvement. The tasks of the steering committee can also be transferred to the regular organization.

In this phase the SPC approach should also be broadened to other parts of the organization. Already in phase 3 the activities in production can have their effect on development, purchasing, customers, maintenance and other supporting activities. In phase 4, however, the SPC approach should be actively extended to these areas.

Since SPC is based on prevention instead of detection, it is a logical step to start using SPC to reduce variation in developing products and processes development. Another logical extension of SPC is to suppliers and purchasing. The only way to prevent failures in incoming material is the use of SPC by suppliers. Also suppliers of machinery and tools should adapt SPC. The in-

house acquired experience with implementing SPC in production can be used to convince other departments and the suppliers of the necessity to use SPC, and to assist with the implementation. In this phase other steering committees, chaired by the managers of the corresponding departments, should be installed to guide the implementation in the various departments.

The main purpose of SPC is to describe and to know the process; to search for and to improve weak points; to define effective measurements and control loops; and to assess the performance as a basis for continuous improvement. This concept can also be expanded to non-production departments. When it is implemented in all parts of the organization, and customers and suppliers are involved as well, this approach leads to TQM. However, this will take at least five more years: the implementation in a department will take approximately one-and-a-half years because of a limited capacity to introduce changes, and because not all departments will start at the same time.

3. Organizational structure for SPC implementation

The organization structure that is used to implement SPC consists of process action teams, a steering committee and top management. The structure depicted in Figure 2 stresses the fact that both top management and steering committee should mainly play a supporting role for the PATs.

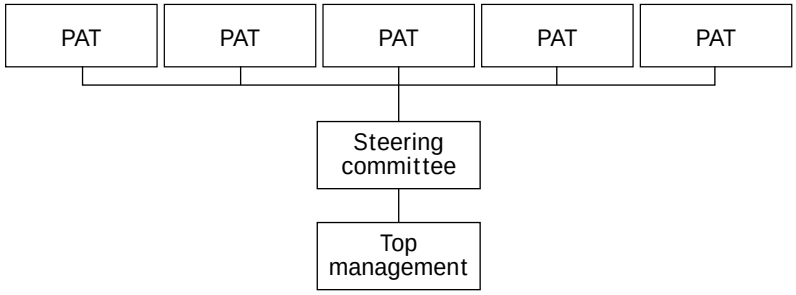

Figure 2.
Organizational structure for SPC implementation

Top management

Top management has given commitment and has delegated the management of the implementation to the steering committee. Progress is monitored based on reports from the steering committee.

Steering committee

Although the PATs are the core of the SPC implementation, the steering committee plays an important role in initiating and controlling the implementation process. To ensure management commitment in production and also related departments, the manager operations should be chairman of the steering committee and managers of purchasing, development, quality and maintenance should also be members of the steering committee. Although in the first three phases the projects will be concentrated on production, involvement and commitment of other disciplines is necessary because the SPC

projects will have consequences for related departments. To ensure management commitment in production and also related departments, the manager operations should be chairman of the steering committee and managers of purchasing, development, quality and maintenance should also be members of the steering committee. The SPC consultant and SPC co-ordinator should also be part of the steering committee. Below, the main tasks of the steering committee are listed.

(1) Initiation and promotion:
- formulate goals and form teams;
- stimulate SPC awareness through personal involvement;
- initiate promotion activities such as SPC news and bulletin board;
- stimulate teambuilding and recognition;
- reward results.

(2) Providing method and means:
- provide ten-step method (see section 4);
- ensure availability of time for SPC activities;
- initiate training and external support;
- provide extra budget to realize improvements.

(3) Controlling:
- monitor progress of PATs;
- assess problems, ensure progress;
- set priority for quality activities;
- assess results and certify teams when ready;
- make sure that the control plan is developed.

(4) Reporting to top management:
- report on progress and results;
- advise on quality strategy;
- perform cost-benefit analyses.

Process actions teams

It is important to realize that SPC cannot be implemented by a few engineers or staff members. SPC should be implemented by teams which include people from all departments involved, but especially operators. Their knowledge and commitment are crucial to make SPC successful.

Therefore the approach is based on teams called process action teams or PATs. They should consist of representatives of all directly involved disciplines. A typical PAT consists of: two to five operators (depending on the number of shifts) and their supervisor, a process engineer, maintenance engineer, internal customer, and an SPC expert. If necessary a development engineer, quality engineer and someone from the purchasing department should be part of the

team, but *ad hoc* support may be sufficient. The PAT is chaired by the person who has the technical responsibility for the process, generally a process engineer. The secretary should be someone with experience in writing reports, for example a development engineer. His/her task is to make reports on the results and planned activities.

The team members receive a short three-hour introduction to SPC from the SPC expert. The training is comparable with the introduction for top management during the awareness day, but should be adapted to their level. The rest of the training will be on-the-job, by working through the ten-step method, and by following through the SPC expert. Because not all operators can be part of a PAT (for practical reasons) it is important that the team members communicate the activities, problems and results of the project with their colleague operators.

The main goal of the PATs is to bring the process under control using the ten-step method and consequently to adapt an organization that supports SPC. The time spent on using the ten-step method and related activities besides the meetings may vary from two hours for a normal member to four hours for the secretary. Meetings should last between one-and-a-half to two-and-a-half hours and should be held at regular times and intervals. The steering committee should enable all members to spend time on the project.

4. Methodological part of the framework: the ten-step method

The team receives an assignment from the steering committee. The commitment of the steering committee can be stressed when one of its members attends the first meeting of the PAT. The assignment is written down on a standard form which is signed by each team member. It contains:

- team members and team name;
- goal to be achieved;
- the frequency of reporting to the steering committee;
- the time required from each team member.

The primary goal is to bring their process under control using the ten-step method described in this section. The method has been developed and applied for implementing SPC in the earlier mentioned companies (cf. section 1). It is laid down in a workbook that includes a brief instruction for each step and standard forms for the results. The advantage of using such a workbook is the possibility for training on-the-job, standardization of terminology and the opportunity to structure and monitor the implementation. The activities and a typical time frame path are depicted in Figure 3.

The steps can be grouped around the main purposes of SPC as mentioned in section 2:

- Steps 1, 2 and 3: to describe the process and search for weak points;
- Steps 4 and 5: to search for improvements for weak points and to implement them;

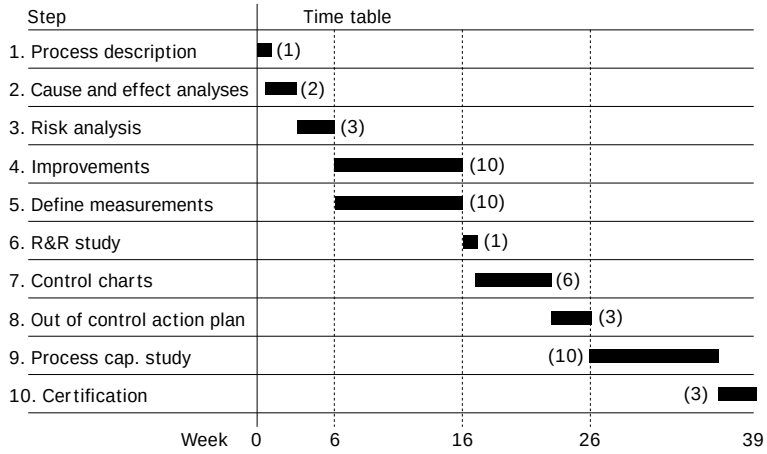

Figure 3.
Steps and typical time path of SPC methodology

- Steps 6, 7 and 8: to define effective measurements and control loops to control the process;
- Steps 9 and 10: to assess the performance and arrange for continuous improvement.

The main purpose of this article is not to describe all steps comprehensively, but to give an overview. For each step first a brief description of the activities is given. Then a statement of the methodological goal, the organizational goal, and the results are listed. Although the goals of each step are quite universal, the activities may have to be tailored to the situation. Therefore each step is concluded with a few suggestions.

Step 1: Process description

Description of activities. In this step the process is described and the boundaries of the process under study are determined. If possible, the process should be divided into process steps that include only one distinct transformation. The process steps should be numbered. It is important to describe the actual situation. The results are written down on a standard form.

- Methodological goals: demarcate process: zoom in to important part; make detailed description of actual situation as perceived by all team members; define process steps.
- Organizational goals: initiate team; show commitment.
- results: process description form with process step numbers and names.

Suggestions. In order to achieve a comprehensive overview, for large processes it may be necessary (for large processes) to zoom in and describe the process in two or three levels. Visual techniques like flowcharts can be helpful, but there is a real danger that they may become an aim in themselves. In this step already some improvements can be found by comparing work methods of different operators and engineering information.

Step 2: Cause and effect analyses

Description of activities. For the important process steps described in step 1 the main problems (causes) and their effects are listed. Using Ishikawa diagrams can be helpful (Whadsworth *et al.*, 1986). The problems should be process related, i.e. disfunctioning elements of the process as perceived by operators. Effects should be product-related problems or disruptions of the process leading to downtime. The importance of causes and effects should not be discussed to avoid limited creativity. The importance is determined in step 3: risk analysis.

- Methodological goals: describe main causes for problems and their effects in each process step.
- Organizational goals: collect and exchange process knowledge within a team.
- Results: list of possible cause and effect relations.

Suggestions. If the cause of a major problem is not known, it should be left open. In the risk analysis this will receive high priority. If the number of cause and effect relations would become too high (e.g. more than 100), then for the sake of clarity and time, it is better not to describe all relations but only those that are related to the most important and frequent effects. A Pareto of problems can be helpful to determine this priority (see also section 5).

Step 3: Risk analysis

Description of activities. In this step for each cause and effect relation the relative importance is calculated using a technique similar to failure mode and effect analyses (FMEA) (e.g. Stamatis, 1995). The risk priority of each combination is calculated by multiplying scores for:

- the frequency of occurrence of the cause;
- the severity of the effect of the cause;
- how well the cause can be detected and resolved when an effect occurs.

Scores rate from one for low frequency to ten for high frequency and so on. If the cause of a problem is not known, the score for detection is valued ten, because the cause can not be resolved. Relations with high risk numbers should be analysed for possible improvements in step 4.

- Methodological goals: find most risky cause and effect relations that should be improved;
- Organizational goals: agree on importance of cause and effect relations between team members of different background/departments;
- Results: FMEA table sorted on risk level of cause and effect relations.

Suggestions. To assign numbers to risk elements sometimes requires abstract thinking. Furthermore, assigning numbers can be subjective. However, the

process of discussing the risk numbers gives more insight in the reason of the high risk and helps in reaching consensus. If the frequency of the cause and the severity of the effect are subject to discussion, it may be useful to study historical data or to monitor the process using a logbook for some time in order to augment the judgements.

Step 4: Improvements

Description of activities. In this step the teams should generate and implement improvements to lower the risk of the most important relations. Here we use the Pareto principle: about 20 per cent of the highest risk scores generate about 80 per cent of the problems in the process. The improvements can be found in three different types:

- The frequency of occurrence can be lowered.
- The process can be changed in such a way that the causes do not have effects.
- The activities to detect and resolve the cause can be improved.

Often the phenomenon mentioned as a cause in steps 2 and 3 is not the real problem that should be tackled. Therefore problem solving techniques (Whadsworth *et al.*, 1986) should be used to find root causes or process improvements using existing knowledge and available data. However, sometimes the root causes of problems are not known. In these cases process knowledge should be expanded by measurements and analyses in step 5.

The improvements generated in this and previous steps are listed on a form. The planning and the responsible team members should be listed as well. This list is used to monitor the progress throughout the rest of the project. When improvements are made the risk analyses should be updated in order to check whether they were effective.

- Methodological goals: generate and implement improvements; check success of improvements;
- Organizational goals: use multi-disciplinary teams; control activities to implement improvements;
- Results: list with improvements and planning and responsible people for implementation.

Suggestions. The activities in this step can vary significantly from project to project. Also improvements can vary from organizational (e.g. procedures) to technical (e.g. machine adjustments). Multi-disciplinary teams can be very effective in solving problems. Although process engineers and maintenance engineers play an important role in actually changing the process, the operators should be involved too. Involvement improves their understanding of the process, they can assist in testing and implementing improvements, and involvement will improve commitment to the suggested improvements.

Step 5: Define measurements

Description of activities. To find root causes for problems and possible improvements, both process parameters and product characteristics should be monitored. The team should select the parameters for controlling the process. A plan is made to collect, to monitor, and to analyse the measurements. This is part of the control plan, a survey of all measurements in the total process.

- Methodological goals: select control parameters; make control plan;
- Organizational goals: improve data collection;
- Results: data for analysing root causes; selected parameters for process control; control plan items.

Suggestions. The measurements should explicitly be directed towards improving the process. This should result in a lower risk. The goal of the next steps is to make sure that the process will be in control.

Step 6: Repeatability and reproducibility study (R&R study)

Description of activities. The team should check whether the measurements used to monitor the selected process or product characteristics are suitable. Both systematic error and variation of the measurement should be determined. In practice the systematic error of the measurement method is often checked by calibration, but variation is often not known. Therefore a repeatability and reproducibility study (R&R study) is carried out and analysed (e.g. Kane, 1989).

The measurement error consists of the variation in the measurement device itself (repeatability) and the variation in using the measurement devices (reproducibility). Often the reproducibility is caused by differences between operators that perform the measurements. Repeatability is caused by differences between measurements by one operator. The total variation is related to the tolerance width (upper tolerance limit – lower tolerance limit) and should be less than 30 per cent and ideally not larger than 10 per cent (see the manual of Chrysler, General Motors and Ford, 1994).

If the repeatability is too large this can be compensated by repeating the measurements and taking means instead of individual data. If the reproducibility is too large the differences between the operators should be eliminated. If this is not possible another measurement method device or way of measuring should be used.

- Methodological goals: verify the suitability of measurement and sources of variation;
- Organizational goals: stress importance of accuracy and precision of measurements;
- Results: sufficiently precise measurement methods.

Suggestions. Sometimes there are other sources of variation involved, e.g. temperature of the environment. If this is the case the study should be changed to include this factor. The help of the SPC expert is necessary to design and

analyse the experiment. Standard R&R studies are designed for quantitative measurements. However, when attributive data or destructive measurements are involved, the experiment should be tailored to the situation (see e.g. Futrell (1995) for subjective classifications).

Step 7: Control charts

Description of activities. In this phase the team should gain insight in the characteristics that can be used to control the process. The control chart should be used to achieve this. In most cases it will concern product characteristics, in other cases process characteristics are the best parameters to monitor for disturbances in the process.

The most important function of a control chart is to detect when a process is out of control. This means that the control chart will discriminate between common causes of process inherent variation and special causes of variation. This is achieved by using control limits based on measurements from the process itself.

To calculate the limits a two-step procedure is applied. First preliminary limits are calculated based on all measurements. Points outside the limits indicate special causes of variation. If there are such points, it is the case that the team should analyse the measurements to find the special causes of variation and to improve the process. Trend plots and control chart patterns should be used to analyse the process. Simple tools such as trend plots, histograms and scatterdiagrams (Whadsworth *et al.*, 1986) can be used for analysis. In some cases, however, the analyses are more complex so that the help of the SPC expert is necessary. Based on the knowledge from the analysis, the team should return to step 4 to search for improvements. After the process is brought under control (i.e. only process inherent variation remains), the second step of the procedure is to recalculate the control limits based on in-control data.

The control charts can only be used for product assurance after the process has been brought in control and a process capability study (step 9) has been used to make sure that process variation fits within the specification limits.

To make control charts effective to control the process an out of control action plan is needed (see step 8).

- Methodological goals: process analyses; process control/detect process disturbances; product assurance;
- Organizational goals: introduce tool to judge process status universally among the organization;
- Results: well-described measurement, knowledge on the level of control of the process, control limits for process inherent variation.

Suggestions. The type of control chart can vary depending on characteristics of the process and the product to be controlled. In standard textbooks often the $\bar{X}$-R or $\bar{X}$-s charts are suggested. However, in our experience it shows that this type of chart is often misleading because the right conditions are not present.

(Roes and Does, 1995). But there is a good alternative: the moving range method has shown to be applicable in many situations. Often, however, the type of chart has to be tailored to the situation with the help of the SPC expert. For a more detailed discussion on differences in control charts we refer to the literature (Montgomery, 1996; Quesenberry, 1995; Wheeler, 1991).

Step 8: Out of control action plan (OCAP)

Description of activities. The control chart can only become effective as a control tool when there is knowledge on which action has to be taken when an out of control situation occurs. The OCAP should provide the operators with diagnostic knowledge to determine the causes of the out-of-control situation and the actions to be taken to resolve the problem. Also the necessary actions to deal with the products produced when the process is out of control should be included. The target situation is to give the operators as much responsibility as possible. The use of flowcharts to represent the OCAP has shown to be very helpful (cf. Sandorf and Bassett, 1993).

Especially in the beginning, the OCAP should be combined with a logbook in which all disturbances are described. A Pareto analysis of problems can be used to find weak points in the process.

- Methodological goals: document process knowledge;
- Organizational goals: assure universal approach among operators and shifts; document responsibilities for actions; delegate control to operators;
- Results: a description of how to operate in out-of-control situations.

Suggestions. New process knowledge should result in an update of the OCAP. A Pareto analysis of OCAP actions can be performed to determine the main problem areas of the process. The OCAP can also be used to document how non-conforming or out-of-control products should be processed.

Step 9: Process capability study (PCS)

Description of activities. The process capability study provides a means to measure the level of statistical and technical control of the process. In this way it can be judged whether the level of control is satisfactory to meet specification limits. If the process is in statistical control, the percentage of non-conforming products can be predicted. To judge the level of statistical control a histogram and recent control charts should be included. Finally, process capability indices can be calculated to quantify the ratio between tolerance width and process inherent variation (C_p index) and the effect on this ratio due to a deviation of the position of the process mean from the target value (C_{pk} index).

For a more detailed description of process capability studies and process capability indices we refer to literature (e.g. Kotz and Johnson, 1993).

- Methodological goals: to make process performance measurable and comparable in time; judge centring of the process; estimate the percentage non-conforming products (product assurance);

- Organizational goals: way of communicating process performance;
- Results: C_p, C_{pk}, percentage non-conforming products.

Suggestions. It is important to make sure that a comparable period of time including similar sources of variation is used when capability indices are used to benchmark the process in time. Normally a minimum of 50 to 100 measurements are necessary to calculate C_p and C_{pk}. If less measurements are used, e.g. because of low volume production, one should use confidence intervals to compensate for the limited number of data. One should also be careful in interpreting the results if the process is not normally distributed.

If control charts are used to monitor process characteristics, a PCS is only applicable when specifications of the process characteristics are present and the relation with product characteristics is exactly known.

Step 10: Certification

Description of activities. In this final step the activities of the PAT and the performance of the SPC point will be evaluated by the steering committee. A standard checklist is used to make sure that the PAT knows what is expected. The PAT will check for completeness and if necessary a brief period of training is organized to ensure that all operators are familiar with the implemented SPC point. The process will be audited by a representative of the steering committee (preferably the quality manager) and the manager of the production department. The audit includes the activities on the production floor and a check on the follow-up activities by a process improvement team (PIT) as described below. When the performance is approved a meeting is organized in which the PAT members receive a certificate as an official reward for their results.

In this phase, arrangements are made for maintaining and improving the SPC point. Often the PATs are changed into PITs, which will (be part of the regular organization). The PITs have to be part of the regular organization. The task of a PIT is to continue searching for improvements, to perform regular checks of control limits and capability, and to adapt the OCAP, FMEA and process description if new process knowledge is obtained.

- Methodological goals: to check the results of the project; assure control and arrange continuous improvement;
- Organizational goals: stimulate and reward efforts of operators; ending the PAT project; setting the stage for continuous improvement;
- Results: SPC implemented for this process; process under control; startup of PIT.

Suggestions. The members of the PIT might be the same as the PAT members, but in order to broaden the SPC knowledge and involvement, it may be wise to include other operators in the team. Furthermore, participation of the SPC co-ordinator and members of other supporting departments should become more

ad hoc. To stress that SPC is now mainly the responsibility of production, one of the operators or their direct supervisor should chair the PIT.

To broaden the scope of TQM and to limit the number of meetings for operators, other aspects such as safety, ergonomics, reduction of waste, and logistics can be included in the assignment of a PIT. This will also keep the attention of operators, when there are little SPC problems. If the certificate is valid for one year only and reaudited afterwards, this will also stimulate the continuing attention of the PIT. Especially if there are only few SPC problems, care should be given to keep the assignment challenging. Another device to keep the focus on SPC is to reaudit an SPC point yearly.

5. Discussion and lessons learned

The framework was used successfully in several organizations, ranging from mass-production of simple products (e.g. diodes), small batch production of various medium complex products (e.g. printed circuit boards), to low volume production of complex products (e.g. wafer steppers).

The organizational part of the framework is to be applicable in most organizations without large modifications. Using the four phases and the presented structure presented ensures management and operator commitment, teamwork and a goal-oriented project approach instead of ad hoc fire-fighting activities of one or a few individuals. Most organizational pitfalls are dealt with.

The methodological part of the framework is more subject to tailoring owing to differences in the situation. Although the goals of the ten-step approach presented in section 4 are quite universal, some ways to tailor the method to the situation were discussed. In some organizations it might be possible, however, that the focus and the sequence in the ten-step method need adaption. Below, two situations are briefly discussed.

Complex and large processes/rapid changing products and processes

The following case concerned an organization with a very complex process and product, with many innovations. To limit the amount of time necessary to study the large number of cause and effect relations, and to prevent the process being changed before it was described and analysed, the organization chose to concentrate on observed problems instead of all cause and effect relations, as suggested in step 2. A moving window of three months was used to study cause and effect relations of problems observed in this period (steps 2 and 3) and to find improvements (step 4).

Parallel to these activities, measurements were performed on the most relevant characteristics (step 5) to find more problems and to calculate temporary control limits. The remaining steps were applied in the standard way.

Large product variety in small batches/low volume

Classical SPC was developed for mass production situations. However, many organizations produce only small batches of various product types on the same

process or low volume of more or less the same products. In such organizations process-orientation of SPC should be stressed, instead of the traditional product orientation. The analyses will be the same, but the statistical techniques should be adapted as described by Wheeler (1991) and Quesenberry (1995).

Tailoring the method to the processes and products involved requires expert knowledge. By describing the essential functions of the method and possible alternatives, some suggestions for tailoring activities are presented in this paper, but the help of an SPC expert is often required. However, the goal of the organization should be to acquire the necessary knowledge so that in the end, training can be given by the organization's own SPC co-ordinator.

The framework presented in this paper has been applied successfully within various companies. It gives a practical approach for implementing SPC in production, including both methodological and organizational plans. The project approach and workbook method stimulate an organization to get started with SPC. The applicability of the method is improved by the discussion of the goal of each step and possible situational differences. In this way organizations are enabled to tailor the method to various production processes. In the end the SPC concept can also be applied to other processes in the organization, thus setting the stage for TQM.

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