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Statistical Process Control as a Service: An Industrial Case Study

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Abstract

Strong operations support is one of the key requirements for competitive success of modern manufacturing organisations. An important aspect of operations support is Statistical Process Control (SPC); the use of statistical methods for monitoring and control of manufacturing processes and products. However, implementation of SPC requires a certain amount of statistical knowledge and understanding. Although this is not an issue for big companies (e.g. in automotive sector), smaller companies are unable to provide the required knowledge in-house. In this paper, a service-driven approach for SPC is proposed, in which SPC is outsourced through the use of modern information and communication technologies, such as web services. This Statistical Process Control as a Service approach is illustrated and discussed through an industrial case study.

1. Introduction

Statistical Process Control (SPC) is a powerful collection of problem-solving tools useful in achieving manufacturing process stability and improving capability through the reduction of variability [1]. It may be used when a large number of similar items is being produced. The underlying assumption is that good items are produced when processes are in control with respect to target values. The main objective of SPC is to give a signal when the process changes, i.e. its mean moves away from the target value and/or its variability increases.

In essence, SPC is used to support manufacturing operations. When a signal shows that the process is changing, it is the up to the machine operator to trigger a corrective action. Traditionally, the most important SPC tool is control chart, which graphically represents process data and shows whether the process is under statistical control or not.

Implementation of SPC requires a certain amount of statistical knowledge and understanding, and is often integrated with commercial SCADA, MES, and/or ERP software. While bigger companies are able to afford integrated solutions, smaller companies frequently resort to manual methods, or are even left without SPC [2-4]. Furthermore, development of custom solutions is expensive and requires expert knowledge which smaller companies are unable to provide in-house.

In this paper, a service-driven approach for SPC is proposed. It is shown how modern information and communication technology (ICT) solutions can be used to build a distributed electronic SPC system (eSPC). The core of the system is a web service, which provides the means for remotely generating SPC reports such as control charts. The architecture of the system is presented along with an implementation of a user interface. The system is demonstrated in an industrial case study of plastic tube production.

The remainder of the paper is structured as follows. In section 2, a literature review of SPC, control charts, and service-oriented architecture (SOA) in manufacturing is presented. Section 3 introduces the proposed approach of SPC as a Service, including the system architecture and the inner workings of the system. Section 4 presents the case study and section 5 concludes the paper.
2. Literature review

In this section, two main topics are reviewed. The first one is SPC with control charts and the second one is SOA in manufacturing. Together, they form basis for SPC as a Service concept, presented in section 3.

The main reason for implementation of SPC in manufacturing processes is the need for higher and constant quality. Quality can be seen in various dimensions; level of performance, reliability, durability, serviceability, aesthetic, features, perceived quality, and conformance to standards [5]. This is the traditional way to describe quality and is summed up as “quality means fitness for use”. In contrast to the traditional definition that is consumer oriented, the modern one, “quality is inversely proportional to variability” [1], is primarily concerned with manufacturing aspects [6]. An important interpretation of the modern definition is that “quality improvement is the reduction of variability in processes and products” [1]. In this view, SPC is seen as a mechanism for controlling variability.

In SPC the process is observed as a system with a set of inputs and outputs, and is controlled according to quality-related specifications set during product development. It is important to recognize that product quality is strongly related to the manufacturing process. To produce high quality outputs, process parameters are set specific values that correspond to nominal or target values. The actual values can differ from nominal values in the predetermined area between an upper specification limit (USL) and a lower specification limit (LSL).

Control charts are one of the primary and well known techniques of SPC. A systematic use of control charts is intended to reduce variability and therefore, according to the definition, improve process quality. Many types of control charts are known, differing with respect to specifics of the controlled phenomena. Control charts can be roughly divided into control charts for variables and control charts for attributes [1].

Although the use of control charts is fairly simple, it is not always done correctly and systematically. In the light of SOA, SOM [e.g., 7-10] and IPS2 [11] an option is to implement control charts in a form of a service [12-16], to ensure correctness and a clear definition of SPC role within a manufacturing system.

“A service is defined as an activity that a service provider performs according to a beneficiary's request, with the objective of changing the conditions under which the beneficiary operates” [17]. Use of services brings external knowledge, expertise and abilities. Service providers are usually specialized and can therefore perform requested actions better than the beneficiary himself.

SOA is based on information communication technologies and mainly uses internet-based technologies to support the integration of systems that offer and use services [18].

Huang et al. [19] propose a product service system in which various information services support production along a supply chain. Furthermore, in [10], this approach is extended to material-related services, and called manufacturing oriented services (MOSs).

Building on the MOS concept, Zupančič et al. [12] present the functional diagram of a basic service unit, shown in Fig. 1.

A service unit creates new value by providing services. Together with service consumers, service units form a manufacturing oriented service network, where various services can be consumed by work systems or other services according to a set of rules and conventions. A detailed explanation can be found in [12].

In the next section, an example of a service unit for SPC is described.

3. Distributed SPC system: eSPC

This Section presents the distributed electronic SPC (eSPC) concept and ways of its realization. eSPC is a web service and a corresponding web application, providing SPC functionality through generation of control charts and other SPC reports. The role of eSPC in operations support is illustrated in Fig 2.

The input for eSPC is process data, obtained by a data acquisition system, and quality related data such as target values and specification limits, determined by an expert. The output is control chart and other SPC data in XML form.
A functional overview of eSPC usage is presented in Fig. 3, which shows how eSPC transforms raw process data into control charts viewable by the user. The process consists of three steps: (1) data transfer, (2) data processing, and (3) display of SPC data.

**Data transfer**

In the data transfer step, production data is sent to eSPC through web service methods. Methods are available for specification of a new part, specification of a new measured characteristic, and insertion of a new measurement. All data is stored in a database, which resides on the web server.

The minimal required database schema is shown in Fig. 4. The schema is based on the following concept. A manufacturing organization performs several processes. For each process, several characteristics can be observed. Each characteristic consists of a set of measurements and SPC related data such as control limits. Each user of the eSPC service has individually granted permissions to access data of an organization.

**Data processing**

In the data processing step process data is transformed into SPC data. The transformation consists of calculation of statistics for each sample, and application of rules which determine whether the statistics of samples are within limits and thus in control. In addition to the limit checking, rules (e.g. Western Electric rules [20]) are applied to identify out of control samples.

SPC data is sent back to the user in form of XML reports. XML structure for control charts is shown in Fig. 5.

A control chart report specifies a name generated from product and characteristic data, a centre line along with control limits, and includes an array of data points, each associated with a value and a Boolean variable specifying whether the data point is out of control. This is all the data that is required to draw and display a control chart.

```
<ControlChartReport>
  <Name></Name>
  <CenterLine></CenterLine>
  <LowerControlLimit></LowerControlLimit>
  <UpperControlLimit></UpperControlLimit>
  <Data>
    <DataPoint>
      <Value></Value>
      <OutOfControl></OutOfControl>
    </DataPoint>
  </Data>
</ControlChartReport>
```

Fig. 3. Functional diagram of eSPC

Fig. 4. eSPC minimal database schema

Fig. 5. XML structure of a control chart report
Display of SPC data

Finally, the data is displayed in a web browser by a web application. The web application consists of several screens:

- a control panel, showing an overview for a chosen process,
- control charts, showing detailed charts for a characteristic,
- histograms, probability diagrams and statistics screen displaying statistical information and distribution of the data.

Control panel

The control panel is the main screen of the application. For a chosen process, all control charts of its characteristics are shown in one place. The colouring of the charts is similar to that of traffic lights; green charts signify that the characteristic is in control, yellow ones that the characteristic exceeds warning limits, and red ones that the characteristic is out of control. In this way the operator is alarmed in a transparent manner simply by glancing at the control panel.

Control charts

The control charts screen displays detailed control charts for a chosen characteristic. Samples which are out of control are clearly marked in red. Several well established types of control charts are provided i.e. x-R, EWMA, CUSUM, Hotelling T².

Other screens

Other screens include histograms, probability diagrams, and general statistics of data. Together, they provide means for analysis of the observed data; especially for checking whether the data is normally distributed. This is important, because the control charts theory assumes normal probability distribution. This may seem trivial, but when the data is not normally distributed, SPC alarms may be triggered for improper reasons.

Fig. 6. The Control panel screen

Different control charts are used simultaneously for a more certain “process out of control” detection in various real situations. Shewhart’s X-R charts are basic control charts and are effective for detection of large shifts in process. EWMA control charts are on the other hand effective for detection of smaller shifts. CUSUM control charts are used for trend detection and can reveal minute changes caused for example by machine wear that tends to move the process out of control. Multivariate Hotelling T² charts take into account correlation between different measured parameters and sometimes show that process is out of control even if control charts for individual parameters do not detect the change.

Control limits can be calculated from sample points, or are predefined. Furthermore, historical data can be viewed from control charts screen by defining a time window to be observed.

Fig. 7. The Control charts screen

Fig. 8. The General statistics screen
4. Case study

The primary reason for using control charts is quality management which is often required by business clients. This includes both production of quality products as well as generation of appropriate documentation. The study presents the use of eSPC in a case of thermoplastic tube production.

The particular manufacturer is a small on-demand supplier of extruded plastic tubes. A lot of its customers are beginning to demand documentation about manufacturing process for specific manufactured items. The manufacturer decided to satisfy the demand with the use of SPC and control charts. To ensure documentation quality, traceability, quality analysis possibility, and gain a competitive edge, the use of the outsourced eSPC was selected as best solution for the given problem.

The process of plastic tube extrusion is observed. For the finished tube to be acceptable, it has to have specific material properties that can be reached only by controlled heating during extrusion. The critical target parameter, ie. the temperature during extrusion, is specified by the customer. The manufacturer therefore has defined target temperature points with tolerances that must to be reached during manufacturing and has to provide documentation that the material was treated correctly during tube extrusion process. It is requested by the customer that all non conformative tubes are excluded from delivery.

The diagram in Fig. 9 presents the basic structure of deployed eSPC service for temperature control in four heating zones and two zones in extrusion area. The temperatures are measured by a programmable logic controller (PLC) and forwarded to a personal computer (PC) that is connected to the internet.

Fig. 9. Case study: use of eSPC for temperature control

Fig. 10. Control panel showing a process out of control event

Fig. 11. Hotelling $T^2$ chart showing the event from Fig. 10.

The PC runs a program that is capable to connect with the eSPC web service. The gathered data are then transmitted to eSCP and saved in the online database.

Beside SPC, eSPC is also providing data storage and therefore continuous accessibility of data. On request, the data is analyzed and control charts are generated.

Online information is displayed in an intuitive and understandable manner, as shown in Figs. 10 and 11. Both figures display control charts for temperature in tube extrusion process. On some charts it can be clearly seen that at some point a major jump in temperature occurred. In this case the change in temperature was caused by the operator.

Fig. 10 shows that not all charts have detected the change and even if they did it is not marked as "process out of control" event in all cases. For this reason the control panel is designed to show multiple control charts side by side. In this kind of situations the use of multivariate Hotelling $T^2$ chart is also a good idea as shown in Fig. 11.

Information provided by eSPC acts as documentation for the customer. This kind of documentation can be viewed anytime and anywhere, as long as the traceability of products related to the processes is achieved.

Besides process documentation gathering, eSPC control charts are also used as a real time control
mechanism. A machine operator receives a warning when process could be going out of control even if he is not beside the machine. In this way he is able to react and improve conformity with the requested process parameters.

5. Conclusion

In the article, successful development and implementation of SPC as a Service is presented. The focus of the SPC service is on control charts with statistical tools and transparent online graphical representation of results in real time. eSPC is created as a lightweight and inexpensive building block that can act as a replacement for paper SPC and documentation in small or large distributed manufacturing companies.

The case study illustrates how to use the SPC service in a small company to increase its capabilities in process quality management and process control. Present and past information about manufacturing processes are readily available to the manufacturer and customer from anywhere and at anytime.

Analysis of the data, gathered from eSPC, can also be used for production monitoring and management in its broadest sense. This kind of information is interesting for process operators, production managers, quality personnel, production planning, upper level management, etc.

The presented use of service oriented principle in manufacturing could be widely implemented in other areas of manufacturing or manufacturing support in the future. The key issue here is that competent solutions and expertise can be provided to manufacturing companies, which are usually lacking in-depth knowledge on advanced methods.

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