VIEW POINT

REALIZING THE VALUE OF STATISTICAL PROCESS CONTROL AS AN OPTIMIZATION TOOL IN THE PROCESS INDUSTRY

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Contents

Introduction

1.1 Process industry

Unlike discrete manufacturing, every enterprise and sub-segment of the process industry is unique in its complexity and diversity of operations. While some manufacturers use industrial-scale reactors to produce tons of primary chemical products, others manufacture limited quantities of special additives used for specific purposes. However, irrespective of the scale of operations, enterprises are minimizing their dependence on skilled labor. Progressive enterprises are adopting integrated data tools, advanced control systems, and automation to improve process yield as well as quality.

1.2 A manufacturer's perspective

According to Douglas C. Montgomery (2005), quality is one of the most important factors influencing the selection of products and services. Statistical Process Control (SPC) is a strategic tool to improve processes, and thereby augment productivity and quality. SPC is based on Walter A. Shewhart's theory of process variability, which is applied not only in manufacturing processes but also in service operations for quality assurance[1]. SPC emphasizes prevention over detection. SPC charts enable enterprises to monitor process performance in real time and identify unfavorable trends or process changes before it causes quality issues. Notably, SPC can be applied across the process industry value chain (Figure 1). It adds value in core areas, including R&D, sourcing of raw materials, processing, and manufacturing.

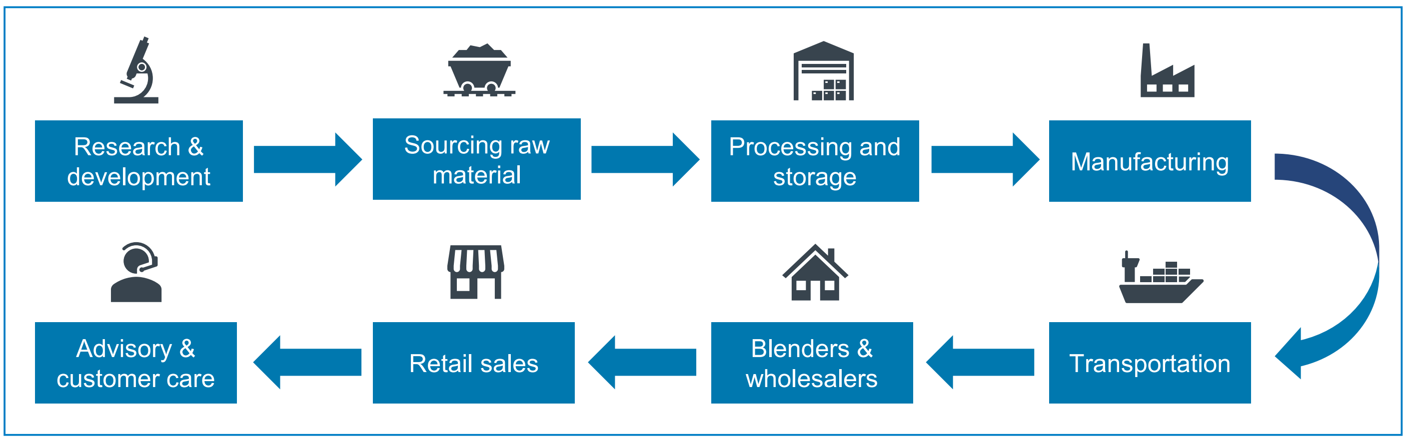


Figure 1: SPC in the process industry

1.3 New technologies and market trends

The process industry is moving toward digitalization and is investing significantly in multiple fields, according to the DigiChem SurvEY 2022[2]. The focus areas include Industry 5.0 technologies such as IIoT, MES, big data, and AI / ML. Figures 2 and 3 provide responses to the DigiChem SurvEY 2022 on the level of digitalization in enterprises.

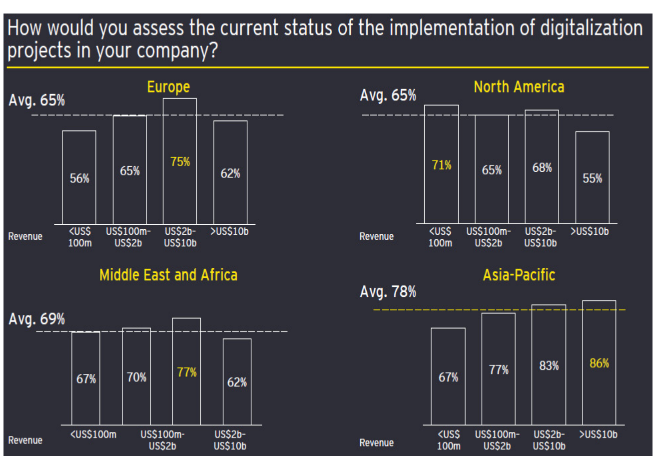


Figure 2: DigiChem SurvEY 2022

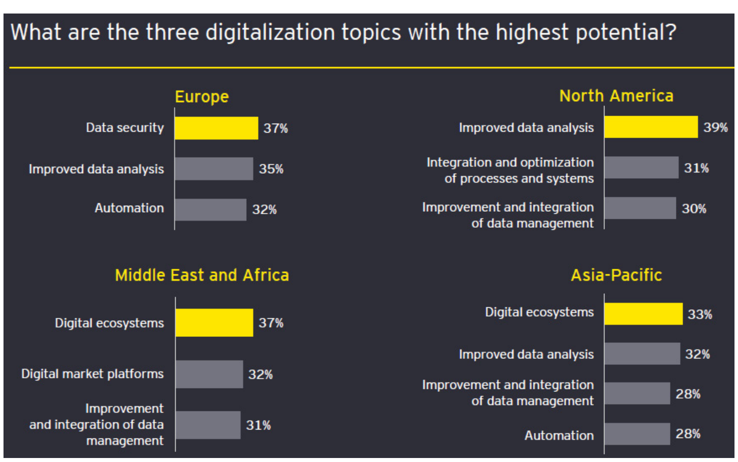


Figure 3: DigiChem SurvEY 2022

Process control tools and data techniques maximize business functions and industrial processes (Figure 4), an imperative in the context of increased focus on decarbonization and inclusive growth.

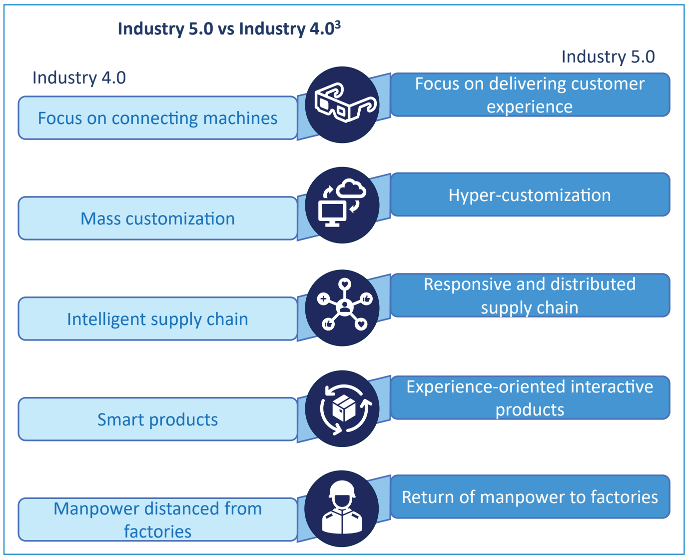


Figure 4: Industry 5.0 in the process industry

Industry 5.0 aspect	Potential of SPC
Customer experience – internal and external	Real-time data-based refinement of processes and products based on industry trends / market analysis / customer feedback
Hyper-customization	Use of digital twins to visualize new products – Customization of products (automotive / F&B / FMCG, etc.) based on consumer inputs
Responsive and distributed supply chain	Quality and performance-based decisions by multiple stakeholders. Contracts can be negotiated using real-time vendor performance trends
Experience-oriented interactive products	Integration of customer interaction and feedback – feature testing and product performance data analysis

Figure 5: Value of SPC

Significantly, SPC and data tools can empower the chemical industry to pivot to Industry 5.0[3] (Figure 5).

2.0 Data collection: Methodology and process control

The implementation of SPC requires a nuanced understanding of – the specific process, parameters to be monitored, and the instrumentation used for measuring the parameters. Such holistic knowledge facilitates a systematic approach to data collection, analysis and process control. Data can be collected in two ways for SPC: a particular product measurement or via process instrument readings.

The process industry has developed best practices for specifying, designing, implementing, and operating process control systems. For instance, current good manufacturing practices (cGMP), American National Standards Institute (ANSI) standards such as ANSI/ISA-88 (batch process control), ANSI/ISA-84 (safety instrumented systems), ISA-101 (human machine interface), ISA-106 (procedural automation), and ANSI/ISA-18.2 (alarm management).

MES streamlines management of manufacturing operations at large plants. MES also supports the use of process control systems and complements the ANSI/ISA-95 standard[4].

Process manufacturers should adopt best practices for accurate data collection and decision making while developing new process control systems or enhancing existing systems. In addition, enterprise data analysis tools such as WinSPC, Zontec, XLSTAT, SCADA, Minitab, Enact®, and ProFicient TM may be implemented to maximize the value of data.

Process data is used by SPC tools in various forms to improve quality and productivity.

3.0 Process industry use cases

A thorough knowledge of the process is an imperative to implement SPC. A few use cases from the process industry are described here.

3.1 Use case # 1: Food industry – Wax control in edible oil

The parameter that significantly affects oil quality is the presence of wax. Wax adds turbidity and blemishes the appearance of oil. SPC can be applied to improve vegetable oil processing and reduce wax content. Evaluation of waxes and wax-like substances during the freezing step is carried out by the "cold test". Sunflower oil remains transparent till the wax content is below 10 mg /kg. Therefore, this value is taken as the upper limit of the permissible values for the wax content in sunflower oil.

In a study, SPC was implemented to: a) optimize parameter consistency, b) enhance process efficiency, c) improve economic performance, and finally d) assess process stability. Several statistical tools were used in the study: 1) Histograms, 2) Shewhart Charts, 3) Ishikawa Diagrams, and 4) Pareto Chart.

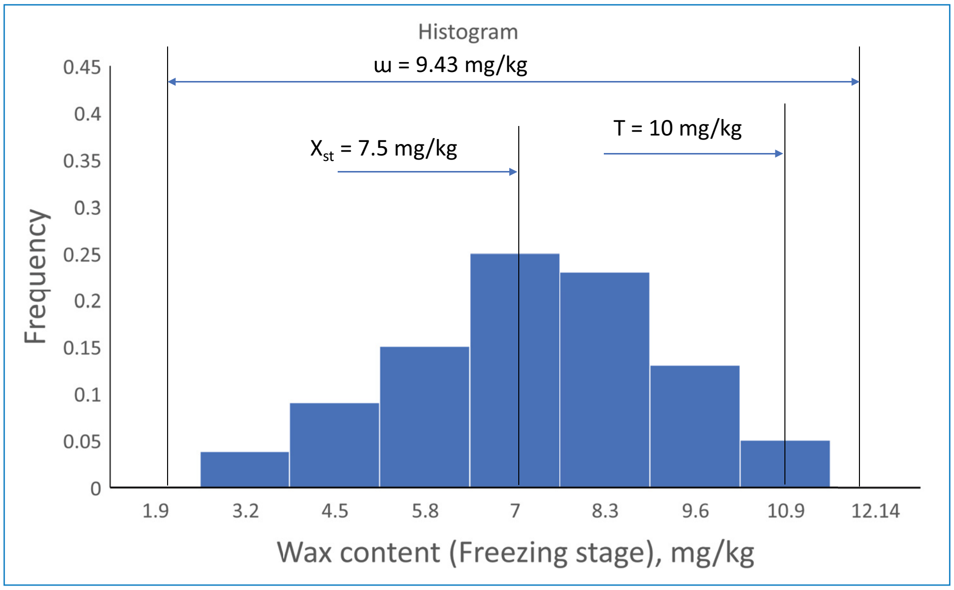
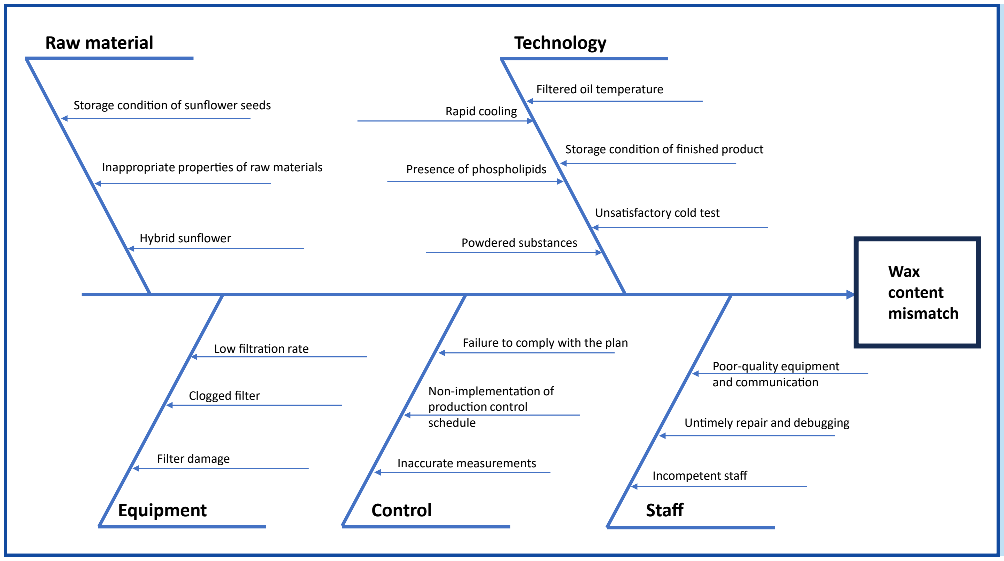


Figure 6. The histogram of the normal distribution of wax content.

The normal distribution plot predicted 5% probability of wax content exceeding the permissible limit in the final product (Figure 6). The study analyzed the influencing factors.



The cause-and-effect diagram (Figure 7) (Ishikawa diagram) demonstrated that possible reasons for the presence of wax and non-compliance of the oil with the established requirements are clogged filter, low filtration rate, high temperature of the filtered oil, rapid oil cooling, damage to the filter or filter cloth, and powdery substances

Figure 7: Cause-and-effect diagram

The well-known 80/20 Pareto principle states that 80% of non-conforming products are caused by 20% of the influencing factors. The Pareto diagram (Figure 8) led to the conclusion that the highest percentage of defective oil was caused by low filtration rate, use of powders, and temperature of the filtered oil. Further analysis revealed that the basic factor influencing the value of wax content in the final product was the quality of feedstock. The filtration rate, filter powders, and temperature of filtered oil were found to be the other causes of production defects.

The application of statistical methods for the development of corrective measures leads to the optimization of quality control criteria[5].

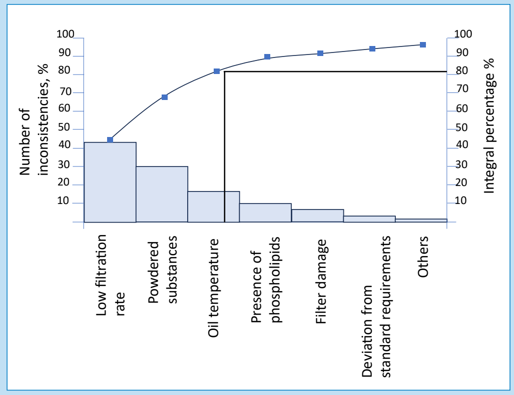


Figure 8: Pareto diagram

3.2 Use case # 2: Plastics industry – Weight control of injection molded parts

Manufacturing products through injection molding involves a precise set of specifications. Variables such as the speed of the machine, mold design and setup, raw materials, and operating conditions are controlled during operations to get the desired product quality. Figure 9 provides details of how the weight of a plastic part is controlled in the injection molding process using SPC.

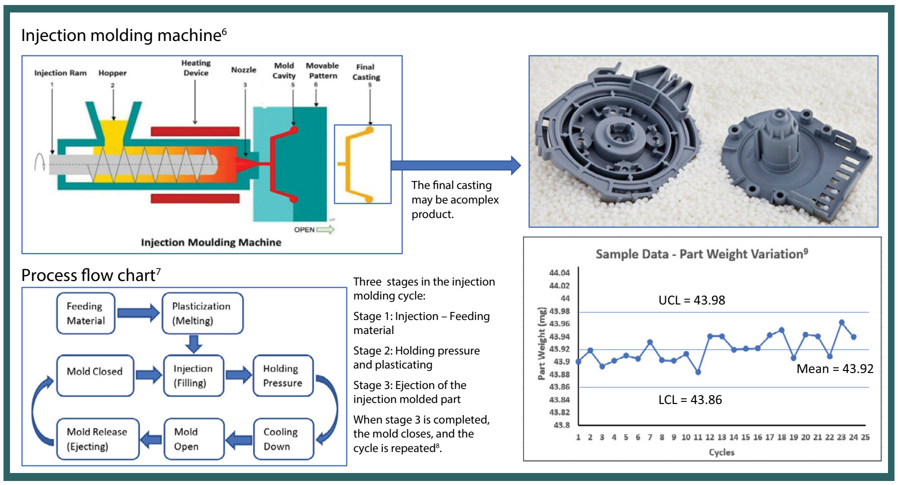


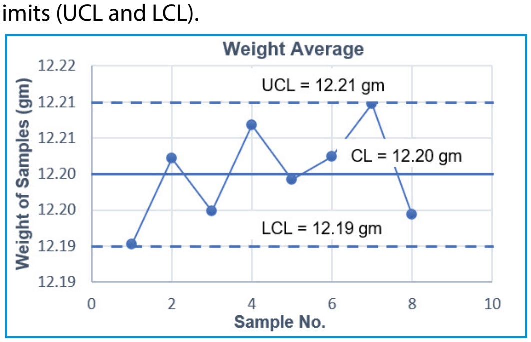
Figure 9: Weight control in injection molding

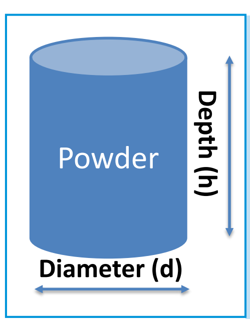
Process control for part weight: More than 30 variables are considered by a molder for molding machine operations. For plastic parts with high precision requirements, weight is a critical factor. Weight control also has commercial implications as it reduces the cost of materials. It has been established that the settings for packing pressure, barrel temperature, and mold temperature have a significant effect on the product weight[10].

3.3 Use case # 3: Pharma industry – Control of the drug filling process

The pharma industry uses simple SPC tools such as a control chart to fill powder drugs. Typically, the machine settings for the final product fill weight are set up based on the operator's experience, which leads to variations, rejections and inconsistencies.

Using SPC for optimal filling: A sample SPC chart is shown in Figure 10. The average (X) and variation in the sample data is analyzed against limits (UCL and LCL).



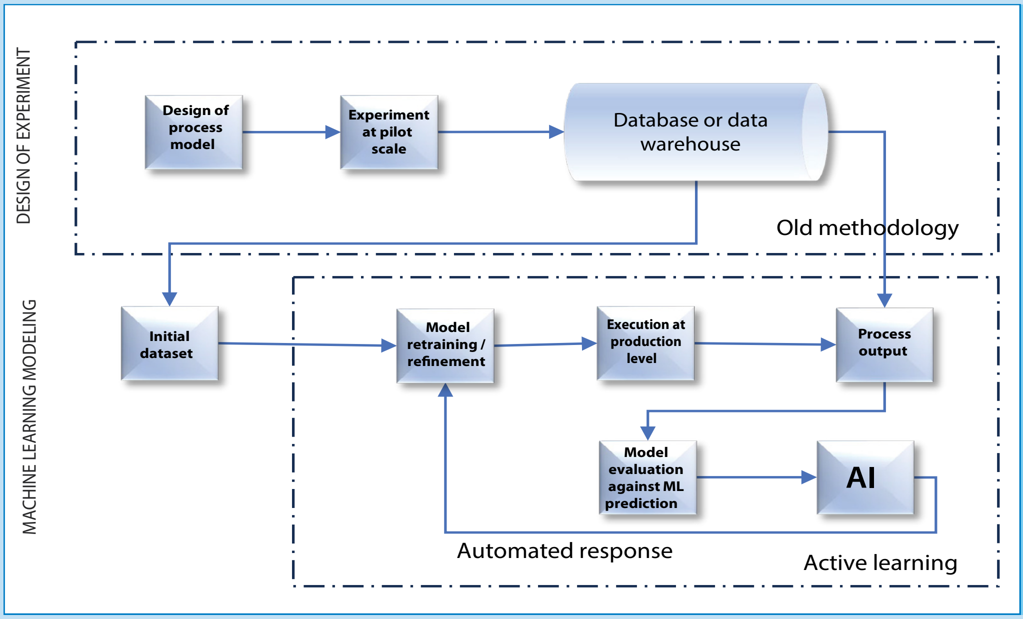


SPC output: The weight of powder in a dose (a cylindrical slot) can be calculated based on the drug density (known data) and other parameters (depth - **h** and diameter - **d**) that can be adjusted for consistency and accelerated filling process.

Figure 10: Sample control chart

4.0 AI-enabled SPC boosts process operations

The process industry has invested in IT systems and digital infrastructure, which generate enormous volumes of data, but actionable intelligence is rarely harvested from this data. Now, access to scalable computational power and advanced analytical tools empower the industry to gather relevant information from multiple sources[11] and apply it meaningfully.



SPC enables more stringent control of manufacturing processes through effective utilization of real-time data. Further, the outcomes of SPC analysis can be used for Design of Experiments (DOE). The data generated from DOE can, in turn, be used to train AI / ML models to boost manufacturing processes. Finally, SPC helps enterprises improve process efficiencies, implement cost control measures, and meet statutory mandates such as GHG emissions limits[12].

Figure 11: Conventional methods vs digital integrated learning model

As a starting point, supervised ML models can be used to predict the output of a process developed / designed using SPC-based control inputs in an active learning loop (Figure 11). In the use cases discussed above, the real-time values of critical parameters affecting the finished product, identified via SPC analysis, can be fed into the supervised model to control the process and ensure quality.

Figure 12: Benefits of SPC on the cloud

SPC tools can be implemented on the cloud (SaaS). Cloud-hosted SPC technology offers several advantages (Figure 12), which transforms process manufacturers into smart and efficient enterprises[13-14].

Paint, intermediate and specialty chemicals, pharmaceuticals, plastics, food, and agrochemical manufacturers that are currently using SPC for process optimization can now use SPC for robust process control via AI / ML. Cloud technology coupled with SPC increases the efficiency of operations and ensures consistent quality, while rationalizing costs.

5.0 The future

Efficient use of data is essential for enhancing quality, a differentiator in the competitive process industry. SPC, which has predominantly been a reactive / passive methodology, is evolving into a proactive state with advances in Industry 5.0 technology and data analytics. The combination of SPC and technologies such as IIoT, MES and AI / ML is set to redefine the process industry.

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