

MANUFACTURING CONTROL

This book describes design patterns for flexible manufacturing control. There has been control in manufacturing since its beginning. Originally, there was manual control as we measured and poured material, and manually controlled temperatures by adjusting air and fuel valves. While this is still done in many industries, we now have advanced automated control using state-of-the-art electronics and computer systems producing everything from aspirin to zippers. Yet all manufacturing control systems, manual and automated, have similar goals—the transformation of raw materials and energy into products using personnel and equipment. Manufacturing controls are the systems and procedures we use to run the physical production process. This includes automated control provided by devices such as programmable logic controllers (PLCs), distributed control systems (DCSs), and open control systems (OCSs). It also includes manual systems that may use paper or computer screens to guide operators through the production process.

As global competition in manufacturing has increased, there is increasing demand for flexible manufacturing systems. Flexible manufacturing is generally defined as a method of production where the same equipment can be used to make multiple products. For example, an automotive factory may be able to produce different car models based on customer demand. Another example is a processed food factory that is able to make many different types of soup, all using the same basic preparing, cooking, and canning equipment.

One problem that occurred as automated control was added to manufacturing is that control system programming became a critical path in both initial startup and upgrades. Often the physical equipment can be reconfigured in days, if not minutes, but unless the control system was designed for reconfiguration, the control system may take weeks or months to reconfigure and reprogram. This book provides design patterns that eliminate control system reprogramming and the bottleneck it creates in flexible manufacturing systems. The patterns can be applied to production that is fully automated, partially automated, or entirely manual.

The design patterns described in this book have been effectively applied in multiple industries. Manufacturing applications include pharmaceuticals, specialty chemicals, petrochemicals, consumer packaged goods, food and beverages, and bulk chemicals. Products include shampoo, toothpaste, beer, soda, paper, soap, electronic boards, steel, aluminum, textiles, rubber, and prepared food. The design patterns have been applied in almost every kind of batch, discrete, and continuous manufacturing application.

Some of the applications were in flexible manufacturing facilities, but many were in single-product facilities. Even in single-product facilities, the design patterns provided faster control system design and implementation. The design patterns are flexible enough to handle the majority of typical manufacturing control problems.

The design patterns described in this book are based on the ANSI/ISA 88 Batch Control System standards, and on extensions to the standards that allow them to be used in non-recipe execution systems. The name of the standard is *Batch Control*, but developers of the standard and users of the standard believe that it might have better been named *Flexible Control*. The standard is not about batch manufacturing, but rather is a model for flexible control system designs that are robust to changes.

NOTE The official standard is ANSI/ISA-88.01-1995, Batch Control Part 1: Models and Terminology. The international equivalent is IEC 61512-1:1997, Batch Control Part 1: Models and Terminology.

1.1 Production Processes

Any physical production processes can be roughly categorized as one of three types: batch, continuous, and discrete. Most manufacturing facilities have a combination of production processes, such as continuous main production and discrete packaging, or continuous preproduction, a batch main production, and final discrete packaging.

1.1.1 Batch Manufacturing

Batch processes are characterized by generation of finite quantities of material, called a *batch*, at each production cycle. Material is produced by subjecting specific quantities of input materials to a specified order of processing actions using one or more pieces of equipment.

Batch processes are inherently discontinuous processes. The batch goes through discrete and different steps as it is transformed from raw materials, to intermediates, and to final materials. Processed material is often moved, in total, between different vessels for different processing steps. Control of batch processes is not discrete or continuous, but it has the characteristics of both.

Many pharmaceutical, specialty chemical, food, and consumer packaged goods are batch processes. They may be batch processes because the underlying chemistry or physics can only be done on all the material at once. For example, cooking a pizza at home can only be done on the entire pizza, baking a cake can only be done on the whole cake, and washing clothes can only be done on an entire load at once.

Some batch processes are defined as *batch* because there are more product types than production lines, and each production line must be able to produce several different products. This is common in electronics, semiconductors, food processing, consumer products, and specialty chemical production. For example, the same production equipment may produce batches of chocolate cookies in the morning and sugar cookies in the afternoon.

1.1.2 Continuous Manufacturing

Continuous processes are characterized by the production of material in a continuous flow. Continuous processes deal with materials that are measured by weight or volume, without a discrete identity for any part of the produced material. Materials pass through different pieces of specialized equipment, each piece operating in a steady state and performing one dedicated part of the complete process. Once running in a steady state, the process is not dependent on the length of time it operates. Many bulk chemicals are produced in continuous production systems.

Startup, transition, and shutdown do not usually contribute to achieving the desired processing. Material produced during these times often does not meet end product quality specifications and must be handled separately. Startup, transition, and shutdown, however, are important events that require specific procedures to be followed for safe and efficient operations.

1.1.3 Discrete Manufacturing

Discrete processes are characterized by production of a specific quantity of material, where each element of the material can be uniquely identified. Discrete processes deal with material that is counted, or could be counted. In discrete processes, a specified quantity of material (maybe just one element) moves as an entity between different pieces of processing equipment. The assembly of computer circuit boards is an example of a discrete process. Usually, multiple elements are processed using the same equipment configuration and raw materials.

Startup, transition, and shutdown often produce the desired end product. Startup, transition, and shutdown are usually tightly controlled because they significantly impact the overall equipment efficiency. These events require specific procedures to be followed to place production equipment in the right state to make the desired product.

1.2 ISA 88 Productivity Increases

The ISA 88 standard has been applied in a wide range of industries and production process types with repeatable productivity improvements.

- Reports on its use have consistently documented over 30% savings in time and/or effort compared to traditional control strategies [1,2]
- Savings of over 50% in the total project effort compared to the previous best methods has also been documented [3,4]
- Developers of ISA 88 systems have also consistently reported more consistency in batch-to-batch timing, process quality, and final product quality [5]
- Implementations have reported a 20% increase in production capacity using the ISA 88 models [6], and in at least one case has reduced batch cycle times by 66% [7]
- ISA 88 systems that have employed recipe automation have reduced operational errors and bad batches. In the manufacturing of energetic organics, off-specification products were reduced from 15 to 20% to less than 2% of the batches produced by applying the ISA 88 models [8]
- ISA 88 also increased control system code reusability. The following table lists control system code reusability as seen across multiple projects [9]
- When ISA 88 has been used in validated environment, such as those regulated by the U.S. Food and Drug Administration, validation savings of 40% have been reported [10]

Element	Percent of Reuse (%)
Procedural Logic	70–100%
Equipment Phase	70–100%
Equipment Module	20–100%
Control Module	90–100%

- Some projects have reported the following improvements from a single project through the application of the ISA 88 models and automation [11]:
 - 30% savings in implementation cost
 - 50% reduction in number of operators
 - 10% reduction in batch cycle time
 - Reduction in abnormal occurrences
 - Reduction in product variability
- Even incremental implementations of the models into existing operations has resulted in the following savings [12]:
 - Conformance to specification increased from 96% to 100%
 - 20% reduction in batch cycle times was achieved
 - More complex control strategies were implemented, improving control of the process
 - Production yields increased by 5%
 - Process operators are now process managers instead of being just data takers, equipment watchers, and sequence implementers
 - Process development/change time has been reduced
 - Process improvements are quickly consolidated with changes to the recipe formula and procedural elements

Benefits from applying the ISA 88 models are well-documented. The design patterns in this book define consistent and well-proven patterns that follow the ISA 88 models and can be applied to a wide range of manufacturing areas.

1.3 S88 and NS88 Design Patterns

The ISA 88 Batch Control standard is a *standard* and not a tutorial, so it defines terminology and an abstract model without specifying how the abstract model should be applied in real applications. Since ISA 88's

original release in 1995, there have been many applications of the standard and a commonly accepted method for implementing the standard has emerged. The S88 and NS88 design patterns are methods for implementing the standard.

S88 is the design pattern for Batch manufacturing control.

NS88 is the design pattern for Non-stop manufacturing control.

The S88 and NS88 patterns are based on the following:

- What is written in the ISA 88 standard
- Information and examples that were used during the development of the standard
- Applications of the standard using custom software
- Applications of the standard using commercially available software
- Applications of the standard in batch production systems
- Applications of the standard in non-batch production systems

The S88 Design Pattern applies to batch production. It is based on the abstract models defined in the ISA 88 standard, but with significant extra details on the definition of patterns for control system programs. The S88 pattern applies to inherently discontinuous processes, where a product goes through distinct process steps that may occur in different pieces of equipment.

The NS88 Design Pattern applies to non-stop production, which is an inherently continuous process in either discrete manufacturing or continuous manufacturing. These are processes where a production run (or batch) may be processed by a train of equipment and the equipment may be processing multiple batches at the same time (usually during product switchover). The NS88 Design Pattern is a modification of the S88 Design Pattern for non-stop production.

1.4 Reading This Book

The S88 and NS88 design patterns are made up of several different elements and all of the design elements must be applied to achieve the benefits seen from ISA 88 implementations.

Chapter 2 describes design patterns. Using patterns is a common engineering practice, but if you are not familiar with them, especially in the context of system design, then this chapter provides a brief design-pattern overview. This chapter also describes the UML notation that is used throughout the rest of the book.

Chapter 3 describes the top pattern in S88—the separation of recipes from physical equipment. This separation occurs even if the control is performed manually. This chapter also describes the three types of control (coordination, procedural, and basic) that are used in the S88 and NS88 patterns. Read this chapter to understand the critical difference between what is defined in a recipe and what is placed in equipment control.

Chapter 4 describes the design pattern for recipes. It defines four types of recipes (general, site, master, and control), the elements of a recipe, the structure of a recipe procedure, and how a recipe is linked to equipment. The equipment hierarchy pattern is also introduced and the top-level elements are defined for batch, discrete, continuous production, and storage. Read this chapter to understand the role that recipes perform in the design pattern.

Chapter 5 describes the pattern for automated equipment control. This pattern defines a hierarchy of elements (process cells, units, equipment modules, and control modules) and defines the control aspects of each element. Each element performs a specific role in the overall pattern: basic control in control modules, equipment procedure control in equipment modules, coordination control in units, and procedural and coordination control in process cells. Read this chapter to understand how to organize PLC, DCS, and OCS control codes for flexible manufacturing.

Chapter 6 describes the pattern for manual control. This pattern defines how manual operations can be integrated with an automated recipe execution system and still achieve the goals of flexible manufacturing. This chapter also describes the method for implementing incremental automation, reducing the need to reengineer and fully automate a system in order to gain the advantages of using the S88 Design Pattern. Read this chapter to understand how to apply the design patterns to manual operations.

Chapter 7 describes the NS88 Design Pattern for non-stop production operations. This is a modification of the S88 pattern to support systems where multiple batches may be in a unit at the same time. This pattern supports a wide range of manufacturing applications and allows the use of commercial recipe-execution software in discrete and continuous manufacturing. This pattern was designed to support the needs for non-stop switchover of products, as well as support controlled startup and shutdown of production facilities. The NS88 pattern also provides a reusable structure for switching conveyor lines, valve arrays, and other material-path switching systems. Read this chapter to understand how to organize PLC, DCS, and OCS control codes for flexible manufacturing control in discrete and continuous production.

Chapter 8 describes how to apply the S88 and NS88 patterns in continuous production where there may be multiple products produced and material that may be recycled during production. The pattern may be applied to startup, shutdown, and product switchover. Read this chapter to understand how to apply S88 and NS88 in pure continuous operations with multiple product streams.

Chapter 9 describes the pattern to use for production areas where there may be splitting and merging of batches (or production runs). This pattern allows the use of commercial recipe-execution software for those industries that regularly combine batches for common processing, or split a single batch for separate processing. Read this chapter to understand how to partition work centers for flexible manufacturing control.

Chapter 10 is a short summary of the main concepts in the previous chapters.

Notes

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- [9] Givens, Mark P., and Andrew McDonald. "Repeated S88 Success Yields Cost Reductions at Large Consumer Products Company." Transactions from the World Batch Forum, 2001, Orlando, NJ.