Preface

You see it all the time: a new head of a department, or of a company for that matter, comes into a new position in the industrial automation environment from a different industry. The press release talks in glowing terms of the skills and capabilities the new office holder had in his or her previous position. This person "will leverage his strengths and capabilities to help usher in a new era." They have to hit the ground running and start producing yesterday.

However, there is a catch. Over the past fifty years, the field of industrial automation has evolved from a number of independent technical fields, such as instrumentation, electronics, maintenance, plant operations and computer science. These traditionally independent fields converged to form today's industrial automation. This convergence contributes to making the study of industrial automation much more confusing than it really should be. Part of the reason for this is that any technology-based area of study has its own idiosyncratic terminology, jargon, and slang, including acronyms. This can provide a huge barrier to developing a functional understanding for anyone walking into the industry. As a mathematics professor proclaimed to a class finishing their first year of graduate school, "We spent the first year learning the words and now it's time to learn some math." There is more truth to this than any of us might like to admit.

When the digital computer showed promise as a tool to solve industrial automation problems, the lexicon of computer technology merged with the lexicon of pneumatic and electronic instrumentation and control systems. It was not surprising that instrument companies divided into two groups, the instrument and control experts and the computer gurus. These two groups had great difficulty talking to each other because they did not have a common language. Sometimes the same acronym had two very different meanings. SPC to the computer professionals in automation companies may have meant set point control while to the operationally focused team it meant statistical process control.

To exacerbate this situation, a considerable amount of the technology and terminology associated with industrial automation comes from digital computer markets and technologies. The reason this adds a level of confusion is that computer science is one technical field in which the terminology is not driven by academics; rather it is driven by marketing departments. Digital Equipment Corporation introduced their Programmable Data Processor (PDP) series of computers to the marketplace a number of years ago as the world's first minicomputer. The word minicomputer became a part of Digital's marketing campaign. Digital intentionally did not define this word because by not defining it they could more easily claim, without having to technically justify their position, that competing computer companies did not really make a minicomputer. College professors spent the next twenty years trying to develop a technical definition for "minicomputer," and to the best of the authors' knowledge they were never truly successful. This characteristic of the lexicon has resulted in a set of words and phrases in industrial automation like distributed control system (DCS), programmable logic controller (PLC), and manufacturing execution system (MES) to name only a few; terms used daily, but not well defined.

There are aspects of industrial automation based on rich and deep technology that require considerable in-depth study to understand them, but from a functional perspective most of industrial automation is pretty straightforward. The catch is that the field is dominated by technologists who cannot help but try explaining relatively simple issues in excruciating technical detail, causing many an eye to glaze over.

There are a slew of books that provide detailed explanations of each of the major aspects of industrial automation, including all the mathematics and formulas and dynamic models. These are important books for those getting into the heavy detail. But the end result is that without a preliminary understanding of industrial automation, these are very difficult to comprehend.

Our purpose in writing this book is to provide a basic functional understanding of industrial automation. It has been very tempting to delve into technical details in a number of topics, but that is not what this book is all about.

There are people moving into industrial automation as part of their professional development. That movement includes, but is not limited to, executives who have come into industrial automation after leading companies in other markets. That level of change is good for industrial automation as new approaches and ideas often accompany new talent. We find that there are many people becoming associated with the world of industrial automation from a variety of other related disciplines, such as information technology or accounting, who require a basic level of understanding of automation to perform their job functions more effectively. These people who are new to this field need a way to quickly educate themselves with the technology and terminology; time is of the essence. We hope this book fills that need.

We have structured the material in this book to progress from the most basic subject matter through more advanced automation topics. Depending on your background and level of exposure to manufacturing processes and automation, you may want to consider skipping over some of the earlier chapters and proceed directly to the chapters of prime interest.

CHAPTER 1

Manufacturing and Production Processes: The Raw Facts

When it really comes down to it, companies exist to earn a profit. Manufacturers are no different. Simply put, manufacturing is the making or processing of raw material into finished products, especially by a large-scale industrial operation. Before discussing the three different types of manufacturing processes, let's take a quick look at the basic components and characteristics common to every manufacturing process.

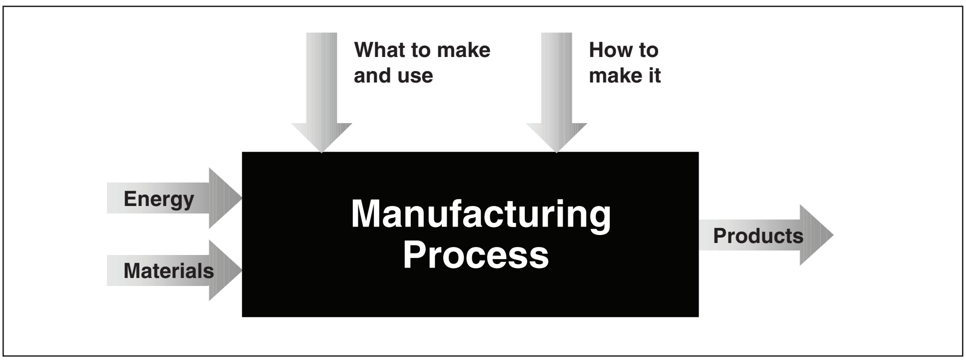


Figure 1-1 General Manufacturing and Production Process

Every manufacturing process is designed to transform raw materials into products through the utilization of basic production resources, such as equipment, tools, energy, and manpower. Figure 1-1 shows that the primary inputs to a manufacturing process include energy and raw materials. The primary output of a manufacturing process is one or more products or grades of product.

Gasoline is a perfect case in point. A quick snapshot of the process (a more in-depth version is discussed below) has crude oil coming to a plant after being pumped out of the ground. It then goes through a complex heating and cooling process where one of the end results is gasoline, which you use to fill up your SUV.

In multiple-product manufacturing operations, manufacturers often need to make decisions on what product they want to make at any point in time, and if there are multiple options within the process, how they should make the product. These two functions are scheduling and production planning. These basic components and concepts hold for any manufacturing process.

Three types of manufacturing processes exist: continuous, batch, and discrete. All three of these manufacturing process types have the basic characteristics discussed above, although they are very different in key aspects of their operation. These processes are not mutually exclusive as there are manufacturing operations that include all three types, although operating only one of the three is common. Manufacturing professionals often refer to the operation of a plant according to the dominant manufacturing process type employed. For example, an oil refinery may be referred to as a continuous process plant, even though there may be other types of processes going on at the plant.

Continuous Processes

"Continuous" simply means a manufacturing process where raw materials and energy are consumed in a continuous stream, and a product results. That product continues to be made in an ongoing manner once the process starts. Take, for example, the float glass process (Figure 1-2). Sand and other ingredients continuously feed into a large furnace. After the raw materials melt, they flow onto a molten metallic bed, where they form a sheet. After being formed, the molten glass sheet is allowed to cool slowly, and as it cools, it hardens into a continuous plate of glass that is then annealed to prevent internal stress and finally cut into sections. Once a float glass plant starts up, it typically operates continuously for years.

Products produced via a continuous manufacturing process typically do not have to be made this way. They can also be made in a discontinuous manner. The production of plate glass is a perfect example. In the eleventh century, manufacturers made glass panes one at a time using a glass blowing process with a flattening process. Although this process worked quite well, it was very limited in terms of the amount of glass a manufacturer could produce. A float glass plant operating in a continuous manner can produce much more glass than a discontinuous glass-making

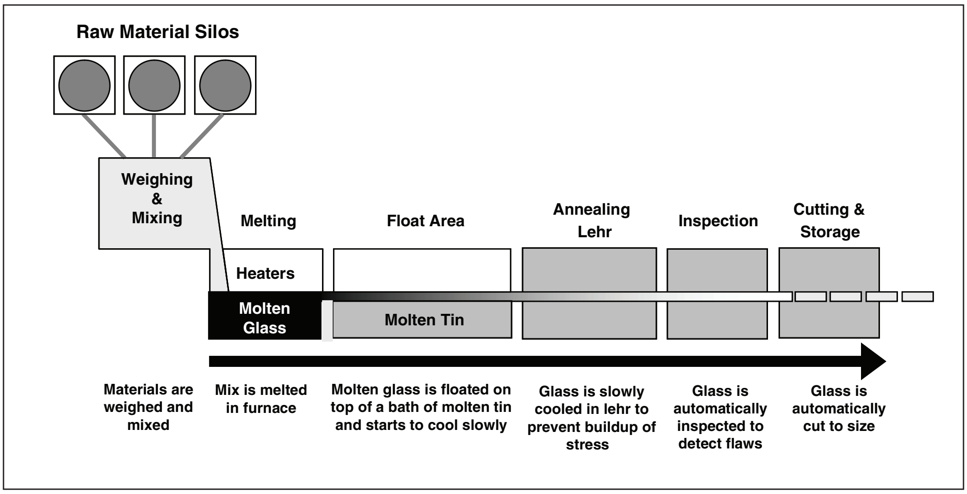


Figure 1-2 Float Glass Plant

process can. Continuous processes increase the level of production a manufacturer can achieve.

Continuous processes make the most sense when the market demand for the product is high, and the output of the manufacturing process has to be equally high in order to meet the demand. Therefore, it is important to understand that designing a continuous process to manufacture products is a decision based on big market demand for the product. Gasoline is a good example.

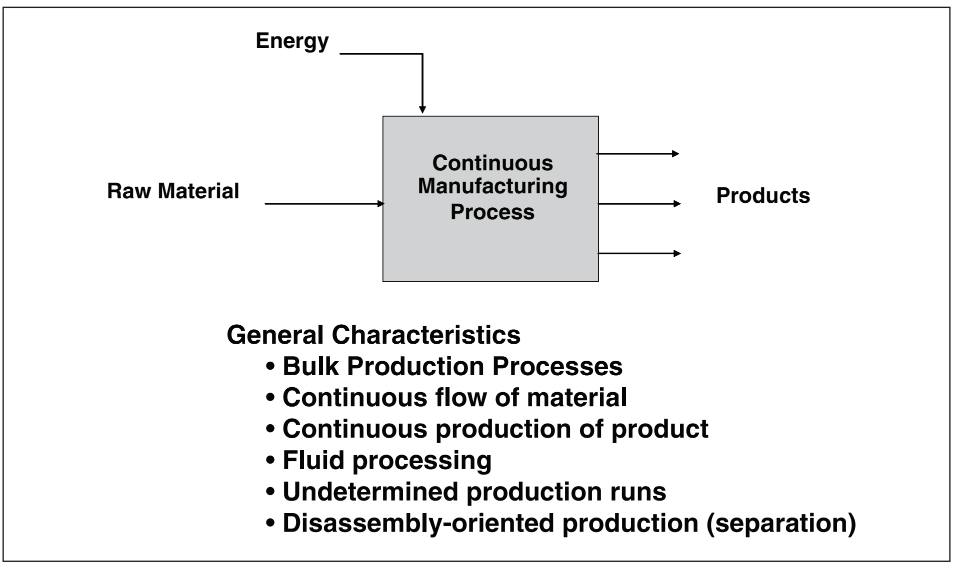


Figure 1-3 General Characterization of Continuous Processes

There are a number of characteristics typical of continuous processes (Figure 1-3). One is that most continuous processes are fluid-based. That is, they involve a significant amount of either liquids or gases as raw materials or intermediates in the processing. In order to make product on a continuous basis, there must be a continuous amount of materials on hand, which are naturally available as fluids. The glass plant example is interesting in this respect. It starts with a continuous charge of a mix of sand and other materials, which, although solid, are composed of small particles and tend to behave in a fluid manner. This mix melts to form a true fluid throughout the base processing steps, then cools to a solid toward the end of the process. This is a continuous process that involves solids, liquids and gases, but it behaves, for the most part, as a fluid process.

Another characteristic of continuous processes is that they tend to have undetermined (open-ended) production runs. As was previously discussed, float glass processes may have production runs that are measured in years. The same is true for oil refineries, which are largely continuous processes. Continuous processes tend to be challenging and take considerable time to start up, so manufacturers want them to operate as long as possible. It is a simple business formula: the more time they operate, the more product they make. The more product they make, the more revenue they generate.

Continuous processes are, for the most part, invisible. This is because much of fluid processing takes place within pipes and vessels, out of the view of operators. Therefore, these processes typically require at least a low level of automation in the form of instrumentation, just to be able to operate effectively. Batch and discrete processes, on the other hand, can often operate quite effectively in manual mode, with no need for any level of automation technology, although there are some complex batch processes that require automation to operate effectively.

Most people envision manufacturing as assembling a final product from a number of subunits, such as assembling an automobile. Continuous processing is often a reverse approach, although there are some assembly-based continuous processes, such as continuous chemical reaction and float glass manufacturing. Often a single feedstock comes in and is processed in such a manner as to pull out the components, each of which may have commercial value. Take crude oil processing, as was mentioned before (Figure 1-4). In this case, the feedstock is crude oil pumped out of the ground. It consists of a number of different hydrocarbon combinations. Most of the individual components in the crude-oil stream have market value when separated from the other components. This separation occurs by heating up the crude to the point of vaporization and then cooling the vapor as it rises through a cooling tower.

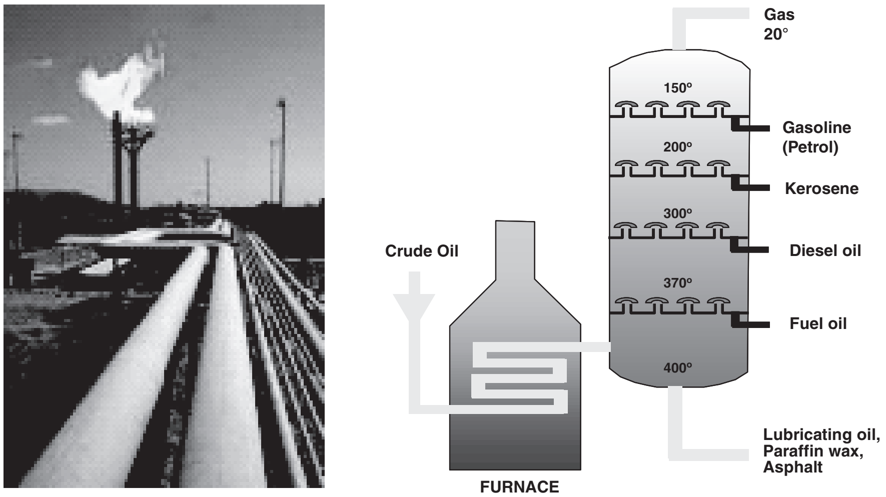


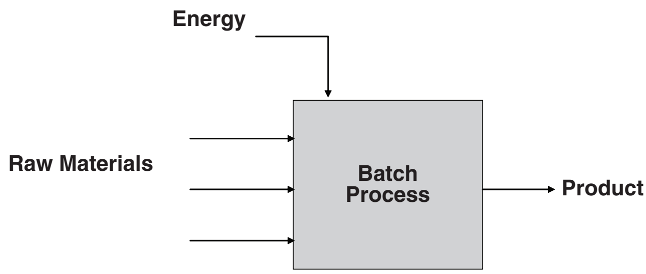
Figure 1-4 Continuous Process Example

Different components of the crude stream condense at different temperatures. As they condense they accumulate in a catch pan and are drawn off. In this case the salable products are fuel oil, diesel oil, kerosene and gasoline with additional byproducts that are converted into products such as lubricating oil, paraffin wax, and asphalt at later stages.

This disassembly process is typical of other continuous processes such as zinc processing, in which the feedstock is ore and the products might include zinc, other metals, and sulfuric acid. In paper mills, the feedstock is small particles of wood that are converted into liquid pulp, and the products are paper, bark, pulp, and turpentine. Many continuous operations involve multiple trains or lines that may interact with each other, which can increase the complexity of the operation.

Batch or Discontinuous Processes

A second type of manufacturing process is the batch or discontinuous process. As the name implies, manufacturers make products in batches or lots as compared to product being continuously produced. Unlike continuous processing, which often involves the disassembly of feedstock into base components, batch processing typically involves assembly-based processes using fluid and dry raw materials and the production of a single product at a time through the process equipment (Figure 1-5).



General Characteristics

- **Discontinuous flow of material**
- **Production of product in batches**
- **Production runs determined by time/end point**
- **Production goes through steps or phases of operation**
- **Fluid and dry processing**

Figure 1-5 General Characterization of Batch (Discontinuous) Processes

Batch plants are those with a preponderance of batch processing and may include multiple process trains that can operate in parallel. A train is a collection of process equipment used to process a complete batch of product. Therefore, even though batch processes typically produce a single product at a time, a plant often simultaneously produces multiple products through different process trains.

Batch processes consist of a discontinuous flow of raw and processed materials. The raw materials are ingredients; each is typically introduced sequentially into the process in a prescribed order, and in prescribed amounts. This is the recipe. The order of processing is typically referred to as the phases of operation or the steps of the process. Sometimes a step is considered to be a segment of production within a phase. The ingredients come together to produce an expected quantity of finished product. With batch processes, a predetermined endpoint, usually defined by time or by the value of one or more process variables, determines the end of production.

Perhaps the simplest way to think about batch processes is to consider baking a birthday cake. In making the cake, we use a set amount of ingredients, mix them in a predefined sequence, charge them to a cake pan and put the pan in the oven until the cake is ready to help celebrate the 8^{th} anniversary of our spouse's 39^{th} birthday. The phases of this operation would be mixing, baking, and cooling. The endpoint of the baking phase is either determined by the time the cake is in the oven, or by an analytical endpoint measurement (sticking a toothpick into the cake) or both. We accomplish this batch process by following the recipe. An industrial cake baking plant would essentially do exactly the same things, in greater quantity, and would repeat the process to produce a larger quantity of cakes. In an industrial setting, candles are optional.

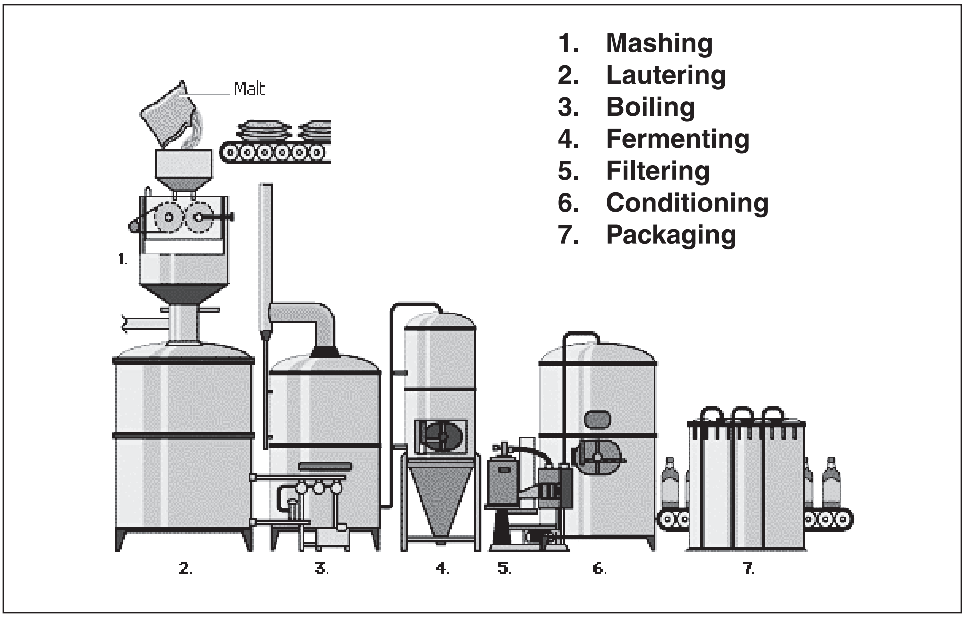


Figure 1-6 Batch Process Example

Beer brewing is a classic batch process that typically proceeds through seven phases of operation as the materials move from vessel to vessel in the brewery (Figure 1-6). The first phase is mashing, and it involves the mixing of milled grain and malt with water and heating the mixture to allow the enzymes in the malt to break down the starch in the grain into sugars. Phase two, lautering, involves the separation of the water and sugars from the spent grain. The third phase is the boiling of the extracts (called worts) to ensure that the mix is sterile, and the adding of hops to the boiling mixture to control flavor and aroma in the mixture.

The fourth phase is fermentation, which begins by adding yeast to the cooled wort, causing the sugars in the mixture to be converted into alcohol and carbon dioxide. The endpoint of the fermentation phase is determined by the time the mixture has been in the fermenting vessels. After fermenting comes the conditioning phase, in which the mixture is further culled, causing the yeast to settle and the proteins to coagulate, improving the smoothness and flavor of the beer. The beer is then filtered to remove impurities and finally packaged. This is a classic batch operation involving the sequence of a number of phases and the charging of different ingredients in predefined quantities.

Batch processing is much more flexible than continuous processing because a manufacturer can make a different product or product grade, with each batch made through the same equipment. In a brewery, a single type of beer is produced through the process equipment at one time. Most breweries produce multiple types of beer through the same process equipment by varying the recipes used.

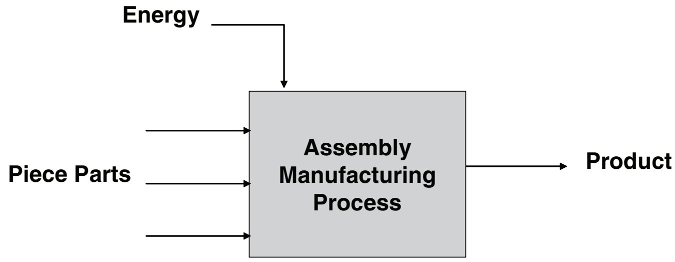
The downside to batch processes is they tend not to be able to get the high levels of production that continuous processes can, simply because they do not produce continuously. Increasing the production rate of batch processes is typically limited by the size of the batches, the time it takes to complete a batch (the cycle time), and the time between batches. Batch operations can have different batches in the same batch train at the same time in order to increase the production rate. This can be done if the different phases use different plant vessels. For example, in a brewery there may be a batch of beer in the mashing phase while another batch is the fermenting phase.

It should be noted that a manufacturer that makes products in a continuous process could also make them in a batch process. The refining of crude oil is essentially a distilling process. Moonshiners have run batch stills for years, and batch stills could distill crude. Batch processing may be the better plant design if flexibility and agility are more important business issues than pure production. There is some thought in this day and age of custom manufacturing that batch production principles will again lead the way.

Discrete Manufacturing Processes

Discrete manufacturing is generally what people think about when they think about manufacturing. It involves the assembly of piece parts into products (Figure 1-7). Discrete manufacturing incorporates the staged assembly of products through a series of work cells. Each work cell has the assembly equipment necessary to complete one stage of the manufacturing process.

Discrete processes tend to be much more parts-oriented than the other two types of manufacturing and much less energy intensive. Discrete manufacturing operations offer the flexibility of batch processing and have some of the flow-through characteristics of continuous processing, but the flow is not fluid. Rather, it is a product being assembled. In a moving assembly-line plant, the product itself also moves through the various stages of production as it is coming together.



General Characteristics

- **Discontinuous flow of materials**
- **Assembly-oriented production**
- **Assembly lines with parts coming together to form products**
- **Staged production through work cells**

Figure 1-7 Generalized Characteristics of Discrete Processes

As with other types of production, one of the economic drivers of discrete manufacturing is to maximize the flow of product through the overall manufacturing operation in order to maximize production. In most cases, human operators train on how to operate in a single work cell and perform the same basic functions repetitively as each new, partially assembled product arrives. Unlike continuous and batch processes, discrete manufacturing processes are very visible to the worker involved in the operations of a work cell. Discrete manufacturing can be effectively implemented in a completely manual manner without the need for any automation or instrumentation. Automation and instrumentation come onto the scene to make discrete manufacturing operations more efficient and effective by improving speed, quality, and repeatability.

An automobile plant (Figure 1-8) is a good example of a discrete manufacturing process. Within a discrete manufacturing plant there may also be batch and continuous operations, such as wastewater management or even painting, but most of the operations are discrete. Automobiles are pieced together on assembly lines characterized with work cells, each completing one stage of the manufacturing process. These stages might include welding the frame together, installing the wheels, and installing the motor on the frame. Manufacturing engineers focus on making sure the parts are in the right place when required, the assembling product is flowing as efficiently as possible, and the work done in each cell is done to the desired quality.

Figure 1-8 Discrete Process Example

In discrete manufacturing processes, manufacturers define quality in terms of defects per millions of parts made. The concept of “defects” does not translate directly in batch and continuous processing since they are fluid processes rather than parts-based processes. There are approaches to discrete manufacturing other than assembly lines, such as fabrication shops, but from an industrial automation perspective, assembly-based discrete processes are the most interesting.

Manufacturing Processes and Industries

As mentioned, you can often find the three types of manufacturing processes in any industrial plant. Figure 1-9 shows a continuum of industries positioned according to the level of automation commonly employed and the type of manufacturing implemented. Plants that tend to have a predominance of continuous processing are in the refining, bulk chemical, gas, power, paper, and mineral processing industries. These industries have been the ones for which the economic proposition has clearly been driven by production volume. Notice that these industries are also in a sector labeled as scientifically-oriented manufacturing. This means that significant scientific analysis went into the design and operation of these processes, and they are well understood in terms of the science behind the production. Most continuous process plants have a high degree of industrial automation.

Toward the middle of the chart are the craft-oriented industries. There are a number of different industries included in this group, such as fine chemicals, bulk pharmaceuticals, beverages, and biotechnology. These industries have a mix of

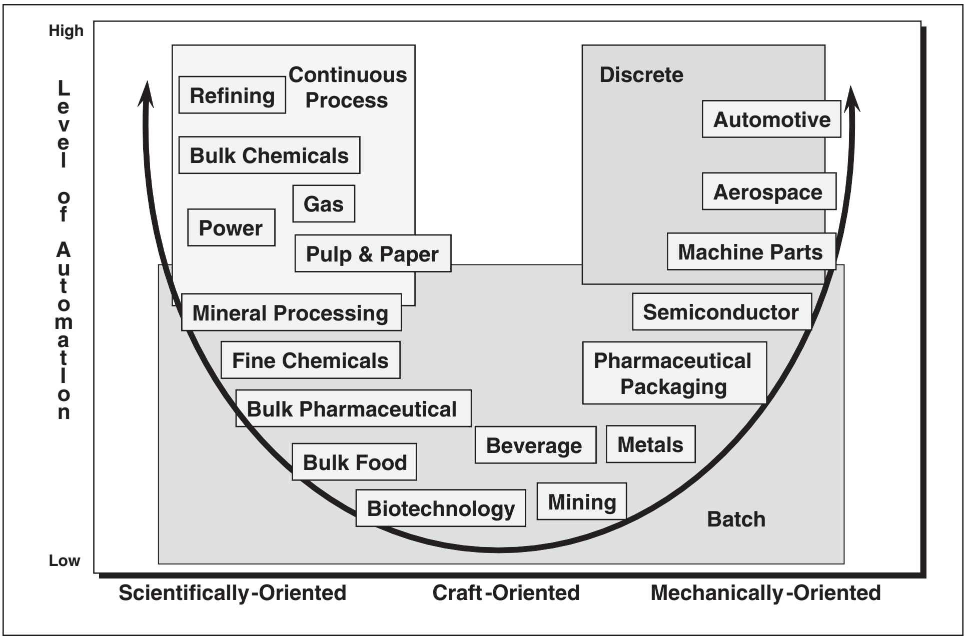


Figure 1-9 A continuum of industries positioned according to the level of automation

processing types but batch often dominates. They are craft-oriented industries because, for the most part, they have not had the level of scientific analysis done with respect to the manufacture of the products, resulting in the manufacturing being more of a craft than a science.

The final category, at the top right of this chart, includes the industries that are more discrete process-oriented. These tend to focus on piece parts being mechanically assembled into products and are categorized as mechanically-oriented industries. The scientifically-oriented industries and the mechanically-oriented industries tend to have greater levels of automation employed than do the craft-oriented industries. This may be because it is easier to automate manufacturing processes that have been scientifically or mechanically well defined compared to the craft-oriented industries, but it is more likely due to the fact that the economic value proposition for automation in continuous and discrete plants has tended to be greater than that for batch plants.

Understanding the basic manufacturing processes and how they come together in manufacturing plants is important to the study of industrial automation. Much of the terminology used in industrial automation comes from basic manufacturing terminology, and different automation technologies have been designed for the different process types. At this point, the material presented in this chapter should provide you with a level of functional understanding necessary to move forward to the following chapters.

Review Questions

1. What is every manufacturing process, regardless of process type, designed to accomplish?
2. What are the three basic types of manufacturing processes?
3. Which of the primary types of manufacturing process involves a predominance of fluid processing?
4. Which of the primary types of manufacturing process involves the assembly of piece parts?
5. What is a manufacturing train?
6. Which of the three basic manufacturing processes is designed to maximize production volume?