Introduction

An **assembly line** is a manufacturing process in which parts (usually interchangeable parts) are added to a product in a sequential manner using optimally planned logistics to create a finished product much faster than with handcrafting-type methods. The assembly line developed by Ford Motor Company between 1908 and 1915 made assembly lines famous in the following decade through the social ramifications of mass production, such as the affordability of the Ford Model T and the introduction of high wages for Ford workers. Henry Ford was the first to master the assembly line and was able to improve other aspects of industry by doing so (such as reducing labor hours, required to produce a single vehicle, and increased production numbers and parts). However, the various preconditions for the development at Ford stretched far back into the 19th century, from the gradual realization of the dream of interchangeability, to the concept of reinventing workflow and job descriptions using analytical methods. Ford was the first company to build large factories around the concept. Mass production via assembly lines is widely considered to be the catalyst which initiated the modern consumer culture by making possible low unit-cost for manufactured goods. It is often said that Ford's production system was ingenious because it turned Ford's own workers into new customers. Put another way, Ford innovated its way to a lower price point and by doing so turned a huge potential market into a reality. Not only did this mean that Ford enjoyed much larger demand, but the resulting larger demand also allowed further economies of scale to be exploited, further depressing unit price, which tapped yet another portion of the demand curve. This bootstrapping quality of growth made Ford famous and set an example for other industries.

Consider the assembly of a car: assume that certain steps in the assembly line are to install the engine, install the hood, and install the wheels (in that order, with arbitrary interstitial steps); only one of these steps can be done at a time. In traditional production, only one car would be assembled at a time. If engine installation takes 20 minutes, hood installation takes 5 minutes, and wheel installation takes 10 minutes, then a car can be produced every 35 minutes.

In an assembly line, car assembly is split between several stations, all working simultaneously. When one station is finished with a car, it passes it on to the next. By having three stations, a total of three different cars can be operated on at the same time, each one at a different stage of its assembly. After finishing its work on the first car, the engine installation crew can begin working on the second car. While the engine installation crew works on the second car, the first car can be moved to the hood station and fitted with a hood, then to the wheels station and be fitted with wheels. After the engine has been installed on the second car, the second car moves to the hood assembly. At the same time, the third car moves to the engine assembly. When the third car's engine has been mounted, it then can be moved to the hood station; meanwhile, subsequent cars (if any) can be moved to the engine installation station.

Assuming no loss of time when moving a car from one station to another, the longest stage on the assembly line determines the throughput (20 minutes for the engine installation) so a car can be produced every 20 minutes, once the first car taking 35 minutes has been produced.
Assembling of the cars

History of Assembly lines

Overview: a culmination of many efforts

The assembly line concept was not "invented" at one time by one person. It has been independently redeveloped throughout history based on logic. Its exponentially larger development at the end of the 19th century and beginning of the 20th occurred among various people over decades, as other aspects of technology allowed. The development of toolpath control via jigs, fixtures, and machine tools (such as the screw-cutting lathe and milling machine) during the 19th century provided the prerequisites for the modern assembly line by making interchangeable parts a practical reality. Before the 20th century, most manufactured products were made individually by hand. A single craftsman or team of craftsmen would create each part of a product. They would use their skills and tools such as files and knives to create the individual parts. They would then assemble them into the final product, making cut-and-try changes in the parts until they fit and could work together (craft production). The transition to other methods began as creativity and logic took advantage of the opportunities that the aforementioned machining developments presented. Thus, before the modern assembly line took shape, there were prototypical forms in various industries, as outlined below.

The Terracotta Army (circa 215 BC)
The Terracotta Army commissioned by the first Chinese Emperor Qin Shi Huangdi is a collection of about 8000 life-sized clay soldiers and horses buried with the emperor. The figures had their separate body parts manufactured by different workshops that were later assembled to completion. Notably, each workshop inscribed its name on the part they manufactured to add traceability for quality construction.

Venetian Arsenal (1500s)
At the peak of its efficiency in the early 16th century, the Venetian Arsenal employed some 16,000 people who apparently were able to produce nearly one ship each day, and could fit
out, arm, and provision a newly-built galley with standardized parts on an assembly-line basis not seen again until the Industrial Revolution.

Ford model T assembly line

Block production at Portsmouth: Brunel, Maudslay, et al. (1800-1820s)
Probably the first linear and continuous assembly line of post-Renaissance times were the Portsmouth Block Mills created in 1801 by Marc Isambard Brunel (father of Isambard Kingdom Brunel), with the help of Henry Maudslay and others, for the production of blocks for the Royal Navy. This assembly line was so successful it remained in use until the 1960s, with the workshop still visible at HM Dockyard in Portsmouth, and still containing some of the original machinery.

Eli Whitney (1780s-1820s)
Eli Whitney is sometimes credited with developing the armory system of manufacturing in 1801, using the ideas of division of labor, engineering tolerance, and interchangeable parts to create assemblies from parts in a repeatable manner. But Whitney's contribution was mostly as a popularizer rather than "the inventor" of repeatability. He was probably inspired by several others (including Honoré Blanc), or at least by the contemporary zeitgeist that was building around such ideas. Thomas Jefferson had tried to bring a French mechanic (who was almost certainly Blanc) and his methods to America in 1785, but the project never went anywhere. A few years later, Whitney and his American contemporaries succeeded in introducing the relevant concepts (interchangeable parts, toolpath control via machine tools and jigs, transfer of skill to the equipment, allowing use of semi-skilled or unskilled machine operators) to American firearm manufacture.

Meatpacking industry (1860s)
The meatpacking industry of Chicago is believed to be one of the first industrial assembly lines (or dis-assembly lines) to be utilized in the United States starting in 1867. Workers would stand at fixed stations and a pulley system would bring the meat to each worker and they would complete one task. Henry Ford and others have written about the influence of this slaughterhouse practice on the later developments at Ford Motor Company (see below at Ford Motor Company (1908-1915)).

Firearms, clocks, et al. (1860s-1890s)
The Industrial Revolution in Western Europe and North America, but perhaps most
especially in Great Britain and New England, led to a proliferation of manufacturing and invention. Many industries, notably textiles, firearms, clocks and watches, buttons, horse-drawn vehicles, railroad cars and locomotives, sewing machines, and bicycles, saw expeditious improvement in materials handling, machining, and assembly during the 19th century, although modern concepts such as industrial engineering and logistics had not yet been named.

**Ransom E. Olds (1890s-1900s)**

Ransom Olds patented the assembly line concept, which he put to work in his Olds Motor Vehicle Company factory in 1901, becoming the first company in America to mass-produce automobiles. This development is often overshadowed by the independent redevelopment of assembly-line work at Ford Motor Company a few years later (see below), which introduced the ramifications of the method to a wider audience.

**Ford Motor Company (1908-1915)**

The assembly line developed for the Ford Model T had immense influence on the world. Despite oversimplistic attempts to attribute it to one man or another, it was in fact a composite development based on logic that took 7 years and plenty of intelligent men. The principal leaders are discussed below.

The basic kernel of an assembly line concept was introduced to Ford Motor Company by William "Pa" Klann upon his return from visiting a Chicago slaughterhouse and viewing what was referred to as the "disassembly line", where animals were butchered as they moved along a conveyor. The efficiency of one person removing the same piece over and over caught his attention. He reported the idea to Peter E. Martin, soon to be head of Ford production, who was doubtful at the time but encouraged him to proceed. Others at Ford have claimed to have put the idea forth to Henry Ford, but Pa Klann's slaughterhouse revelation is well documented in the archives at the Henry Ford Museum and elsewhere, making him an important contributor to the modern automated assembly line concept. The process was an evolution by trial and error of a team consisting primarily of Peter E. Martin, the factory superintendent; Charles E. Sorensen, Martin's assistant; C. Harold Wills, draftsman and toolmaker; Clarence W. Avery; and Charles Ebender. Some of the groundwork for such development had recently been laid by the intelligent layout of machine tool placement that Walter Flanders had been doing at Ford up to 1908.

In 1922 Ford (via his ghostwriter Crowther) said of his 1913 assembly line, "I believe that this was the first moving line ever installed. The idea came in a general way from the overhead trolley that the Chicago packers use in dressing beef."

Charles E. Sorensen, in his 1956 memoir *My Forty Years with Ford*, presented a different version of development that was not so much about individual "inventors" as a gradual, logical development of industrial engineering:

"What was worked out at Ford was the practice of moving the work from one worker to another until it became a complete unit, then arranging the flow of these units at the right time and the right place to a moving final assembly line from which came a finished product. Regardless of earlier uses of some of these principles, the direct line of succession of mass production and its intensification into automation stems directly from what we worked out at Ford Motor Company between 1908 and 1913. Henry Ford is generally regarded as the father of mass production. He was not. He was the sponsor of it."
As a result of these developments in method, Ford's cars came off the line in three minute intervals. This was much faster than previous methods, increasing production by eight to one (requiring 12.5 man-hours before, 1 hour 33 minutes after), while using less manpower. It was so successful, paint became a bottleneck. Only japan black would dry fast enough, forcing the company to drop the variety of colors available before 1914, until fast-drying Duco lacquer was developed in 1926. In 1914, an assembly line worker could buy a Model T with four months' pay.

Ford's complex safety procedures—especially assigning each worker to a specific location instead of allowing them to roam about—dramatically reduced the rate of injury. The combination of high wages and high efficiency is called "Fordism," and was copied by most major industries. The efficiency gains from the assembly line also coincided with the take-off of the United States. The assembly line forced workers to work at a certain pace with very repetitive motions which led to more output per worker while other countries were using less productive methods.

Ford at one point considered suing other car companies because they used the assembly line in their production, but decided against, realizing it was essential to creation and expansion of the industry as a whole.

In the automotive industry, its success was dominating, and quickly spread worldwide. Ford France and Ford Britain in 1911, Ford Denmark 1923, Ford Germany 1925; in 1921, Citroen was the first native European manufacturer to adopt it. Soon, companies had to have assembly lines, or risk going broke by not being able to compete; by 1930, 250 companies which did not had disappeared.

### Production line

A production line is a set of sequential operations established in a factory whereby materials are put through a refining process to produce an end-product that is suitable for onward consumption. Typically, raw materials such as metal ores or agricultural products such as foodstuffs or textile source plants (cotton, flax) require a sequence of treatments to render them useful. For metal, the processes include crushing, smelting and further refining. For plants, the useful material has to be separated from husks or contaminants and then treated for onward sale. Early production processes were constrained by the availability of a source of energy, with wind mills and water mills providing power for the crude heavy processes and manpower being used for activities requiring more precision. In earlier centuries, with raw materials, power and people often being in different locations, production was distributed across a number of sites. The concentration of numbers of people in manufactories, and later the factory as exemplified by the cotton mills of Richard Arkwright, started the move towards co-locating individual processes.

### Mass production

Mass production (also called flow production, repetitive flow production, series production, or serial production) is the production of large amounts of standardized products, including and especially on assembly lines. The concepts of mass production are applied to various kinds of products, from fluids and particulates handled in bulk (such as
food, fuel, chemicals, and mined minerals) to discrete solid parts (such as fasteners) to assemblies of such parts (such as household appliances and automobiles).

Use of assembly lines in mass production

Mass production systems are usually organized into assembly lines. The assemblies pass by on a conveyor, or if they are heavy, hung from an overhead monorail. In a factory for a complex product, rather than one assembly line, there may be many auxiliary assembly lines feeding sub-assemblies (i.e. car engines or seats) to a backbone "main" assembly line. A diagram of a typical mass-production factory looks more like the skeleton of a fish than a single line.

Robots palletizing food in a bakery

Advantages and disadvantages

The economies of mass production come from several sources. The primary cause is a reduction of nonproductive effort of all types. In craft production, the craftsman must bustle about a shop, getting parts and assembling them. He must locate and use many tools many times for varying tasks. In mass production, each worker repeats one or a few related tasks that use the same tool to perform identical or near-identical operations on a stream of products. The exact tool and parts are always at hand, having been moved down the assembly line consecutively. The worker spends little or no time retrieving and/or preparing materials and tools, and so the time taken to manufacture a product using mass production is shorter than when using traditional methods.

The probability of human error and variation is also reduced, as tasks are predominantly carried out by machinery. A reduction in labor costs, as well as an increased rate of production, enables a company to produce a larger quantity of one product at a lower cost than using traditional, non-linear methods.

However, mass production is inflexible because it is difficult to alter a design or production process after a production line is implemented. Also, all products produced on one production line will be identical or very similar, and introducing variety to satisfy individual tastes is not easy. However, some variety can be achieved by applying different finishes and decorations at the end of the production line if necessary.
Assembly Workstation

A designated location along the work flow path at which one or more work elements are performed by one or more workers.

Typical operations performed at manual assembly stations

Manning level

Average manning level:

Where

\[ M = \text{average manning level of the line}, \]
\[ w_u = \text{number of utility workers assigned to the system}, \]
\[ n = \text{number of workstations}, \]
\[ w_i = \text{number of workers assigned specifically to station } i \text{ for } i = 1, \ldots, n \]

Alternative Assembly Systems

- A single station manual assembly cell
  
  It consists of a single workplace in which the assembly work is accomplished on the product or some major sub assembly of the product.

- Assembly cells based on worker teams
  
  It involves the use of multiple workers assigned to a common assembly task.

- Automated assembly systems
  
  Use automated methods at workstations rather than humans. These can be type IA or type IIIA manufacturing systems.

Analysis of single model assembly lines