THE INNOVATORS II

Engineers and the Launching of the Twentieth Century

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Chapter Five
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FORD, SLOAN AND THE AUTOMOBILE

The automobile is the preeminent machine of the modern world. In 1900, there were 8,000 registered automobiles in the United States; by 1939 there were 26 million.¹ The car gave Americans a personal mobility and freedom unknown in the nineteenth century, and by 1939 auto manufacturing had become America's leading industry. But in 1900, the future of the car was hardly clear. The market for automobiles then was small and exclusive, and cars powered by steam and electricity vied with those powered by gasoline. The car began to reach a mass market after Henry Ford's introduction of the gasoline-powered Model T in 1908. America eventually outgrew Ford's vision of a rugged egalitarian car, and a great rival, the General Motors Corporation under Alfred P. Sloan, pulled ahead of Ford in the 1920s by meeting a growing demand for variety.

The Coming of Automobiles

The railway locomotives of the nineteenth century were external combustion engines, in which a coal-fueled boiler heated water into steam. The steam went at high pressure into side cylinders, where it pushed pistons and rods attached to them. These rods turned the locomotive wheels. At the 1876 Philadelphia Centennial Fair, Niklaus Otto of Germany demonstrated a new kind of piston engine in which the fuel burned inside the piston cylinder and not in a separate compartment (Fig. 5-1). Otto's internal
ATMOSPHERIC GAS ENGINE.

By Langen & Otto.

"The Great Exhibition, 1876."

Otto Engine

Source: Phillip Sandhurst, The Great Centennial Exhibition
Philadelphia, 1876, p. 358

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combustion engine went through a cycle of four piston strokes. On the first down stroke, a mixture of coal-gas and air entered the piston cylinder. On the up stroke, the piston head compressed the mixture. An electric spark then ignited the fuel, causing another down stroke that delivered power to turn an attached wheel. A second up stroke exhausted waste gases. Modern automobile engines adopted the four-stroke cycle (Fig. 5.2). Otto sold his machine as a stationary engine. In 1885, the German Karl Benz placed a gasoline-fueled engine on a three-wheeled carriage and began making cars. Gottlieb Daimler, whose company later merged with Benz, built a more stable four-wheeled gasoline car the following year, and Émile Levassor of France built a car with the engine mounted in front instead of under the seat or in back. The brothers Charles and Frank Duryea of Springfield, Massachusetts, designed and drove a four-wheeled gasoline car in the United States in 1893 and by the mid-1890s automobile manufacturing in America was underway.

The early gasoline car was not an easy machine to own. The engine was noisy, produced a sooty exhaust, and needed highly flammable fuel. A driver had to turn a hand crank in front of the car to start moving the pistons and mechanical breakdowns were frequent. Steam and electric vehicles at first offered attractive alternatives. Steam engines had been used to power carriages and tractors in the nineteenth century. In 1898, the Stanley brothers began manufacturing steam-powered cars in Watertown, Massachusetts, that burned kerosene instead of coal. Stanley steamers could drive as fast as gasoline cars with internal combustion engines. The Stanley cars took thirty minutes
External and Internal Combustion

A railway locomotive employed an external combustion engine that burned fuel in a separate compartment to heat water into steam. The steam heated under pressure and then went to piston-cylinders on each side of the locomotive. The high-pressure steam drove pistons connected to rods in a reciprocating motion that turned the locomotive wheels.

In an internal combustion engine, fuel burned directly in a piston cylinder in a series of timed bursts. The engine drew a mixture of fuel and air into the cylinder and then compressed and ignited it. The combustion pressure drove the piston.

The stationary Otto engine burned a mixture of coal-gas and air. In automobiles, liquid fuel was more efficient and burned a mixture of gasoline and air.

The Four-Stroke Engine Cycle

![Diagram of the four-stroke engine cycle]

In modern automobile engines, the piston goes through the Otto cycle of four strokes. An intake stroke draws a mixture of fuel and air into the cylinder. A compression stroke compresses the mixture for ignition. A spark then ignites the mixture, causing a combustion or power stroke. An exhaust stroke expels the waste gases.

to start and had to stop frequently for water, but after 1901, steamers made by the rival White firm began to use preheated water and condensers to recycle steam. The Stanleys eventually adopted similar devices. Steam cars were complex and difficult to maintain, though, and most steam car makers switched to manufacturing gasoline cars with internal combustion engines in the decade after 1900. The Stanleys continued to make steam cars but preferred to make them by hand, which limited their market to several thousand owners. The Stanley firm went out of business in the mid-1920s.4

Electric battery-powered cars also appeared in the 1890s. These could be recharged with direct current at central power stations, which were happy to sell power in hours of off-peak usage. With rectifiers to convert A.C. to D.C., alternating current could be used for recharging as well. Electrics were silent, clean, easy to drive, and reliable, and found a ready market, especially among women. Electric cars had a range of about fifty miles and needed several hours to recharge, but they were well-suited for driving short distances in town. Electric cars failed, though, for cultural reasons as much as for technical ones. Gasoline cars appealed to men, who enjoyed the challenge of driving and maintaining them. As gasoline cars gradually increased their speed, a key attraction to male drivers, they left electrics behind. Touring the countryside by automobile was also an ambition of most early car buyers and the limited range between recharging meant that electrics could not be used for travel over long distances. Women who had bought electric cars remained loyal to them; but the invention for gasoline cars of small electric starting motors in 1912 made hand cranking unnecessary, and new women drivers began
to switch. Canned gasoline was easy to distribute through the network for distributing kerosene illuminants and repair garages later sold gasoline from pumps. The electric power network did not reach most suburban households until the 1910s and 1920s, too late to give electric cars outside the cities a nearby supply of electricity.\footnote{5}

But in one respect cars using internal combustion engines were no better than early steam and electric vehicles: their high cost. Purchase prices of $500 to $1,000 or more at the turn of the century permitted only the wealthy to buy automobiles. In Europe, cars were built in small numbers by firms whose names became synonymous with wealthy owners, such as Rolls-Royce in England and Bugatti in Italy. In the United States, luxury cars like the Pierce-Arrow also served a small market that could afford them.\footnote{6} The manufacturing of early cars followed craft traditions, in which a few highly-skilled workmen assembled each car in place in small workshops or factories. Buyers usually purchased cars directly from the factory and relied on urban garages or their own servants to maintain and repair them. The small scale of early automobile-making also made it possible, however, for entrepreneurs with little capital to enter the business. Henry Ford was one of these entrepreneurs.

Henry Ford

Henry Ford (1863-1947) grew up on a farm outside Detroit, Michigan (Fig. 5-3). He was fascinated by engines at an early age, worked as a steam engine repairman in the
1880s, and studied an Otto engine that came to the area. In 1891 he left for Detroit, where he worked as an engineer for the city’s Edison Illuminating Company and built a gasoline car in his free time. In June 1896 he successfully drove the car, a motorized carriage on four bicycle wheels that he called a “quadricycle.” In August, at a convention of the Edison companies in New York City, Ford met Thomas Edison, who encouraged him to keep working on a gasoline car. With the backing of the mayor and other investors, Ford resigned from Edison in 1899 and formed the Detroit Automobile Company. His share in the company was meagre, though, and his failure to produce a workable design forced the company to dissolve in November 1900.7

To raise capital for a new company, Ford decided to win fame as a racecar builder. Ever since the steamboat, new forms of transportation had proved themselves in races, either to beat a fixed time or to race competitors to finish in the fastest time. In 1807, Robert Fulton’s steamboat reached a speed of four miles per hour in a trip up the Hudson river from New York City to Albany and back. In 1896, Frank Duryea beat a Benz car in a road race from New York City to Irvington-on-Hudson and back.8 Returning to the family farm, Henry Ford built a racecar and entered a meet held at Grosse Pointe, Michigan, on October 10, 1901, with a prize of $1,000. Alexander Winton of Cleveland, a carmaker and the country’s foremost racecar driver, also entered and was expected to win.
After the starting gun, Winton took an early lead but Ford began to gain on him as the local crowd cheered him on. Winton's car then developed engine trouble and Ford caught up and won the race, gaining Ford the gratitude of Detroit and the backing of new investors. The investors didn't give Ford the freedom he wanted, though, and he left in March 1902. The company reorganized under Henry Leland and took the name Cadillac.

Ford gave racing one last chance. On October 25, 1902, Winton returned to Grosse Pointe to avenge his earlier defeat and Detroit eagerly awaited the rematch. A racing cyclist, Barney Oldfield, agreed to drive a new and more powerful car that Ford built (Fig. 5-4). Winton did not finish the race and Ford's car won, setting an American record of under 1 minute 6 seconds per mile.9

Ford organized a third company, the Ford Motor Company, in June 1903 with the principal backing of Alexander Malcomson, a coal dealer. Ford had a larger share now and he ran the engineering side while Malcomson's accountant, James Couzens, managed the rest of the business. The new firm survived and expanded by innovating in two ways. First, with the help of capable machinists such as C. Harold Wills, Ford introduced cars that embodied his intuition, against the conventional wisdom of the time, that cars could be lighter in weight and greater in power. Second, Couzens established a strong network of dealerships. He demanded that dealers pay the company in advance for the cars they sold instead of paying after selling them. Distributors also had to offer repair services to owners. Dealers who accepted these conditions discovered that they could make money, and the guarantee of service helped build the reputation of Ford cars.10
Ford and Barney Oldfield with 999 racer.
Ford's first car, the Model A, sold 1,700 cars in its first fifteen months. With this success, Ford was able to stay in business without having to rely on outside money. But his desire to make low-priced vehicles for a larger market came into conflict with Malcomson and his partners, who wanted the company to produce higher-priced models for wealthier buyers. After producing two high-priced models, the Models B and K, Ford bought out Malcomson in July 1906 and became majority owner of the company. He quickly brought out a new car, the Model N, that weighed 1,050 pounds but could reach a speed of 45 miles per hour and sold for $600. The Model N raised Ford Motor Company sales from 1,600 cars in the 1905-06 season to 8,243 in 1906-07. Ford set his sights even higher and began planning the breakthrough car that became the Model T.

The Revolution of 1908

Ford rolled out the first Model T in 1908 (Fig. 5-5). The new car weighed 1,200 lbs. and could go no faster than the Model N, but it delivered greater power to the wheels and incorporated several important innovations, principally the use of vanadium steel, a lightweight alloy that afforded the strength of a heavier car. Ford also designed the car for unpaved country roads with the body high above the ground. The Model T had an ungainly appearance as a result but could drive through mud and grass that other cars could not. Shifting gears was simpler than in any other car on the market, a crucial
MODEL "T" FORD 1908
Built by the Ford Motor Company of Detroit, Michigan, it was one of the first of 15 million Model "T's" manufactured by this company.
attraction to the ordinary buyers Ford wanted to reach. He also designed the car so that it could be understood and maintained by its owner.\textsuperscript{12}

The Model T depended on three core systems to work: electric ignition, chemical combustion of the fuel, and mechanical transmission of power from the engine to the wheels. The Model T engine had four vertical cylinders and a piston in each cylinder connected to a crankshaft underneath. When the pistons began moving, the crankshaft rotated. Gears (in a box called the "transmission") carried this rotation to a central driveshaft running lengthwise under the car to a "differential" gear that turned the rear axle and its wheels (Fig. 5-6).\textsuperscript{13}

To start the car, a driver turned a hand crank in front. The crank turned the crankshaft and also turned a magneto, a circular case in which a flywheel with magnets rotated around a fixed wire coil. The flywheel generated electricity in the same manner as a rotating armature in an electric generator. The electricity went to four small coil units (transformers) that stepped down the current and raised the voltage. The voltage from each coil went through a revolving contact called the distributor that fired a sparkplug in each cylinder in a rapid sequence (Fig. 5-7). The firing ignited a mixture of gasoline and air that had entered the cylinder through a carburetor, and the combustion pushed down the piston in each cylinder.
Fig. 5-7

The Model T: Ignition and Fuel Systems

Electric Ignition

By turning a hand crank, the driver rotated a magneto that sent an electrical current to four coil units (small transformers), which stepped up the voltage. The high voltage went to a distributor (called a "commutator" in the Ford engine), which sent voltage to each spark plug in rapid sequence, causing ignition of the fuel mixture in the cylinder. Once the engine began running, the crankshaft took over from the hand crank.

Fuel System

Gasoline, stored in the fuel tank, went through a carburetor that mixed the fuel with air. On the intake stroke of the piston, the fuel mixture entered the engine cylinder. Combustion transformed the fuel, represented below by octane (C₈H₁₈) and oxygen (O₂), into the waste products water (H₂O), carbon monoxide (CO), and carbon dioxide (CO₂):

\[ C₈H₁₈ + 10.5 O₂ \rightarrow 9 H₂O + 4 CO + 4 CO₂ \]

Octane  Oxygen  Water  Carbon Monoxide  Carbon Dioxide

Source: Ford Owners Manual (1914), p. 45 (ignition diagram). 1. Other elements present in the fuel (e.g. nitrogen) and waste gases (e.g. nitrous oxides) are omitted.
The crankshaft connected the pistons so that when one piston went down, the one next to it went up. Each cylinder went through a cycle of four strokes. Engineers measured the average power of combustion on the piston head using the same formula, \( PLAN / 33,000 \), that James Watt had developed in the eighteenth century for measuring the horsepower in a piston steam engine. In an internal combustion engine, automotive engineers called the result of this formula the \textit{indicated horsepower} (Fig. 5-8).\(^{14}\) In the Model T at its top speed of 37 miles per hour, the indicated horsepower was about 23 Hp. Friction losses in the cylinders caused the power that reached the crankshaft, known as the \textit{brake horsepower}, to be less, just under 20 Hp. Further losses in the transmission of brake horsepower to the wheels reduced the power at the wheels, or \textit{traction horsepower}, to about 12 Hp. The Model T was still an efficient car for its time.\(^{15}\)

The traction horsepower had to be sufficient to grip the road and move forward. On an unpaved road, resistance to the wheels was greater than on a paved road; and as speed increased, resistance of the air became greater. The Model T was built for a nation of mostly unpaved roads, and speeds above 37 mph were not normally required. The car's traction horsepower was sufficient to drive at this top speed (Fig. 5-9).\(^{16}\) The gearing system in the car enabled it to climb hills. The principle of gearing was similar to that on a bicycle. By changing gear on a bicycle, a rider could shorten or lengthen the distance traveled by each revolution of the pedal. In low gear, each pedal rotation caused the back wheel to turn much less than in high gear and made pedaling easier going uphill. The chain transmissions on bicycles were not practical for cars, and instead rotational
The Ford Model T had a four-cylinder engine that operated on a four-stroke cycle (left). The diagram shows the position of the pistons at the start of each stroke. The combustion or power stroke is called the "explosion" stroke.

Each cylinder produced one power stroke for every two revolutions of the crankshaft. Thus, in a four-cylinder engine, there were two power strokes per revolution.

The average power on the piston head produced by combustion was the indicated horsepower of the engine: \( P_i = \frac{\text{PLAN}}{33,000} \). The indicated horsepower of the Ford Model T at its top speed of 37 miles per hour was:

Pressure \((P)\) on piston head = 70 pounds per square inch (estimated average)
Length \((L)\) of piston stroke = 4 inches
Area \((A)\) of piston head = \(D^2 \pi / 4\) where \(D\) is diameter of the cylinder
Number \((N)\) of power strokes = 3000 per minute (1500 revolutions per minute)

\[
P_i = \frac{\text{PLAN}}{33,000} = \frac{(70)(0.33)(11.1)(3000)}{33,000} = 23.5 \text{ Hp}
\]

The brake horsepower or power at the crankshaft was about 85% of the indicated horsepower at the car's top speed:

Brake Hp \((P_b)\) = \(P_i (0.85)\) = 20 Hp

The traction horsepower or power reaching the wheels was about 60% of the brake horsepower at the car's top speed:

Traction Hp \((P_t)\) = \(P_b (0.60)\) = 12 Hp

Source: Ford Owners Manual (1914), p. 18 (illustration); PLAN data computed from Allan Nevins, Ford, Vol. 1, pp. 387-393, and from Floyd Clymer, Henry's Wonderful Model T (1955), p. 127 (Fig. 20).
The Model T: Traction

The Model T needed to deliver enough power to the wheels to meet the traction horsepower required to overcome the resistance of the road and the resistance of the air at a given speed. The formula for traction horsepower is \( TV / 33,000 \). \( T \) is for traction force in pounds and \( V \) is for velocity in feet per minute.

Traction Force

Resistance of the road, also known as rolling resistance, is the product of a road coefficient \((C_R)\) and the weight of the car \((W)\). The road coefficient represents the condition of the road surface.

Resistance of the air, or drag, is the product of a drag coefficient representing the shape of the car \((C_D)\), the air pressure on the front of the car in pounds per square foot \((p)\) at a given speed, and the surface area of the car’s front \((A_F)\) in square feet:

\[
C_R = \text{coefficient of road resistance (0.015 for a paved road)}
\]
\[
W = \text{weight of car (1200 pounds for the Model T)}
\]
\[
C_D = \text{coefficient of drag (about 1.0 for the Model T)}
\]
\[
p = \text{air pressure (0.00257 } V^2) \text{ (at 37 mph = 3.5 pounds per square foot)}
\]
\[
A_F = \text{frontal area of the car (about 28 square feet for the Model T)}
\]

Adding rolling resistance and drag gives the traction force:

\[
C_R W + C_D p A_F = \text{Traction Force (T)}
\]
\[
(0.015)(1200) + (1.0)(3.5)(28) = 116 \text{ pounds}
\]

Traction Power

At its top speed, the Model T had a velocity of 36.86 miles per hour, which we round to 37. To convert \( V \) into miles per hour, we divide by 88 (88 feet per minute equals one mile per hour) and restate the formula for traction power as \( TV / 375 \):

\[
TV = (116)(37) = 11.4 \text{ Hp} = \text{Traction Hp required to drive}
\]
\[
375
\]

The traction horsepower requirement of 11.4 Hp was under the 12 Hp that the Model T could deliver to the wheels at 37 miles per hour.

Source: Society of Automobile Engineers, Transactions (1915), p.190 (road coefficient \( C_D \)); other data given or computed from Floyd Clymer, Henry’s Wonderful Model T (1955), p. 127 (Fig. 20).
power from the crankshaft went to a solid driveshaft through a transmission box containing gearwheels of different sizes. The Model T had two forward gear settings, high and low, and one setting for driving backwards (Fig. 5-10).

The Ford Assembly Line

The Model T was an immediate success. But demand soon exceeded Ford's ability to manufacture the car by conventional methods. In common with other car makers in 1908, Ford built his cars from components supplied by others. Each car was assembled in place by workers who moved from car to car on the factory floor. To assemble a chassis required about twelve hours. Ford and his engineers studied the assembly process closely. They soon realized that they could accelerate production if the workers stayed in one place and the parts to be assembled came to them by conveyor systems. By the earlier methods, each worker had to perform a multitude of tasks requiring many skills. With a moving assembly, workers could now specialize in a single task, and these tasks could be sub-divided. Moving to a much larger plant in the Highland Park section of Detroit in 1910, Ford developed over the next four years a production system consisting of a major assembly line fed by sub-assembly lines on which workers each performed a single repetitive task. The process reduced the time needed to make the chassis from twelve hours to 93 minutes (Fig. 5-11).
The velocity of the Model T can be calculated from the formula:

\[ V = \left( \frac{N_C}{r} \right) \pi D_w \]

where \( N_C \) is the number of crankshaft revolutions per minute (rpm), divided by the gear ratio \( r \), the ratio of crankshaft to driveshaft rpm, and then multiplied by the circumference of the wheel, \( \pi \) (\( \pi \)), times the wheel diameter \( D_w \).

The maximum crankshaft speed of the Model T was 1500 rpm. The gear ratio in high gear was 3.63 / 1 and the diameter of the wheel was 2.5 feet, giving a velocity:

\[ V = \left( \frac{N_C}{r} \right) \pi D_w = \left( \frac{1500}{3.63} \right) (3.14) (2.5) = 3243 \text{ feet per minute} \]

Dividing by 88 to convert feet per minute into miles per hour, the car could travel 36.86 miles per hour in high gear.\(^1\)

In low gear, the car could travel only 13.4 mph at the top crankshaft speed of 1500 rpm. But at 13.4 mph in high gear, the crankshaft turned only 546 rpm. At 13.4 mph in low gear, the engine delivered more power (1500 rpm) to the wheels. In low gear at a lower speed, the car could more easily drive uphill or on rough roads.

Source: Floyd Clymer, *Henry's Wonderful Model T* (1955), p. 127 (Fig. 20). \(^1\) To convert to mph, 3243 feet per minute \( \times \) 60 minutes/5280 feet per mile = 3243 / 88 = 36.86 mph.
"Ford Model T Chassis, ca. 1914"

"Static Assembly Line, Ford Model T Chassis Assembly, ca. 1910"

FIG. S-11
(Source: Henry Ford Museum)
The idea of a moving assembly was not new; the meat packing industry had developed it earlier. What made Ford's assembly line revolutionary was his combination of a moving assembly with another American idea, manufacturing with standardized and interchangeable parts. Ford demanded of his suppliers that every part be machined to high tolerances so that all were exactly the same, and to ensure high standards he eventually produced all of his parts for himself. As a result, workers could rapidly assemble cars without having to adjust parts that didn't exactly fit. The rapid mass production of inexpensive well-built cars followed. In 1909 the Model T runabout sold for $825. By 1916, the price had fallen to $345. Sales rose from 78,440 cars in 1911-12 to 751,287 in 1916-17 (Fig. 5-12). Rival auto makers began to imitate Ford's methods and total car production in the United States rose to 1,745,702 in 1917. By then Ford had captured 43% of the market and was by far the largest car company. 19

To sustain his success, however, Ford had to overcome two challenges: a charge of patent infringement and a high turnover in his labor force. In 1879, the lawyer George Selden of Rochester, New York, had patented an internal combustion engine. By filing a series of amendments, Selden had postponed the commencement of his patent until 1895, by which time it was clear that a market existed for cars. Patent law protected an invention for seventeen years and Selden sued Alexander Winton successfully in 1903 for infringing his claim. The major auto makers then formed an association that paid royalties to an electric vehicle company to which Selden had transferred his patent. Ford refused to join and the association filed suit. In 1909, a federal district court in New
FIG. 5-12
(Source: Henry Ford Museum)
York upheld the Selden patent and threatened to put Ford out of business. An appeals court ruled in Ford's favor 1911, however, by noting that Selden had only patented a two-stroke engine, not the four-stroke engine used by Ford and most other car makers. With only one more year of the Selden patent remaining, the association declined to take the case to the U. S. Supreme Court and the public hailed Ford as a giant killer.\textsuperscript{20}

Labor proved to be a second challenge. The reduction of work to a single task afforded employment to less skilled workers, including large numbers of immigrants from Europe, many black migrants from the American south, and some women and disabled people. But the grinding repetition of the assembly line produced a high turnover each year. Line workers earned about $2.50 a day for a nine-hour day, a rate typical of other firms in the auto industry. In 1914, Ford dramatically raised the wage to $5.00 a day for an eight-hour shift. Ford acted from mixed motives. He needed to reduce turnover and he wanted to prevent labor unions from attracting support. But he also wanted workers to benefit from the efficiency of their work and to be able to buy cars. His competitors denounced Ford as a socialist and again the public hailed him as a man of the people. His acclaim unfortunately proved short-lived.\textsuperscript{21}

\textit{Alfred P. Sloan and General Motors}

The First World War of 1914-18, which the United States entered in its last two years, strengthened demand for motor vehicles but also caused enormous price inflation.
By 1920, the dollar had lost half of its purchasing power and the five-dollar day meant less. More seriously for Ford, a great new rival to his company was emerging, General Motors. Under Alfred P. Sloan, who headed the firm in the 1920s, GM displaced Ford as the largest car manufacturer by responding more flexibly to changing demand.

General Motors had its origins in 1904, when a successful carriage maker, William C. Durant, switched to cars and took over a small auto manufacturing company founded by David Buick in Flint, Michigan (Fig. 5-13). In 1908, Durant merged Buick with the Oldsmobile firm of Ransom Olds to form General Motors, adding the Cadillac and Oakland (later renamed Pontiac) companies in 1909. By 1910, with its popular Buick Model 10, General Motors sold more cars than Ford. Durant had financed his expansion with money borrowed from New York banks, however, and a short recession in 1910 caused his bankers to call in their loans. He lost control of GM, which soon fell behind Ford in its share of the market. Durant then launched a new company with the Swiss racecar driver Louis Chevrolet and bought back control of General Motors in 1916, adding the Chevrolet company to its roster. But Durant lost control again in the recession of 1920. At that time, the DuPont family of Delaware had a substantial investment in GM, and Pierre S. DuPont took over as the company's president from 1920 to 1923.22

Alfred P. Sloan had headed a roller bearing company that General Motors acquired in 1916 (Fig. 5-14). In 1918 Sloan joined the managing committee of General Motors and in 1920 he became the principal assistant to Pierre DuPont. At Sloan's
urging, the auto company made two crucial changes. First, instead of the centralized and rigid management that Ford imposed on his own company, GM created a small executive staff that issued broad numerical targets for sales, market share, and profits, leaving the operating divisions of the company (Cadillac, Buick, Oldsmobile, Pontiac, Chevrolet) wide latitude in meeting them. Second, GM provided consumers with more choice. Each of the five GM divisions served a particular market, with Cadillac providing the most expensive cars and Chevrolet the least costly ones. Most of the working parts of GM cars were standardized but body shape and other visible details varied. Annual style changes also became a feature of GM by the 1930s. Sloan's innovations appealed to the social differences in society that Ford's Model T stood against. But Sloan, who became president of General Motors in 1923, also responded to a public demand for greater variety in cars that Ford was unwilling to meet.23

By the 1920s, the public had begun to tire of the Model T. Better roads made its ruggedness less attractive. The basic design of the car didn't change, and as sales fell, the company finally phased it out in 1927 and began marketing new cars across a range of prices. By then General Motors had taken Ford's place as the largest U. S. auto company.24 Ford believed that producing an affordable and reliable car was ethical as well as profitable.25 But his success depended on rigid standardization, and an autocratic tendency in his personality grew stronger in his later years. In a 1915 libel suit, he declared, "History is more or less bunk." He denounced banks, unions, and jazz music for undermining the small-town way of life, even as his automobiles were helping to end
the isolation of rural America. In the early 1920s, Ford paid for a series of anti-Semitic articles in a local newspaper that he owned, for which he apologized in 1927. In his later years, Ford exemplified the danger of believing that success in one area of endeavor entitled him to trust his judgment in others. He willed his fortune to establish the Ford Foundation, however, which he left free to support more inclusive goals for society and the world.26

Sloan's management of General Motors was not without controversy either. In the early 1920s, the company overruled his advice to produce an innovative air-cooled Chevrolet engine to compete with the water-cooled engines used in other cars. The new engine was rushed into production before its design had been fully worked out and tested, and cars with the new engines could not be sold. But Sloan was skeptical as much because the engine was innovative as because the innovation was poorly executed. He believed that the market for cars was maturing and that General Motors would succeed primarily by meeting the need to replace automobiles already in use.27 Sloan demanded that new cars incorporate improvements only after careful study and agreement within the company. One other innovation by GM in the 1920s, the development of leaded gasoline, led to serious trouble. Cases of lead poisoning among chemical workers who produced the additive raised public concerns that GM and the oil companies tried to dismiss. Public health authorities in the 1920s approved leaded gasoline, which remained in use until environmental concerns led to its phasing out in the 1970s.28
Science made little contribution to the automobile in its early years. But the automobile assembly line became an example to many of a new ideal of "scientific management" articulated by Frederick Winslow Taylor. In an influential 1911 book, Taylor argued that industry needed to make every task more efficient by knowing the action of every worker at every moment. To design their assembly line, Ford managers employed time and motion studies of the kind urged by Taylor, and the regimentation that followed caused some social critics to see in modern engineering a totalitarian imperative to seek and impose a "one best way."^29

There is no evidence that Ford was inspired by Taylor, whose goal was to measure and reward the productivity of individuals, while Ford's aim was to standardize the output of each worker.^30 Regarding a "one best way," recent scholarship has questioned whether the automobile industry itself followed a single predetermined path.^31 Taylor saw only the efficiencies to be squeezed out of a technology that was already established. If Ford had tried to do the same, he would have improved the static assembly of cars instead of abandoning it for a moving assembly line.^32 The idea that there is an optimal solution to every technical problem is fundamentally to misunderstand technology. Although it involves calculations, engineering is not just mathematical problem solving in which there are right answers and wrong answers. Numbers always constrain what engineering can do but the engineer always has a choice in what to design. The consequences of technological choice are never a matter of inherent or technical necessity.
Americans changed their way of life as they came to rely more and more on automobiles. The car and the road brought together all four principles of network, process, machine, and structure: electricity for ignition; gasoline for fuel; the internal combustion engine; and the new roads and bridges stimulated and required by the car. After the breakthrough innovation of the Model T, the automotive industry followed the pattern of other industries in shifting, during the 1920s, to the more incremental kinds of change associated with an established technology and market. In the meantime, a second great use for the internal combustion engine, in the airplane, made an even more radical change in transportation possible: human flight in heavier-than-air craft.

References

1. For automobile registrations in 1900 and 1939, see Automobile Facts and Figures 1940 (Automobile Manufacturers Association, Detroit, 1940), p. 11. These numbers do not include trucks.


(Smithsonian Institution Press, Washington, 1994); and David A. Kirsch, The Electric

6. On early European luxury cars, see again James M. Laux, The European Auto
Industry, pp. 1-50. On the Pierce-Arrow company, see Beverly Rae Kimes, "The Pierce-

7. The classic biography of Henry Ford is the three-volume study by Allan Nevins with
Frank Ernest Hill, Ford: The Times, the Man, the Company; Ford: Expansion and
Challenge 1915-1933; and Ford: Decline and Rebirth 1933-1962 (Charles Scribner's and
Sons, New York, 1954-63). For a recent biography, see Douglas Brinkley, Wheels for
the World: Henry Ford, His Company, and A Century of Progress (Viking Books, New
York, 2003). On Ford's early life, the quadricycle, his meeting with Edison, and his first
company, see ibid., pp. 1-37.

8. For an account of the Fulton race, see David P. Billington, The Innovators: The
Engineering Pioneers Who Made America Modern (John W. Wiley and Sons, New York,
1996), pp. 42-44. On the Duryea race, see Richard P. Scharchburg, Carriages Without
Horses, pp. 121-125.


14. For Watt's horsepower formula, see John Farey, *A Treatise on the Steam Engine: Historical Practical and Descriptive*, Vol. 1, (Longman et al., London, 1827), pp. 438-440. Automotive engineers also refer to the average pressure on the pistons as the

Average pressure $P$ is inferred. Ford's method of calculating horsepower in the Model T was $D^2 n / 2.5$, where $D$ is the diameter of the wheel in feet, $n$ is the number of crankshaft revolutions per minute, and 2.5 was an empirical number. See the *Ford Owners Manual* (1914), p. 30. With $D = 3.75$ and $n = 4$, Ford's formula gave the Model T a horsepower of 22.5.

15. To calculate brake horsepower, engineers multiply the speed of the crankshaft ($N_c$), in revolutions per minute, by the turning force or torque ($T_o$) of the crankshaft, measured in foot-pounds using a meter called a brake (brake horsepower is named for this kind of brake, not for the car's brakes). This result is multiplied by $2\pi$ and divided by 33,000 foot-pounds per minute. For the Model T at about 37 mph, $T_o \cdot N_c \cdot 2\pi / 33,000 = (70)(1500)(6.28) / 33,000 = 19.98$ Hp.
16. Engineers today also refer to traction horsepower as the road-load or vehicle road-load power.


19. For the prices of Ford cars from 1908/9-1916/17, see Floyd Clymer, *Henry's Wonderful Model T*, pp. 109-121. For Model T production figures, see *ibid.*, p. 134. Ford sales data were based on a fiscal year, not a calendar year, but Ford's share of the market may be estimated from these figures, using for comparison the historical data for annual U.S. automobile production in *Automobile Facts and Figures 1940*, p. 5.

21. On the five-dollar day and Ford's relations with labor, see Stephen Meyer, *The Five Dollar Day: Labor Management and Social Control in the Ford Motor Company, 1908-1921* (State University of New York Press, Albany, 1981). Ford tried to regulate the private lives of his workers through his company's Sociological Department. These efforts helped some but were regarded by many as intrusive. Ford's hostility to labor unions was shared by other manufacturers of his time and Ford was the last of the big three automakers to accept unionization of his workforce, after a strike, in 1941.


Best Way: Frederick Winslow Taylor and the Enigma of Efficiency (Viking Press, New York, 1997). For the idea that modern technology is a system crushing everything into a "one best way," see Jacques Ellul, The Technological System (New York, 1984)

30. On the difference between Taylor and Ford, see David Hounshell, From the American System to Mass Production, pp. 249-253.


32. See again David Hounshell, From the American System to Mass Production, pp. 252-253.