Suppliers and Product Development in the Early American Automobile Industry

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Joint product development, in which suppliers and automakers share the responsibility for component design, has given Japanese auto companies an important competitive advantage in both quality and new model lead times [Clark, 1989]. In contrast, U.S. automakers until recently left little room for suppliers' participation in the design process; vendors typically manufactured components to assembler-provided drawings. Although joint engineering is usually regarded as distinctively Japanese [Nishiguchi, 1994], American automotive suppliers often participated in component design before 1920. There were three overlapping stages in product design in the early American auto industry.

While pioneering auto builders like Henry Ford and Alexander Winton designed their cars in detail, suppliers' engineering contributions were crucial in making a car sufficiently reliable and cheap to be attractive to consumers. Vendors like George Holley and Cleveland Cap Screw solved critical design problems in carburetion and valve production, enabling their customers, Henry Ford and Alexander Winton, to overcome what historian of technology Thomas Parke Hughes has termed "reverse salients" in an advancing technological front [Hughes, 1983].

After these engineering issues had been resolved, and as consumer demand for automobiles took off, over a hundred car makers entered the market between roughly 1903 and 1918. Nearly all assembled their automobiles from outsourced motors, transmissions, and chassis. The presence of a technically sophisticated supplier base enabled these builders to produce automobiles without large fixed capital investment or much technical expertise [Seltzer, 1928, pp. 19-21]. Vendors were therefore responsible for most of the engineering that went into assembled cars; components were usually off-the-shelf parts that the assembler merely installed.

The third stage of product development arrangements began with the rise to dominance of vertically integrated, high-volume producers between 1910 and 1920. By 1920, Ford and GM produced three-quarters of the automobiles sold in the United States. From then until the restructuring forced

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by the Japanese challenge in the 1980s, suppliers' role in product design was steadily reduced. Suppliers increasingly produced components on the basis of customer drawings and specifications, technical information that could easily be provided to other suppliers. Increased barriers to entry into automotive assembly during this period were both a cause and an effect of suppliers' reduced role in product design. These barriers were a cause of reduced supplier involvement, since Ford and GM vertically integrated design even more than production. However, increased barriers to entry into automotive assembly were in part a result of the big firms' strategy. Their vertical integration meant that independent suppliers of key components could no longer reach minimum efficient scale, meaning that small automakers no longer had access to independent design expertise for many components [Helper, 1990].

Suppliers and Critical Design Problems in the Early Automobile Industry

Despite the legends of lone heroic inventors tinkering with their first automobiles under primitive backyard conditions, the first automobile builders relied on an existing network of supplier firms skilled at producing precision components for bicycles and carriages. Early builders like Henry Ford designed their automobiles themselves but contracted out much of their machining and fabrication. When Ford designed his first car for the market in 1902, he estimated total development cost at $4,000, enough for "a little money for parts and helpers." In the fall of that year, Ford and about ten employees worked on the prototype; the only tools in the shop were two lathes, two drill presses, a milling machine, a wood planer, a hand saw, a grinding wheel, and a small forge. As his biographers Allan Nevins and Frank Hill described the design process, Ford "had the general idea of a light, simple, low-priced machine, and some notion as to details." Ford's chief designer, C. Harold Wills, made his "general conception specific," turning Ford's ideas into working drawings. The other employees built the prototype, perhaps offering suggestions as they went [Nevins and Hill, 1954, pp. 225-29].

When Ford began production of this car in the winter of 1903, he contracted with the Dodge brothers, owners of "one of the best machine shops in the Middle West," to deliver 650 completed chassis, "ready for wheels, tires, bodies, and related parts," for $250 each. Ford agreed to advance $15,000 to the Dodges to cover the first 60 chassis if they used the sum to invest in machinery and tools specifically for his contract. Ford paid for the following forty units in cash as completed, and afterward paid the Dodges on a semi-monthly basis. As Nevins and Hill related, "This contract, advantageous to both sides, suggests a strong mutual trust between Ford and the Dodge Brothers, who had been acquainted for years." Their shop, employing about 150 men, "was practically turned over" to Ford production. While the Dodges built the chassis, "of course all designs came from Ford and Wills" [Nevins and Hill, 1954, pp. 230-32].

Carburetion was a critical design problem in early gasoline motors. Ford, like many other builders, cast about for an effective carburetor and settled on a mix of units from two vendors, Kingston and Schebler, in his first production run. These carburetors proved "unsatisfactory," leaving Ford and Wills "stumped." They called in George Holley, an early automobile builder himself, who had earned a strong reputation in carburetor design. As Holley later recalled, "I found Mr. Ford with Mr. C.H. Wills sitting in the pattern shop on a bench, and they told me they would like to have me design a carburetor for their new car." Holley's carburetor, "embodying some principles laid down by Wills and Ford," was a success [Nevins and Hill, 1954, pp. 232-33].

Alexander Winton, another pioneering builder, had engaged in production of luxury automobiles since 1900. Winton, unlike Ford, started by making most of the machine in his factory. A bicycle manufacturer since 1891, he had acquired both the equipment and expertise to turn out automobiles in quantity. Trading on the elegance and distinctiveness of his cars, he asserted that outsourcing detracted from an automobile's quality. In a 1908 promotional piece, Winton proclaimed that "every maker ought to be personally responsible for the cars which leave his factory." He claimed to "know to the minutest detail" the materials and workmanship that went into each car [*The Auto Era*, Sept. 1908, p. 9]. The automaker who assembled cars was only "a parts manufacturer's selling agent, a mere middleman, an economic intruder" [*The Auto Era*, Dec. 1913, pp. 3-4].

But Winton turned to outside vendors when he faced two critical design problems. Like Ford, he had trouble finding an effective carburetor, calling carburetion a "great bugbear" [Winton Marque Files, 1907]. Initially Winton designed his own carburetors, but his 1906 Model K used Holley's units [Winton Marque Files, 1906]. Winton may have switched because Ford and Olds, two of the largest American builders, had great success with Holley's design. In 1907 Winton returned temporarily to an in-house design, but by the end of the decade his cars used a mix of carburetors from several vendors.[1] The firm's engineering records between 1910 and 1914 also show that Winton put prospective components through a battery of harsh tests in the shop and on the road, tests in which suppliers' chief engineers often participated [Engineering Data and Laboratory Records, Winton Marque Files].

Early manufacturers like Winton also had trouble manufacturing valves. Automakers in the first few years of the century had two choices. They could machine a valve from nickel-steel, a relatively expensive grade of steel, discarding as much as three-quarters of the blank. This produced a reliable but costly valve. Or they could somehow fasten a nickel-steel head to a carbon-steel stem, yielding a cheaper but less reliable valve. As one of Winton's contemporaries recalled, "He screwed [heads] on, and he riveted them on, and he cut them out of steel, but they didn't work" [Crawford, 1955]. In 1903, Charles Thompson, an engineer at Cleveland Cap Screw, devised a method to

[1] However, in 1916 and 1918 Winton used one supplier of carburetors, Rayfield, for both of his models [*The Automobile*, December 30, 1915 and January 3, 1918].

electrically weld a nickel-steel head to a carbon-steel stem, yielding a cheap and durable valve. Winton gave Cleveland Cap Screw a sole-source contract to fill all his valve requirements, but the firm lacked enough machinery to meet his orders. Winton advanced the firm $25,000 to buy the equipment to turn out valves. Two years later he and two executives from Winton Motor Carriage secured a controlling interest in the firm; Winton headed the board of directors but left day-to-day operations in the hands of Charles Thompson [Board of Directors Minutes, Sept. 21, 1905, TRW Inc. Records]. The stock undoubtedly made a fine addition to Winton's portfolio, but he also gained control of the firm to ensure access to an important source of supply.

Standardized Components and "Piratical Skimmers," 1903-1918

Automobile pioneers like Ford and Winton retained responsibility for their vehicles' designs but turned to outside suppliers for machining and fabrication, and for help in overcoming technical problems. But the majority of automobile firms between roughly 1903 and 1918 assembled their vehicles from off-the-shelf components. A typical mid-priced car from this era contained an outsourced motor, carburetor, transmission, brakes, electrical system, and axles. Winton's distrust of assembled cars had some justice: Ford biographers Nevins and Hill charged that many of those produced before 1910 were a "mass of faults: slack bearings, badly aligned bolt holes, loose nuts, pipes crookedly fitted, and parts poorly machined" [Nevins and Hill, 1954, p. 323]. Automobile pioneer Benjamin Briscoe labeled such assemblers "manufacturing gamblers," speculators who "had adopted methods that were described as 'plunging.'" These "piratical...'skimmers' did not have a worthy car or any manufacturing ability," but did succeed at selling a few cars and much watered stock. Briscoe blamed these producers for bringing upon the early industry a "great deal of discredit," especially in the eyes of bankers and investors [Seltzer, 1928, pp. 32-33].

The Daisy company of Flint, Michigan, a typical assembler from the early industry, announced in the summer of 1902 that it was entering the automobile market. Planning "a standard machine in all respects," Daisy "resolved not to waste time or money in experimental work...While the body design will be somewhat original in many respects, the remainder of the parts will be secured from makers of standard parts, all of which can be assembled without delay." It is unknown whether Daisy completed its announced initial production run of 100 vehicles [*Motor Age*, Aug. 28, 1902, p. 21].

Assemblers like Daisy who did not want to expend much engineering effort bought major components from suppliers like the Lindsay Automobile Parts Co. An Indianapolis supplier of transmissions, motors, and running gears, Lindsay took out full-page advertisements in the 1902 and 1903 trade press, boldly asking car builders: "DID IT EVER OCCUR TO YOU that you can save both time and money by getting our complete running gear?... DON'T WASTE YOUR TIME trying to build gasoline motors, when you can get them from us for less money than you can make them yourself." The firm also offered to equip their running gears with bodies, requiring the car maker only to label and sell the finished vehicle [*Motor Age*, Jan. 8, 1903, p. 29 and Feb. 12, 1903, inside back cover].

Other firms repeated Lindsay's sales pitch. Andrew Lee Dyke was an automobile pioneer who built St. Louis' first car in 1898 and who wrote a popular series of repair manuals during the first two decades of the century. Foreseeing "that the automobile supply business would become a distinct branch" of the industry, he threw over car building for parts jobbing in 1899. Although "there was at the time but a small demand" for auto parts, he claimed to be the "first in America" to dedicate his firm solely to supplying the emerging industry. Dyke, like Lindsay, produced complete running gears, "and from the way orders are being received it is safe to assume that there will be a hundred or two new automobiles in the country that were never inside a factory other than Dyke's." The Neustadt-Perry Co. of St. Louis conducted a similar business and marketed "designs of steam and gasoline carriages for which it makes complete sets of parts...The company will furnish the buyer with assembling blueprints" [*Motor Age*, June 26, 1902, p. 12]. A firm wishing to sell automobiles quickly and easily needed only to purchase chassis from Lindsay or Dyke, or kits from Neustadt-Perry. Few builders went to that extreme, but the option nevertheless existed.

It remained possible for assembly-only firms to enter the automobile market until the late 1910s. Growing demand for automobiles ensured that a distinctively styled machine built of standard components found customers. Ned Jordan, for instance, relied on sporty styling and eye-catching advertising to market his car. One auto historian stressed that Jordan bought parts of the highest quality for his car, but dryly noted that "probably it was the racy wire wheels" that he "liked best" about his car; "mechanics never interested him much" [Kimes, 1985, p. 726]. Jordan's first model, built in 1916, used an off-the-shelf motor, gearset and clutch, carburetor, ignition, lighting and starting system, and axles. The trade press noted the difficulty of turning out "a really distinctive automobile from standardized parts." But the Jordan's body and interior gave the car "a character of its own...apparent at first glance and intensified by a close examination" [*The Automobile*, July 20, 1916, pp. 98-9].

A look under the hood reveals just how standardized the Jordan was. The motor is a good basis for discussion because it was the most complex component to design and to build; an automobile company's decision to manufacture its own motor or to buy from a vendor provides a rough indication of product development expertise and manufacturing skill. Six other builders used the same motor as the Jordan. Continental, which produced this motor, sold five different engine types – four six-cylinder models and a four-cylinder plant. Of the 177 models offered for sale by 109 American builders, Continental motors powered 16 models turned out by 12 firms. Six of these assemblers used Continentals exclusively, while the remaining six used a motor from a different vendor in each model. Only two of its customers produced over ten thousand cars in 1916; the top producers in that year (Ford, Willys-Overland, Maxwell, Chevrolet, Buick, Dodge, and Studebaker) all designed and built their own engines. Twenty-four other firms bought carburetors from Stromberg, Jordan's vendor; only two (Studebaker and Overland) commanded respectable market shares. But three (Hupmobile, Packard, and Winton) of the seven makers who also installed Bijur electrical systems were established builders. Finally, six (Dorris, Locomobile, Marmon, Pierce-Arrow, Stutz, and Winton) of the 22 builders who used Bosch ignitions also shared the luxury and performance market with Jordan [*The Automobile*, July 20, 1916, pp. 88-91, Dec. 30, 1915, pp. 1246-53].

Whereas these components were off-the-shelf parts, the car's axles were somewhat customized. The Timken-Detroit Axle Company, which supplied Jordan, claimed that its engineers worked closely with their customers' engineers, especially during a vehicle's design. Timken's advertisements continually stressed its close technical ties to its customers; one piece told the prospective automobile owner that "Timken axles in your car, no matter what its size or price, were selected and installed only after many conferences between Timken engineers and the engineers of the car builder" [*The Auto Era*, Feb. 1916]. In 1917 the company told automakers that they could not include Timken axles "merely to furnish a selling point; *they must be built in* – not tagged on." Timken refused "to deliver motor-car axles except on definite assurance from the car builder that the car on the street will carry out the promise of the car on paper." To assure that the finished vehicle matched its design drawings, Timken "insist[ed] upon knowing" the weight of the car, the size and output of the engine, the chassis' weight distribution, and "all other details of construction which in the slightest degree" affected how the axles functioned as integral parts of the completed car [*The Auto Era*, Aug. 1917].

These advertisements accurately portrayed Timken's sales policy. Eugene W. Lewis, the firm's sales manager in this period, recalled that "overload and overpower" often led to broken axle shafts and knuckles; customers' complaints "were continually coming in" to early assemblers who used undersized axles. Such failures reflected equally poorly on the axle manufacturer and on the auto assembler; a stranded motorist did not know or care whether the builder had installed axles of the proper size. Lewis's experiences in selling axles to the Auburn company for one of its early models confirmed these fears.[2] The Eckert brothers, designers of the Auburn, claimed

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[2] Lewis was vague about the date of this incident, but it certainly occured before 1912, and probably before 1905. The Auburn company began production of its first car, a one-cylinder, in 1903 and followed with a two-cylinder in 1905. It introduced a four-cylinder model in 1910 and a six-cylinder in 1912 [Georgano, 1969]. A Timken-Detroit advertisement in late 1910 listed all the firm's customers; Auburn is not mentioned, making it unlikely that Timken supplied axles for the four-cylinder Auburn introduced that year [*The Automobile*, Dec. 29, 1910, p. 114]. Technical details of American cars for 1916 and 1918 show that Auburn made its own axles for its four-cylinder and six-cylinder models [*The Automobile*, Dec. 30, 1915, pp. 1246-47; and Jan. 3, 1918, pp. 60-61].

that it would weigh about 2,600 pounds and they requested Timken to provide axles to match. Lewis doubted this figure; the Eckerts, like the "majority of builders at the time," had only a rough idea of their car's weight. Its wheelbase led Lewis to a back-of-the-envelope estimate of 4,000 pounds, but he "could not get them to give me the exact weight of the car." In order to get "proof of the actual weight" of the finished car, he bet the brothers 100 Havana cigars each that it would weigh 4,600 pounds. Not wanting to show up his customer, he hoped that this figure was "sufficiently high so that I would be sure to lose." The completed car weighed 4,400 pounds, and Lewis came dangerously close to winning "the bet I did not want to win" [Lewis, 1947, pp. 196-97].

A survey of Timken-Detroit's customer base in 1910 and 1916 supports Lewis's view that the firm could ill afford to trust the engineering skill of many of its customers. In 1910, 35 auto builders used Timken axles; all of them were either small-volume producers or makers of high-end luxury cars [*The Automobile*, Dec. 29, 1910, p. 114]. Timken retained only nine of these accounts by 1916. Of the remainder, two firms were making their own axles, three switched vendors, and 21 exited the industry. In 1916, a total of seventeen firms used Timken axles; eleven of these also outsourced their motors, possibly indicating that they assembled their vehicles and possessed only slight manufacturing ability. The remaining six auto companies, who did design and make their own motors, were luxury builders (Cadillac, Dorris, Lozier, Peerless, Premier, and Winton) [*The Automobile*, Dec. 30, 1915, pp. 1246-53]. These companies touted their technical expertise and quality of construction as selling points, and, as Winton's engineering records indicated, they worked closely with vendors' engineers before agreeing to install outsourced parts. These builders would have insisted on close technical contact during a model's design and manufacturing [Engineering Data and Laboratory Records, Winton Marque Files].[3]

Timken's diverse customer base helps explain why it remained an independent supplier. None of the 35 automobile producers that used Timken-Detroit axles in 1910 were high-volume producers; Timken also supplied about 30 truck manufacturers as well as several rail-car and heavy equipment makers. Its fortunes were therefore not tied to the fates of one or two automakers. Timken also produced tapered roller bearings in its Canton, Ohio, plant. Bearings and axles are complementary parts: all axles use bearings, and many bearings go into axles. So Timken Roller Bearing in Canton had an assured customer in Timken-Detroit Axle, and the axle plant enjoyed a dependable source of bearings. Finally, both axles and bearings were specialized components requiring skilled laborers, special steel alloys,

[3] The entry of Dec. 11, 1913, in Winton's engineering record book contains a comparison of various technical characteristics of a Timken-Detroit front axle and an axle of Winton's design. The Winton axle was apparently never used, but this entry suggests that Alexander Winton considered, however briefly, taking axle production in-house. Other entries reveal ongoing relationships with the chief engineers of Delco (Kettering) and Bosch (Kliesrath).

accumulated expertise, and a great deal of dedicated equipment. These requirements placed their manufacture out of reach of nearly all automakers. Even Ford bought his Model T axles from the Dodge Brothers before they began automobile production themselves in 1914 [Sloan, 1941, pp. 70-71]. General Motors satisfied its own axle and bearing requirements only after buying out Weston-Mott Axle Company and Hyatt Roller Bearing Company in 1916.

The histories of those two companies had much different outcomes than Timken's. Both Weston-Mott and Hyatt had sold axles and bearings to the auto industry since about the turn of the century and had worked together almost as closely as the two Timken plants. As Alfred Sloan, then president of Hyatt, reminisced decades later, Hyatt was Weston-Mott's major bearings supplier; the two companies "were interdependent to an extraordinary degree" [Sloan, 1941, p. 48]. In 1905, Sloan learned that Weston-Mott was planning to move from its Utica, New York, factory to a new plant in Flint, Michigan. William C. Durant and J. Dallas Dort, who had just recently refinanced Buick, offered the axle company a free factory near the Buick plant. Weston-Mott offered a $500,000 stock issue to finance the move, with Durant and Dort paying in cash for a fifth of the stock [Sloan, 1941, pp. 43-48].

As Sloan related, Weston-Mott's move introduced two elements of uncertainty into Hyatt's business plans. He feared that Weston-Mott's other customers "who were rivals of Buick" would be "disturbed" that their axle supplier "was moving hundreds of miles to put up a factory next door" to Buick. If they transferred their business elsewhere, Hyatt stood to lose a great deal of sales volume. "Suppose," Sloan also worried, "this move became a merger?" [Sloan, 1941, p. 45].

The Decline of Supplier Participation in Product Development, 1910-1920

Sloan called Weston-Mott's relocation "a trivial incident of itself," but believed that it was "the first step in the integration of the automobile industry. Thereafter, bit by bit, we were to see a constant evolution bringing" automakers and suppliers "into a closer corporate relationship" [Sloan, 1941, p. 44], culminating with GM's acquisition of both Weston-Mott and Hyatt (along with several other major parts producers) in 1916. Vertical integration in the auto industry between 1910 and 1920 proceeded in two directions. As large makers like Ford and GM gained a dominant share of the market, they designed and produced more of their parts requirements in their own factories. They also gradually internalized the design of those components that they continued to purchase from vendors. By the end of the decade, the engineering capabilities of the auto supply industry were visibly weakened.

The experiences of Louis Perlman, the inventor of the demountable rim, illustrated how the market power of the large, integrated manufacturers eroded incentives for suppliers to innovate. In 1913 Perlman filed suit against the Standard Welding Company, a Cleveland firm that had been infringing Perlman's 1906 patent. In early 1916, he finally secured an injunction. The trade press foresaw "serious consequences" for "many car concerns" because over 700,000 cars slated for production that year used demountable rims, and Standard Welding supplied "a large percentage" of them [*The Automobile*, March 9, 1916, p. 470]. A week later, however, the trade press insisted that automakers were not "seriously concerned" about the injunction. An anonymous Detroit producer thought that "the suit will have no direct bearing" on his firm; he "would simply make" Standard Welding pay Perlman royalties, an additional cost that Standard "would have to absorb." In any case, he added, other rim designs "could be resorted to" if Perlman and Standard Welding were unable to come to terms [*The Automobile*, March 16, 1916, p. 515].[4]

Another incident shows in greater detail how large auto companies forced suppliers to share proprietary designs with competitors. The Steel Products Company of Cleveland, forerunner of today's TRW, owned a cluster of patents giving it a virtual monopoly on the manufacture of electrically-welded automobile components, especially valves, which accounted for about 50 percent of the company's sales in 1916. These patents ensured that nearly all valves in cars other than Fords (which used a different valve design) were purchased from Steel Products. As the firm's president Charles Thompson recounted, "[T]he entire valve business enjoyed by the Steel Products Company" in 1916 was "attributable to the ownership of patents and patent rights, and to that alone." In a statement to the Bureau of Internal Revenue, the company estimated that its patent rights covering the manufacture of electrically welded automobile parts accounted for all but a minor percentage of its $6 million in sales between 1911 and 1916 [Tax Return Depositions, n.d.]. But good relations with customers were also important; Thompson knew all too well that suppliers who too strongly asserted their patent rights risked losing major accounts.

In 1914 a competitor of Steel Products, the Schweppe and Wilt Company of Detroit, obtained a patent on the manufacture of drag links, an electrically welded component used in the steering mechanism. This "absolutely standard" patent was so basic to the design of the steering system that "General Motors spent a fortune trying to avoid" it [Tax Return Notes, n.d.]. Even so, TRW president Frederick Crawford recalled that Schweppe and Wilt "had no alternative but to grant some licenses under its process." Already by 1916, "it had become almost standard practice among the automobile companies to insist that a supplier of automobile parts make available to them additional sources of supply" in order to avoid "a complete tie-up of the automobile companies' production." Because of its monopoly on drag links, Schweppe and Wilt fell into "great disrepute with purchasing agents," and its relations with its customers "were becoming more and more strained." In early 1917, Schweppe and Wilt gave in and licensed Steel Products and another

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[4] Within a few months Perlman Rim Corporation joined Weston-Mott, Hyatt, Delco, New Departure, Jackson-Church-Wilcox, and Remy Electric as wholly owned parts subsidiaries of General Motors.

company to make drag links under its patent, but it fixed their prices and production volumes [Tax Return Depositions, n.d.].

In 1919 the automakers discovered that Schweppe and Wilt had only "outwardly met" their "objections," and they bitterly protested the firm's price-fixing. Instead of providing more liberal licensing arrangements, the company countered by trying to reassert its monopoly. It ended its licensing agreements and served notice to automobile manufacturers that future purchases of drag links from other suppliers would expose them to legal action. Buick, "one of the principal customers" of Steel Products, peremptorily told the firm to resolve the infringement controversy; otherwise, "it would be compelled to transfer its business elsewhere" [Tax Return Notes, n.d.]. Seeking to avoid legal entanglements and the loss of an important customer, Steel Products ended the issue in April 1920 by buying out Schweppe and Wilt "at an exorbitant price solely in order to acquire that company's drag link patents." Because Schweppe and Wilt had tried to maintain a monopoly, Steel Products "inherited ill will" along with the drag link patents "to such a degree that it was confronted with a real problem among its customers" [Tax Return Depositions, n.d.].

Conclusion

This paper has looked at a variety of arrangements for product design in the first twenty years of the American auto industry. Each of these arrangements is very different from the one commonly observed in the United States in the 1980s, in which many vendors without engineering capability scrambled to win short-term, non-exclusive contracts to produce customer-designed components [Helper, 1990; Helper, 1991]. Although little studied in the past, the organization of product design is intimately tied up with the overall evolution of the American auto industry.

The innovations of early suppliers were instrumental in creating a viable product. Historians of the automobile have long pointed out that machinists like the Dodge Brothers and Leland & Faulconer provided the requisite manufacturing expertise and facilities to transform the designs of pioneers Ford and Olds into finished cars [Nevins and Hill, 1954, pp. 222-33]. But the engineering talent of men like George Holley and Charles Thompson of Cleveland Cap Screw proved equally important in settling the basic form of the internal-combustion automobile. Holley's carburetor is an excellent example of "black-box" design [Fujimoto, 1995], in which suppliers designed parts within broad constraints specified by customers.

Between about 1903 and 1918, the major technical features of the automobile remained unchanged.[5] In this period over a hundred firms entered the automobile market, and nearly all took only minor roles in the designs of

[5] Of course, important innovations still occurred, such as Kettering's invention of a reliable electric starter in 1911 [Borth, 1966, pp. 89-90].

their cars. A large network of vendors – selling standard, off-the-shelf engines, transmissions, ignition and lighting systems, and the like – made it possible for assemblers with little knowledge of automotive design to bring their cars to market. Ned Jordan, for example, was a newspaper reporter and advertising manager before he started his automobile company. And Eugene Lewis, sales manager for Timken-Detroit Axle Company, headed off a major reliability headache for Auburn by convincing that car's designers to install properly sized axles.

A good example of standardization is the Continental motor, an apparently identical component used by a number of automakers. Seen from today's perspective, it is remarkable that an automaker would allow a supplier to determine the design of such a key component as the engine, which is a major selling point for the final consumer and whose characteristics determine so much of the rest of the car's design. The Timken axle also represents a role reversal from today's practice: the supplier took the lead in telling the automaker how to design the car in order to make best use of the supplier's part.

The third period in our typology is marked by the consolidation of market share in the hands of giants like Ford and General Motors between 1910 and 1920, and the subsequent exit of smaller firms in the following decade. Scale economies derived from specialized tooling drastically lowered unit costs for high-volume producers and further strengthened their leading positions. Firms with the capital to do so bought out key vendors to establish greater control over price, quality, and delivery of important parts.[6]

But the shift of product design functions from suppliers to auto companies was an important part of this process as well. This shift had two main consequences. Customers who designed their own parts were able to lower their procurement costs; they easily and frequently switched vendors on the basis of price, merely by providing their drawings and specifications to the lowest bidders. Smaller auto companies found it increasingly difficult to locate suppliers who were able to design important components like motors and transmissions. Those firms that had previously relied on the engineering expertise of their vendors soon exited the market.

A comparison of this evolution with the Japanese case yields some surprising conclusions. Japanese automakers began in the 1930s by importing many parts and making others in-house because of a lack of suitable suppliers. Gradually, however, the automakers encouraged suppliers to develop design capabilities of their own, and vendors increasingly shouldered responsibility for product development. According to Fujimoto, automakers partly borrowed this "black-box" system from the aircraft industry, and partly developed it independently as a result of Toyota's experience with Nippondenso, its in-house supplier of electrical parts, which Toyota was forced to spin off in 1949 [Fujimoto, 1995].

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[6] In addition, some manufacturers in the mid-price range may have done themselves in by moving "upmarket" into the luxury market – making vehicles that they themselves wanted to drive, rather than cars that would appeal to consumers [Davis, 1988].

Thus, the evolution of product design responsibility in the United States was the opposite of the course taken in Japan. This evolution also included a stage, largely unknown in Japan, in which vendors developed and sold their own standardized parts. This difference can be partly accounted for by differences in industrial history. In the United States, manufacturing was already well-developed when the auto industry began. Turn-of-the-century carriage and bicycle firms, and their suppliers, possessed much of the skill and equipment necessary for early automobile production. Auto assemblers were able to draw upon vendors' experience in order to avoid the expense, technical expertise, and managerial skill required for vertical integration [Seltzer, 1928]. Japan industrialized later and Japanese automakers had no carriage or bicycle industry from which to draw engineering knowledge and manufacturing skill.

However, the divergent trends in the amount of supplier participation in product development are the opposite of what a technological determinist would predict – the United States, the nation that initially had a supplier base with extensive engineering expertise, ended up with a parts industry that participated little in component design. A key factor in explaining this divergence is the rapid concentration of market share in the hands of vertically integrated automakers like Ford and General Motors. This concentration gave high-volume producers both the incentive and the capability to avoid sharing bargaining power with suppliers, even at the cost of quality problems and increased new-model lead times [Helper and Levine, 1992].

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