Automotive Informatics: Information Technology and Enterprise Transformation in the Automobile Industry[1]

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Introduction

This essay examines the role of information technology (IT) in the transformation of the automobile industry during the 20th century, including the complements, enablers, and constraints that make the industry one of the largest and most influential enterprises in history. It adopts a view of IT as *deep infrastructure* capable of producing the vital *information capability* necessary for transformation. The focus on infrastructure entails consideration of factors often considered obvious, mundane, and pervasive compared to the exciting accounts of new IT applications involving the Internet and the World Wide Web. Yet, as the analysis reveals, this powerful industry transformation occurred as a result of the slow accretion of new capability enabled by information technologies over a long period of time.

The objective of the essay is two-fold. Most obvious is the effort to tell a story about the historical role of IT in the industry and to use the insights gained to predict important transformations yet to come. In this particular instance, the historical account argues that the most powerful influences arise from government and industry record-keeping systems and process control devices, while relatively little effect has been seen from the Internet and the Web. The prediction is that these influences have so dramatically shifted the liability and market characteristics of the industry that the industry itself is in the process of shifting from one that sells its products to a service industry that never sells what it manufactures. The prediction is deliberately provocative but is justified by the analysis. Nevertheless, the history and prediction are merely illustrative; whether they are "right" or "wrong" is less important than the analytical strategy they reveal.

The second objective is the explication of an analytical strategy for considering transformation arising from use of IT. A common failing of transformational accounts is the lack of a sufficiently broad and systematic view of the industry in context and the role of that context in shaping the industry's destiny. Admittedly, it is difficult to capture the complexity of even simple industries; it is much harder with something as large and

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complicated as the automobile industry. Still, we strive to be comprehensive on all the essential factors of transformation.

The Industry in Context[2]

The automobile industry is technologically intensive, systemic, and institutionalized. It has been technology intensive since 1885 when Gottlieb Daimler perfected a high-speed internal combustion engine with a sufficiently wide power band to enable controlled acceleration of a light vehicle. It is has been highly systemic since 1907 when Henry Ford revolutionized production through large-scale parts standardization and process engineering.[3] The industry has from its inception been tied irrevocably to local and national governments, as well as to other industries that are themselves highly institutionalized.

The automobile industry today is arguably the world's largest coordinated production system. Some statistics are shown in Table 1.

Table 1. Car Industry Indicators

Global autos in use 2001	About 550 million
Global autos produced in 2001	40 million
U.S. family cars in use in 2001	135 million cars (24% of global); 215 million with SUVs, minivans, and pickups
U.S. new vehicle assembly companies in 2001	11 in the U.S.
U.S. new auto production in 2001	About 5.5 million
U.S. auto parts suppliers	About 5,000
U.S. auto parts supply employment	About 550,000
U.S. NAICS code 33611 "Automobile Manufacturing"	
Companies	About 200
Employees	About 120,000
Revenue	About $100 billion
Value-added	About $30 billion

The automobile industry has extraordinary global reach. There is approximately one automobile for every 11 people on Earth, although the distribution is uneven: The ratio in the United States is one for every two or three people. The new vehicle industry is economically important; the value of new auto production and sales is between one-tenth and one-eleventh of the total GNP. New auto manufacturing as measured under NAICS code 33611 employs about 0.5% of the U.S. population, and adding the parts supply

[2] The automobile industry is one of the most extensively researched sectors of enterprise. The brief citations herein do not do justice to the great wealth of work on which our understanding of the industry depends.

[3] Ford's Model T was the product of the world's first vertically integrated mass production system that, in 17 years, reduced the vehicle assembly time by a factor of 24 and the selling price by a factor of 3.

industry raises that figure to about 2.5%. In fact, the automobile industry, if considered broadly to include everything that makes the use of automobile transportation functional, is of enormous importance in the United States. It has been estimated that one out of every seven jobs here is tied to the automobile through its effects on manufacturing of new vehicles and parts, fuel, service, insurance, and so on.

The data further show that the number of automobiles in use dominates global production of new automobiles by a factor of nearly 14:1. If the "automobile industry" incorporates both new vehicles and those already on the road, it is overwhelmingly a *used vehicle* industry. The average service life of an automobile has been rising as the market's global growth has been decelerating. The average age of a car is now about eight years in the United States, the highest in history. The main reason for this is increased global competition and the resulting radically improved vehicle quality, part of which has been the result of intensified uses of IT. The inevitable consequence of this trend is that production will continue to face constrained growth in future even while the total population of vehicles expands and some promising new markets such as China emerge. This change is directly reflected in several contextual measures. Ownership of automobiles per household is rising, as seen in the trend toward construction of U.S. housing with garages for three or more vehicles. The manufacturing side of the industry is also experiencing significant growth, with some OEMs reporting spare parts sales accounting for between 6% and 10% of total revenue. There also has been almost explosive growth in the so-called "specialty equipment" aftermarket that provides equipment and services to customize and augment used vehicles. New automobile dealers have increased their involvement in used vehicle markets that they used to despise, while OEMs actively seek to gather a larger fraction of those markets through institution of manufacturer-certified used vehicle programs and other marketing strategies.

Curiously, the industry is not following the pattern of the typical "maturing" industry, in which demand is saturated and manufacturing becomes essentially a contest among efficient producers. Even among OEMs a number of surprises in recent years have upset the market saturation hypothesis: the sudden popularity of minivans and SUVs, the surge in light truck sales, and the success of upscale brands representing image and status. And automobile use continues to rise in both developed and developing countries. The industry, if one looks beyond the new vehicle sector, is not "mature" at all; it is in a continual state of flux and could change in dramatic new directions as a result of innovations in underlying technologies (e.g., fuel cells), production and manufacturing technologies such as build –to order and componentization (see, e.g., Helper and MacDuffie 2001; Holweg and Pil 2001), and changes in distribution and service networks (e.g., intelligent cars). This turbulence has been a hallmark of the industry since its inception (see, e.g., Abernathy and Clark 1985) and is likely continue in the future. The industry has also gone through more than one cycle of rapid expansion. In 1900 there were more than 50 automobile OEMs in the United States; by 1930 there were only a handful. That trend has repeated itself on the global scale: The number of OEMs rose during the industrial expansion after WWII and then entered a period of consolidation over the past two decades.

Finally, the key purpose of the industry—the automobile itself—has become interwoven into many infrastructures of modern life (see, e.g., Edwards 2001).

The automobile industry was the first systematic global industry and arguably launched the modern era of enterprise through its exploitation of mass production and the invention of both continuous production lines and Alfred P. Sloan's M-form organization. The industry was instrumental in the creation of the U.S. middle class by enabling production of vast quantities of goods at constantly decreasing prices and by stimulating the economy in ways that required steady wage increases for industrial workers. The industry was extraordinary in the speed with which it generated wealth for entrepreneurs, but it also spread the wealth throughout the society rather than leaving it concentrated in the hands of a few.

Automobile design and use has become an essential feature of cultural identity. The shared mission of both OEMs and buyers is to make automobile choices a mechanism for expressing social status and individual personality. The realm of the auto extends to the creation and support of a number of large, complementary industries such as insurance, fuel supply, parts and service provision, road building, transportation planning, trucking, and so on. The auto is deeply embedded in regulatory and other institutional sectors of society at the local, national, and global levels. It is no wonder that Peter Drucker has called it "the industry of industries."

IT as an Engine of Industry Transformation

This analysis requires a broad view of both the automobile industry and IT. For our purposes, the industry includes all of the activities and infrastructure required to make automobile transportation possible. Beyond OEM and sales, this includes all of the tiers of supply in original production, and the servicing of automobile transport thereafter (fuel, insurance, streets/highways, regulation, resale, disposal). Information technology includes all modes of information collection, processing, storage, and dissemination. In addition to modern digital technologies, this includes manual methods that have been part of the industry from the earliest days.

Our focus is on *embedded* information capability. This means that the capability has evolved and been adopted and adapted to play vital and ongoing roles in the industry. Three kinds of capability are examined: (1) enhanced product platforms, (2) production and distribution systems, and (3) use and service monitoring. Each of these can be broken into specific regimes defined by either product or service boundaries or specific institutional or regulatory authority, as shown in Table 2. There is no inherent ordinality to this list—none of the regimes is presumed to precede the others in time or importance. There are also overlaps among the regimes: For example, telematic services might include entertainment (downloading music or offering e-mail services), passenger safety (automatic call back to a service center using location-based data and analysis of vehicle status), customer relationship management (profiling user habits; producing service reminders automatically), and risk mitigation (setting car insurance premiums based on usage and driving habits). This scheme is not a definitive classification structure; it merely serves to provide order to an otherwise unwieldy topic.

Table 2. Regimes of IT impact in Car Industry

IT impact realm	Product, process, or regulation regimes	Examples of IT applications and impacts
Use and service monitoring	Property regulation, risk mitigation, and complementary asset provision	Car and driver registration services, insurance
Enhanced product platforms	Atmospheric emissions control	Embedded digital fuel and emission control systems
	Passenger safety	Air bag and collision detection systems
	Entertainment, conviviality, and control	Sound systems, hands-free phones, remote control
Production and distribution systems	Expediting and coordinating production and distribution	MRP, ERP systems, supply-chain management (EDI, e-collaboration, e-markets)
	Manufacturer–customer relationship construction and maintenance	Car service history, customer profiling/service (On-Star), intelligent service management

Use and Service Monitoring with IT

Property Regulation, Risk Mitigation, and Complementary Asset Provision

In the earliest days of the automobile, ownership was restricted to the upper classes and to organizations that could afford expensive specialty-built chassis and coaches. When the auto came within reach of common people, it had a profound effect on the economics of households and communities. For most households an automobile remains the second most expensive piece of personal property, after a residence. Residential property law had evolved over centuries and was well established by the automobile era. No similar evolution had taken place to deal with autos. There was no established registry of ownership, and given their extraordinary theft potential (both valuable and made to be driven away), it became necessary very early to develop an official registration system so that thieves could be prosecuted and stolen property identified and restored to rightful owners (Bonnier 2001). It also soon became clear that automobiles in the hands of inexpert operators could cause mayhem, resulting in death, injury, and destruction of property. It thus became necessary to regulate operation, which meant creating a registry of legitimate operators and licensing those who met the criteria. These registries were the first systematic records systems involving individuals and households since the development of vital statistics registration (birth, marriage, death) and land records tied to individual owners (Bonnier 2001). Moreover, the fact that autos changed hands and individuals changed residences meant that these records systems required updating much more frequently than earlier systems (automobile and operator registration in many locales predated metered utility services—water, electric, gas, telephone—that later necessitated ubiquitous records systems). These automobile-related records were instrumental in ways that soon became evident.

The potential for loss quickly demonstrated the need for risk mitigation in the form of insurance, which required accurate historical records on both automobiles and operators so that premiums could be set appropriately. This meant that insurance records had to be interoperable with the official registries maintained by the government. This interaction made it possible to deliver rewards and sanctions for operator behavior: Good drivers could be given discounts while bad drivers paid higher premiums or were refused service altogether. As the systems grew more sophisticated, the disparate records of various locales were linked such that accidents or violations occurring anywhere would be known to the insurance provider as well as to law enforcement. Given the important role of automobiles in the commission of crimes, vehicle and operator registries became important tools of law enforcement generally. While not directly part of the automobile realm, such uses of automobile-related records have provided powerful incentives for governments and other institutions to improve records systems (Bonnier 2001).

The growth of automobile use quickly spawned demand for improved roads. Road construction is enormously expensive, and with the exception of a few limited-access facilities (turnpikes, bridges, tunnels), roads must be provided as public goods, open to all users. Making the entire population pay for an expensive infrastructure that only some (would use is economically dysfunctional, so the early vehicle records systems provided a ready mechanism for collecting revenues. Fees to help pay for roads could be imposed not only on sale or resale but annually for operation. These revenue collection mechanisms were essential complements to the excise taxes levied on motor fuel, tires, batteries, and other supplies.

The extensive record keeping related to automobiles resulted in time-series databases that facilitated systematic analysis. The data were valuable for market analysis and advertising, for assessment of road use patterns for highway planning, and for the study of population mobility in land use planning, which raised the question of privacy long before it became a Web issue (Bonnier 2001). In time, they became essential to the implementation of regulatory requirements related to atmospheric emissions, passenger safety, and a variety of other problems. Most of the early records systems were manual and paper based, but the industry quickly adopted new technologies as they became available. Systems today are continuously being upgraded to new levels of reliability, accuracy, and usability.

Enhanced Product Platforms

Atmospheric Emissions Control

Automobiles work by mixing fuel with air, compressing the mixture in a cylinder, and capturing the energy released by its combustion. The inevitable result is atmospheric emission of gases and other materials: carbon dioxide, carbon monoxide, oxides of nitrogen, unburned hydrocarbons, and other gases and particulates. This was not considered a problem for many decades; indeed, smoke in the air was often equated with industrial progress. Also, the pollution from mobile sources dissipated rapidly, and there simply were not that many vehicles in use. That all changed around the middle of the century when residents of communities such as Los Angeles began to notice a persistent cloud of brownish-gray gas that seemed like a mix of smoke and fog. This “smog” proved to be a revolutionary issue for the automobile industry.

Researchers at Caltech demonstrated in 1956 that smog was not merely collected emissions but was actually "produced" by sunlight acting on precursor chemicals contained in automobile exhaust and other sources. Photochemical smog became a political issue in the early 1960s in the Los Angeles area largely because the region's combination of mountains, prevailing winds, and atmospheric "inversion" trapped the gases and allowed the smog to concentrate. The Surgeon General's 1964 report on the health risks of smoking coincided with a growing sense that smog might have serious health consequences. In 1968 Congress passed the Clean Air Act mandating air quality standards, and California set its own even stronger standards. The U.S. auto industry initially fought the standards, arguing that meeting them would be either impossible or prohibitively expensive, but foreign competition produced new technologies to meet them, and this plus other factors shifted the focus of the entire industry toward finding solutions to the emissions problem.

A number of technologies had been developed to alter combustion temperatures and re-circulate exhaust gases through the combustion process, but these were not terribly effective. The big breakthrough was the development of the three-way catalytic converter, whose potential had been demonstrated in theory and in highly controlled test conditions, where it converted more than 98% of harmful gases into harmless byproducts. It had a serious drawback, however: The combustion process had to operate very near to stoichiometric conditions. Even minor deviations resulted in a catastrophic decline in cleaning efficiency. The only way to obtain the right operating conditions was to make micro adjustments in the fuel/air ratio on a continuous basis, a huge obstacle. The Lambda-sond solution developed in the mid-1970s by Volvo consisted of a special sensor between the exhaust manifold and the catalytic converter chamber that would sense oxygen partial pressure so sensitively it could detect even minor deviance from stoichiometric optimum. The sensor relayed its information to a computer that contained state tables directing the carburetor or fuel injection system to make adjustments in the fuel/air ratio in real time to keep the output gas in stoichiometric balance. This was the first application of modern IT to in an automobile engine for emissions control and was incorporated in Volvo's 240 model sold in California in 1976.

This general strategy was exploited aggressively in the following years as the demands for reduced emissions were joined with expectations of improved fuel economy following the energy crises in the 1970s.[4] The general trend was toward incorporation of a larger variety of sensors and variables to more finely tune engine performance, which over the years has resulted in standardized interfaces for computer-controlled performance analysis and emissions control. Simultaneous improvements in combustion chamber design, valve performance, fuel injection, and other technologies eventually resulted in automobiles that were remarkably clean while still developing considerable power as a function of their fuel consumption level. The success of this technological development is seen clearly in the dramatic decreases in air pollution throughout metropolitan regions wherever it has been applied.

[4] The technology also improved engine performance dramatically, assisting in the effort to remove the octane-enhancing agent tetraethyl lead from gasoline, a move necessitated by concerns about lead poisoning in the atmosphere.

The story of atmospheric emissions control highlights one critical application of IT, but there is another, more subtle implication. California's aggressive pursuit of lower emissions proved the need not only for the manufacture of new autos with lower emissions but for the maintenance of those low emissions. The OEMs had repeatedly complained that the emissions control equipment would fail or wear out in time, presenting the customer with an expensive repair bill. The prospect of angry customers turning on the regulators might have caused the regulators to back off, but that is not what happened. They simply ordered the OEMs to implement warranties on all components related to the emissions control system for five years or 50,000 miles, thus forcing the OEMs to take responsibility for used vehicle performance as well. The rise of automobile-related records played a crucial role in the subsequent evolution of this mandate and produced surprising results when considered in light of other factors.

Passenger Safety

Early automobiles were extremely unsafe by today's standards. They were basically carts powered by an engine instead of draft animals. They handled poorly, their brakes were inadequate, they were prone to mechanical failures, and they provided passengers almost no protection. Design and technical progress improved passenger safety. John and Horace Dodge introduced the first all-steel car bodies in mass production in 1914. Polyvinyl acetate laminated safety glass was introduced in 1938. Many minor improvements in brakes, tires, steering gear, windshield wipers, and other components appeared over the years. The OEMs in Europe had started to focus on passenger safety in the 1950s: Volvo began incorporating the now universal three-point shoulder/lap seat belt in its vehicles by 1960, and several European manufacturers were building their models with disc brakes at least on the front wheels.

The U.S. OEMs were less attentive to safety until the publication of Ralph Nader's path-breaking book *Unsafe at Any Speed* (Nader 1965). Nader's book went far beyond claims that many automobiles were unsafe for passengers; it accused the OEMs of knowingly making unsafe vehicles when they had the means to do much better. The OEMs reacted at first through denial and public relations efforts while making modest efforts to improve safety. Their slow approach came to an abrupt end in 1972 when a seemingly routine lawsuit erupted into one of the largest product liability judgments ever handed down. The case involved a 1972 Pinto hatchback that was rear-ended, rupturing its gas tank against its differential housing and spraying fuel throughout the passenger compartment. The fuel ignited and the two occupants were terribly burned, one dying within days and the other surviving with permanent disfigurement and handicaps. The trial revealed that the highest level of Ford's management knew that this specific design flaw could be remedied at a cost of $4–$8 per vehicle, but management proceeded with production without remediation because the likely losses from such accidents were low enough to make the fix uneconomical. The jury returned a verdict for the plaintiffs of $3 million in direct damages and $125 million in punitive damages.

During the 1970s and 1980s U.S. insurance companies aggressively lobbied for safety regulations for new automobiles, and the OEMs began to take passenger safety more seriously. Information technology played an important role through automatic braking systems that reduced skidding, deceleration-detecting air bag systems for supplementary restraint in the event of a crash, and automatic warnings for the driver of conditions such as doors ajar and brake system failure. Recent efforts at intelligent vehicles and highways (so-called intelligent transportation systems) are aimed largely at safety concerns as well as expediting travel time. Yet again, as with emission controls, the rise of record keeping systems would prove to have important effects on passenger safety.

Entertainment, Conviviality, and Control

Some aspects of driving were considered entertainment from the start. Sporting models were produced and racing became popular very early. The first automobile radio was installed in a 1919 custom Cunningham town car, and in 1930 the Galvin Manufacturing Corporation developed the first mass production car radio and sold it under the name "Motorola." From that time the automobile evolved as a platform for entertainment while under way. In the early 1960s Earl Muntz began aggressively marketing the continuous loop four-track magnetic tape cartridge as an aftermarket product for cars. In 1965 Edwin Lear, who had played a pioneering role in car radio, introduced an eight-track continuous loop magnetic tape cartridge system with superior price–performance, and the format was quickly adopted by recording companies. The era of custom sound had begun, and the technology rapidly evolved to include FM stereo radio, compact cassette tape decks, compact audio CD decks, and MP3 players.

Custom sound systems were popular in the aftermarket throughout the 1970s and 1980s, and the OEMs, recognizing the profit potential, began to incorporate sophisticated systems in their models, even listing the brand names of the systems as a key selling point. This explicit incorporation of equipment from up-market audio companies signaled a direct connection between the traditional home entertainment market and the automotive environment. This occurred during a period when even more people were leaving the cities for the suburbs, thus increasing their commuting time—time now available for listening to music or the radio. The compact cassette had allowed people to record music at home for playback in their cars, and the audio CD and digital MP3 have accelerated the trend. The automobile has become an extension of the home-based entertainment zone, and that trend is continuing with flat-screen LCD displays and DVD players that allow passengers to watch recorded material in the car.

Another dimension of automobile-based entertainment is voice communication. The first radiotelephones were installed in autos in the 1940s but were used mainly for business. Casual use emerged with analog cellular telephony in the mid-1980s and accelerated after the introduction of digital cellular in the early 1990s. The first cellular phones were, in fact, explicitly designed for automobile use. The high power demands of the analog transceivers and the poor battery technology of the time made so-called mobile cellular radios cumbersome. The advent of the lightweight digital handheld telephone freed the user from connection to the automobile, but the phones could be used while driving through a "hands free" systems (increased risk of accident from driver distraction has caused some jurisdictions to outlaw telephone use without a hands free system).

The growing functionality of digital cellular communications allows the telephone to be incorporated in the automobile platform to communicate the status and location of the car for potential service providers and also to control different functions within the car. For example, the OnStar[5] service, which is available for many GM-manufactured vehicles, provides roadside assistance for finding directions, unlocking doors if locked out, remote vehicle diagnostics, personal calls, and other needs, including stolen vehicle tracking or summoning emergency assistance. The success of OnStar as conceived is debatable, but it represents the first instance of the automobile as an *addressable device in a wireless communications network*.

Telephony is only the beginning of wider network possibilities. Traditional telephony, which is now largely digital, might be moving toward a new paradigm called "voice over Internet protocol" (VOIP) that uses digital packet-switching to replace the traditional circuit-switched system. With VOIP a cellular phone is basically an Internet terminal, capable of carrying not only voice, but any other service possible over the Internet. In addition, location-finding technologies such as the Global Positioning System enable cellular telephone devices to provide pinpoint geographic location. Whether embedded in an auto's electronics or plugged in by the operator inserting a cell phone into a slot, digital cellular telephony can become a tool by which every vehicle becomes part of a large network.[6] Some attempts are also on the way to view cars as active routers in such networks, sending and receiving packets and routing them to their final destinations.

Information technology lies at the heart of the likelihood that every new automobile will become an addressable node in a global communications network. By combining technologies such as geographic location, automobile performance monitoring, operator behavior, and time monitoring, it is easy to imagine the evolution of services such as real-time dynamic insurance pricing or dynamic time-based and use-based pricing of roads and other infrastructural services. The vehicle would keep track of where and when it is driven as well as all stops and other actions taken.[7] An insurance company would charge premiums as a joint function of the place and time and the way the vehicle is being operated. The potential for surveillance with such technology is obvious, and the full behavioral aspects of such a scenario are not yet clear. Still, it is likely that many people will trade at least some information about their whereabouts for benefits such as dramatically lower insurance premiums or special offers delivered to them in their automobile for products or services available in the immediate vicinity. Such technology also has important implications for managing other kinds of automobile-related risk, including monitoring the whereabouts of minors or tracking individuals under court-ordered restraint.

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[5] See http://www.onstar.com/us_english/jsp/index.jsp. The discussion of OnStar is for illustration only. Similar solutions are also under way by other OEMs (for Ford see http://www.databaseanswers.com/telematics_ford.htm; for Daimler-Chrysler see, e.g., http://java.sun.com/products/consumer-embedded/automotive/whitepapers/ITCruiser-Whitepaper.pdf) and by competing independent service providers such as ATX technologies (see http://www.atxtechnologies.com/index.asp).

Production and Distribution Systems

Expediting and Coordinating Production and Distribution

Much recent research on IT in the automobile industry has focused on production and distribution of new vehicles and remarketing of used vehicles as part of the e-business transformation (see, e.g., summaries in Helper and MacDuffie 2001). This is appropriate given the important strides made in coordinating manufacturing and distribution networks. It is also useful to recognize the long history of organizational innovation in the industry. The development of production engineering and large-scale vertical integration of production at Ford early in the century was a watershed in the history of enterprise. Walter Chrysler's innovations in non-vertical integration through exploiting the independent parts supplier industry created an OEM that bought rather than made a large fraction of its products. Alfred Sloan in the 1920s and 1930s developed the so-called M-form organization, the multidivisional strategy that maintained uniform production of core components by dedicated divisions but decentralized design, motors, and marketing to the brands across the spectrum of price points. The M-form organization became the paradigm for the remainder of the 20th century. Even American Motors, an amalgamation of companies that were losing market share, contributed innovations in the form of extensive outsourcing of content and supply chain management in the 1960s and 1970s.

Important contributions were made by the OEMs of Sweden, France, Germany, Italy, Britain, and Japan as well. Of particular importance to IT's role in transformation is the Japanese development of techniques for quality assurance and lean manufacturing. The hallmarks of these developments are the evolution of a particular supplier–OEM relationship called the "voice" model and the use of an innovative information management process called the kanban system for coordinating production. The supplier–OEM tradition arose after WW II when Japan was struggling to rebuild its shattered industries with a depleted workforce and a dramatically changed social structure imposed by the occupation A key part of the rebuilding was the establishment of strong bonds between labor and management that included long-term job security in exchange for labor willingness to work across boundaries between trades and to join management in problem solving. This cooperative strategy extended to suppliers and OEMs; the OEMs agreed to stay with key suppliers in good times and bad, while suppliers agreed to help the OEMs with improvements in design, production, and efficiency. The kanban system was a formalized feedback system using paper cards that would accompany part and component production and at key points in the processes be passed back up through the supply chain to streamline the flow. The system enabled the just-in-time inventory control strategy that eventually caught on among the global OEMs. The Japanese auto industry established itself as the producer of high quality, reliable cars that could be sold at the lower price end of export markets in the United States and Europe. Japanese technical innovation also demonstrated that it was possible to do some things that the more established automobile industries did not believe possible, as with the Honda CVCC engine.

Meanwhile, the U.S. industry was pursuing strategies that were more dependent on exploiting information technologies, especially digital computers and process control devices in manufacturing. The important breakthrough was numerical computer-controlled (CNC) tools that could be programmed to machine specific shapes with great precision and rapid throughput. The ability to program robotic tools to execute complex tasks on a repetitive basis allowed them to spread into body painting, glass handling, and other tasks that carried potential for causing problems in worker safety and health. The technology also eventually extended to the assembly process, with entire assembly lines choreographed by computers.[8]

The development of computer-aided design tools that can produce "programs" for CNC tools based on higher level geometric specifications soon became a part of the manufacturing technology. Initially, CAD/CAM tools were used to automate manual drafting, but as mathematical modeling was incorporated they began to be used for integrated solid modeling, wherein defined geometries could be tested through finite element analysis and other techniques before being fabricated. A designer could design a part, input the parameters of expected use, specify materials and processes for manufacturing, and execute a set of virtual tests to determine whether the part would meet performance expectations. This dramatically reduced the amount of experimental engineering required to create reliable and cost-effective components and has been extended to whole modules and to vehicles as a whole (such as crash testing). Geometric models are now widely used in the early phases of product design for simulation and to obtain feedback from potential customers. These systems offer a suite of tools for integrated product management across the whole value chain and life cycle and are used in computer-based modeling of the production process to facilitate materials requirement planning (MRP).[9]

MRP, the other OEMs' answer to the Japanese kanban strategy, emerged from the need to get better control over inventory and inbound and outbound logistics, as well as to coordinate manufacturing costs. The early MRP systems were expanded to incorporate a broad array of manufacturing resources and eventually to embrace the enterprise as a whole through enterprise resource planning (ERP), such as SAP's R3 and MySap software suites[10] and similar software platforms. German manufacturers, especially Daimler, have been leading adopters of this technology. The next steps in this area are more standardized interfaces and processes for managing data through industry-wide product specification standards and standardized business processes such as EbXML.[11]

These developments have not yet produced an impact as strong as the Japanese revolution in quality assurance and lean manufacturing, but their accumulated effects have been important. Automobile production world-wide is far more efficient than ever, as can be seen in declining car prices and improved quality, reliability, and durability. This is partly due to major improvements in materials technology—plastics, coatings, lubricants, and so on—but ultimately is due mainly to advancing knowledge about how to build what the market needs efficiently and effectively. In contrast to just two decades ago, it is now difficult to buy a new automobile of poor quality.

An important area of IT application during the past decade has been supply chain intermediation. Individual OEMs have constructed their own IT-based supply chain coordination mechanisms, all variants of the value-added network applications that draw upon electronic data interchange (EDI) standards.[12] Although EDI specifications offer general industry-wide standards for exchange of documents in the supply chain (e.g., ANSI X12 and its subgroup ASC X12H, or U.N. EDIFACT), each OEM has adapted these standards to its specific purposes. These systems link suppliers to OEMs and facilitate the documentation of order entry and fulfillment, inventory information, and payments. During the past five years this closed hub-and-spoke model has been expanded in two ways. First, many of the large players have adopted the concept of on-line supplier market portals that match supplier capabilities and OEM needs through auctions and other coordination mechanisms. The major example of this is Covisint,[13] a Michigan company created by a number of U.S. OEMs and their major suppliers to create a marketplace for auctions in which demand and supply can be matched throughout the industry and to develop tools whereby design and production collaboration between suppliers and OEMs can take place. It was hoped that Covisint, launched with great fanfare in December 2000 and riding the crest of the dot.com wave,would revolutionize the supply chain, driving down prices and improving coordination among suppliers and OEMs, but it has failed to achieve its goals of becoming a market clearing mechanism for high value-added parts and transacting $300 billion in business. There have been many successful auctions through Covisint, but most have been for commodity parts; there is little evidence that it has changed the operation of the supply chain, and there are doubts about whether it can support the full array of relationships between OEMs and suppliers now common in the industry.[14]

Another important development in supply chain intermediation has been the emergence of e-collaboration systems or supplier collaboration portals. They offer a unified channel for suppliers to interact on product design information, quality statistics, order cycle fulfillment, demand estimation and planning, and logistics. The main value of these systems[15] has been cost dramatic reductions compared to Value-Added Network-based solutions, easy global reach of technologies enabling global coordination, and integration of supply chain information in one accessible platform. These systems are in their early phases of adoption, but they already have changed supplier relationships in specific situations.

Marketing and distribution have been influenced by IT in two basic ways. The first is by providing purchase-relevant information, although such services have been around in print form for a long time. The Kelley Blue Book of prices was first published in 1926, and automobile magazines containing new car reviews are as old as the industry. Extending these publications to the Web was not difficult.[16] More important, users can compare features and prices of specific models and find a large amount of information on any given model quickly. The general view among marketing and distribution experts is that such services have dramatically reduced the traditional advantage of dealers over buyers by shifting the information asymmetries to the benefit of buyers.

The second form of IT-enabled marketing and distribution has been the reference provider that attracts potential buyers with the promise of attractive pricing and matches the buyer with a dealer willing to sell at the price the intermediary has negotiated. There was much speculation about whether the OEMs could begin selling directly to customers using the Web, thus starting disintermediation, but most U.S. states forbid the direct sale of automobiles from OEMs to customers, and in any case, the dealers provide important services that OEMs would have difficulty providing currently. The services that have emerged in cyberspace have demonstrated that the right kinds of services available on the Web can provide an important consolidation function, bringing potential buyers into an investigation of particular brands and models, collecting data from the customers, and passing that information on to participating dealers in the customer's area.

Some of these services, such as Auto-by-Tel.com[17] or CarsDirect.com,[18] place possible customers in touch with dealers and also provide meta-markets for other car-related services such as insurance, car loans, and so on. Others, such as FordDirect.com,[19] are a joint effort of OEMs and dealers to steer customers to particular products and to offer possibilities to configure and specify cars to order. And still others, such as AutoNation.com,[20] are basically the Web storefronts of large dealer chains of both new and used cars. The effect of these services on consolidating distribution channels seems to be less significant thus far than the effect of the prepurchase information services. Yet, considerable evidence suggests that customers are increasingly turning to the Internet for key parts of their purchasing activities.

After-Sales Markets: Manufacturer–Customer Relationship Construction and Maintenance

There has always been a peculiar relationship between automobile manufacturers and customers. Few mass-produced products have inspired the same brand recognition and loyalty that automobiles do. The cultural and social presence of the automobile even extends to national identity, with considerable anxiety expressed when an iconic marque goes out of business (e.g., American Motors) or is purchased by a foreign OEM (e.g., BMW's acquisition of Rolls-Royce). This kind of relationship might be important for the manufacturer in its efforts to persuade purchasers to be repeat customers, but it does not attach to specific vehicles owned by specific customers, especially after warranty expiration, nor to used car resale. With one exception, the only residual relationship between the manufacturer and customers is the replacement parts market. The exception is financing.

The Commercial Investment Trust Company partnered with Studebaker to create the first automobile financing program in the United States in 1915. Other OEMs developed their own financing subsidiaries, some of which are among the largest financial companies in the world. Financing new purchases connected the OEMs to their customers in important ways, incorporating into their records systems employment, income, and other information that would never have been collected in a straight sales transaction. Although there was relatively little exchange of this information between the manufacturing and marketing arms and the financial subsidiaries, the latter were creating within the OEMs the skills in large-scale records systems that would prove important later. The collateral for the loan was the vehicle itself, and the company's rights of ownership had to be recorded to enable recovery in the event of loan default. Thus, the OEMs began to develop interorganizational information systems involving government regulatory agencies.[21]

Financing has also evolved in subtle ways. The rise of leasing as an alternative to purchase became popular in the 1980s and is now stabilized at the level of 25% of all car "trades." The reasons for this are complex, and their analysis is beyond the scope of this paper. Some are institutional in origin and relate to taxation rules that make it more economical to lease in certain situations. Some of them are competitive and deal with the need to increase customer loyalty and to better understand customer behaviors. The fortunes of OEM-based leasing have waxed and waned for various reasons, not the least being their lack of expertise on running large leasing programs. The important fact of leasing is that it has demonstrated an operationally viable alternative to outright ownership that might be a harbinger of things to come.

With a lease, the automobile user establishes and maintains a very different relationship with the dealer and the OEM than in the past. In the traditional sales model, the buyer could disregard the OEM once the warranty was ended. Similarly, when the primary source of dealer profit was new car sales, the only incentive the dealer had to engage the buyer after purchase was to cultivate future purchases. With the market decreasingly a matter of new car sales, dealers as well as OEMs are trying to garner a larger share of what used to be the aftermarket. Leasing contributes to that trend, because when a lease expires the user looks for a replacement vehicle while the used vehicle returns to inventory. Even if leased autos account for only a fraction of total new vehicle transactions, the OEMs and dealers must develop complete protocols for handling leases, building the capacity to treat all transactions as though they were leases even though not all are.

This becomes significant when added to the fact that the relationships among OEMs, dealers, and buyers have changed dramatically. The main causes of this are the increased service life of automobiles together with a major change in warranty structures. New vehicle warranties were introduced very early to induce customers and to redress variance in materials and build quality, but it was in the interest of the OEM to make the warranty as restrictive as possible. For many decades the standard U.S. new car warranty was 12 months or 12,000 miles. Now it is difficult to find warranties shorter than 36 months or 36,000 miles, and competition has made warranties a major factor in marketing. Hyundai's recent introduction of a 10-year, 100,000-mile power train warranty far exceeds any previous standard warranty, but warranties of five or more years are not uncommon. The "power train" clause is important, because it denotes that different aspects of an automobile might be handled differently. Consumables such as fuel, lubricants, tires, batteries, and light bulbs were almost never covered by new car warranties. Similarly, crash damage was covered not by warranty but by insurance. The warranty declared only what the OEM determined to be its responsibility. The increasing standard warranty is an explicit recognition that the OEM is accepting more responsibility for the vehicle after sale.

In fact, U.S. OEMs have been forced to accept a large increase in responsibility for the after-sale lives of their automobiles.The federally mandated warranty on emissions-related components in effect required manufacturers to assume liability for mechanical system failures of a large part of the vehicle's value for a long time into the future. Because every manufacturer had to meet the mandate, there was no comparative advantage in simply abiding by the law, but there was potential marketing advantage by extending the warranty significantly to cover major aspects of the vehicle that tend not to fail, thereby making it seem that the company was voluntarily accepting responsibility for its products in a most laudable fashion. An OEM that failed to offer the new, higher standard warranty risked appearing as though it was not confident in the quality of its product. In fact, the new Hyundai warranty was created explicitly to overcome the company's image as a builder of inexpensive and not particularly reliable cars. Conversely, prestige marques were able to stay with somewhat shorter standard warranties because the consumer knew those companies' reputations for quality and reliability. The rise in the standard warranty was accompanied by the advent of an "extended warranty," for a significant additional fee. In just two decades, the effective warranties on the majority of new cars sold in the United States exceeded seven years and 70,000 miles.

Extended warranties are, in essence, automobile health insurance contracts, and the financial paper on them is usually held by a financial firm rather than an OEM. The financial firms' return is generated the same way as with health insurance: through actuarial analysis of the likely benefits to be paid out and establishment of premiums that will cover those costs and return a profit. The relationships among the user, dealer, and OEM shift dramatically under this model. In the past, once a vehicle was out of warranty, the owner had to pay the dealer or an independent service agency for repairs. Dealers did not necessarily relish working on older models because they wanted to avoid the arguments with owners over high service costs and they did not want to deal with the supply chain problems of servicing older vehicles. The average dealer would thus fill this service with a 50/50 mix of warranty and "customer pay" work despite the fact that the latter category dwarfs the former. The independent service market was there for older vehicles, and the dealers were happy to see the older vehicles go there. OEMs cared mostly about reimbursing dealers for warranty service. The situation today is very different.

Improved customer information on new automobile characteristics and pricing make it more difficult for dealers to make large profits on new car sales. At the same time, the extended warranty structure has brought a boon in profitability of service. The vehicle owner has, in effect, "prepaid" the repair costs of and does not need to haggle over the price of service. The OEM or the financial company that pays for the repair is interested only in meeting the legitimate claims against the warranty. The dealer is in an excellent position to conduct service in a way that produces profits. In many cases, dealers make substantial profits from selling extended warranties themselves and thus can offer lucrative sweeteners such as forgiveness of deductibles if the purchaser brings the vehicle to the dealer for all service needs. In this way, new car dealers and OEMs have become much more tightly coupled to the automobile user base.

The other way in which the relationship between OEMs and customers has changed is through passenger safety. The 1972 Pinto incident established the precedent that the

OEM carried liability for product design as well as for quality. This was a vital distinction, with tremendous implications. The concept of OEM responsibility for build quality was already well established. The OEM would take care of problems directly attributable to the manufacturing process, and it was assumed that normal operations would reveal such problems. Even when a defect tied to manufacturing resulted in a significant loss, the liability was linked only to that particular instance, and there was no assumption that the manufacturer had any way of knowing that the event might occur. Design liability, on the other hand, creates responsibility for the entire class of losses that might occur as a result of a defect and creates the potential for much more serious liability if it can be demonstrated that the manufacturer should have known, or even worse did know, about the defect. Since the Pinto judgment, statute and case law have refined the parameters of design liability, with far-reaching implications.

It seemed that the only big implication of the Pinto case was that manufacturers have to be more careful in design. Of course, this is true, and safety design has become a major concern as well as a marketing claim, backed up by government-sanctioned crash tests. The deeper story, however, lies in residual liability when good faith design efforts are insufficient. No complex artifact like an automobile can be designed to be perfect, and every vehicle on the road is "unsafe" in some sense. Tens of thousands of deaths and millions of injuries each year attest to this. The question is, what liability does a manufacturer have for a defect discovered after the product is built and distributed? As the law and practice have developed, the answer is, until the problem has been fixed in all good faith. This is the origin of product safety recalls, which are a major factor in the U.S. automobile industry. Manufacturers become aware of safety-related defects and issue recalls to owners of the vehicles. The recalls typically state the nature of the problem and what might go wrong under certain conditions and instruct the owner to bring the vehicle to an authorized service center (usually a dealer) for repair at the manufacturer's expense. Note that in many cases a design defect if safety related will be repaired at the manufacturer's expense even though the vehicle is out of warranty. Of course, not every possible safety concern for every vehicle on the road results in a recall. But the ubiquity of the recall practice has radically changed the relationship between manufacturer and customer.

Returning to the perspective of IT, automobile-related record keeping did not evolve for executing product recalls but for the purposes described earlier: property registration, operator regulation, tax collection, financing, and insurance. Nevertheless, the systems created for those purposes enabled the recalls seen today. Without extensive record keeping it would not be possible to make a good faith effort to fix every vehicle still in operation within the jurisdictionby notifying everyone who owns such a vehicle, regardless of how many times ownership has changed hands since the original sale.

The combination of the records systems, long-term warranty structures, a product design liability, and performance mandates on emissions have fundamentally altered the relationship between the OEMs and automobile users, expanding it to include owners who might never have purchased a new car. Moreover, the situation now encompasses a constellation of players—OEMs, users, dealers, financing companies, insurance companies, and government agencies. In the years to come this will also include parts manufacturers as technologies such as radio frequency identifiers (RFIDs) are used to identify major components of the car so that inspections can be made more accurately and reliability and safety information can be transmitted nearly immediately upwards in the value chain.

Conclusion: IT and Enterprise Transformation in the Car Industry

IT has been profoundly important in the transformation of the automobile industry, but the process has been far more subtle and complicated than the rhetoric about the Internet and the Web suggests. Transformation has been a slow, infrastructural, accretionary process that has produced powerful cumulative effects. The industry made significant use of IT long before the era of digital computers or even electronic unit record equipment. In fact, the close association of information capability and the automobile industry began not long after the invention of Hollerith card sorting technology. The automobile industry coevolved with modernIT and in myriad ways incorporated that technology as it grew, so the full effects are difficult to spot because they are infrastructural and invisible.

The only visible change of importance for the industry due to the Internet and the Web has been the rise in information access for purchasers, which has eroded much of the traditional advantage in information asymmetry held by dealers. There is no sign of radical disintermediation and probably will not be as long as distribution regulations remain unchanged. The other major experiment to transform the industry by changing the supply chain (e.g., Covisint) has proved to be less significant than predicted. In time, radically increased information sharing and distribution through e-collaboration platforms and improved effectiveness of the supply chain through integrated software platforms and deployment of intelligent RFID tags could have major impacts. CAD/CAM systems are being used as product life cycle management tools and integrated into enterprise resource planning systems. Their significance lies in their ability to speed up the cycles between design and manufacturing and make product design increasingly collaborative and information intensive.

The most important impacts of IT in the transformation of the industry have been in the enhanced product characteristics of the vehicles and in the evolution and diffusion of records systems. The former has seen the automobile evolve into a platform of integrated computing technologies so extensive that a contemporary model has more than 60 processors that collectively have as much computing power as a desktop PC. The latter has transformed the relationship between OEMs, dealers, automobile users, and other actors and enabled sustained institutional regulation and new market-based services. These kinds of changes are deeply infrastructural and typically visible only on breakdown (Star and Ruhleder 1996). Such infrastructure is so familiar that it escapes notice, but it is the most important factor in any long-term assessment of socio-technical change (Edwards 2001).

It is difficult to predict the future, but one can argue fthat the industry will be transformed from its old role as a product industry into what is essentially a service industry. This does not mean that there would be no “product”; rather, there could be a shift in what is considered essential to being competitive within the industry. The industry of the future could be focused on providing personal rapid transit and related services (entertainment, safety, risk mitigation, information support) for individuals and households, and within this model the product itself could play a minor role. Under such a scenario one can easily imagine a shift from individual ownership toward a rental or service provisioning model.[22]

The likelihood of a shift from product to service becomes more salient when considering that OEMs have been forced to internalize negative externalities generated by automobile use. Air pollution and passenger safety hazards have become their responsibility, and the European Union recently adopted rules making them responsible for final disposal of the automobiles they manufacture, bringing their responsibility full circle, from initial manufacture to final disposal. The time may come when they will be unable to deflect liability arising at any point in the life cycle. This is important in its own right, but takes on greater importance given the dramatic growth in the population of used vehicles. Thus, the question arises, Why would an OEM that cannot shed the liability of its products and that seeks to capture more value from those products throughout their life cycle ever sell the products in the first place? It would seem more sensible to build, field, and dispose of the products through the life cycle and collect rents on use and ancillary services along the way.

Many arguments can be raised against this scenario—intransigent customer behavior, cultural preference for ownership, regulatory interventions such as antitrust—but there is no reason *in principle* why the industry might not shift toward a rental model. Moreover, IT is making such a shift increasingly feasible. The serious impediments that exist arise mainly from the industry's lack of experience with the idea, the inertia of existing ways of doing business, and the predictable opposition of incumbent interests that benefit from the current arrangements. Such impediments might prove insurmountable, and others could be added. Our purpose is to illustrate the potential magnitude of the transformation now under way.

Two issues deserve more detailed discussion. One is the growing vehicle service life in light of design liability and warranty obligations. No machine lasts forever, so the problem is bounded, but there is a big difference between 10 and 25 years. This becomes more salient given discussions under way regarding the so-called modular vehicle platform concept (Helper and MacDuffie 2001; Holweg and Pil 2001). In this design, an expensive platform contains the major motive and control systems of the vehicle, while interchangeable body components allow the vehicle to be reconfigured over time. The idea has emerged in part to cope with the challenge of deploying vehicles propelled by hydrogen fuel cells, which will be expensive to produce and will last a long time. The customer would obtain the platform on a long-term contract and reconfigure the vehicle's other parts as necessary.[23] The required records systems already enable such long-term strategies, and IT can greatly assist in the design, manufacture, and operation of such vehicles. Such a scheme need not involve customer ownership at all; it lends itself readily to the rental model. It is not important for our purposes whether the shift to long-lived platforms comes to pass. The point is that the transformation scenario of moving from product to service is robust across a number of feasible futures.

A different but somewhat related question is the likely rise in cross-border aftermarkets. For the past half century the main focus of the industry has been new vehicle manufacture and sale. The international dimensions of this revolve around economies of production and distribution, compliance with regulatory standards and content expectations, and provision of adequate service infrastructure. The traffic in used automobiles across borders has been an altogether different matter. Used vehicles move across country boundaries from "higher" to "lower" in socioeconomic terms. Vehicles that no longer pass the strict German safety inspections are sold across borders into countries that have lower regulatory constraints. The European Union's normalization of regulations and lowering of trade barriers across borders should accelerate transborder sales of automobiles. A similar phenomenon is under way in North America as trade barriers fall. The trend could be accelerated by growth in information services that facilitate such sales, increased interoperability of government records systems, and the ongoing globalization of the OEMs and large suppliers. The opening of truly international markets in used cars would bring changes not heretofore seen in the industry. How such a shift would alter the likelihood of a shift from product to service is difficult to determine, but it is not difficult to imagine multinational corporations developing offerings to provide a growing portion of the world's population access to personal rapid transit using fleets of vehicles owned from beginning to end by OEMs.

Our goal has been the explication of the mechanics of transformation in the automobile industry as a result of information capability brought by new information technology. Critics can refute the historical account, and time will tell whether our predictions will hold up. These stories are not particularly important in and of themselves. Their main role is to serve as vehicles to demonstrate a strategy of analysis that embraces much broader definitions of industry and much broader definitions of IT than transformation accounts typically embrace. This strategy is fraught with difficulties and risks, particularly related to the complexity of the stories that emerge. Nevertheless, such strategy is warranted given the extraordinary importance of IT in the transformation of human enterprise.

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