Automotive Informatics: Information Technology and Enterprise Transformation in the Automobile World

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Administrative Preface: This paper is still under construction. It is undergoing extensive expansion, editing and revision. Comments, criticism, and questions are welcomed and can be addressed to the author. The Automotive Informatics Research Collaboratory (AIRC) includes John Leslie King and Vladislav Fomin at Michigan, and Kalle Lyytinen and Sean McGann at the Weatherhead School of Management at Case-Western Reserve University. AIRC is investigating the effects of use of information technology in the automobile world. It is affiliated with the Global Electronic Commerce project coordinated by the Center for Research on Information Technology and Organizations at the University of California at Irvine. This research is supported in part by the National Science Foundation's Digital Society and Technologies Program.

Abstract

This paper investigates the effects of information technology on the automobile industry, broadly defined. The automobile industry is far larger than just the suppliers and original equipment manufacturers that produce new automobiles. The phenomenon of automobile transportation includes the used automobile realm, which is 13 times larger than the new automobile realm, plus all the complementary components such as after-market parts, service, insurance, highways, fuel, etc. When this larger "automobile world" is examined, the effects of information technology go far beyond the contemporary accounts of IT in new vehicle design, systems control, manufacturing, sourcing, and marketing. These are all important, to be sure, but an historical assessment of the automobile world reveals that more subtle and powerful effects can be traced to the intersection of IT-enabled record keeping coupled with a steady rise in regulation that forces the automobile OEMs to internalize negative externalities associated with automobile transportation, such as atmospheric emission control and passenger safety improvement. It is argued that the cumulative effects of these changes, together with other IT-influenced factors, are slowly transforming the realm of automobiles from a product industry to a service industry.

Introduction

The automobile industry is often characterized in terms that limit the scope of discussion to the manufacture and sale of new automobiles. This paper broadens the scope to include the broad set of complements, enablers, and constraints that make the industry one of the largest and most influential human enterprises in history. Moreover, we argue in this paper that the role of information technology has been profound in the slow transformation of the industry from its original status as a product industry into what is increasingly a service industry in which “product” is something far different from what it was when the industry first became a powerful global force. The role of information technology in this process has never been in the foreground: it has always been infrastructural, making possible subtle but profound changes in nearly every aspect of the industry.

Before proceeding, we acknowledge that the automobile industry is one of the most extensively researched sectors of enterprise, and a great wealth of information and insight is available to the student of the subject. We do not profess to be experts on the industry. Rather, our interest arises from long study of the application of information technology to complex domains of human activity, and especially to domains that are themselves technologically intensive, systemic, and institutionalized. The automobile industry is technology-intensive, and has been from its beginning. Gottlieb Daimler perfected the high-speed internal combustion engine in 1885, creating the first engine with a sufficiently wide power band to enable controlled acceleration of a light vehicle, and the industry has been a wellspring of technological innovation since. It is also has been highly systemic since the early part of the 20th century. Ransom Olds first applied the concept of systematic assembly processes to the industry in 1901, and Henry Ford brought the world large-scale parts standardization and process engineering in 1907. Ford’s Model T was the product of the world’s first vertically integrated mass production system that, in a period of 17 years, reduced the assembly time of a vehicle by a factor of 24 and the selling price by a factor of three. Finally, the industry is highly institutionalized, tied irrevocably to the institutions of local and national government, as well as to other industries such as insurance that are themselves highly institutionalized.

Our purpose in this paper is to examine the mechanisms and logic of transformation in a world of rapidly changing capabilities in information processing and communication. In this, we depart somewhat from the contemporary practice of focusing on the ways in which specific information technologies (e.g., the Internet and World Wide Web) change specific practices in the industry as it currently operates. Our focus is more upon the slow accretion of capability enabled by information technology that, in time, results in fundamentally new characteristics in the industry. This kind of transformation takes decades. Thus, our focus incorporates not only modern information technologies (e.g., computers and networks), but the precursors of these technologies such as records systems, as well as contemporary information management techniques such as the kanban system used so successfully in Japanese automobile manufacturing. In a way, this paper’s main interest is in the relationship between *information* and the automobile realm. In the following sections we will examine the characteristics of the automobile industry. This basis construction will be used to assess the ways in which information has evolved to affect the industry, and over time, transform it.

The Industry Today

The automobile industry, broadly considered, is arguably the world's largest coordinated production system in terms of the economically measurable value-added it provides. Some statistics that characterize the industry are shown in Table 1.

Global autos in use 2001	About 550 million
Global autos produced in 2001	40 million
US cars in use in 2001	135 million (24% of global)
US new vehicle assembly companies in 2001	11
US new auto production in 2001	About 5.5 million
US auto parts suppliers	About 5,000
US auto parts supply employment	About 550,000
US NAICS code 33611 "Automobile Manufacturing"	
Companies	About 200
Employees	About 120,000
Revenue	About $100 billion
Value-added	About $30 billion

Note: approximate values are used to indicate the magnitudes; actual values are very close, and shift from year to year due to entry/exit as well as changes in definition.

Some interesting insights are possible from these data. One is that the automobile industry has extraordinary global reach. There is approximately one automobile for every eleven people on Earth. Of course, the distribution of automobiles is uneven: the ratio in the United States is approximately one automobile for every two or three people. The new vehicle industry is economically important, and the value of new auto production and sales is equal to between one tenth and one eleventh of total GNP. New auto manufacturing as measured under NAICS code 33611 employs about one half of one percent of the US population, and adding the parts supply industry as a whole raises that figure to about 2.5 percent. 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 be estimated that one out of every seven jobs in the United States is tied directly to the automobile through its effects on manufacturing of new vehicles and parts, fuel, service, insurance, and so on.

Along these lines, the data show that the number of global 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 automobiles already on the road, the industry is overwhelmingly a *used vehicle* industry. The average service life of an automobile has been rising as global population growth has been decelerating. The inevitable consequence of these trends is that the production of new automobiles will face constrained growth compared to past decades, even while the total population of vehicles on the road expands This is directly reflected in several contextual measures. Ownership of automobiles per household is rising, as seen in the trend toward construction of merchant housing in the US with garages for three or more vehicles. The manufacturing side of the automobile industry is also experiencing significant growth in its spare parts market, with some OEMs reporting spares sales accounting for between 6% and 10% of total revenue, and there has been almost explosive growth in the so-called "specialty equipment" aftermarket that provides equipment to customize used vehicles. New car dealers are increasing their involvement in used car sales, and the OEMs are actively seeking to gather a larger fraction of the used car market through institution of manufacturer-certified used vehicle programs and other strategies.

The important thing to recognize from these trends is that the automobile realm is not following the pattern of the typical "maturing" industry, in which demand is saturated and manufacturing becomes essentially a contest among efficient producers. For one thing, even in the OEM new vehicle realm there have been a number of surprises in recent years that upset the market saturation hypothesis: the sudden popularity of minivans and SUVs, the surge in sales of light trucks, and the success of upscale brands that cater to customer sense of image and status. Still, even if those surprises were absent, the constrained demand in the new automobile sector is still overshadowed by the fact that automobile use continues to rise in both developed and developing countries. The industry, if one looks beyond the suppliers and OEMs of the new vehicle sector, is not "mature" at all; it is in a continual state of flux and could change in dramatic new directions. This turbulence has been a hallmark of the auto industry since its inception, and is likely to be the case into the future. The industry has 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, as the number of automobile OEMs rose at mid-century, and then entered a period of consolidation over the last two decades. New technology and techniques for production have also dramatically affected the automobile industry, and will continue to do so into the future as with the accelerating effort to create vehicles that can use dramatically different power sources such as hydrogen fuel cells.

The final point in our characterization of the automobile industry today is the remarkable extent to which the key artifact and purpose of the industry – the automobile in the provision of personal rapid transit – has embedded itself into many infrastructural aspects of life. The automobile industry was the first systematic global industry, and arguably launched the modern era of enterprise through its exploitation of mass production. It is not exaggerating to say that the industry was instrumental in the creation of the US middle class through enabling production of vast quantities of needed goods at constantly decreasing real prices, and stimulating the economy in ways that required steady increases of the wages of industrial workers. The automobile industry was extraordinary in the speed with which it generated wealth for entrepreneurs, but it was also remarkable in the way it spread the wealth throughout the society rather than leaving it concentrated in the hands of a few. Automobile design and use has become a fundamental component of cultural identity, as well, through the shared project of both OEMs and the buying public to make choices in automobile purchase a mechanism for expressing social status and individual personality. The realm of the automobile extends to the creation and support of a number of large, complementary industries such as automobile insurance, fuel supply, parts and service provision, road building, transportation planning, trucking, and so on. And, last but not least for our purposes, the automobile is deeply embedded in regulatory and other institutional sectors of society at the local, national, and global level. There is no other industry quite like it.

Six Regimes of Transformation

The objective of this paper is to review the role of information technology as broadly constructed earlier in the slow transformation of the automobile industry as broadly constructed over the past century. We reiterate the need to incorporate both pre-digital information technologies as well as contemporary non-computer based information management practices in this study because they are essential to understanding how the industry has evolved. We include as part of the automobile industry the broad sweep of activities and infrastructure required to make automobile transportation possible. We break this analysis into six regimes of change:

- Property regulation, risk mitigation, and complementary asset provision
- Atmospheric emissions control
- Passenger safety
- Entertainment, conviviality, communications and control
- Expediting and coordinating production and distribution
- Manufacturer-customer relationship construction and maintenance

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 who could afford expensive specialty-built chassis and coaches. When the automobile came within reach of common people, it has a profound effect on the economics of households and communities. The automobile was, and for many still is, the second most expensive piece of personal property behind a residence. Residential property law had evolved over centuries, and was well established by the beginning of the automobile era. No similar evolution had taken place to deal with automobiles. There was no established registry of ownership to determine which specific automobiles belonged to which people. Given the extraordinary theft potential of automobiles (they were both very valuable and made to be driven away), it became necessary very early to develop an official registration system for automobiles so thieves could be prosecuted and stolen property could be identified, recovered, and restored to rightful owners. It also became clear relatively rapidly 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 set by the registry. These registries of automobiles and their operators were the first systematic records systems involving individuals and households since the development of vital statistic registration (birth, marriage, death) and land records tied to individual owners. Moreover, the fact that automobiles changed hands and individuals moved from place to place meant that these records systems required updating much more frequently than earlier records systems tied to individuals and households. It is important to remember that 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 through automobile theft or accident quickly demonstrated the need for risk mitigation in the form of insurance. Insurance required accurate records on both automobiles and their operators, as well as ongoing records on the histories of those automobiles and operators. In order to be profitable, insurance companies had to know the value of the automobiles they were insuring and the operator histories of those they were insuring so premiums could be set appropriately. This meant that insurance company records had to be interoperable with the official registries maintained by the government. The interaction of these records made it possible to construct an ongoing structure of rewards and sanctions for operator behavior: "good drivers" could be identified and given premium discounts, while "bad drivers" could be given higher premiums or refused service altogether. As the systems grew more sophisticated, the disparate records of various states and locales were linked together such that accidents or traffic violations occurring anywhere would be known to the insurance provider as well as to law enforcement. Given the important role of automobiles in the society at large, and particularly in the commission of crimes, vehicle and operator registries became important tools of law enforcement generally. Criminal investigators frequently use such registries to establish the identity of individuals who might be linked to a crime as a victim, perpetrator or witness. 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.

The growth of automobile use quickly spawned demand for improved roads that were essential to getting the full benefit of the automobile – speed, comfort, and reliability. Road construction has always been enormously expensive, and with the exception of a few limited-access facilities (turnpikes, bridges, tunnels) roads had to be provided as public goods, open to all users without specific fees for use. The challenge of paying for such roads was serious because making the entire population pay for expensive infrastructure that only some would use (e.g., automobile users) was economically dysfunctional. The records systems for automobile ownership and operation provided a ready mechanism for collecting revenues specifically from owners and operators. Fees to help pay for roads could be imposed on automobile registration 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 used by automobiles.

The rise of extensive record keeping related to automobiles resulted in time-series data bases that facilitated systematic and scientific analysis of many issues related to automobile production and use. These data were valuable for market analysis and advertising, for assessment of road use patterns for highway planning, for the study of population mobility in land use planning, and many other purposes. In time, they became essential to the implementation of regulatory requirements related to atmospheric emissions, passenger safety, and a variety of other problems that are discussed in more detail below. Most of the early records systems were manual and paper-based, but they quickly adopted new technologies such as electromechanical unit-record equipment and digital computers as they became available. Today, such systems are heavily computerized, and are continuously being upgraded to new levels of reliability, accuracy, and usability.

Atmospheric Emissions Control

Automobiles burn liquid hydrocarbon fuels such as diesel and gasoline by mixing the fuel with air, compressing the fuel/air mixture in a cylinder, and capturing the energy released by combustion to move the vehicle. The inevitable result is atmospheric emission of gasses and other materials resulting from the combustion process: carbon dioxide, carbon monoxide, oxides of nitrogen, unburned hydrocarbons, and other gasses and particulates. This was not considered a problem for many decades, in part because the society was used to living with air fouled from combustion by-products (indeed, smoke in the air was equated with industrial progress in many cases), in part because the pollution from mobile sources such as automobiles dissipated into the atmosphere rapidly and blew away, and in part because there simply were not that many vehicles in use. That all changed around the middle of the 20th century when residents of communities such as Los Angeles began to notice a strange and persistent cloud of brownish-gray gas in the atmosphere that seemed like a mix of smoke and fog. Smog, as the phenomenon became known, proved to be a revolutionary issue for the automobile industry.

The relationship between automobile and other emission sources and Smog was difficult to determine until researchers at Caltech demonstrated in 1956 that Smog was not merely the collected clouds of emissions from autos and stationary sources. Smog was actually manufactured in the air by sunlight acting on precursor chemicals contained in automobile exhaust and other sources. Photochemical Smog became a political issue in the early 1960's in the Los Angeles area due in large part to the fact that the region's combination of mountain ranges, prevailing winds, and atmospheric "inversion" trapped the gasses below the mountain ridge lines and allowed the Smog to concentrate. The US Surgeon General's 1964 report on the health risks of smoking tobacco coincided with a growing sense that Smog might have serious health consequences. The US Congress passed the Clean Air Act in 1968 that mandated air quality standards, and California acted on its own to set even stronger standards. There was controversy over whether stationary sources (e.g., power plants) or mobile sources (e.g., automobiles) were most responsible for meeting the new standards, but scientific evidence and political pressure required action on all fronts. The US automobile industry initially fought the standards, arguing that it was either impossible or prohibitively expensive to meet the standards. However, foreign competition produced new technologies such as the Honda Motor Controlled-Vortex Combustion Chamber (CVCC) engine that allowed its Civic model of 1969 to come in well below the mandated standards. The Japanese automobile industry had been gaining steadily against the US OEMs for some time, and this plus other factors shifted the focus of the entire industry toward finding technological solutions to the emissions problem.

A number of technologies concentrated on altering combustion temperatures and recirculating exhaust gasses through the combustion process, but these were not terribly effective. The big breakthrough was the development of the three-way catalytic converter that used rare earths or metals (e.g., platinum, palladium, rhodium) to catalyze reactions that would oxidize CO into CO_2 and hydrocarbons into CO_2 and water vapor, while at the same time reduce oxides of nitrogen into N_2. The potential of the three way catalytic converter had been demonstrated in theory and in highly controlled test conditions, where it converted more than 98% of the harmful gasses into harmless byproducts. However, it had serious drawback: it had to operate very near to stoichiometric conditions. Even minor deviations from stoichiometry resulded in a catastrophic decline in efficiency. The only way to obtain the right operating conditions was to make micro adjustments in the fuel/air ratio on a continuous basis, which was a huge obstacle given the dynamics of automobile engines and operating conditions. The solution, developed in the mid-1970’s by Volvo, was the Lambda-sond system. This system consisted of a special sensor between the exhaust manifold and the catalytic converter chamber that would sense oxygen partial pressure so sensitively that it could detect even minor deviance from stoichiometric. The sensor relayed its information to a digital processor 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 engine’s output gas in stoichiometric balance. This was the first application of modern information technology to the control of an automobile engine for purposes of emissions control, and was incorporated in Volvo’s 240 model sold in California in 1976.

The general strategy of the computer-controlled, three way catalytic converter 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 early and late 1970’s. The general trend in the technology was toward incorporation of a larger variety of sensors to more finely tune engine performance and emission control (e.g., sensors for atmospheric temperature and pressure, engine temperature, throttle position, transmission operation, vehicle speed). Simultaneous improvements in combustion chamber design, valve performance, fuel injection and other technologies eventually resulted in automobiles that were remarkably “clean” and developed far more usable power as a function of their fuel consumption than ever before. The success of this technological development is seen clearly in the changes in the condition of the air in the Los Angeles region where the story began. Between 1965 and 2000 the number of automobiles and other vehicles in the region increased dramatically, while air pollution dropped dramatically.

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

Passenger Safety

Early automobiles were extremely unsafe by today's standards. They were basically over-the-road carts powered by an internal combustion engine instead of draft animals. They handled poorly, their brakes were inadequate, they were prone to mechanical failures at inopportune moments, and they provided passengers almost no protection. Design and technical progress improved passenger safety. The Detroit brothers 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 OEM industry in Europe had started to focus on passenger safety in the 1950's: Volvo, for example, patented and began incorporating the now universal three-point shoulder/lap seat belt in its vehicles by 1960, and several European manufacturers were building all of their models with disc brakes at least on the front wheels.

The US OEMs were less attentive to safety issues until the publication of Ralph Nader's path-breaking book *Unsafe at Any Speed* in 1965. Nader's book was a shock to the industry because it went far beyond claims that many automobiles were unsafe for their passengers; it directly 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 the safety of their products. Their slow approach to the subject came to an abrupt end in 1972 when a seemingly routine lawsuit over an accident involving a Ford Pinto erupted into one of the largest product liability judgments ever handed down. The case, Grimshaw v. Ford Motor Company, involved a 1972 Pinto hatchback purchased new by the Gray family in late 1971. In May of 1972 Mrs. Gray and 13-year-old Richard Grimshaw were driving on Interstate 15 near San Bernardino, California when the Pinto suddenly stalled and coasted to a halt in the middle lane. A1962 Ford Galaxie rear-ended the Pinto, rupturing the Pinto's gas tank against its differential housing, and spraying fuel throughout the passenger compartment. The fuel ignited and both passengers were terribly burned. Mrs. Gray died within days of congestive heart failure from the burns, while Grimshaw survived with permanent disfigurement and handicaps. The trial revealed that the highest level of Ford's management knew that this specific design flaw in the Pinto could be remedied at a cost of less than $10 per vehicle, but management proceeded with production without remediation because the likely losses to the company 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 US automobile insurance companies became aggressive lobbyists for regulations that would impose safety standards on new automobile manufacturing, and the OEMs began to take passenger safety more seriously. Information technology began to play an important role in safety through automatic braking systems that reduced skidding, deceleration-detecting air bag systems for supplementary restraint in the event of a crash, and various kinds of 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. However, as with the case of emission controls, the rise of automobile-related record keeping systems would prove to have one of the most important effects on passenger safety, as will be discussed below.

Entertainment, Conviviality, Communications and Control

At least some aspects of driving an automobile were considered a kind of entertainment from the start. “Sporting” models were produced as soon as the large sedans, 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 on the automobile began to evolve not only as an entertaining vehicle to drive or ride in, but as a platform for entertainment while underway. In the early 1960s Earl Muntz adapted the continuous loop four-track magnetic tape cartridge invented by George Eash and began aggressively marketing it as an after-market 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. The eight-track format was quickly adopted by recording companies that began to sell prerecorded cartridges. 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.

Media transport was only one aspect of the growth of the entertainment dimension of automobiles. Custom stereo and surround-sound systems were popular in the aftermarket throughout the 1970s and 1980s, and the OEMs began to recognize the profit potential. By the late 1980s the OEMs were beginning to incorporate sophisticated sound systems as options in their models, and in a major departure, listed the brand names of the suppliers of the systems as a key selling point. This was an important development because the explicit incorporation of equipment from up-market audio companies such as Infinity, JBL and Bose signaled a direct connection between the traditional home entertainment market these companies had served and the environment of the automobile. This occurred, as well, during a period when an increasing number of people were leaving the cities for the suburbs, increasing their commuting times in their automobiles, and thus creating a growing amount of time during each day for listening to music or the radio while driving. The compact cassette had ushered in an era in which people could record music from their home entertainment systems and play it in their cars, and the era of the audio CD and, especially, the digital MP3, has accelerated the trend. In many ways the automobile has become an extension of the home-based entertainment zone, and that trend is continuing with the addition of flat-screen LCD displays and DVD players that allow passengers to watch recorded television or cinema content in the car.

Another dimension of automobile-based entertainment is voice communication. The first radiotelephones were installed in automobiles in the 1940s, but were used mainly for business purposes. The advent of casual telephone use in automobiles emerged as part of the rise of analog cellular telephony in the mid-1980s and accelerated after the introduction of digital cellular in the early 1990s. The first cellular telephones were, in fact, explicitly designed for automobile use. The high demands for power 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 telephone (and its user) from connection to the automobile, but also introduced entirely new problems and possibilities. Handheld cellular telephones could be conveniently plugged into “hands free” systems to allow use while driving, though many drivers chose to simply talk on the phones as though they had nothing else to do. Use of a cellular telephone not on a “hands free” system while driving has been prohibited in some locales, and studies of accident incidence have shown that many accidents can be traced to driver distraction while talking on the phone. At the same time, the growing functionality of digital cellular communications enables the possibility of incorporating the personal cellular telephone as a key item in the automobile platform.

Digital cellular telephony has already been incorporated into automobile platforms through such services as OnStar, the GM service that comes packaged with Cadillac automobiles to provide for roadside assistance and other needs. The success of OnStar as conceived is debatable, but the idea behind it is important because it envisions the automobile as an *addressable device in a wireless communications network.* There is considerable speculation that traditional telephony, which is now largely digital rather than analog, will move to a new paradigm called “voice over Internet Protocol,” or VOIP, that uses the packet-switched concept of the Internet to replace the circuit-switched concept of the traditional telephone system. In the VOIP model a cellular telephone is basically an internet terminal, capable of carrying not only voice service but any other kind of service possible over the Internet. In addition, technologies such as Global Positioning Satellite sensing or base-station triangulation make it possible for cellular telephone devices to provide for pinpoint geographic location. Whether embedded in an automobile’s electronics or “plugged into” the automobile’s electronics by the operator inserting a personal cellphone in a slot, digital cellular telephony can become a tool by which every vehicle on the road becomes part of a huge network capable of providing communications and entertainment in ways never before imagined.

Information technology is at the heart of the recent advances in communications and entertainment technologies in automobiles, but not merely because of digital processors embedded in sound systems, navigation systems and so on. The truly remarkable change now underway is the likelihood that every new automobile will become an addressable node in a global communications network. Combined with technologies such as geographic location, automobile performance monitoring, operator behavior, and time monitoring it is easy to imagine the evolution of previously impossible services such as real-time dynamic insurance pricing. In this model, the vehicle would keep track of where it is driven by time of day, as well as all stops and other actions taken with the vehicle. An owner could contract with an insurance company that would provide coverage and charge premiums as a joint function of the actuarially established likelihood of suffering accident or other loss as a function of place and time, and the way the vehicle is being operated at the time. The potential for surveillance is obvious with such technology, 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 of their automobile. Such technology also has important implications for managing other kinds of risk, including monitoring the whereabouts of individuals under court-ordered corrections such as house arrest or activity constraints. Again, some of these implications figure into the broader ecology of records systems discussed earlier.

Expediting and Coordinating Production and Distribution

A great deal of recent research on information technology in the automobile industry has focused on production and distribution of new vehicles and remarketing of used vehicles. This is an appropriate focus of work, given the important strides made in recent years. It is also useful to recognize the long history of organizational innovation in the automobile industry since it started. As mentioned earlier, the development of production engineering and large-scale vertical integration of production at the Ford Motor Company in the first two decades of the 20th century was a watershed in the history of enterprise. This was followed by Walter Chrysler’s innovations in non-vertical integration through exploiting the independent parts supplier industry to create an OEM that bought rather than made a large fraction of the content of its products. Alfred Sloan in the 1920’s and 1930’s developed the so-called M-form organization, the multi-division strategy that maintained uniform production of core components such as chassis and electrics dedicated divisions such as Fisher Body and AC Delco, but decentralized design, motors, and marketing to the brands across the spectrum of price points, from Chevrolet to Cadillac. The M-form organization became the paradigmatic industrial organization form 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 1960’s and 1970’s before the company finally fell apart. This list includes only US OEMs; there were vitally important contributions by the OEMs of Sweden, France, Germany, Italy, Britain and Japan, as well.

Of particular importance to the discussion of information technology’s role in transformation is the Japanese OEM development of techniques for quality assurance and lean manufacturing. The two hallmarks of these developments are the evolution of a particular supplier-OEM relationship and the use of an innovative information management process called the kanban system for coordinating production. The supplier-OEM tradition in Japanese automobile manufacturing arose from the period after WW II in which Japan struggled to rebuild its shattered industries with a depleted workforce and a dramatically changed social structure imposed by the occupying forces. A key part of the rebuilding process 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 for production. This cooperative strategy extended to the relationships between suppliers and OEMs, in which 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 kanban system enabled the Just-in-Time inventory control strategy that eventually caught on among the global OEMs. The Japanese automobile industry established itself as the producer of high quality, reliable cars that could be sold at the low price end of export markets in the US and Europe. In addition, Japanese technical innovation demonstrated that it was possible to do some things that the more established automobile industries in other countries did not believe possible, as with the Honda CVCC engine example above.

As Japan's post-war automobile industry was developing its strengths, the US industry was pursuing strategies that were more dependent on new information technologies, especially digital computers and process control devices. The breakthroughs of importance in this era were the advent of numerical computer-controlled machine tools that could be programmed to machine specific shapes with great precision and rapid throughput; the development of computer-aided design tools and, soon thereafter, analysis tools that allowed designs to be tested through finite element analysis and other techniques before they were actually fabricated; and the construction of computer-based modeling of the production process to facilitate materials requirement planning. The NCM technologies were originally developed as part of the US Cold War defense buildup for use in the aerospace industry, but soon migrated to other industries such as automobiles. The main advantage of the technology was the ability to program robotic tools to execute complex tasks on a repetitive basis, and this eventually spread beyond machine tools into such tasks as automobile body painting, glass handling, and other tasks that required a high degree of accuracy and 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.

CAD tools also grew out of the aerospace industry, and quickly spread to many other industries. Initially, these tools were mainly used to automate the old manual drafting process, but they began to have much more important utility as the analytical capacity of mathematical modeling was introduced. 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 on the part to determine whether it would meet performance expectations. This dramatically reduced the amount of experimental engineering required to create effective components, and in time was extended to modules and to vehicles as a whole. The modeling tools for materials requirement planning, known as MRP, emerged from the need to get better control over inventory and inbound and outbound logistics. In a way, it was the US OEM answer to the Japanese kanban strategy. In time, the early MRP systems were expanded to incorporate a broader array of manufacturing resources, and eventually to embrace the enterprise as a whole through Enterprise Resource Planning, or ERP.

None of these developments in IT application produced the striking results of the Japanese revolution in quality assurance and lean manufacturing, but the marginal and accretionary effects of these innovations have been important. Automobile production on a world-wide basis is far more efficient than in the past, and the character of the product in terms of initial build quality, reliability, and longevity improved greatly. This was partly due to major improvements in materials technology in plastics, coatings, lubricants, and so on, but ultimately, it was due mainly to advancing knowledge about what the market needed and how to build it. Amazingly, it is actually difficult to buy a new automobile of poor quality these days.

Perhaps the most enthusiastically discussed areas of IT application to the automobile industry in recent years have been in supply chain intermediation and in marketing and distribution. Individual OEMs have constructed their own IT-based coordination mechanisms for supply chains over the years, many of which are variants of the value-added network applications from the 1970's such as electronic data interchange. These systems linked suppliers to OEMs and facilitated the documentation of order entry and fulfillment. This concept has been expanded greatly by the idea of the on-line market intermediary that matches supplier capabilities and OEM needs through auctions or other mechanisms. The most spectacular example of this is Covisint, a Michigan company created by the "big 3" US OEMs (GM, Ford, Daimler-Chrysler) and a number of major suppliers. The idea behind Covisint is to create a marketplace for auctions in which demand and supply can be matched, and to develop tools whereby collaboration between suppliers and OEMs on design and production can take place. Covisint launched with great fanfare in December of 2000, riding the crest of the dot.com wave. It was hoped that the exchange would revolutionize the supply chain, driving down prices and improving coordination among suppliers and OEMs. The results have been disappointing thus far. Although Covisint survived the fall of the dot.com world, it has consistently failed to achieve its goal of becoming a market clearing mechanism for high value-added parts such as major components and subsystems. There have been many successful auctions through Covisint, but the majority have been for commodity parts such as fasteners. Moreover, there is little evidence thus far that the experiment has changed the operation of the supply chain.

The application of IT to marketing and distribution has taken a number of directions, but most of the efforts can be summarized as one of two basic ideas. The first is provision of purchase-relevant information, in which a web site provides prospective buyers with product characteristic and price information that should be useful in selecting a vehicle and negotiating a good price for it. Such services have been around in print form for a long time. The Kelley Blue Book of automobile prices was first published in 1926, and automobile magazines containing new car reviews are as old as the industry. Extending these publications to the World Wide Web was not difficult. The more important contribution of the new services is their ability to allow users to do close comparisons of features and prices of specific models, and to find a large amount of information on any given model quickly. The general view among the marketing and distribution experts in the automobile industry 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. At one point there was much speculation about whether the OEMs could begin selling automobiles directly to customers using the World Wide Web, but this is not possible for legal and other reasons. Most US states forbid the direct sale of automobiles from OEMs to customers, and in any case, the dealers provide important services in new car purchases that OEMs would have difficulty providing. The services that have emerged have demonstrated that the right kinds of services available on the World Wide 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 place possible customers in touch with dealers of a wide variety of automobiles. Others such as ForeDirect.com are a joint effort of OEMs and dealers to steer customers to the purchase of a particular OEMs products. And still others such as AutoNation.com are basically the Web storefronts of large dealer companies. The effect of these kinds of services on actual marketing and distribution outcomes seems to be less significant thus far than the effect of the pre-purchase information provision services. Still, there is considerable evidence to suggest that customers seeking new automobiles are increasingly turning to the network for key parts of their purchasing activities, and it is expected that this area of application will become more important in the future.

Manufacturer-Customer Relationship Construction and Maintenance

There has always been a peculiar relationship between automobile manufacturers and customers. Few mass produced products inspire the 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 (e.g., American Motors) goes out of business or is purchased by a foreign OEM (e.g., BMW's acquisition of Rolls-Royce). Still, this kind of relationship between manufacturer and customer was at best indirect and psychological. It might have been important for the manufacturer in its efforts to persuade purchasers of its current cars to be repeat customers, but it did not attach to specific vehicles owned by specific customers, especially after warranty expiration and used car resale. With one exception, the only residual relationship between the manufacturer and customers as time went on was the replacement parts market. The exception was financing.

The Commercial Investment Trust Company partnered with Studebaker to create the first automobile financing program in the US in 1915. From there, a number of OEMs developed their own financing subsidiaries, some of which grown to be among the largest financial companies in the world. Financing new automobile purchases connected the OEMs to their customers in important ways, incorporating into the company's records systems customer employment, income, and other information that would never have been collected in a straight sales transaction. Although there was relatively little interaction between the manufacturing and marketing arms of the OEMs and their financial subsidiaries with respect to this information, the financial subsidiaries were creating within the OEMs the skills in large-scale records systems that would prove important later. Among other things, financial systems had to be tied to governmental registration systems such as automobile licensing. The collateral for the loan was the vehicle itself, and the financing company's rights of ownership had to be recorded with the government to enable recovery in the event of loan default. Thus, the OEMs began to develop inter-organizational information systems involving government regulatory agencies. Interestingly, OEMs did not engage in provision of automobile insurance. A few OEMs have experimented with offering insurance to purchasers of their automobiles, but the practice has never caught on. Insurance requires even more extensive information about individuals than financing, including government-kept data on operator licensing and driving behavior (e.g., chargeable violations and accidents). Nevertheless, over time the records systems involving financing, insurance, property and operators did co-evolve and become intertwined, and to a growing degree, interoperable.

Financing has also evolved in subtle but important ways that are likely to be significant in the future of the industry. One of these is the rise of automobile leasing as an alternative to outright purchase. The reasons for the rise of leasing are complex and beyond the scope of this paper, but they are largely institutional in origin, especially with respect to taxation rules that make it more economical to lease than to own in certain situations. The fortunes of OEM-based automobile leasing (i.e., where the OEM leases the vehicle to the user) have waxed and waned for various reasons, not the least being OEM lack of expertise on running large leasing programs. The important fact of automobile leasing is that 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. The user never really owns the vehicle, and thus cannot walk away from the relationship with the OEM without relinquishing the vehicle. In the traditional sales model, the buyer could disregard the OEM altogether once the warranty was ended – in fact, the OEM did not want to hear form the buyer after that point. Similarly, as long as 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 new car purchases. As noted earlier, however, the automobile market considered broadly is decreasingly a matter of new car sales, and dealers as well as OEMs are trying to garner a larger share of the action in what used to be the after-market. Leasing contributes to that trend, because the user bringing in a vehicle coming off lease is both looking for a replacement vehicle and returning the used vehicle to the OEM and dealer inventory. Even if leased autos only account for a fraction of total new vehicle transactions, the OEMs and dealers must develop complete protocols for handling lease transactions. They must build the capacity to treat all vehicle transactions as though they were leases, even though not all transactions are leases.

This becomes significant when added to the fact that the relationship between OEMs, dealers, and vehicle buyers has changed dramatically in the past few decades. The main causes of this change are the aforementioned increase in the service life of automobiles together with a major change in warranty structures. New vehicle warranties were introduced very early to induce customers and 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 new car warranty in the US market was 12 months or 12,000 miles, whichever came first. That has remained the standard warranty in the European market until recently. It is now difficult to find new car warranties in the US shorter than 36 months or 36,000 miles, and competition has made warranties a major factor in marketing. Hyundai Motor Company's recent introduction of a standard 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 conditional "power train" clause is important here, because it denotes that different aspects of an automobile might be handled differently under each warranty structure. Consumables such as fuel, lubricants, tires, batteries, and light bulbs were almost never covered by new car warranties, and still are not. Similarly, damage was not covered by warranty, but by insurance. The warranty declared only what the OEM determined to be its responsibility. The interesting thing about the increasing standard warranty is its explicit recognition that the OEM is accepting more responsibility for the vehicle after sale.

In fact, US OEMs have been forced to accept a very large increase in responsibility for the after-sale lives of automobiles they produce. Recall the discussion earlier about the federally mandated warranty of five years or 50,000 miles on the emissions-related components of automobiles sold in the US. This, in effect, required manufacturers to assume liability for mechanical systems failures of a large part of the vehicle's value for a long period of time into the future. Given that 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 emissions-control warranty concept 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 (e.g., Mercedes Benz) were able to stay with somewhat shorter standard warranties because the consumer public knew those companies' reputations for quality and reliability. The rise in the standard warranty on new automobiles was also accompanied by the advent of the purchaser-bought "extended warranty" that, for a significant additional fee paid upon purchase of the vehicle, added years and miles to the warranty program. In the space of just two decades, the effective warranties on the majority of new cars sold in the U.S. exceeded seven years and 70,000 miles.

The rise of new warranty structures has had a remarkable effect on the relationships between OEMs, dealers, and automobile owners. Extended warranties were usually not structured as standard warranties. They are, in essence, automobile health insurance contracts, and the financial paper held on those warranties was usually held by a financial firm and not by an OEM. The financial firms' return on these is generated exactly the same way returns are generated on health insurance: through actuarial analysis of the likely benefits to be paid out over the life of the policy, and establishment of premiums that will cover those costs and return a profit. The agency relationships between vehicle 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 directly for repairs. Dealers, for their part, provided service mainly to honor warranty obligations, and to maintain contact with buyers who bought new cars frequently. Dealers did not 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 independent service market was there for older vehicles, and the dealers were happy to see the older vehicles go there. OEMs cared only about reimbursing dealers for warranty service. The situation today is very different. Improved customer information on new automobile characteristics and pricing make it much 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 in service. The owner of the vehicle has, in effect, "prepaid" the cost of the repair through the warranty, and does not need to haggle over the price of the 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 of arbitrage to conduct service in a way that produces substantial profits. In many cases, dealers make substantial profits from selling extended warranties themselves, and are thus in a good position to offer lucrative sweeteners to purchasers of new cars such as forgiveness of repair deductibles if the purchaser brings the vehicle to the dealer for all service needs. In this way, new car dealers and OEMs that traditionally concentrated only on new automobile manufacture and sale, and then virtually eliminated their contacts with purchasers until the next new car purchase, 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 the problem of passenger safety. The 1972 Ford Pinto incident discussed earlier was a turning point in the history of the automobile industry. It established the precedent that the OEM carried liability for product design as well as for product build quality. This was a vital distinction, with tremendous implications. The concept of OEM responsibility for build quality was already well established, as suggested by the new car warranty. The OEM would take care of any problems directly attributable to the manufacturing process under warranty, and it was assumed that normal operations during warranty would reveal such problems. Even when a defect tied to manufacturing resulted in a significant loss (e.g., brake failure due to a defective master cylinder), the liability was linked only to that particular instance, and most important, there was no assumption that the manufacturer had any way of knowing that the event might occur as it did. Design liability, on the other hand, creates responsibility for the entire class of losses that might occur as a result of the defect, and opens the manufacturer up to much more serious liability if it can be demonstrated if the manufacturer should have known, or even worse did know, about the defect. The Pinto judgment established design liability for automobiles of a kind never before seen. In the years following, statute and case law refined the parameters of this liability with far-reaching implications.

On the surface, it would appear 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 design for safety has become a major substantive concern as well as a marketing claim backed up by government-sanctioned tests involving crash dummies and other photogenic paraphernalia. The deeper story of design liability, however, lies in residual liability when good faith design efforts are insufficient. No complex artifact like an automobile can be designed to be perfect on any characteristc, and every vehicle on the road is "unsafe" in some sense of the term. 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 that is 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 US automobile industry. Manufacturers become aware of safety-related defects in design and issue recalls to owners of the specific vehicles in question. 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 will be repaired at the manufacturer's expense even though the vehicle is altogether 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.

The central part of this story from the perspective of information technology comes back to the rise of automobile-related record keeping. Record keeping never evolved for the purpose of executing product recalls for vehicle emissions or safety problems. It evolved for the purposes described earlier: property registration, operator regulation, tax collection, financing, and insurance. Nevertheless, the records systems created for those purposes enabled the recall structures seen today. Without extensive record keeping that ties specific vehicles to specific owners at specific geographical addresses it would not be possible to issue good-faith notification of recall. A manufacturer issuing a recall is not required to fix every vehicle with the defect. For one thing, some of them have been destroyed already, and others have been transferred out of the recall jurisdiction (e.g., out of the country). The manufacturer has to make a "good faith effort" to fix every vehicle still in operation within the jurisdiction, and the only practical way to do this is to notify everyone who owns such a vehicle, regardless of how many times ownership has changed hands since original sale. The records systems that evolved over the decades enable this notification, and the expectations of good faith now require that manufacturer exploit every available means for notification. The combination of the records systems, the rise of long-term warranty structures, and the changing character of product design liability and performance mandates on emissions have come together in a way that fundamentally alters the relationship between the OEMs and automobile users. That relationship, which was once limited to a new car warranty and, sometimes, a financing contract, has expanded to include Nth hand owners who might never have purchased a new car. Moreover, the relationship is not merely between the OEMs and automobile users, but among a constellation of players including the OEMs, users, dealers, financing companies, insurance companies, and government agencies such as motor vehicle departments.

IT and Enterprise Transformation

The essential argument of this paper is that information technology can be implicated as a profoundly important force in the transformation of the automobile industry, but the process of transformation is far more subtle and complicated than the rhetoric about the Internet and the World Wide Web would suggest. In fact, the only clear change of importance for the industry based on the Internet and the World Wide Web has been the rise in information access for automobile purchasers on product characteristics and pricing, which has accelerated the erosion of the traditional advantage in information asymmetry held by dealers over buyers. The other large experiments, from changing the supply chain (e.g., Covisint) to revolutionizing sales (e.g., Auto-by-Tel) have thus far proved to be far less significant than their proponents hoped. The most important impacts of information technology in this transformation have been deep in the infrastructure of the vehicles themselves (e.g., emissions control, safety, entertainment), and in the records systems that have fundamentally important in altering the relationship between OEMs, dealers, automobile users, and other actors in the automobile realm. It is not surprising that this kind of change is difficult to see. A key characteristic of infrastructure is that it becomes deeply embedded and routine, and in fact, only becomes visible on breakdown. It is so familiar that it escapes notice. But it is important, and in many cases, it is the most important factor in any assessment of socio-technical change.

The significance of the transformation underway is striking. Perhaps the most intriguing observation is that the logical consequence of the trends described in this paper is the eventual transformation of the automobile industry from its old role as a product industry into what is essentially a service industry. Naturally, this does not mean that there would be no “product” in the industry: the heart of the business is the automobile itself, after all. Instead, the key shift is in the classification of what is considered to be essential to the industry when it is defined broadly as the enterprise of providing personal rapid transit for individuals and households. In this definition, the important change would be away from individual ownership of automobiles in the traditional sense of the term, and toward a kind of rental model.

There are several reasons to argue that such change might occur. The deepest and most intractable arises from the changes over the past three decades, during which major externalities arising from automobile use have been captured and forced back on OEMs for internalization. Long gone are the days when the OEMs could manufacture and sell automobiles with no thought to air pollution or passenger safety hazards that accompanied their products. The trend in recent years has been to add to the OEMs responsibility for such externalities. One striking example is the European Union's adoption of rules requiring that OEMs be the residual claimants for waste disposal on the automobiles they manufacture. With this rule, the OEM's responsibility goes full circle in the life-cycle: from initial manufacture to recycling and waste disposal. In time, it is easy to imagine that OEMs will be unable to deflect liability for any number of serious externalities arising from automobile use. At the same time, the OEMs are recognizing the dramatic growth in the population of used automobiles relative to new automobiles, and are seeking to participate more in the value-added activities of that used market. The question inevitably arises, then: why would an OEM that cannot avoid liability through the life cycle of its products, and that wants to capture more value from that life cycle, ever sell the asset in the first place?

It is easy to come up with a multitude of practical answers to that question, but it is important to note that they are only *practical*: there is no sound reason *in principle* why the automobile industry as we now know it will not shift away from ownership to a rental model. In fact, there is a strong economic argument to suggest that the rental model would make sense, and there is mounting evidence from the changes already underway in warranty and service structures and leasing options to show that is feasible. The main impediments to this shift are a lack of experience with the details of making it work and the predictable risks of incumbent interests that benefit from the current arrangement and would probably not benefit from a new arrangement. Granted, these are not trivial impediments. They might in fact prove insurmountable. The value of raising the possibility is in illustrating the possible magnitude of the transformation now underway as a result, at least in part, of the incorporation of information technology into the automobile realm. Stranger things have happened already in the automobile world, not the least of which was the transformation of the industry itself from one of craft production to mass production, with its enormous implications for many aspects of human welfare.

In the mean time, while waiting for the transformation from product to service, there are two other important but less spectacular changes that deserve discussion. One is the implications from growing vehicle service life in light of unclearly limited design liability and warranty obligations. No machine lasts forever, so the problem is bounded. Still, there is a big difference between automobiles whose effective service lives are 25 years vs. 10 years.   This becomes a more salient matter given the discussions underway regarding the so-called modular vehicle platform concept. In this design, an automobile consists of an expensive platform that contains the major motive and control systems of the vehicle, and any of several interchangeable body components that allow the vehicle to be reconfigured at the will of the user 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. In this model, the customer would buy the platform on a long-term loan (perhaps 15 to 20 years) and reconfigure the vehicle's other parts as necessary over time. There is no question that the required records systems already enable such long-term ownership strategies. There also will be a great deal of information technology involved design, manufacture, and operation of such vehicles. In addition, it is worth noting that such a scheme lends itself to the idea of a ubiquitous rental market for vehicles, as discussed above. But this scenario has its problems, not the least of which it presumes a serious slowdown in technological progress. A useful analog is the personal computer market, in which the sale of new computers is not based on the failure of older computers to perform as designed, but rather the result of price-performance obsolescence. The newer computers are so much cheaper and better that it does not make sense to hang on to older computers, even though they work just fine. Regardless of whether this scenario for long-lived products evolves, there remains the fact that service life is rising and that the world is inheriting a growing base of legacy vehicles with uncertain mechanisms for remediation of externalities. The US has already created a system whereby the OEMs effectively are responsible for emissions control and passenger safety standards 10 years after manufacture, but who will play this role for vehicles 20 years after manufacture?

A different but somewhat related question is the likely rise in cross-border markets in automobiles. For the last half century the main focus of the international dimension of the automobile industry has been new car assembly and sales. This subject has been complicated in its own right, with institutional entanglements over issues such as compliance with regulatory standards, content expectations, and provision of adequate service infrastructure. In contrast, the traffic in used automobiles across borders has been much less significant and, where it occurs, it has developed its own cultural signature. When used vehicles move across country boundaries, they often move from “higher” to “lower” in socio-economic terms. Vehicles that no longer pass the strict German safety inspections, but that still have years of usable service, are sold across borders into countries that have lower regulatory constraints and, usually, lower standards of living. A similar phenomenon occurs between the United States and Mexico. This pattern is already being upset by the emergence and expansion of the European Union, which normalizes regulations and lowers barriers of trade across borders. It also is likely to be affected by the growth in information services that facilitate cross-border markets for used automobile sales, and the interoperability of government records systems that facilitate ownership transfers. Finally, the globalization of the OEMs and large suppliers through mergers and acquisitions increases the likelihood that the supply chains necessary to support such trade will be provided. The opening of truly international markets in used cars would bring changes not heretofore seen in the automobile industry.

Conclusion

The story of information technology in enterprise transformation in the automobile industry is one of slow, infrastructural, accretionary change that produces powerful cumulative effects. The contemporary developments in the Internet and the World Wide Web might very well, in time, produce such changes. To this point, they have not yet done so, and it is difficult to predict whether or how they will. The history of the automobile industry has from the start been one of complementary use of information technology. This was true long before the era of digital computers or even electronic unit record equipment: in fact, it begins not long after the invention of the Hollerith card sorting technology that gave birth to the modern computer age. The automobile industry co-evolved with modern information technology, and in myriad ways, incorporated that technology as it grew. The full effects of such evolution are difficult to spot because they take a long time and so much of what is important becomes infrastructural and invisible. That is the reason why a broader view of enterprise transformation is necessary to understand the effects of a class of technologies as broad as information technology on an industry as large, diverse, and complex as the automobile industry.