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Forging New Corporate Alliances between the Auto Industry and the Electronic Device and Component Industry:
Opportunities and Challenges for the Electronic Device and Component Industry in Automotive Electronics

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Economic and Industrial Research Department
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Forging New Corporate Alliances between the Auto Industry and the Electronic Device and Component Industry: Opportunities and Challenges for the Electronic Device and Component Industry in Automotive Electronics

Summary

1. Auto electronics are making inroads in three central areas: (1) control systems, such as power train and steering systems and antilock braking systems (ABS); (2) structural systems, such as air-conditioning, gauges, and airbags; and (3) communication and entertainment systems, which include car navigation units and in-car local area networks (LAN). Electrical and electronic auto parts already account for a significant share of all auto parts; in Japan, electronic-related parts are worth an estimated ¥6.7 trillion — approximately 35 percent of the value of all shipped auto parts. Automobiles are expected to employ even more electronics in the coming years as electronics technology plays a commanding role in addressing environmental issues as well as public demand for greater automotive safety and comfort. The growth of auto electronics will also be driven by wide-scale deployment of controls that integrate pre-crash safety and intelligent transport systems (ITS).

2. The procurement base for electronic parts and materials has been broadening as electronics continue to contribute more to a car's value. Collaborations with electronic device and component manufacturers are expected to increase because of the rising number of technical problems that automakers cannot resolve on their own, such as improving battery performance or efficiently developing embedded software. The electronic device and component industry is pouring an increasing amount of R&D resources into the auto sector; the percentage of the industry's total R&D spending devoted to the auto sector jumped from 4.1 percent in 1999 to 7.3 percent in 2006. On the other hand, the electronic device and component industry has found the auto sector a difficult one to crack. Automakers place much more stringent requirements on their suppliers — in terms of quality, reliability, and supply responsibilities — than the consumer electronics industry does. Nevertheless, the time is probably ripe for the electronic device and component industry to reconsider how it might bring together knowledge, and build win-win alliances, to overcome the divergent business practices resulting from the auto industry's position as a bridge sector spanning several industries.

3. Semiconductors are the central component in automotive electronic controls. Automotive applications for semiconductors occupy a 7.1 percent share, worth 18.6 billion dollars in 2006, of the global semiconductor market. The automotive semiconductor market is projected to see an average annual growth of 7.8 percent over the five-year period between 2006 and 2011, which will outstrip the average growth of the semiconductor market overall (an estimated 4.8 percent per year over the same period). Some electrical/electronic architecture manufacturers produce automotive semiconductors on their own, but they appear to hope that semiconductor producers will tackle fields in which they are not involved or which are too complex for a single company to develop. What electronic device and component manufacturers need to do is to identify which areas the competitive products they offer are best suited for — drive-train systems (such as batteries), comfort and safety systems (sensors, cameras, etc.), or information systems (car navigation units, ITS, etc.). Beyond this, if electronic device and component makers can move past just being supplementary part suppliers and combine cost competitiveness with new concepts, they will likely be able to deepen their relationships as partners with automakers and electrical/electronic architecture venders. This requires firms to leverage their broad semiconductor and electronic component product lines and put know-how and design assets accumulated from consumer electronics to good effect in

automotive applications.

4. The transformations brought on by advances in electronics to the corporate alliances in the auto-parts industry can be considered from five viewpoints: (1) the replacement of mechanical systems with electronic controls, (2) the move to electric-powered cars, (3) the progression of integrated LAN-based controls and establishment of next-generation communication standards, (4) the increasing efficiency of automotive software development, and (5) the advancement of multimedia and audio/video functions centered on in-car information terminals. Of the various corporate alliances, most automaker and electronic parts supplier tie-ups involving lithium-ion batteries — the heart of electric-powered vehicles — comprise joint development and, in some cases, even include capital investments. From the perspective of the electronic device and component industry, securing stable buyers is essential in mitigating the risks associated with the prior investment needed to develop next-generation vehicles. The ideal situation for these firms is to develop products in cooperation with a specific automaker, then to expand business horizontally to other clients. Complicating this ideal, however, is the fact that joint-venture contracts are likely to contain clauses restricting horizontal expansion. And partners, having developed products intended to differentiate their brand in the marketplace, have little desire for those products to be sold early on to other companies. How firms weigh the pros and cons of building partnerships, based on forecasts of shipment volumes and technical synergies, is thought to contribute to the differences found in corporate alliances in the lithium-ion battery business.

5. The move to increasingly integrate and coordinate electronic controls in cars is causing the burden of developing software embedded in electronic control units (ECU) to soar. The quality of in-car software has a profound impact on technologies that aim to add more value to automobiles, namely through better fuel economy performance and safety. Consequently, new corporate alliances are being sought that can erect frameworks permitting efficient software development. The auto industry is considering an approach whereby it would standardize software in the platform field and leave the application field to individual firms, which would try to differentiate their products' functions. The movement to standardize ECUs, which previously were developed individually for each application, and integrate key ECUs can be regarded as a new offshoot of the modularization trend. In the near future, auto-parts makers may well be "tripolarized" into three separate camps: (1) those with the development capacity to integrate entire systems, including platforms, (2) those that develop applications and mechanical subassemblies based on established platforms and specifications, and (3) those that specialize in mechanical development and do not get directly involved with ECU development. The mechanical specialists in this third group face the greatest threat from deteriorating business conditions. They must leverage their mechanical control expertise, proactively build their own partnerships with electronic component and device makers, and regain the initiative in system integration and cost controls.

6. It is becoming increasingly common for companies in the electronic component and device industry to sell their device-control expertise to other firms; soon, firms will probably be able to create at least commodity-level products simply by assembling inexpensive parts procured from sources around the world. The distributed business model is becoming more persuasive, not only at the end-product level but also at the level of semiconductors, where control expertise is embedded. Circumstances in the auto industry, however, are different. The functions of cars are realized through the integration of tens of thousands of parts, which requires the special expertise of the automaker. Thus, automakers are expected to remain the central players in upstream areas, such as overall system design based on automotive-control know-how. Full adoption of fabless-foundry models is seen to be difficult, at best, in semiconductors as well, since the required quality and reliability levels are far higher than those for consumer electronics. What is considered more likely are takeovers by electronic device and component makers of Tier 1 auto-parts producers. Corporate alliances could also be altered by advances in digital controls,

brought about by technical innovation in automobiles and fundamentally different from the knowledge capital automakers possess. Electric cars, heralded as the future incarnation of the passenger vehicle, may have the potential to revolutionize automotive systems.

7. Other than in China, future auto-sales showdowns are expected to take place in India, the Middle East, Africa, and other developing regions. Competition between global automakers over the development of low-cost cars is intensifying. Yet it is no easy matter to develop cars in the ¥300,000 to ¥500,000 range and maintain quality and a brand image; even the lowest priced cars must perform well enough to meet environmental and safety standards. To produce cars this cheaply priced, makers are thought to keep tight control over costs apportioned to parts and materials; this means that electrical components, which have to satisfy legal requirements, are kept to a bare minimum. Thus, in an environment of razor-thin profit margins, it is important that makers of electrical/electronic architecture earn by selling in volume. They must expand sales by diversifying their customer base and work to slash costs by changing materials, reducing the amounts of materials used, and improving production processes. High prices greatly reduce the percentage of cars in developing countries that are equipped with safety accessories such as ABS or airbags, or options such as air conditioners, music systems, or car navigation units. Yet there are definite latent needs for increased safety and comfort. The first electrical/electronic architecture manufacturers that can drastically cut their production costs from today's levels will have an enormous market waiting for them. Japanese makers are expected to tackle this challenge head on.

[M. Shimizu (E-mail: report@dbj.go.jp)]

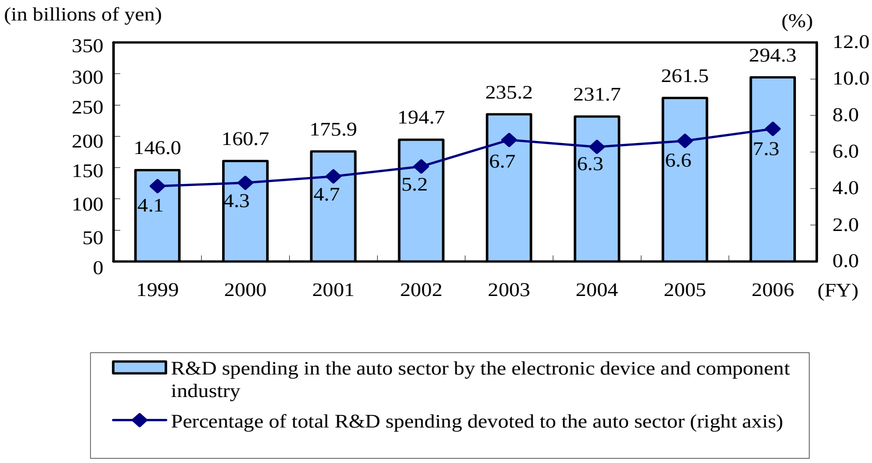
Introduction

The procurement base for electronic parts and materials is broadening as automobiles rely increasingly on electronics. Greater collaboration with electronic device and component manufacturers is expected because of the rising number of technical issues that automakers cannot resolve on their own, such as improving battery performance or efficiently developing embedded software. Statistics show that the electronic device and component industry is pouring an increasing amount of R&D resources into the auto sector; the percentage of the industry's total R&D spending devoted to the auto sector jumped from 4.1 percent in 1999 to 7.3 percent in 2006. Total R&D spending rose by an average of 1.9 percent per annum over this same period, but auto-sector spending was much faster at 10.5 percent (Figure 1).

On the other hand, the existence of numerous entry barriers has made the auto sector a difficult one for the electronic device and component industry to crack. Nevertheless, the time is probably ripe for the electronic device and component industry to reconsider how it might bring together knowledge, and build win-win alliances, to overcome divergent commercial practices resulting from the auto sector's position as a bridge sector spanning several industries.

In this paper, after analyzing how the growing use of auto electronics is changing conventional corporate alliances and business environments in the auto-parts industry and considering new opportunities and challenges for the electronic device and component industry, we propose a number of policies by which these industries can build deeper cross-industry partnerships.[1]

Figure 1. Transitions in Auto-Sector R&D Spending by the Electronic Device and Component Industry



Source: "Reports on the Survey of Research and Development," Ministry of Internal Affairs and Communications.

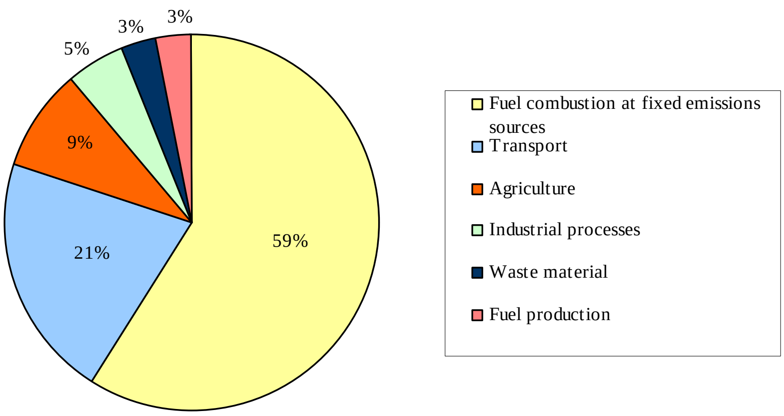
[1] This paper revises and expands upon Chapter 2 of "Current Conditions and Future Directions of Electronics in the Automotive Industry" (a 2006 subsidized research and study project) and Chapter 3 of "Study on Changes to the Business Environment and Corporate Alliances in Auto Parts and Related Issues" (a 2007 subsidized research and study project). Both are published by the Economic Research Institute of the Japan Society for the Promotion of Machine Industry.

I The Growing Importance of Car Electronics

The City of London announced in February 2008 that it would be introducing a series of graduated charges of up to 25 pounds a day (approximately ¥5,100) on high CO_2 emitting vehicles entering the city limits. The maximum levy will apply to the Range Rover and other four-wheel-drive vehicles and sports cars such as the Porsche 911. Commuting to the city in one of these vehicles 20 days a month, for example, would cost upward of ¥100,000. On the other hand, vehicles with low CO_2 emissions will be exempt from the charges; thus, drivers of the Toyota Prius, the Honda Civic Hybrid, and other similar cars will not be affected by the new charges.[2] The City of London has set a target of reducing greenhouse gas emissions by 60 percent from 1990 levels by the year 2025. This scheme will both reduce car congestion in the city and encourage the use of low CO_2 emitting vehicles.

The transport sector continues to emit into the atmosphere an increasing amount of greenhouse gases, which are one cause of global warming; more vehicles are on the road and these vehicles are traveling longer distances. In OECD countries, the transport sector's contribution to total emissions of greenhouse gases is predicted to rise from about 20 percent in 1995 to 30 percent in 2020 (Figure 2).[3] At the same time, automotive growth is expected to mushroom in non-OECD countries, such as China, India, and Latin American countries. All this adds up to a sobering sense that the automotive industry cannot survive if ways to cope with global warming are not found. Automakers are, consequently, prioritizing the development of practical technologies to curb CO_2 emissions. One initiative is Nissan Motor's "Nissan Green Program 2010," released in 2006. This program emphasizes the manufacturer's commitment to developing eco-friendly technology that will slice its vehicles' CO_2 emissions by 40 percent in the next ten years.[4]

Figure 2. Greenhouse Gas Emissions by Sector in OECD Countries (1998)



Source: Taken from *OECD Environmental Outlook to 2020*, Environment Directorate, OECD [original source: United Nations Framework Convention on Climate Change].

[2] Examples of cars that will be liable to the higher charge are the Porsche 911, most BMW 7 series, Range Rover, Land Rover Discovery, Toyota Land Cruiser, Volkswagen Touareg, and the Mercedes M Class. Examples of cars which will be eligible for the 100% discount are the Seat Ibiza Ecomotion, Volkswagen Polo BlueMotion, Toyota Prius, Toyota Aygo, Peugeot 107, Citroen C1, and the Honda Civic Hybrid. See the following Web address for more details: http://www.london.gov.uk/mayor/congest/docs/decision-statement02-2008.pdf.

[3] See *OECD Environmental Outlook to 2020*, Environment Directorate, OECD.

[4] See http://www.nissan-global.com/JP/NEWS/2006/_STORY/061211-01-j.html.

The well-to-wheel energy efficiency of gasoline-engine vehicles is 14 percent; this means only about one-seventh of the potential energy in crude oil taken from the ground is actually used (Figure 3). This poor efficiency stems from the large amounts of energy lost as heat during combustion and lost through cooling at the radiator. Since the internal-combustion engine is very likely to remain the automotive power plant of choice for the foreseeable future, there is a pressing need to develop technologies that make engines more fuel efficient.

One alternative to this scenario is the hybrid electric vehicle (HEV), which combines a gasoline engine and electric motors to reduce its impact on the environment. Interest is growing in HEVs because of their dramatically higher energy efficiencies, which result from energy regeneration during deceleration and from a high-efficiency primary engine. Practical "plug-in" hybrids, which can be charged from a household power socket, are also on the horizon. And in the mid-to-long term, attention is focusing on fuel-cell cars and electric cars, which run solely on electric motors, as the next vanguard of environmentally friendly vehicles. Fuel-cell cars are particularly attractive because they generate no CO_2 — only water vapor. Electricity generated through a chemical reaction in the fuel cells between hydrogen and oxygen powers the electric motors that propel the car.

Electronics technology has a huge role to play not only in combating environmental issues but also in addressing demands for greater automotive safety and richer entertainment systems that provide more traveling comfort and pleasure. The use of electronics in cars will surely take another large step forward as pre-crash safety devices, which prevent or avoid automobile accidents, are installed on a wider range of cars and as intelligent transport systems (ITS) arrive that enable interactive control between roadway infrastructures and the vehicles they carry.

Figure 3. Automotive Energy Efficiencies

	Well to Tank [%]	Tank to Wheel [%]	Well to Wheel [%]
Gasoline cars	88	16	14
Gasoline hybrid cars (Prius)	88	37	32

Fuel efficiency (well to tank) (%) × vehicle efficiency (tank to wheel) (%) = total efficiency (well to wheel) (%)

Notes: Well to tank: Efficiency from extracting and producing the fuel to fueling the vehicle.
Tank to wheel: Efficiency of consuming the fuel in the tank and powering the car's wheels.
Source: Prepared from Toyota Motor materials.

II Auto Electronics Market Where Competing Corporate Cultures Clash

1. Allure of the Market's Scale and Stable Growth

Auto electronics are making inroads in three central areas: (1) control systems, such as power train and steering systems as well as antilock braking systems (ABS); (2) structural systems, such as air-conditioning, gauges, and airbags; and (3) communication and entertainment systems, which include car navigation units and in-car local area networks (LAN) (Figure 4). In the first area, development of electronics for engine regulation and the power train must keep pace with regulations that set mileage and gas emission targets. New electronics technology used in structural systems, such as braking, steering, and suspension, is obliged to undergo rigorous testing and verification since they govern the car's basic propulsion, stopping, and turning operations. Finally, electronics for the third area — car navigation units, audio systems, and the like — essentially involves the conversion of established consumer technology to automotive applications.

As Figure 5 indicates, the value of shipped automotive components in FY 2006 grew by 8.4 percent over the previous year to ¥19 trillion. Two of the fastest growing segments over this time were the electrical devices and electronic parts segment (engine control units, alternators, sensors, etc.), which grew by 20.6 percent, and the electrical and electronic parts for lighting and instruments segment (headlights, switches, wire harnesses, electric motors, etc.), up by 14.1 percent.[5] The total value of electronic parts — when car stereos, heating and cooling equipment, and IT-related devices (such as car navigation units and ETC units) are counted — is estimated at about ¥6.7 trillion, which accounts for roughly 35 percent of the value of all shipped auto parts. The value of global shipments by Japanese electronic parts manufacturers — ¥4.7 trillion in FY 2006[6] — also signals that, for the electronic device and component industry, there are few if any markets this size or with this expected stable long-term growth. This certainly explains the market's attractiveness to so many.

Automotive control units consist of sensors, which gather information about the driving environment or the engine status, an electronic control unit (ECU), which processes signals from the sensors, and actuators, which apply the actual controls (Figure 6).

An ECU incorporated in the engine, for example, is designed to optimize the fuel-air mixture and control the timing of ignition and combustion for the highest efficiency. Inside the unit, analog signals from the sensors are converted to digital signals and input to the microprocessor. The microprocessor makes decisions or calculations according to this information and outputs instructions to power semiconductors to adjust the conditions to achieve optimal combustion. The power semiconductors drive the actuators. Recent high-end cars have as many as 70 microprocessors and close to 100 sensors; electronics and related components make up between 20 and 30 percent of the cost per vehicle. There has been a huge jump in the number of motors used on the actuator side as well.

Power steering units are transitioning to electric systems from the conventional hydraulic-assist systems that run off the engine. Electric power steering gives better fuel mileage because it eliminates the energy wasted by constantly running a hydraulic pump.

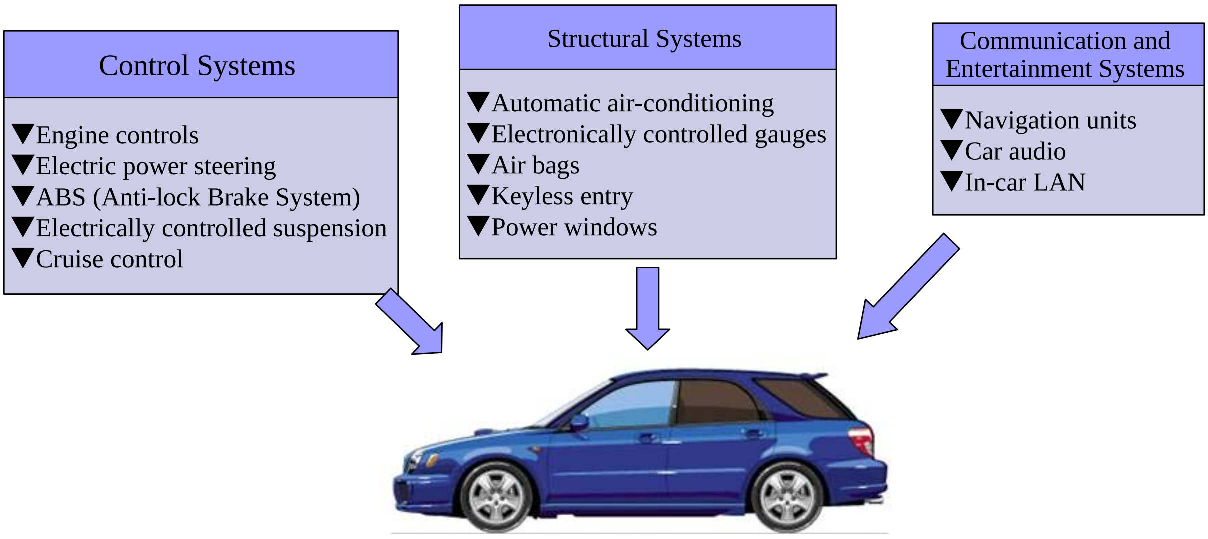
Similarly, some luxury cars now feature electronic parking brakes that operate via a switch rather than the conventional foot-operated parking brake that locks the rear wheels with cable tension. Electronic parking brakes can be designed to engage automatically whenever the transmission is put in park, thereby adding to the vehicle's safety.

This increasing use of electronics and electric power in cars is not only essential to pass environmental and safety regulations but also an important value adder to cars.

[5] See the Survey of 391 Member Firms section in *Trend Survey of Shipped Automotive Components*, Japan Auto Parts Industries Association.

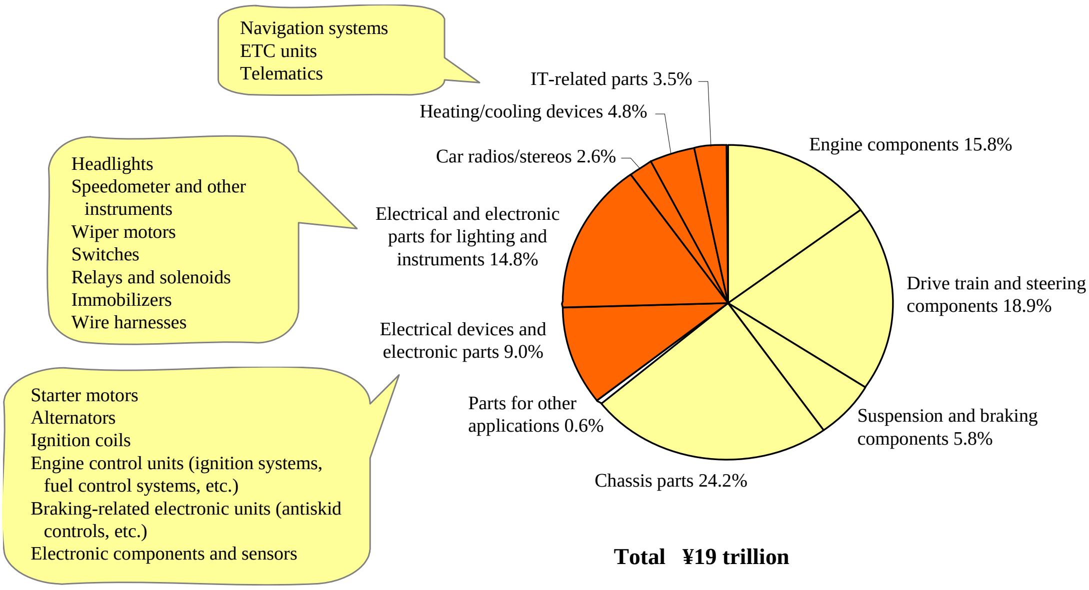
[6] See the Survey of 100 Firms section in *Statistics on Global Shipments of Electronic Parts*, Japan Electronics and Information Technology Industries Association.

Figure 4. Progress of Auto Electronics



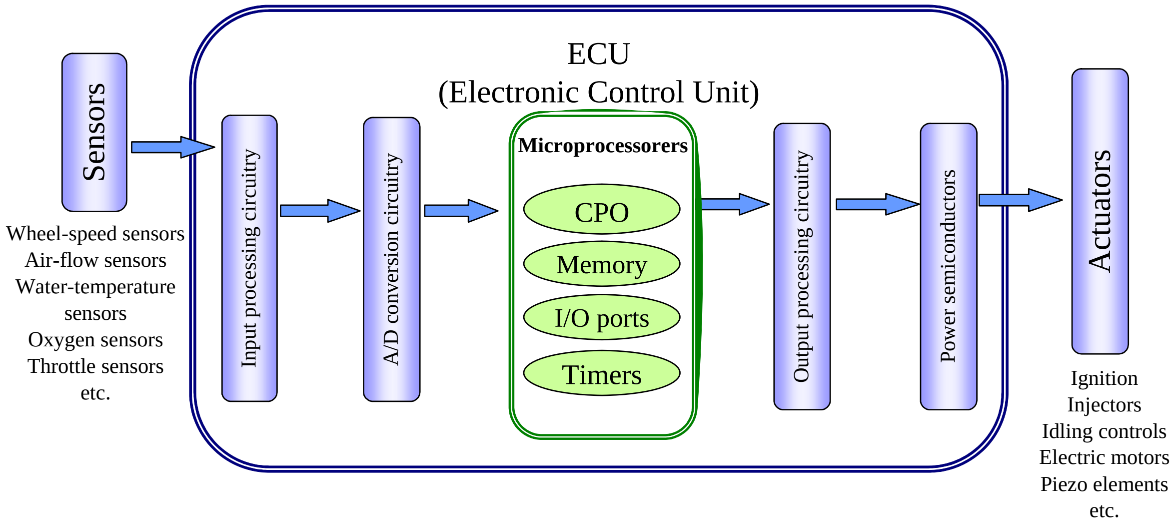
Source: Prepared by the Development Bank of Japan.

Figure 5. Shipped Value of Auto Parts by Category



Source: *Trend Survey of Shipped Automotive Components 2006*, Japan Auto Parts Industries Association.

Figure 6. Structure of Automotive Control Units



Source: Prepared based on "The Illustrated Guide to Semiconductors," Toshiba.

2. Automotive Electronics Face More Rigorous Conditions Than Consumer Electronics

Electronic components for the auto industry are required to meet much higher reliability standards than those for consumer-use electronics (Figure 7). The severe temperature changes automobiles undergo are one reason for the stringent conditions: while engine compartments reach temperatures in excess of 100ºC, cars must also perform in frigid regions where temperatures drop tens of degrees below freezing. One of the effects of this extreme temperature range is the sulfidizing gas that greased areas on and around the engine give off at high temperatures. Because this gas can disrupt electrical circuitry, electronic components are being developed using materials that are highly resilient to sulfidization.

Auto electronic parts must operate reliably for many years in demanding conditions that, aside from temperatures, include high humidity, corrosion, shocks and vibrations, and voltage fluctuations; this is why automotive electronics often have different specifications than those for consumer-use applications.

Electronic components in cars also face the problem of noise generated by the engine and electric motors as well as external noise — electromagnetic fields and radio waves. ECUs and in-car LANs are required to have fail-safe mechanisms to prevent noise from causing them to malfunction. At the same time, the increasing deployment of electrical and electronic devices prompts more pressing demands for low-power consumption, to limit battery loads, and for lighter, more compact form factors, to improve fuel economy and save space. And added to all these requirements are pressures to drive down prices to commodity levels.

On the other hand, auto parts do have the advantage of long production runs once they clear these rigorous quality standards. The product lives of parts for consumer products like flat-screen TVs or mobile phones are very short, around a year or so. Auto parts, however, generally take two to three years to develop and are produced in volume for five to six years. Even after volume production ends, manufacturers must continue to supply the parts for a further ten to 15 years for servicing and repairs. Consequently, one of the most important prerequisites when sourcing auto parts is the ability of the supplier to guarantee stable supplies over many years.

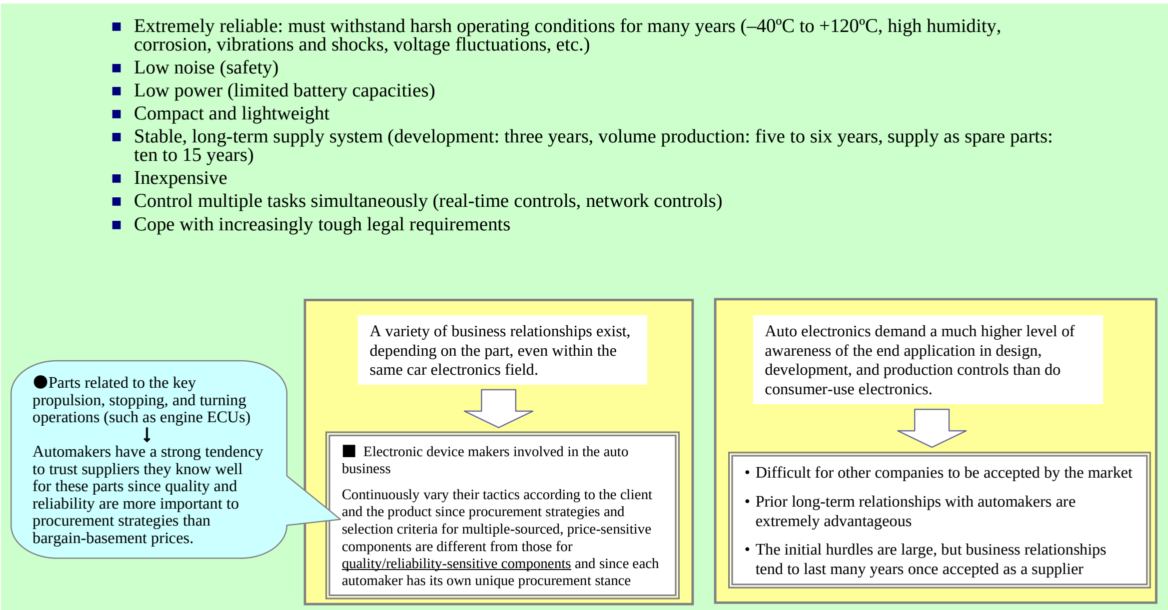
Automakers often bring in suppliers to develop particularly critical parts right from the initial concept stage of a model, a practice known as concept integration. Many electronic device and component manufacturers end up spending several years developing a product together with an automaker or electrical/electronic architecture manufacturer. Component manufacturers must produce parts, even microprocessors, consistent with the client's specifications, which is a major departure from commodity components made for household electronic devices. This leads to business models that are substantially different from consumer-application businesses.

Still, even in the same car electronics world, a variety of business relationships are found depending on the type of part. Automakers are said to have a strong tendency to choose suppliers they know well for components, such as engine ECUs, related to the key propulsion, stopping, and turning operations. For these components, automakers strategically select quality and reliability over the lowest price. Electronic device makers involved in the auto business say they must continuously vary their tactics according to the client and the product since procurement strategies and selection criteria for multiple-sourced, price-sensitive components are different from those for quality/reliability-sensitive components and since each automaker has its own unique procurement stance.

In the auto world, automakers prize track records when selecting suppliers and they question suppliers very thoroughly about their quality assurance systems, naturally enough. Automakers also scrutinize potential suppliers over the stability of their supply system and their capacity to deal with cost reductions. Consequently, electronic device and component makers must maintain a higher level of awareness of the end application in their design, development, and production controls for auto electronics than for consumer-use electronics. This is one of the reasons new entrants find it difficult to be accepted into the auto market.

But from the standpoint of suppliers with a solid track record in the industry, long-term relationships built with automakers become a huge plus because other manufacturers cannot easily enter the market. The initial hurdles are large; however, once chosen, suppliers can expect the business relationship to last many years. This too is a significant difference from the consumer-electronics market.

Figure 7. Stringent Conditions on Automotive Electric Control Systems



Source: Prepared by the Development Bank of Japan.

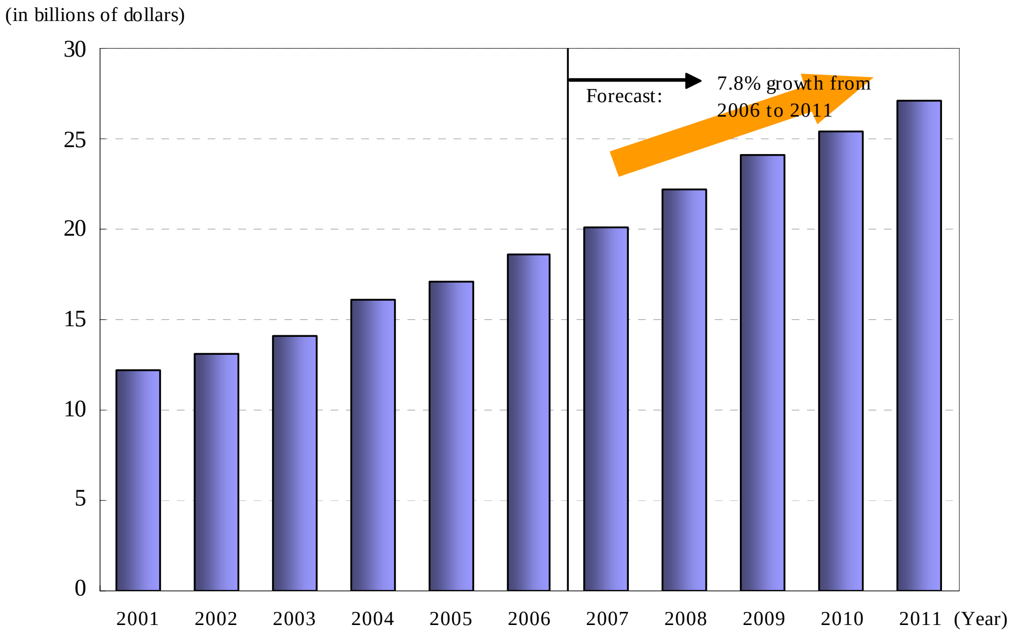
3. The Competitive/Collaborative Relations between Automakers and Semiconductor Producers in the ¥2 Trillion Automotive Semiconductor Market

Semiconductors are the central component in automotive electronic controls. The auto industry is expected to become the next big demand driver for semiconductor applications, which have been largely oriented toward the computer market although they are now diversifying into communications and digital home appliances.

Automotive applications for semiconductors occupy a 7.1 percent share, worth 18.6 billion dollars in 2006, of the global semiconductor market. In the same year, 69.21 million four-wheel vehicles were produced; thus, the average worth of semiconductors per vehicle, estimated by simple division, is 269 dollars. The automotive semiconductor market is projected to see average annual growth of 7.8 percent between 2006 and 2011, which will outstrip the average growth of the overall semiconductor market (an estimated 4.8 percent per year over the same period) by a significant margin (Figure 8).

One cited factor driving expansion in the automotive semiconductor market is, in addition to the natural growth in the numbers of cars produced, the trend to use more semiconductors in each vehicle. The value of per-vehicle semiconductors for gasoline (midsize) cars is anticipated to climb from about 250 dollars in 2004 to more than 350 dollars in 2006 and total just under 450 dollars in 2010. It is worth mentioning that high-end hybrid cars — in which power supply controls are a chief component — are loaded with more than 1,400 dollars of semiconductors per vehicle (2005).[7] Semiconductors are used extensively in engine control units, airbags, car navigation units, and ABS, and they make up a significant portion of the total cost of these devices.

Figure 8. Global Automotive Semiconductor Market Set to Top ¥2 Trillion



Source: Gartner "Dataquest Alert: Semiconductor Market Forecast (4Q07 Update)"; Richard Gordon, 7 December, GJ08018.

[7] Figures supplied by Akira Minamikawa (iSuppli Corporation Japan).

Figure 9 shows that Western semiconductor manufacturers rank at the top alongside Japanese firms in the global automotive semiconductor market by production value. Infineon Technologies, STMicroelectronics, and European manufacturers appear to have far-reaching business ties in the European auto industry, as do Freescale Semiconductor and other U.S. producers in the U.S. auto industry. Japanese producers have ensured themselves a solid market share by concentrating on the Japanese auto world. But in order to further expand their businesses, they face the challenge of beefing up their global expansion efforts; deepening their sales channels in the Western auto industry is an especially important issue.

The general approach in the auto sector is for semiconductor firms to sell discrete power semiconductors and sensors to electrical/electronic architecture makers, who incorporate them in engine controllers and other systems, which are then delivered to automakers. There are some Tier 1 suppliers, however, such as Toyota Motor, Denso, and Bosch, involved in developing and producing semiconductors on their own.[8] The overwhelming strength of these electrical/electronic architecture producers is believed to stem from their integrated semiconductor-to-system development, which allows them to quickly ascertain needs and offer systematic proposals through constant dialog between car design divisions and semiconductor development divisions.

Having said this, both Bosch and Denso, which produce their own semiconductors, consume more than they produce, as the comparison between production and consumption shares in the automotive semiconductor market in Figure 9 indicates. What this suggests is neither company produces all its semiconductors in house; in fact they procure quite a large percentage of the semiconductors they use from external venders. Although philosophies on in-house production versus external procurement vary from company to company, we can guess at the strategy most firms employ — attempt to secure a competitive advantage with development capabilities in all ECUs by developing and producing key semiconductor devices in house and using semiconductor manufacturers for mass produced or readily available semiconductors. From the standpoint of the electronic device and component industry, these sorts of electrical/electronic architecture producers may become both customers and competitors. An important issue for electronic device and component makers then is how to build win-win relationships with these firms while maintaining an acceptable balance of competition and collaboration (Figure 10).

Electrical/electronic architecture makers, for their part, are not comprehensive semiconductor producers. They are believed to want to bring in semiconductor partners to handle areas they lack competence in or development projects too complex for a single company. In view of the circumstances of both sides, complementary roles may well form in which semiconductor manufacturers will avoid areas where electrical/electronic architecture makers have strong competencies but will supply products in areas electrical/electronic architecture makers cannot cover on their own.

Automotive semiconductors themselves span a wide gamut — from microprocessors embedded in ECUs to power semiconductors, analog semiconductors, charge-coupled device/complementary metal-oxide-semiconductor (CCD/CMOS) sensors, and light-emitting diodes (LED), among others.

Power semiconductors are used for AC–DC conversions and for modulating voltages. Large numbers of insulated gate bipolar transistors (IGBT), diodes, and other power semiconductors are used in inverter modules that control HEV motors. An indispensable part of rolling out HEVs en masse then is improving the performance and the price points of power semiconductors. Hurdles to the commercialization of inexpensive, compact, high-performance inverters

[8] Bosch announced in June 2006 it was investing about 550 million euros to expand its Stuttgart semiconductor plant, which uses eight-inch-wafer technology. Denso announced in April 2007 it would be investing a total of about ¥24.0 billion by FY 2015 to establish a new company to produce automotive semiconductor products in Chitose, Hokkaido, Denso's third base after the Kota and Takatana plants in Aichi.

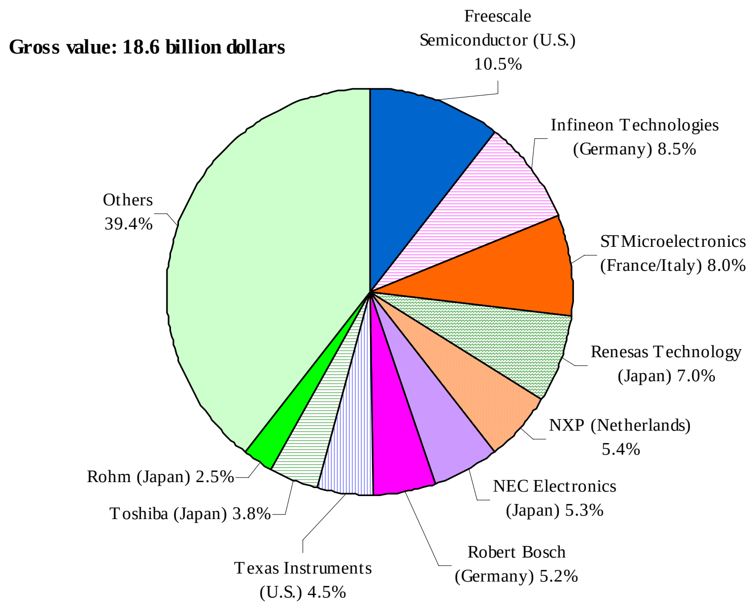
and DC–DC converters[9] include the development of new materials — such as replacing silicon with silicon carbide (SiC) — and competencies in bringing together cooling technologies and substrate-mounting technologies. Electronic device and component makers who have this specialized knowledge can expect opportunities for collaborations with auto-parts venders. Similarly, cars are expected to carry increasing numbers of sensors, as sensors play a significant role in improving environmental and safety performance. Naturally buyers are pressing for performance improvements and lower prices from sensors as well.

It is vital that electronic device and component makers thoroughly investigate which areas the competitive products they offer are best suited for — drive-train systems (such as batteries), comfort and safety systems (sensors, cameras, etc.), or information systems (car navigation units, ITS, etc.). Moreover, to move past just being supplementary part suppliers and potentially deepen their relationships as partners with automakers and electrical/electronic architecture venders, electronic device and component makers should develop the ability to offer cost competitiveness and new concepts. Such a strategy requires firms to sharpen their ability to propose automotive systems containing multiple semiconductors and electronic parts rather than discrete products in a way that is timed to the mid-to-long-term technical development roadmaps of automakers. Automakers will see value in this because it lessens their own development costs. Another requirement for firms to be successful is to leverage their broad product lines and effectively use their accumulated know-how and design assets from consumer electronics in automotive applications.

[9] DC–DC converters are used to scale down the high battery voltages found on hybrid vehicles to the lower voltages needed by onboard actuators.

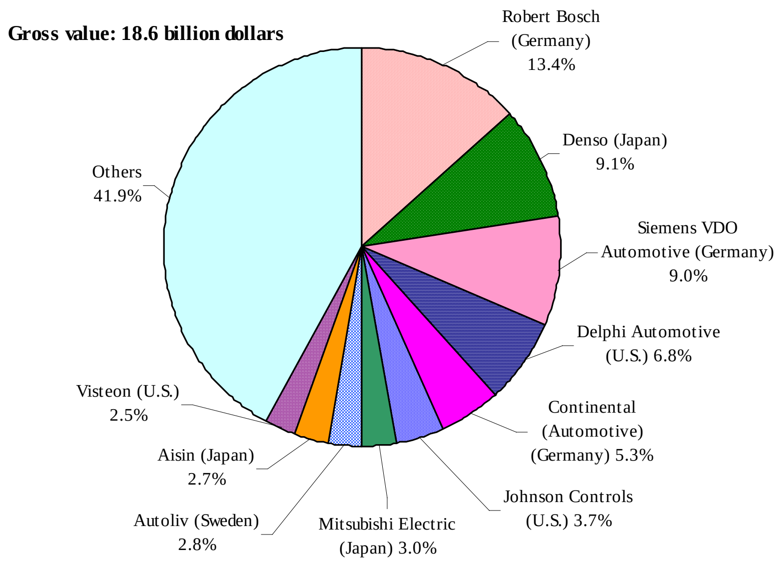
Figure 9. Automotive Semiconductors: Shares by Production Value and Shares by Consumption Value (2006)

Production Value



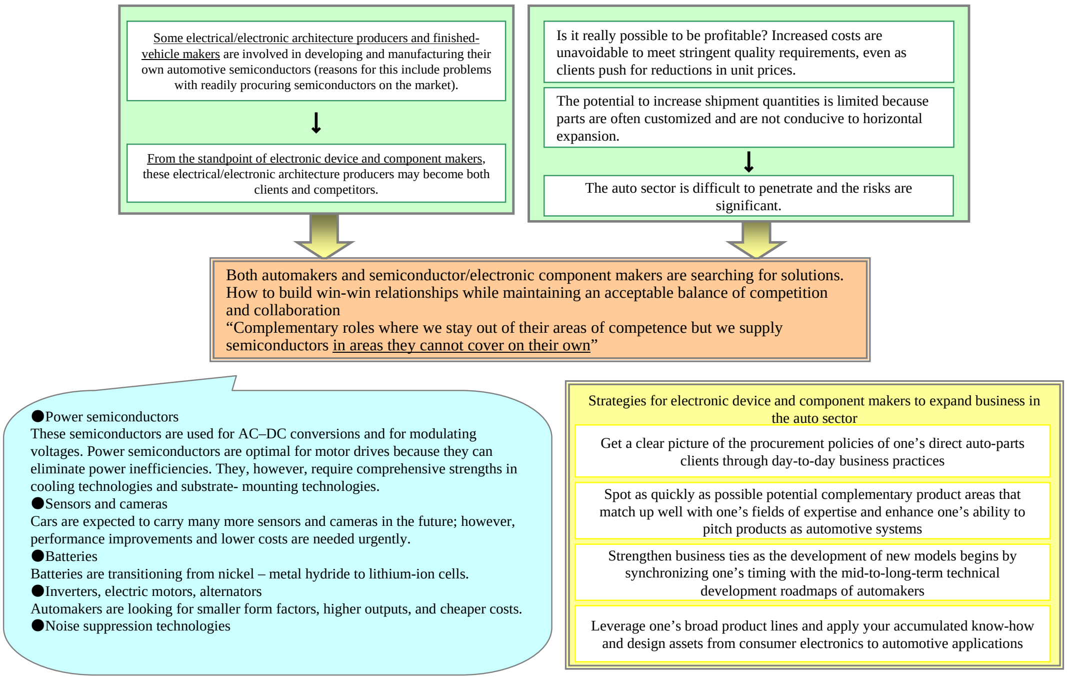
Source: "Top 20 Companies Revenue from Shipments of Total Semiconductor — Automotive," Gartner, March 2007.

Consumption Value



Source: "Leading Automotive Companies' Semiconductor Spending and Regional Consumption, Worldwide, 2006," Gartner, January 2008.

Figure 10. Strategies for the Electronic Device and Component Industry to Expand Its Auto-Sector Trade



Source: Prepared by the Development Bank of Japan.

Figure 11. Auto-Sector Endeavors by Electronic Device and Component Makers

Company	Field or Product
NEC	• Purchased the automotive motor business of Valeo, a large French auto-parts maker (October 2006) → NEC decided it was more effective to enter the auto sector by purchasing an established business and thus save the time it would take to develop a proficiency in producing automotive motors and to establish sales channels to Tier 1 clients • Produces brushless DC motors for electric power steering and electric mirrors, and brush motors for air flows, body closures, power seats, brakes, and steering
Murata Manufacturing	• In a move toward commercializing rechargeable lithium-ion batteries, Murata agreed to a blanket business partnership with Enax and Daiken Chemical to develop, design, manufacture, and sell lithium-ion batteries (September 2006) • Produces large-capacity ceramic capacitors for ECUs, hands-free Bluetooth modules, ultrasonic sensors for rear sonar units, MEMS gyrosensors for navigation, hard-disk shock sensors, and noise suppression components
Kyocera	• The natural advantages of lightweight, thermal-resistant ceramics are becoming more important as more and more ECUs are attached directly to engines, transmissions, motors, and elsewhere; in addition to its high-performance, highly reliable part technologies that are based on material technologies, Kyocera is focusing on enhancing its module-level and system-level design, product development, and production technology capacities • Produces crystal oscillators for ECU/TPMS modules, SAW filters and ceramic resonators for TPMS modules, SAW filters for keyless entry systems, tantalum capacitors, and ceramic capacitors
Hokuriku Electric Industry	• Hokuriku is expanding in the auto sector both domestically and abroad; it beefed up its European operations and design-integration frameworks in 2007 • Produces humidity sensors, highly reliable printed circuit boards, and various sensors for rheostat applications
ALPS Electric	• Produces in-car electrical modules and systems, automotive sensors, automotive digital radio tuners, automotive Bluetooth modules, ETC modules, and sensor switches
TDK	• Produces sensor-related products (NTC thermistors, humidity sensors, gear-tooth sensors, rotational sensors, etc.) and common-mode filters for in-car LANs
Rohm	• Produces very-low-resistance chip resistors, surge-protection chip resistors, chip tantalum capacitors, power modules for power supplies, power supply ICs, LED drivers, smart-key ICs, LSIs for AIE, wireless audio link ICs, talking LSIs, power diodes, and power transistors
Nichicon	• Produces HEV film capacitors, inverter modules, and aluminum electrolytic capacitors
CMK	• Produces highly reliable single-sided, double-sided, and multilayer circuit boards, build-up multilayer circuit boards, and metal substrates
SMK	• Produces force-feedback touch panels, connectors, remote controls, jacks, Bluetooth modules, and automotive camera modules
Mabuchi Motor	• Produces motors for onboard electrical devices (for air-conditioner dampers, door locks and mirrors, power folding mirrors, power units, and optical-axis adjustors)
Mitsumi Electric	• Produces antennas, tuners, high-frequency modules, automotive sensors, camera modules, and other various components

Source: *Dempa Shimbun* (December 7, 2006), with some additional text.

III Business-Relationship Transformations and Opportunities for the Electronic Device and Component Industry Brought on by Car Electronics

The increasing adoption of electronics in automobiles is driving all manner of changes in the business relationships in the auto-parts trade. What sort of business opportunities will these transformations open up for the electronic device and component industry? In this chapter we consider the anticipated business-relationship changes as well as potential business opportunities and challenges for the electronic device and component industry from five viewpoints: (1) replacement of mechanical systems with electronic controls, (2) move to electric-powered cars, (3) progression of integrated LAN-based controls and establishment of next-generation communication standards, (4) increasing efficiency in automotive software development, and (5) advancement of multimedia and audio/video functions centered on in-car information terminals.

1. Replacement of Mechanical Systems with Electronic Controls

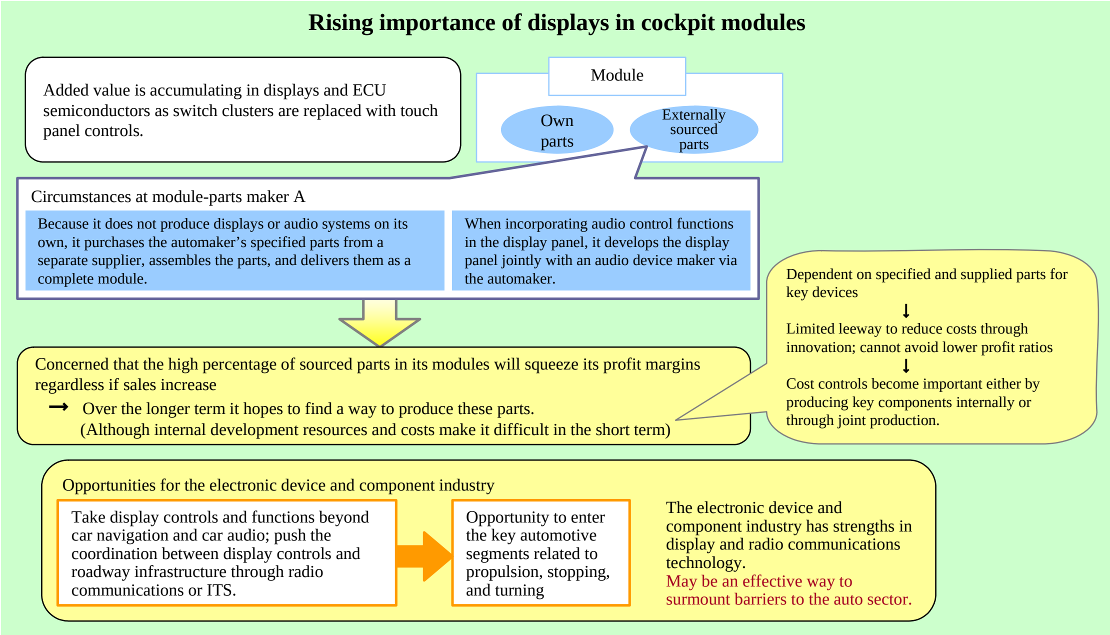
Automotive electronic controls have already supplanted hydraulics, cables, and other mechanical systems in many different areas. This technology turnover is having more than a passing influence on the business structures in the parts trade.

Air-conditioners are an illustrative example of this effect. Control units for manual air-conditioners consisted of a number of wire cables, which the driver would pull and push with slide adjusters to open and close ducts in the air-conditioner unit to regulate the temperature and flow of air. This configuration meant that the control unit and the air-conditioner unit could be separated and, thus, different companies could develop each unit independently. With automatic air-conditioners, however, the control functions that maintain a constant temperature reside in semiconductors in the air-conditioner itself. According to a parts manufacturer in the business, air-conditioner makers are now frequently asked to build control modules as part of the automatic air-conditioner units because of how important software has become to the control system. Concealed in the move to car electronics, then, is the impact of modularizing parts that previously had been produced by separate manufacturers. This implies that a supplier able to develop software and cope with the move to electronic controls will have a leg up in dealings with automakers.

Similarly, more and more cars today use electric power units to adjust seat positions and orientations. Power units occupy a large percentage of the total cost of seats, and the key devices in these units are the electric motors. According to one manufacturer, the number of motors used per seat is soaring as more functions are added to seats. As a result, seat manufacturers' trade with electric motor producers is growing year by year. From the viewpoint of the electronic device and component industry, this represents a new business opportunity arising from the shift to electronics. Potentially firms in the future will deliver not just standalone motors but also modular parts containing the motor with peripheral circuitry and structural components. On the other hand, those seat manufacturers that can produce the key electric components on their own may be able to incorporate within their firm the source of added value, which previously flowed to their suppliers.

A third example is the cockpit module. The cockpit module is the module fastened to a cross-car beam and carries the instrument panel, air-conditioner unit, gauges and meters, airbag modules, electronic control units, car audio systems, and other accessories. Much of the added value found in cockpit modules is now concentrated in the displays and semiconductors as designs replace switches with touch panel controls (Figure 12). Cockpit module parts include some produced in house and some sourced externally. One cockpit manufacturer that does not make its own displays purchases the automaker's specified parts from a separate supplier, assembles the parts, and delivers them as a complete module. And when it comes to incorporating audio control functions in the display panel, the manufacturer — which does not make its own audio devices either — develops the display panel jointly with an audio device maker via the end auto-

Figure 12. From Mechanical to Electronic: Cockpit-Module Case Study



Source: Prepared by the Development Bank of Japan.

maker client. This manufacturer is concerned that the high percentage of sourced parts in its modules will limit its scope for innovation and squeeze its profit margins regardless if sales increase. So although internal development resources and costs make it difficult in the short term, over the longer term the company hopes to find a way to produce these parts on its own.

This is an excellent chance for the electronic device and component industry to enter the automotive power-train sector by pushing the coordination between display operations and functions and roadway infrastructure through radio communications or intelligent transport systems (ITS). Going forward, this may be an effective way for the electronic device and component industry, with its formidable technical development capacities in the display and communications arenas, to surmount the barriers that have so far kept it out of the auto sector.

2. Move to Electric-Powered Cars: Batteries Are the Core of Electric Power Systems

Most automobiles are powered by either gasoline engines or diesel engines. HEVs, the subject of growing demand in recent years, use a fuel-combustion engine and electric motors together as their power plant. With HEVs, however, comes the need to drive the air-conditioner compressor and other outboard accessories with electric motors, since they cannot be driven by the engine's rotation when the car is running on electric motor power alone. Moreover, the successors to HEVs — the next generation of eco-friendly cars now being developed, such as fuel-cell cars and electric cars — drop the engine entirely and only use electric motors. This creates the potential for a sudden upswing in the deployment of electrical and electronic auto parts.

The heart of electric-power cars is the rechargeable battery. Powerful, compact, long-lasting batteries are essential for HEVs, electric cars, and fuel-cell cars alike. Some observers feel the market for HEV batteries, which is growing rapidly, especially in Japan and North America, will be worth more than ¥320 billion by FY 2015.[10] The mainstay of automotive batteries at the present time is the nickel – metal hydride battery, but lithium-ion batteries — widely used in consumer electronics because of their compact form factors and longevity — are

[10] According to materials for a briefing on its mid-term management plan, GS Yuasa Corporation; see http://www.gs-yuasa.com/jp/ir_pdf/2006-06-13.pdf.

widely tapped as the technology of the future. For lithium-ion batteries to be viable for automotive applications, however, they need to have greater capacity, better quality control, and large-scale price reductions through economies of scale (Figure 13).

Generally speaking there are three main approaches car companies take with respect to part sourcing: (1) create the parts using the automaker's expertise, (2) develop the parts with an external supplier, and (3) have an external supplier create the parts with its expertise. When it comes to lithium-ion batteries — the power source, which is to say a core car technology — automakers will surely want to take the first approach if at all possible and try to develop lithium-ion batteries on their own. But when it comes to developing battery technology, the second approach — joint development configurations — is common, since electronic device and component makers have a significant store of expertise in this area from the consumer electronic field. Some automakers have been seen constructing close business relationships in this area, even going as far as making capital investments (Figure 14).

One of the automakers investing in battery technology is Toyota Motor, which is at the forefront of the HEV market. In 1996 Toyota set up Panasonic EV Energy in partnership with Matsushita Electric Industrial. This joint venture develops and produces nickel – metal hydride batteries and lithium-ion batteries used in the Prius and other cars. Recognizing that in order to accelerate HEV development it needed to integrate development of conventional battery technology with in-car system technology, Toyota in 2005 flipped Panasonic EV Energy's holdings ratio from 60/40 in favor of Matsushita Group to 60/40 in favor of Toyota (Figure 15).[11]

Nissan Motor formed a fifty-fifty joint venture with NEC and NEC-Tokin in 2007 called Automotive Energy Supply Corporation with a plan to supply lithium-ion batteries for cars by FY 2009. Automotive Energy Supply Corporation, as an independent corporation, intends to sell batteries to other carmakers besides Nissan.[12] Nissan plans to deliver its own branded hybrid car by 2010 and a next-generation electric car in the early 2010s. To this end, Nissan has launched a dedicated firm in partnership with NEC Group in order to lower its costs and deal directly with volume production.[13] NEC Group, for its part, plans to supply expert lithium-ion battery knowledge and resources built up through the experiences of NEC-Tokin in its consumer-electronics battery business.

There are examples of electronic device manufacturers taking majority investor positions in lithium-ion battery development. The GS Yuasa Group, seeking to expand applications for its lithium-ion battery technology, established Lithium Energy Japan at the end of 2007 in partnership with Mitsubishi Corporation, which aims to enter the battery business and create periphery businesses, and Mitsubishi Motors, which hopes to popularize electric cars as the ultimate in eco-friendly vehicles. Lithium Energy Japan plans to be producing 200,000 batteries a year by FY 2009.

Another camp of electronics manufacturers foregoes capital ties to any specific automaker. Hitachi, with Shin-Kobe Electric Machinery and Hitachi Maxell, set up Hitachi Vehicle Energy in 2004. Hitachi Vehicle Energy has core competencies in all three key components of HEVs — electric motors, inverters, and batteries — and can develop, design, and manufacturer all three as well as offer optimized systems. The company has already sold a total of 200,000 cells to date that are being used by a number of car companies.[14]

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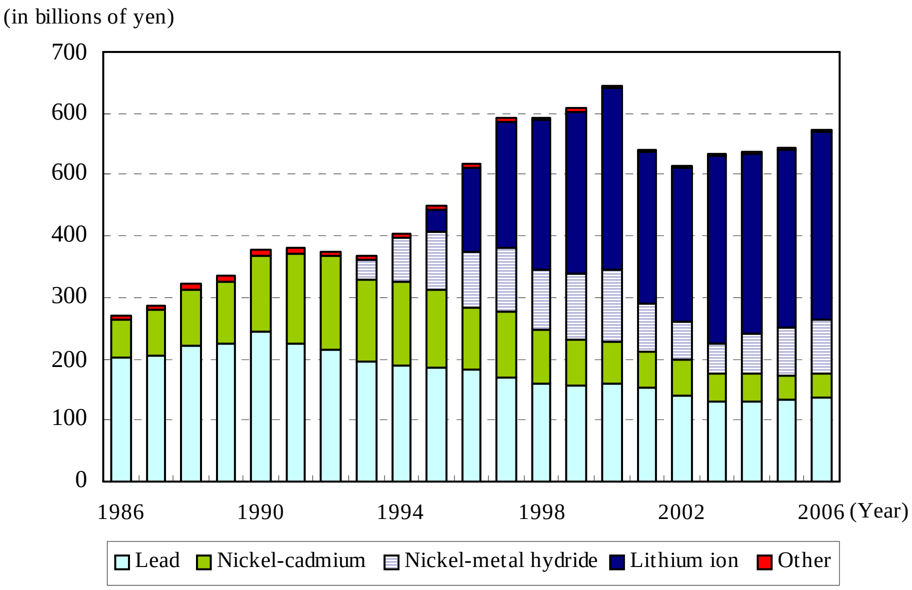
11 Press release, Toyota Motor; see http://www.toyota.co.jp/jp/news/05/Oct/nt05_1008.html.

12 Joint press release by Nissan, NEC, and NEC-Tokin; see http://www.nissan-global.com/JP/NEWS/2007/_STORY/070413-01-j.html.

13 Renault and Nissan Motor announced in January 2008 they, in partnership with a U.S. venture enterprise, had exchanged a memorandum of understanding with the Israel government to supply electric cars and electric vehicle recharging stations to Israel in 2011. Project Better Place, based in California, will construct and operate 500,000 electric vehicle recharging stations across Israel. Nissan, through a joint firm with NEC, will develop and mass-produce battery packs that meet the requirements of the electric cars. See http://www.nissan-global.com/JP/NEWS/2008/_STORY/080121-02-j.html.

14 Press release, Hitachi; see http://www.hitachi.co.jp/New/cnews/month/2008/01/0121.html.

Figure 13. Long-Period Transitions in Rechargeable Battery Sales by Value



Source: Battery Association of Japan.

Figure 14. Rechargeable Batteries, the Core of Electric-Powered Cars

Core of electric-powered cars = rechargeable batteries

Powerful, compact, long-lasting batteries are essential for HEVs, electric cars, and fuel-cell cars alike

The market for HEV batteries, which is growing rapidly, especially in Japan and North America, is predicted to exceed ¥320 billion by FY 2015.

For lithium-ion batteries, which are already widely used in consumer electronics, to be viable for automotive applications they need to have greater capacity, better quality control, and large-scale price reductions through economies of scale.

<u>Automakers' approaches to part sourcing</u>

(1) Create using the automaker's expertise
(2) Develop jointly with an external supplier
(3) Have an external supplier create with its expertise

Lithium-ion batteries … the power source, which is to say a core car technology → automakers will want to try (1) to develop the batteries on their own if possible

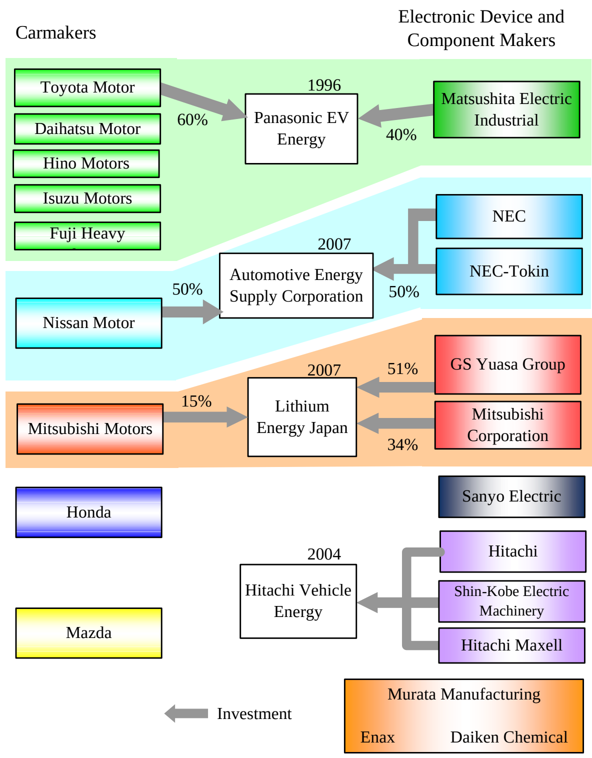
but,

when it comes to developing battery technology → (2) joint development configurations are common, since electronic device and component makers have a significant store of expertise from the consumer electronic field.

Some automakers have been seen constructing close business relationships in this area, even going as far as making capital investments.

Source: Prepared by the Development Bank of Japan.

Figure 15. Alliance Strategies in Automotive Batteries



Panasonic EV Energy: automaker is the majority investor

Automotive Energy Supply Corporation: 50/50 joint venture
Intends to sell batteries to other carmakers besides Nissan as an independent corporation

Nissan	• Deliver its own branded hybrid car by 2010 and a next-generation electric car in the early 2010s • Partnership with NEC Group permits Nissan to lower costs and deal directly with volume production
NEC	• NEC-Tokin has considerable experience through its consumer-electronics battery business • Uses manganese as an electrode material (Manganese is attractive because it produces less heat than cobalt or nickel, so manganese batteries are less likely to ignite, and its known reserves are roughly 60 times those of cobalt.)

Lithium Energy Japan: led by an electronic device manufacturer

- GS Yuasa Group → seeks to expand applications for its lithium-ion battery technology
- Mitsubishi Corporation → aims to enter the battery business and create periphery businesses
- Mitsubishi Motors → hopes to popularize electric cars as the ultimate in eco-friendly vehicles

Non-aligned camp of electronics manufacturers without capital ties to any specific automaker

Hitachi Vehicle Energy	Competent in developing electric motors, inverters, and batteries as well as offering optimized systems
Sanyo Electric	Developing a business model that strives to advance technology and quality and that seeks returns from products while maintaining a distance from domestic and foreign automakers

Weighing the pros and cons of forming a partnership

- ■ Securing stable buyers is essential in mitigating the risks of prior investment needed to develop next-generation vehicles → The ideal: development of products together with a specific automaker and then expansion of business horizontally to other clients
- ■ Joint-venture contracts likely contain clauses restricting horizontal expansion
- ■ Awareness as a partner that if jointly developed products are sold early on to other companies, then differentiation in the marketplace will be difficult to maintain

Source: Prepared by the Development Bank of Japan from company press releases.

Sanyo Electric, though it has ties in technical development of HEV batteries with Ford, Honda, and Volkswagen, is another player in this camp. Sanyo's policy is "to develop a business model that strives to advance technology and quality in our own way and that seeks returns from products while maintaining a distance" from domestic and foreign automakers.[15]

Other new entrants have also been coming on board. Murata Manufacturing, a large electronic component maker looking to get into the battery business early on, received existing lithium-ion battery technology from battery-maker Enax and formed a blanket business partnership with Enax and a third party, Daiken Chemical. This partnership aims to construct R&D and volume production frameworks.[16]

As these examples show, many of the lithium-ion battery business tie-ups between automakers and electronic device and component producers are founded on joint development and include joint capital investments. These joint capital investments take many forms: in some cases the automaker is the majority investor, others are fifty-fifty investments, and in still other cases the battery maker is the lead investor. There are even companies that are going it alone without investment from any carmaker; such firms aim to build broad trading relationships with multiple carmakers.

From the view of the electronic device and component industry, securing stable buyers is essential in mitigating the risks associated with the prior investment needed to develop next-generation vehicles. The ideal situation for these firms is to develop products together with a specific automaker and then expand their business horizontally to other clients. Complicating this ideal, however, is the fact that joint-venture contracts are likely to contain clauses restricting horizontal expansion. And as a partner, the firms are probably aware that if jointly developed products are sold early on to other companies it will be difficult to maintain differentiation in the marketplace. How firms weigh the pros and cons of building partnerships based on expected shipping quantities and technical synergies is thought to contribute to the differences found in each camp's corporate alliances in the lithium-ion battery business.

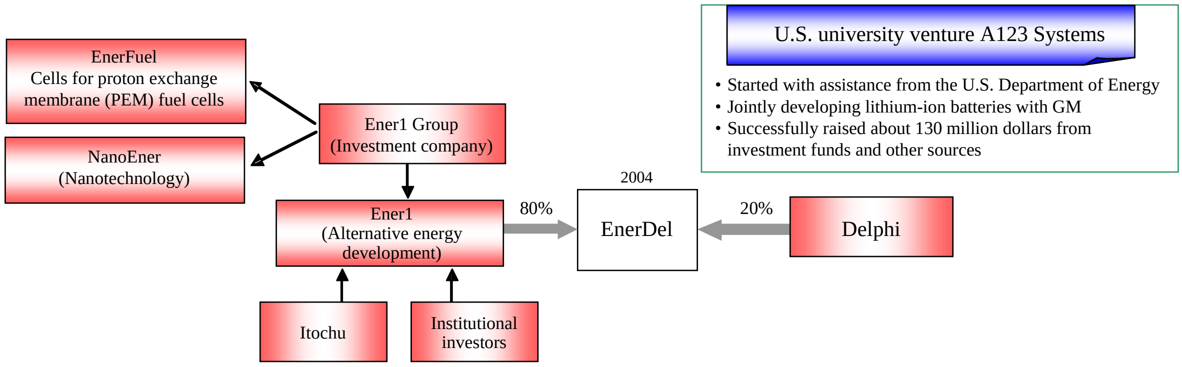
While Japan has held an overwhelming advantage to this point in the lithium-ion field, a series of U.S. venture enterprises, including A123 Systems, EnerDel, Valence Technology, and Altair Nanotechnologies, have been entering the arena (Figure 16).[17] General Motors and A123 Systems, which was established by researchers from MIT, are jointly developing lithium-ion batteries for plug-in hybrid vehicles (PHV), which can be recharged from household power supplies. This group plans to roll out the first PHVs by 2010. Technical innovation in batteries, including upstream materials, is dizzying, and new entrants in the field are not standing pat. Japanese automakers and electronic device and component makers will have to keep a close eye on the latest developments around the globe and look for cross-border alliances with foreign corporations as necessary.

[15] From an interview with Sanyo, *Dempa Shimbun*, January 8, 2008 edition, page 5.

[16] Press release, Murata Manufacturing; see http://www.murata.co.jp/news/2006/060919.pdf.

[17] *Wall Street Journal*, January 11, 2008 edition. Delphi, a major U.S. auto-parts vender, is invested in EnerDel.

Figure 16. Robust Lithium-Ion Battery Development in the U.S.



Source: Prepared by the Development Bank of Japan from corporate Web sites.

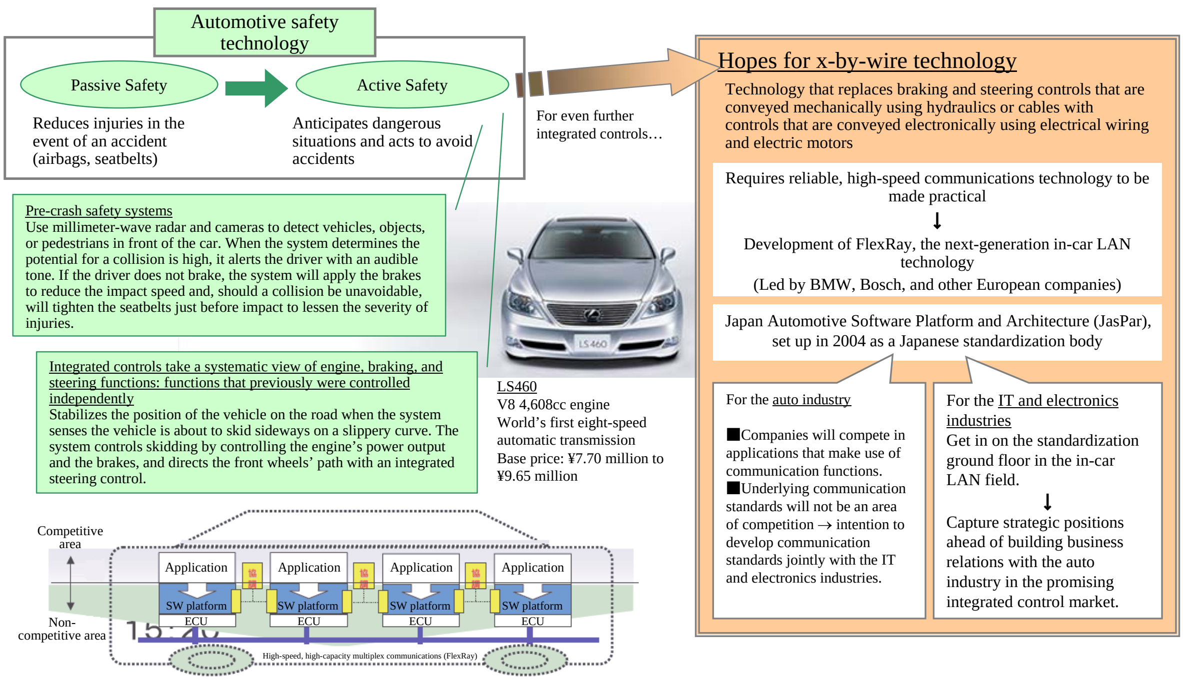
3. Progression of Integrated LAN-Based Controls and Establishment of Next-Generation Communication Standards

Automotive safety technology is transitioning from passive safety, which includes the use of airbags and seatbelts to reduce injuries in the event of an accident, to active safety, which anticipates dangerous situations and acts to avoid accidents. Some luxury cars already feature pre-crash safety systems. These systems use millimeter-wave radar and cameras to detect pedestrians or vehicles in front of the car. When the system determines a collision is possible, it alerts the driver with an audible tone. If the driver does not brake, the system will apply the brakes to reduce the impact speed and, should a collision be imminent, will tighten the seatbelts just before impact to lessen the severity of injuries. Other technologies are being put into practice that stabilize the vehicle's position on the road along curves by integrating control over the engine, braking, and steering functions: functions that previously were controlled independently. Beyond this, hopes are high for x-by-wire systems, which use in-car network technology, to realize even further integrated controls (Figure 17).

X-by-wire is a technology that replaces braking and steering controls that are conveyed mechanically using hydraulics or cables with controls that are conveyed electronically using electrical wiring and electric motors. Reliable, high-speed communications technology is necessary to make x-by-wire practical. European groups, such as BMW and Bosch, have taken the lead in this area and are moving ahead with the development of FlexRay, a new in-car LAN standard (Figure 18). In Japan, manufacturers came together to form Japan Automotive Software Platform and Architecture (JasPar) in 2004 to develop FlexRay. JasPar is a cross-industry standardization body with 112 corporate members (as of September 2007), including 12 automakers, 33 electrical/electronic architecture manufacturers, 42 software-tool venders, 15 electronic device and component producers, and 10 general trading companies.

Although the development of integrated control functions through network technology is a competitive area for all firms, the auto industry has determined that communication standards, which are the foundation of integrated controls, will not be an area of competition. The industry's intention is to efficiently develop communication standards jointly with the IT and electronics industries. The IT and electronics industries, by getting in on the ground floor in standardizing in-car LAN protocols, are believed to be seeking to capture strategic positions that will allow them to expand their trade with the auto industry in the integrated control market.

Figure 17. Progression of Integrated LAN-Based Controls and Establishment of Next-Generation Communication Standards



Source: Prepared by the Development Bank of Japan from the Toyota Motor and JasPar Web sites.

Figure 18. Comparison of In-Car LAN Protocols

	LIN	CAN	FlexRay
Official name	Local Interconnect Network	Controller Area Network	FlexRay
Primary developer	LIN Consortium (consisting primarily of European automakers)	Robert Bosch	FlexRay Consortium (consisting primarily of European automakers)
Transmission speeds	Slow (20 Kbit/s)	Medium (1 Mbit/s)	Fast (10 Mbit/s)
Channels	1	1	1 or 2
Communication method	Event-triggered	Event-triggered	Time-triggered
Applications / pros and cons	• Excellent cost performance in the slow-speed region • Light controls, door-mirror controls, etc.	• Popularized as the current global standard (widely used in key networks, power-train systems, and structural systems) • Because it is an event-triggered format, unpredictable delays can occur easily when multiple events are communicated at one time	• Being pushed for standardization as the in-car LAN protocol for next-generation x-by-wire systems, because of its high speed and high reliability due to its redundant communication channels

Source: Prepared by the Development Bank of Japan from various materials.

4. Increasing Efficiency in Automotive Software Development: The "Tripolarization" of Suppliers

The move to using more electronic controls in cars, and increasingly integrating those controls, is causing the burden — and the cost — of developing ECU-embedded software to soar. The quality of in-car software has a profound impact on technologies that aim to add more value to automobiles, namely through better fuel economy performance and safety. Consequently, new corporate alliances are being sought that can erect frameworks that permit efficient software development.

Until recently in Japan, engineers from Tier 1 suppliers have generally worked with the automaker right from the initial phase to develop the key parts for a new car model. Parts makers frequently create detailed designs working from the automaker's base specifications. Development operations are divvied up between the two sides according to their relative strengths, and the two sides piece together any overlapping issues. There is a strong tendency with ECUs as well to optimize development for specific functions — engine, brakes, or steering; very often ECU development is left in the hands of a few skilled individuals. But this conventional development methodology is quickly reaching its limits.[18] As controls become more deeply integrated, any single change to the software has telling consequences for the entire system. Throw in the worsening shortage of engineers and you have a situation where no automaker can handle ECU integration by itself. Even so, automakers are also increasingly aware they must take the initiative in joint software development; the natural rivalries among parts makers rule this out.

The auto industry is considering an approach whereby it would standardize software in the platform field and leave the application field for individual firms to try to differentiate their vehicles' functions. In this concept, the common platform would allow carmakers to realize integrated controls faster and cheaper than developing everything from scratch, because they only have to develop individual applications, for example, for brakes or for suspension. Daimler, BMW, Bosch, and others in Europe have already launched Automotive Open System Architecture (AUTOSAR), which aims to find common standards for in-car software and electrical/electronic architectures.

The fundamental question for platform development is where to draw the line between what is standardized and what is open to interpretation, and thus differentiation. It may be instructive to see how the mobile-phone sector dealt with this problem in its joint standards development. Renesas Technology — a large semiconductor manufacturer — worked in tandem with NTT DoCoMo, Fujitsu, Mitsubishi Electric, and Sharp to develop a mobile-phone platform that packaged a reference chip set and a basic software suite consisting of the operating system, middleware, drivers, and other assorted programs. This platform has been incorporated in handsets produced by Fujitsu, Mitsubishi Electric, Sharp, and Sony Ericsson.[19] Taking advantage of the common platform has helped handset makers in three ways: it spares them from developing all the basic mobile-phone functions individually, cuts development times and costs, and simplifies handset differentiation and model-line expansion.

It is not exactly fair of course to lump mobile phones and automobiles together since their development processes are dissimilar, but the salient point remains that standardization will not progress without someone seizing the initiative. Automakers are indeed the main players in the in-car software field, but there are expectations electronic component and device manufacturers will also take an active role in platform development, instead of taking a passive stance, if only because it improves their chances of involvement in later application development.

In another sense the movement to standardize ECUs, which previously were developed individually for each application, and to integrate key ECUs can be regarded as a new offshoot of the modularization trend. Past modularization centered on the assembly and integration of me-

[18] "Current Trends in Automotive Control Software," Takashi Shigematsu; see Toyota Technical Review Vol. 49, No. 2.

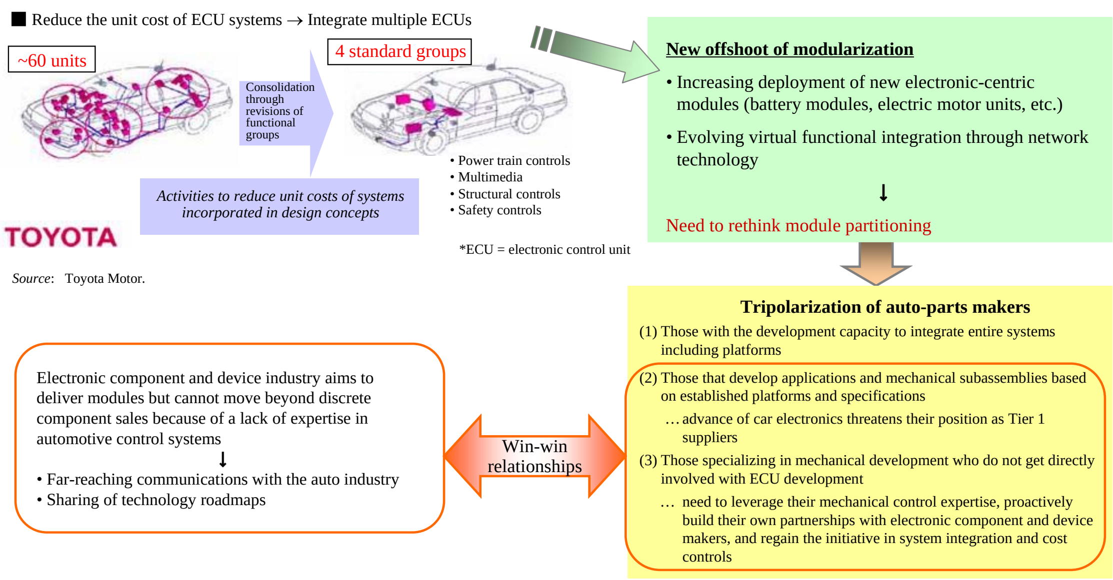
[19] Press release, Renesas Technology; see http://japan.renesas.com/media/company_info/news_and_events/press_releases/2007/1211/20071211j.pdf.

chanical parts. But it is now becoming a trend at the ECU and software level, evidenced by the appearance of new modules whose core is electronics, such as battery modules and electric motor units. Given the increasing deployment of electronic-centric modules and given the evolution of virtual functional integration through network technology that joins these modules together, some observers feel the partitioning of modules must be rethought.[20] In the near future, auto-parts makers may well be "tripolarized" into three separate camps: (1) those with the development capacity to integrate entire systems including platforms, (2) those that develop applications and mechanical subassemblies based on established platforms and specifications, and (3) those that specialize in mechanical development and do not get directly involved with ECU development.

This third group of mechanical specialists faces the greatest threat from deteriorating business conditions. It is crucial these suppliers break their dependence on external procurement of semiconductors and electronic parts where much structural control expertise is accumulated. To do this they must leverage their mechanical control expertise, proactively build their own partnerships with electronic component and device makers, and regain the initiative in system integration and cost controls. It is likely we will see more auto-parts makers buying software businesses since software development has become a vital factor in maintaining competitiveness in modules. Another change we are witnessing is the collapse of the conditions that allowed all automakers to nurture cross-held parts makers; automakers increasingly expect parts makers to build alliances on their own.

Although the electronic component and device industry recognizes it must aim to deliver modules to raise the profitability of its in-car business, industry firms are concerned they cannot move beyond discrete component sales because they lack expertise in automotive control systems. Nevertheless, there is thought to be plenty of potential to form win-win relationships with the auto industry by engaging in far-reaching communications with automakers and sharing technology roadmaps (Figure 19).

Figure 19. Raising the Efficiency of In-Car Software Development



Source: Prepared by the Development Bank of Japan.

[20] "Modularization Strategies of Japanese Automakers and Comparisons with U.S. and European Manufacturers," Takefumi Mokudai and Fujio Iwaki (2007), presented at the Asia-Pacific Automotive Forum, Tokyo 2007.

5. Advancement of Multimedia and Audio/Video Functions Centered on In-Car Information Terminals

Aside from electronics for control and structural systems, a third avenue of car electronics surging forward is multimedia and audio/video electronics. In-car multimedia and audio/video electronics add to the convenience and enjoyment of driving. Leading car companies have already launched services connecting car navigation units and mobile phones wirelessly (with Bluetooth) to offer destination settings and information on neighboring attractions. And with the oncoming establishment of ITS and other public infrastructures, carmakers hope to commercialize services that control cars in conjunction with map and road information and diagnose faults remotely based on stored data on past driving conditions. Essential to bringing about these expectations, however, will be coordinated control of in-car information terminals with the vehicle's control and structural systems.

NEC and NEC Electronics in December 2007 announced they were developing a microprocessor and operating system for a next-generation in-car information platform in partnership with Toyota Motor, Aisin AW, and Denso (Figure 20). The companies claim this development will shorten design cycles, ensure the continuation of developed software assets, and simplify revisions and applications. The three automobile-related companies plan to proceed with development with a target of incorporating the technology beginning in 2010 in Toyota cars outfitted with multimedia information devices. They are also aiming to make their technology into an industry standard and thereby get other automakers and IT corporations to adopt it.[21] While automakers are certainly the central players in development for the environment and safety sectors, they are said to favor repurposing advanced consumer-level multimedia and audio/video technology for automotive applications. This means there is plenty of leeway for electronic device and component producers to take the lead in developing in-car information terminals. It is expected they will actively put forth proposals in this area.

Internet-vehicle convergence is another area gathering widespread attention. If car navigation units can connect to the Net, drivers and passengers will be able to look up nearby attractions and book hotel accommodations much more easily than now. On-demand music and video will also become possible. For car companies, enhanced in-car entertainment will make cars more attractive and easier to pitch to consumers. Certainly questions about greater communication volumes and more base-station installations must be addressed to ensure stable Internet connectivity during highway driving. But backers of WiMAX — a next-generation high-speed wireless communication technology now in development — say that if the technology is employed along highways, uninterrupted Net connections will be possible while driving. We have seen carriers actively collaborate with Google, Yahoo, and other Internet companies as Net access from mobile phones was rolled out on a wide scale. Similarly, the potential is there for closer ties with Net companies in the auto sector.

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[21] NEC Electronics Web site; see http://www.necel.com/news.ja/archive/0712/1103.html.

Figure 20. Advancement of Multimedia and Audio/Video Functions Centered on In-Car Information Terminals

Establishment of ITS and other public infrastructures

↓

Control cars in conjunction with map and road information
Remote diagnostic services based on stored data on past driving conditions

Coordinated control of in-car information terminals with the vehicle's control and structural systems is essential

Moving forward…

Internet-vehicle convergence

WiMAX (a next-generation high-speed wireless communication technology)

- Uninterrupted Net connections will be possible while driving
- Potential for closer ties with Net companies in the auto sector (Google, Yahoo, etc.)

December 2007

NEC and NEC Electronics announced they were developing a microprocessor and operating system for a next-generation in-car information platform in partnership with Toyota Motor, Aisin AW, and Denso

→shortens design cycles, ensures the continuation of software assets, and simplifies revisions and applications

- Automakers are the central players in development for the environment and safety sectors

  But they repurpose advanced consumer-level multimedia and audio/video technology for automotive applications

- Electronic device and component producers have plenty of room to take the lead and actively put forth proposals for the development of in-car information terminals

Source: Prepared by the Development Bank of Japan.

IV The Auto Sector and Emerging Distributed Business Models in the Electronic Device and Component Industry

Dell and others have risen to prominence in the computer industry by outsourcing production to low-cost manufacturers in Taiwan and other locations, leaving them to focus on design, development, and sales in order to differentiate their brand through design and distribution. That this is possible is partly due to the fact that key semiconductor components by Intel and operating systems by Microsoft are sold as industry-wide standard products, which compels computer makers to rely on external venders for device-control expertise. A similar trend is seen in LCD TVs, one of the hottest digital consumer products, where the presence of U.S. fabless companies such as Vizio is on the rise. Their business model is to purchase panels and semiconductor chip sets from third-party venders and outsource assembly. Japan's vertically integrated TV makers in most circumstances produce their own system LSI chips — the key devices for video and audio processing. But the worldwide trend is moving toward distributed business models, in which fabless semiconductor companies specialize in circuit design and software development while semiconductor foundries produce devices to order taking advantage of their cost competitiveness derived from large-scale investment (Figure 21).

In this way electronics firms are selling their device-control expertise to other firms. It is becoming possible to create at least commodity-level products by assembling inexpensive parts procured around the world. The distributed business model is becoming more persuasive not only at the end-product level but also, as we will see below, at the level of semiconductors, where control expertise is embedded.

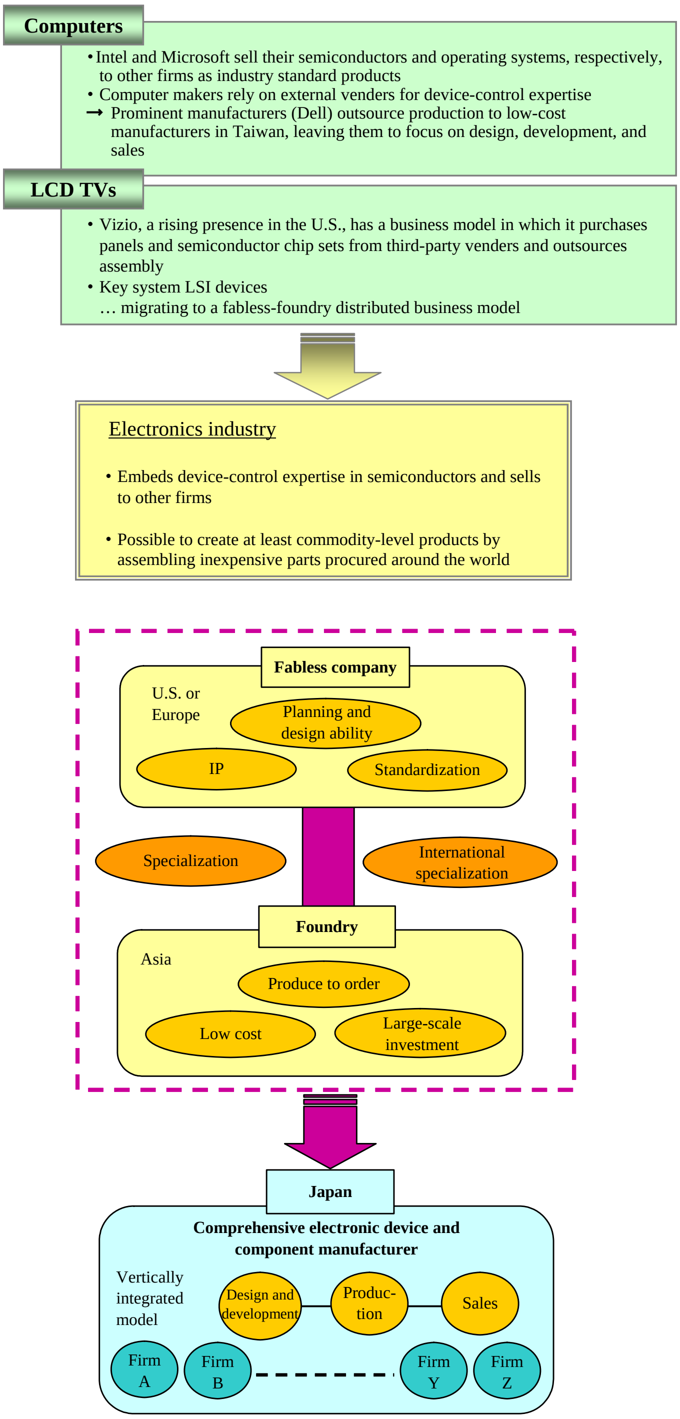
So, as semiconductors become key devices in cars, is it possible for distributed business models to take root in the auto sector, as they have in computers and digital home electronics? The short answer: probably not (Figure 22).

The functions of cars are realized through the integration of tens of thousands of parts, which requires the special expertise of the automaker. Thus, even when automakers do consider adopting distributed frameworks to develop in-car software, the primary objective is to make progress on the structural and hierarchal fronts to cope with ballooning software development volumes. But automakers are expected to remain the central players in upstream areas — overall system design based on automotive-control know-how and the partitioning of software and hardware.

There are several reasons for this. Automakers prioritize reliability over cost when it comes to automotive semiconductors and the required quality levels are a magnitude higher than those for consumer electronics. This makes it necessary to have specialized development frameworks and production controls that are finely tuned to automotive applications. Another difference from the consumer electronics business is product turnaround. Whereas cycles of just six months are common in consumer electronics, automotive applications require secure supplies for at least ten years or so. And since most products are customized, there are limits on their production volumes. This is why vertically integrated semiconductor companies — which handle design, development, and production in a comprehensive fashion — have the advantage in automotive semiconductors. Full adoption of fabless-foundry models is seen to be difficult, at best.

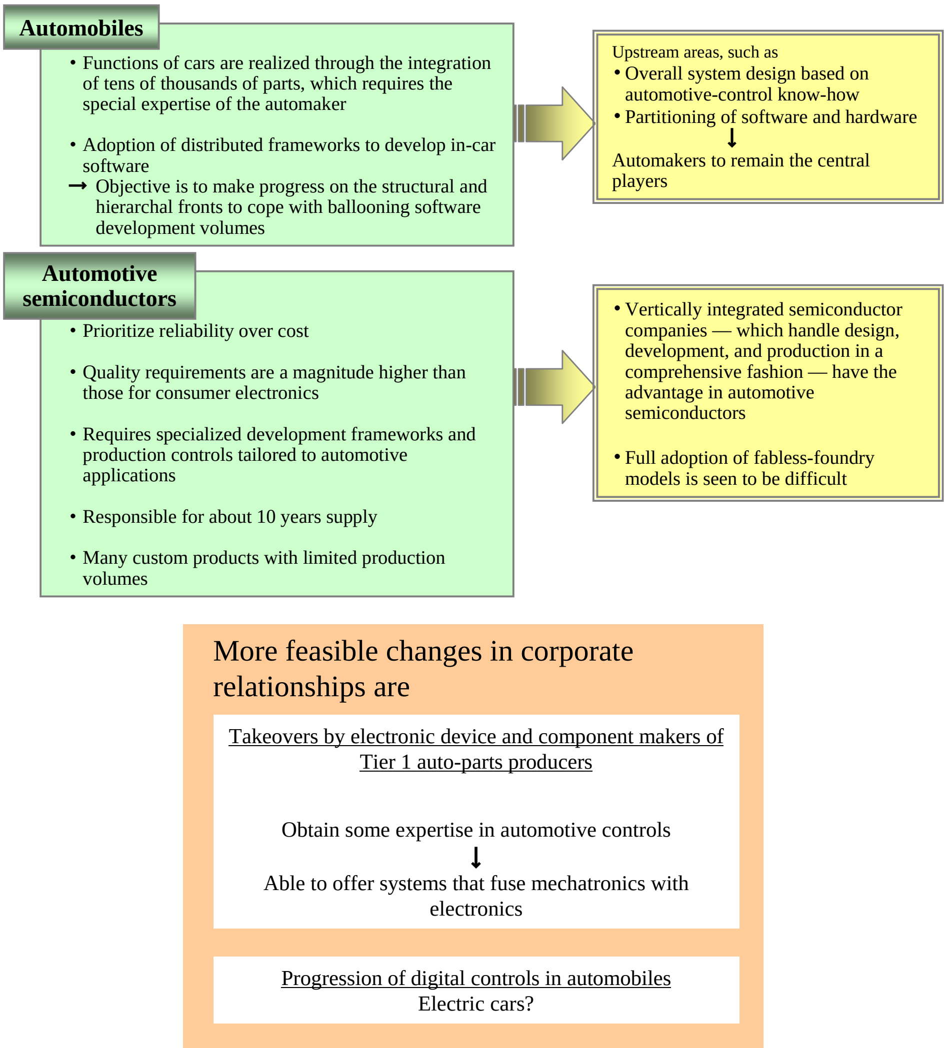
What is considered more likely are takeovers by electronic device and component makers of Tier 1 auto-parts producers. If through strategic acquisitions electronic device and component makers can obtain some control expertise in automotive engines or power trains, they will be capable of offering systems that fuse mechatronics with electronics, which will promote their standing with automakers. Corporate alliances could also be altered by the advancement of digital controls — brought about by technical innovation in automobiles — that are fundamentally different from the knowledge capital automakers possess. Electric cars, which are acclaimed as the future incarnation of the passenger vehicle, are seen as having the potential to revolutionize automotive systems.

Figure 21. Emerging Distribution Business Models in the Electronic Device and Component Industry



Source: Prepared by the Development Bank of Japan.

Figure 22. Potential for Distributed Business Models in the Auto Sector



Source: Prepared by the Development Bank of Japan.

V Directions for Car Electronics in the Promising Low-Cost Auto Sector

Auto sales in the four BRICs countries — Brazil, Russia, India, China — now accounts for 17 percent of the 62.85 million vehicles sold worldwide; more than 10.70 million cars were bought in these four countries in 2005 (Figure 23). If current growth rates continue, the BRICs car market is predicted to become the world's largest in the early 2010s, eclipsing the U.S. market of about 17.00 million vehicles.

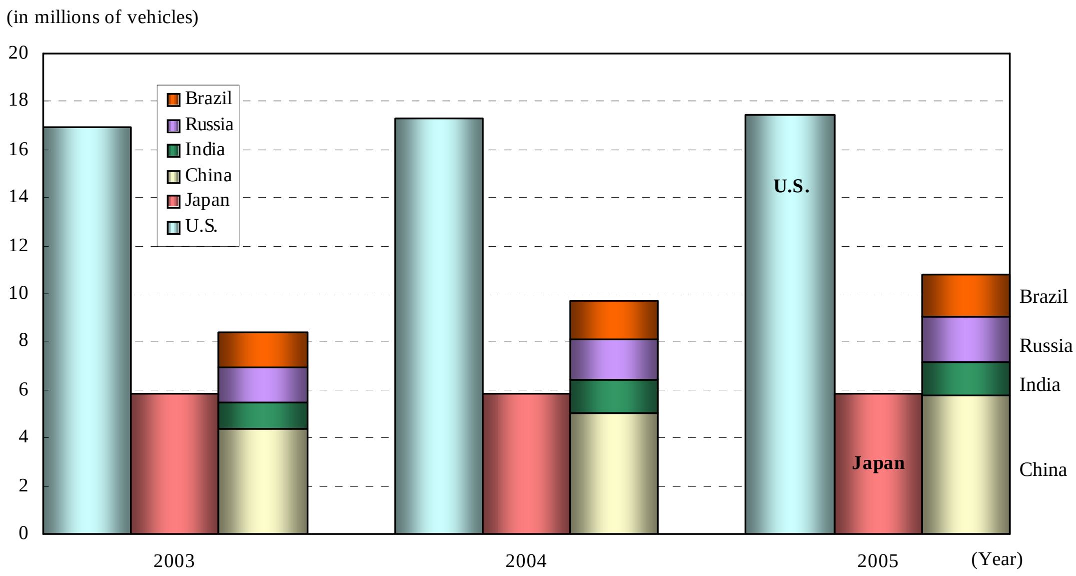
More than half of BRICs sales occur in China, which bought 5.76 million vehicles in 2005. Although only 1.43 million vehicles were sold in India, India's annual growth rate over 2003 to 2005 hit 15.2 percent, overtaking China's 14.5 percent expansion.[22] Other than in China, future auto-sales showdowns are expected to take place in India, the Middle East, Africa, and other developing regions.

The photo in Figure 24 shows the Nano, a one-lakh car (one lakh equals 100,000 rupees, or about ¥280,000) developed by Indian automaker Tata Motors, at the Ninth Auto Expo in New Delhi, India, held in January 2008. The four-passenger Nano is powered by a 623 cubic centimeter, two-cylinder engine that delivers 33 horsepower. With a length of 3.1 meters, a width of 1.5 meters, and a height of 1.6 meters, the Nano is comparable to Japanese mini-compacts, although it has a shorter overall length.

Automobiles are still out of reach for the vast majority of Indians not from the tiny wealthy minority. Motorcycles and scooters are the most popular means of easy transport. At a price of just under 40,000 rupees, two-wheelers are affordable on the average worker's monthly income of about 10,000 rupees (approximately ¥28,000), provided a loan can be arranged.

The cheapest Nano, however, with a price tag of about half that of Maruti Suzuki India's best-selling Maruti 800, will potentially turn motorcycle users into new car buyers. Tata's offering, along with Hyundai Motor, Renault, and others announcing they will roll out vehicles in the 3,000 to 5,000 dollar range, highlights the increasing competition among global carmakers to develop low-cost cars, which will become the prime battleground in the coming years.

Figure 23. Automotive Sales in the U.S., Japan, and BRICs by Volume



Source: Japan Automobile Manufacturers Association.

[22] Growth rates over the same period in Russia and Brazil were 12.6 percent and 9.6 percent, respectively.

Still it is no easy matter to develop cars in the ¥300,000 to ¥500,000 range and maintain quality and a brand image. Moreover, in the Indian market, even the lowest priced cars must possess proper environmental and safety performance to meet India's progressively toughening automotive environmental and safety standards.[23] To produce cars this cheaply priced, costs apportioned to parts and materials are believed to be kept tightly in check, meaning electrical components, which have to pass legal requirements, are kept to a bare minimum.

In this environment of razor-thin profit margins, it is important that electrical/electronic architecture manufacturers earn by selling in volume — through diversification and expansion of their customer base — and cutting costs substantially by changing materials, reducing amounts of materials used, and improving production processes. Japanese manufacturers are also believed to have room in India to construct efficient diversified frameworks between Japan and India to develop embedded software and thus take advantage of the huge local pool of inexpensive, well-trained IT engineers (Figure 26).

An approach Japanese parts manufacturers should explore is cooperating or forming partnerships with Western or local parts manufacturers already in these emerging markets to lower their risks. One example of a company taking this approach is Germany's Bosch, which is expending considerable resources on developing expertise in providing electrical architectures at competitive prices in India and other emerging markets. Bosch, in partnership with a local Indian manufacturer, is pursuing development of an electronically controlled diesel/gasoline direct-injection system as well as tackling the development of in-car networks for local automakers.[24]

Only a small percentage of cars in developing countries are equipped with safety accessories such as ABS or airbags or options such as air-conditioners, music systems, or car navigation units because the current prices are high. Yet there are definite latent needs for increased safety and comfort. The first electrical/electronic architecture manufacturers that can drastically slash their production costs from today's levels have an enormous market waiting for them. Japanese makers are expected to aggressively tackle this challenge head on.

[23] On its Web site, Tata Motors states that the Nano passes all current safety and environmental standards.

[24] According to "Robert Bosch India at a Glance," Robert Bosch India Limited.

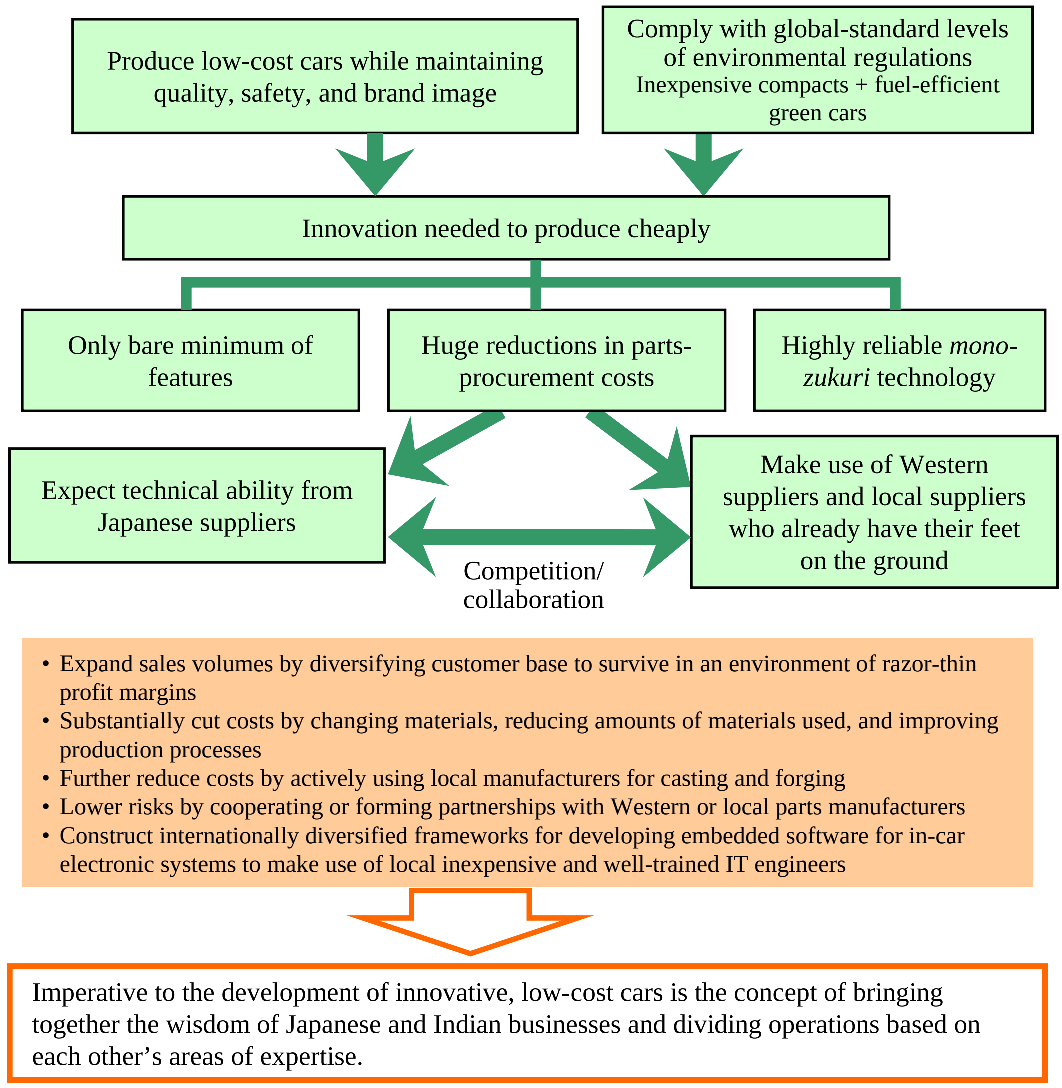
Figure 24. Nano, A Low-Cost Car from India's Tata Motors

Photo taken by the author

Figure 25. Prototype Mini-Car from Bajaj Auto, an Indian Motorcycle Firm

Photo taken by the author

Figure 26. Japanese Automakers' Conceptual Strategy for Low-Cost Cars in India



Source: Prepared by the Development Bank of Japan.

Conclusion

Recognizing the swift advancement of auto electronics, all parties in the auto industry are currently scrambling to construct ties with the electronic device and component industry but, unlike the computer and digital home electronics field, are doing so without a clear demarcation between competition and collaboration. It goes without saying that electronic device and component manufacturers should pour as many resources as they can into satisfying their clients' quality and price demands. But to apply Japan's world leading consumer-electronics technologies to automotive uses, automakers, in recognition of their leadership position, have to step forward and define the competitive from the non-competitive and build cross-industry partnerships in non-competitive areas.

In the West, collaborations between industry, administration, and academia are already actively moving ahead with development of next-generation automotive technologies. In Europe, seven firms — Audi, BMW, Daimler, Bosch, Continental AG, and the semiconductor firms Elmos and Infineon — with assistance from the German Ministry of Education and Research, will be investing more than 500 million euros in a joint project for car electronics technology R&D starting in 2008.[25] The project places emphasis on developing technologies not only for safety aspects, such as driver-assistance systems, but also for environmental aspects, such as improving engine efficiencies and curbing exhaust emissions. In the United States, university-launched venture enterprises are active in R&D. One of these, A123 Systems — which is involved in joint development of lithium-ion batteries with General Motors — was established with assistance from the U.S. Department of Energy and is pursuing development after amassing about 130 million dollars in seed money from funds and other sources.[26]

Referencing these examples, Japan needs to strengthen ties between industry, administration, and academia in the area of next-generation car development as well as harness its world-class *mono-zukuri* [perfection of manufacturing] technology, in collaboration with the electronic device and component industry, and work to take the world lead in standardizing electronic control platforms.

[25] See the Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart (FKFS) Web site, http://www.fkfs.de/no_cache/unternehmen/news-presse/presse-detail/article/37/1/f57022402d/. According to the FKFS, electrical and electronic technologies account for 30 percent of the added value in midsized cars and contribute as much as 90 percent to automotive innovation.

[26] Wall Street Journal, January 11, 2008 edition.

References

Denso Technical Review, Vol. 10, No. 2 (2005).

Institute of Electrical Engineers of Japan, “Jidosha Dengen no 42V-ka Gijutsu (42V Technology for Automotive Power Systems),” Study Committee on 42V Power Systems, eds., (2003), Ohmsha.

Nikkei BP, “Car Electronics no Subete (All about Car Electronics),” Nikkei Automotive Technology (2005).

Seiichi Shin, “Zukai Car Electronics Saizensen (Front Line of Schematic Car Electronics),” (2006) Kogyo Chosakai Publishing.

Toyota Technical Report, Vol. 49, No. 2 (1999).

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