



IS EUROPE IN THE DRIVER'S SEAT? THE COMPETITIVENESS OF THE EUROPEAN AUTOMOTIVE EMBEDDED SYSTEMS INDUSTRY

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EUR 24601 EN - 2010

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JRC 61541

EUR 24601 EN
ISBN 978-92-79-17658-6
ISSN 1018-5593
doi:10.2791/49525

Luxembourg: Publications Office of the European Union

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Printed in Spain

Acknowledgements

This report was commissioned by the Information Society Unit at the Institute for Prospective Technological Studies (JRC-IPTS) and produced¹ by Egil Juliussen and Richard Robinson, two senior experts of iSuppli Corporation,² a global consultancy for applied market intelligence. It is part of the study "Competitiveness by Leveraging Emerging Technologies Economically" (COMPLETE) which is jointly funded by Directorate-General for Enterprise and Industry (DG ENTR) and JRC-IPTS.

The authors would like to thank the numerous industry representatives, academics and staff from public authorities for their comments and reviews of earlier drafts. In addition, Geomina Turlea and Marc Bogdanowicz, both from IPTS, are acknowledged for their support and comments throughout the project.

The research was presented and discussed for validation in April 2010, at an international expert workshop attended by representatives from the European Commission and industry experts (see Appendix 4), all of whom offered many valuable comments and viewpoints. The work benefited from outstanding support from Enrique de Aresti Gutierrez of DG ENTR D.3, European Commission. Finally, the skilful checking and editing of the report by Patricia Farrer (IPTS) is gratefully acknowledged.

Although these contributions were substantial, the responsibility of this final version clearly remains with the authors.

¹ Contract n°: IPTS-2009-J04-17-NCJRC/IPTS

² For more about iSuppli Corporation, see at: <http://www.isuppli.com/Pages/Home.aspx>

Preface

Information and Communication Technology (ICT) markets are exposed to more rapid cycles of innovation and obsolescence than most other industries. As a consequence, if the European ICT sector is to remain competitive, it must sustain rapid innovation cycles and pay attention to emerging and potentially disruptive technologies.

In this context, the Directorate-General for Enterprise and Industry (DG ENTR) and the Institute for Prospective Technological Studies (JRC-IPTS)³ have launched a series of studies to analyse prospects of success for European ICT industries in the face of technological and market innovations.⁴ These studies, under the common acronym "COMPLETE",⁵ aim to gain a better understanding of the ICT areas in which it would be important for the EU industry to remain, or become, competitive in the near future, and to assess the likely conditions for success.

Each of the 'emerging' technologies (or families of technologies) selected for study are expected to have a potential disruptive impact on business models and market structures. By their nature, such impacts generate a moving target and, as a result, classical well-established methodologies cannot be used to define, observe, measure and assess the situation and its potential evolution. The prospective dimension of each study is an intrinsic challenge that has to be solved on a case-by-case basis, using a mix of techniques to establish lead-market data through desk research, expert group discussions, company case analysis and market database construction. These are then combined with reflection on ways and means to assess future competitiveness of the corresponding industries. This process has resulted in reports that are uniquely important for policy-makers.

Each of the COMPLETE studies illustrates in its own right that European companies are active on many fronts of emerging and disruptive ICT technologies and are supplying the market with relevant products and services. Nevertheless, the studies also show that the creation and growth of high tech companies is still very complex and difficult in Europe, and too many economic opportunities seem to escape European initiatives and ownership. COMPLETE helps to illustrate some of the difficulties experienced in different segments of the ICT industry and by growing potential global players. Hopefully, COMPLETE will contribute to a better understanding of the opportunities and help shape better market conditions (financial, labour and product markets) to sustain European competitiveness and economic growth.

This report reflects the findings of a study conducted by Egil Juliussen and Richard Robinson, two senior experts from iSuppli Corporation⁶ on the Competitiveness of the European Automotive Embedded Software industry. The report starts by introducing the market, its trends, the technologies, their characteristics and their potential economic impact, before moving to an analysis of the competitiveness of the corresponding European industry. It concludes by suggesting policy options. The research, initially based on internal expertise and literature reviews, was complemented with further desk research, expert interviews, expert

³ IPTS is one of the seven research institutes of the European Commission's Joint Research Centre (JRC).

⁴ This report is one out of a series, part of the umbrella multiannual project COMPLETE, co-financed by DG ENTR and JRC/IPTS for the period 2007-2010 (Administrative Arrangement ref. 30667-2007-07//SI2.472632)

⁵ Competitiveness by Leveraging Emerging Technologies Economically

⁶ For more about iSuppli Corporation, see at: <http://www.isuppli.com/Pages/Home.aspx>

workshops and company visits. The results were ultimately reviewed by experts and also in a dedicated workshop.⁷

The report concludes that currently ICT innovation in the automotive industry is a key competence in Europe, with very little ICT innovation from outside the EU finding its way into EU automotive companies. A major benefit of a strong automotive ICT industry is the resulting large and valuable employment base. But future maintenance of automotive ICT jobs within the EU is only possible if the EU continues to have high levels of product innovation.

Fortunately, there are several technology and market trends that provide significant opportunities for the European automotive embedded software and system industry. However, there are also growing threats that must be considered and counteracted. Table 1 summarizes the key trends and perspectives on how the European companies can maintain their leadership in the next decade. The summary is organized by the main automotive embedded system categories.

Table 1 - EU Automotive Embedded Systems Competitiveness Summary		
	Key Information	Comments
Core Auto ECUs	<ul style="list-style-type: none"> • EU leadership in multiple domains • AUTOSAR will help retain this leadership • Future AUTOSAR commoditization is a threat 	<ul style="list-style-type: none"> • Engine, chassis, safety and others • EU to lead AUTOSAR updates • Competition from standard systems
EV ECUs	<ul style="list-style-type: none"> • Too focused on combustion engine • EV: when-question, not if-question • EU EV development is behind • EV battery systems need innovation • EV high-voltage electronics is important 	<ul style="list-style-type: none"> • EU strength, but will fade post 2020 • EU has the most to lose • EU effort needed to catch up • EU innovation opportunities • High-voltage chips is EU strength
ADAS and V2X	<ul style="list-style-type: none"> • EU has ADAS leadership • ADAS requires • EU has strong V2X system R&D projects 	<ul style="list-style-type: none"> • ADAS leadership likely to remain • Major future growth market • EU need to lead deployment phase
Infotainment	<ul style="list-style-type: none"> • Strong EU position in current systems • Moving to computer platform architecture • EU software position needs improvement • Genivi software platform is best EU opportunity • Auto App Stores to be important 	<ul style="list-style-type: none"> • Head-unit and navigation strongest • USA leads via QNX and Microsoft • PC and consumer electronics • Auto Android platform is dark horse • EU leadership is needed
Connected Car Applications	<ul style="list-style-type: none"> • EU is behind in connected car applications • eCall regulation would kick-start EU deployment • Multiple communications coming 	<ul style="list-style-type: none"> • USA leads via OnStar and Ford Sync • Software innovation to catch up • V2X is future communication link

Source: Authors' own elaboration.

New software intensive automotive features are and will continue to emerge in multiple segments. The key for the EU automotive industry is to lead and innovate as these technologies emerge and enter volume production.

David Broster
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⁷ See Appendix 4

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Executive Summary

The European automotive industry has done well in the last 40 years despite growing competition from an increasing global market place. In the next two decades, however, the automotive industry in key developed regions such as Europe, North America and Japan, will see increasing competition from low-cost countries that are now building a formidable automotive industry production and consumption market. Similar events have happened in the past in other industries, ranging from ship building and steel production to the PC and consumer electronics industries—at least in the hardware production segments.

This report aims to answer the key question: how can the European automotive industry retain its strong current position and prosper in an increasingly competitive global automotive industry? The short answer is relatively simple: information and communication technologies (ICT) will play a crucial role and the EU must retain its leadership in most automotive ICT segments. The ICT software segment is especially important because it is based on knowledge and innovation, which in theory could be developed in any geographic region.

Economic Overview of the Automotive Industry

The automotive industry is one of the largest industries in Europe and provides significant economic benefits in terms of employment, export value and in many other segments. Table 2 summarizes key trends in the EU automotive industry compared to other major industrial regions.

Table 2 below presents figures for car sales: this measurement (of car consumption) is based on the registrations of new cars in a region. These new car sales can be produced in any region and exported to any region. Global car sales were projected to drop to 63 million units in 2009, but are forecast to top 94 million units in 2020. The EU share of global car sales will decline in the next decade as the developing countries acquire more cars.

Table 2 - EU Position in Automotive Industry (Sales)							
	2008	2009	2010	2011	2012	2015	2020
Global Car Sales (000 vehicles)	66,019	63,186	65,885	69,130	72,710	83,300	94,280
W. Europe Sales Share (%)	23.29	23.65	21.75	21.31	20.97	20.17	19.03
EU27 Sales Share (%)	24.67	24.52	22.93	22.38	22.03	21.15	20.11
USA Sales Share (%)	20.07	16.51	17.67	18.41	19.08	20.00	18.56
Japan Sales Share (%)	7.68	7.28	7.12	6.94	6.78	6.31	5.80
China Sales Share (%)	13.08	19.77	20.70	20.48	20.27	20.12	20.96

Table 3 presents figures for car production: This metric is measured as manufacturing output, and had an even steeper decline than sales in 2009, due to over-production of vehicles in some regions in 2008, as most automotive manufacturers were not able to lower production as fast as the sales declined. Automotive production is projected to increase at a steady rate in the next decade and is forecasted to surpass 95.6 million units in 2020. However, any regional or global recessions will reduce both car sales and production. Most of the European automotive manufacturers sell their cars outside Europe and their success abroad will become increasingly important as a substantial amount of future growth will come from non-EU regions.

The global and European automotive industry has an overcapacity problem and can produce more cars than it can sell. This overcapacity problem has been with the industry for decades and is not likely to go away anytime soon. The result is that styling, price and features are used to differentiate market segments and sell cars. These features are increasingly based on a car's ICT capabilities and this trend will grow stronger in the next decade. There is general agreement in

the automotive industry that electronics systems defined by embedded software have become a key, if not *the* key, technology for the automotive industry.

Table 3 - EU Position in Automotive Industry (Production)							
	2008	2009	2010	2011	2012	2015	2020
Global Car Production (000 vehicles)	70,525	59,452	65,120	69,530	73,700	84,210	95,680
W. Europe Production Share (%)	20.52	20.13	19.99	19.63	19.16	18.11	17.11
EU27 Production Share (%)	25.12	25.17	24.71	24.12	23.54	22.49	21.47
USA Production Share (%)	12.34	10.96	11.01	10.94	10.96	11.45	11.61
Japan Production Share (%)	16.39	13.33	13.68	14.12	14.33	14.21	13.24
China Production Share (%)	13.25	21.09	20.84	20.94	21.21	21.65	22.24

The European automotive industry is strong in automotive ICT products and Table 4 summarizes why this has happened. The key to strong European suppliers is that most ICT products first appear in luxury vehicles. Europe has three major luxury automotive manufacturers, BMW, Mercedes-Benz and Audi. The suppliers to these luxury brands have needed to be innovative in their ICT product development, and many have become world leaders in the automotive ICT segments. European volume manufacturers have benefitted from luxury car innovations, and have migrated leading-edge ICT to the mid-range market segments as prices have declined with volume production and technology advances. ICT business from non-EU automotive manufacturers has typically followed many of the developments of the leading brands within the EU ICT supplier sector.

Table 4 – EU Position in ICT in the Automotive Industry		
	Key Information	Comments
Luxury Auto Position	<ul style="list-style-type: none"> • Luxury cars always ICT • EU has 3 top luxury brands 	<ul style="list-style-type: none"> • Due to initial high ICT price • BMW, Mercedes-Benz and Audi
Strong ICT Suppliers	<ul style="list-style-type: none"> • ICT innovation for luxury brands • Later ICT for volume brands • Non-EU ICT business follows 	<ul style="list-style-type: none"> • Early market entry and leadership • Learning curve and tech advances • From non-EU car manufacturers
Independent Car Suppliers	<ul style="list-style-type: none"> • All key EU suppliers independent • Captive suppliers in USA and Japan 	<ul style="list-style-type: none"> • Strong competition and business savvy • Delphi/Visteon/Denso captive earlier
Key ICT Suppliers	<ul style="list-style-type: none"> • Bosch and Continental are leaders • Autoliv, Hella, Valeo, others 	<ul style="list-style-type: none"> • Across most ICT segments • Leaders in specific ICT segments
Software Companies	<ul style="list-style-type: none"> • Many small, strong companies • Mostly focused on EU ICT 	<ul style="list-style-type: none"> • Focused on specific car manufacturers • Some global success, more is likely
Automotive Semiconductor	<ul style="list-style-type: none"> • Infineon and ST Micro are leaders • NXP and other are strong 	<ul style="list-style-type: none"> • Across many ICT segments • Leaders in specific ICT segments

Second, European automotive suppliers have not typically been captive to any automotive manufacturer, and this has made them very competitive and business savvy compared to the key suppliers in USA and Japan. For example, Delphi was a GM subsidiary until 1999, however the transition to becoming an independent entity created major problems for this company and it has just come out of a four-year bankruptcy procedure. Similarly, Visteon was a Ford subsidiary until 2000 and has also had major problems in becoming an independent company. Visteon filed for bankruptcy reorganization in May 2009. Denso, however, was a captive supplier to Toyota in Japan, but has been much more profitable as an independent automotive supplier company, than either Delphi or Visteon.

The EU has two ICT suppliers that are leaders in multiple ICT segments and are overall global automotive ICT leaders: Bosch and Continental. Several smaller EU suppliers are focused on being leaders in selected ICT segments: e.g. Autoliv, Hella and Valeo.

Europe has many small but highly influential automotive software companies. Most of these were founded as suppliers to specific automotive manufacturers, however many have expanded and now supply to a range of EU and non-EU automotive manufacturers. There are no dominant embedded software suppliers in Europe or any other regions; the market is characterized by many small companies that focus on selected software segment and/or specific automotive manufacturers.

The last part of the ICT supplier value chain is the range of semiconductor companies that provide microcomputer chips, sensors and other electronic components to the automotive sector. The EU has two of the top companies, Infineon and ST Microelectronics, which supply a wide range of automotive semiconductor components. NXP and other semiconductor companies are strong in certain component segments.

Drivers of Change in the Automotive Sector

Automotive technology has changed considerably over the last two decades and much more change is on the way. This report focuses on explaining trends that have impact on ICT and electronics technology used in cars. Both external and internal forces are impacting automotive electronics systems. Table 5 summarizes key trends that are driving forces for automotive ICT products.

Table 5 - Automotive Trends Summary		
	Key Information	Comments
Environmental Issues	<ul style="list-style-type: none"> • Lower emissions • Better fuel efficiency • Less traffic congestion 	<ul style="list-style-type: none"> • Most improvements from ICT • Most improvements from ICT • Emerging ICT shows promise
Accident Cost Mitigation	<ul style="list-style-type: none"> • Passive systems protect in a crash • Active systems avoid crashes 	<ul style="list-style-type: none"> • New systems are ICT based • New ICT warn/correct driver errors
Connected World and Car	<ul style="list-style-type: none"> • Drivers want to be connected • Car systems need connections 	<ul style="list-style-type: none"> • New ICT systems for connection • Emerging ICT functions
Infotainment Expansion	<ul style="list-style-type: none"> • Digital music growth • Mobile device growth • Digital TV/Video emerging 	<ul style="list-style-type: none"> • Used in car audio systems • Connected to car audio systems • Connected to passenger systems

- **Environment issues:** Environmental issues are mostly driven by regulations which aim to lower emissions and fuel usage. These are having tremendous impact on the automotive industry. Reducing emissions and improving fuel-efficiency depend on reducing the weight, optimizing aerodynamics and also on improving the powertrain, and advising drivers on optimized driving or route to follow, notably with the help of electronics and associated embedded applications.⁸ These electronics systems improve the efficiency of the internal combustion engine (ICE) and are key to the development of electric motor-based power systems.
- **Accident avoidance and mitigation:** Accident avoidance and mitigation can be improved by greater use of electronics and software systems in the form of driver assist and ADAS products that ‘correct’ many of the errors made by human drivers.

⁸ http://www.rmi.org/Content/Files/E07-04_Stanford_3Transport.pdf

- **Connectivity:** Many consumers are now used to the convenience of a connected-world through their PCs and mobile devices. Drivers and passengers now want to be connected in the car, and also to have their cars connected. This is particularly the case for a new generation of consumers that have become used to Internet access and mobile phone services. The automotive manufacturers also need connection to test, diagnose and update the many electronics systems in cars because of significant cost savings and reliability improvements.

Table 6 gives more information on the key impacts of the above trends by automotive domain.

Table 6 - Key Automotive Trends		
	Key Information	Comments
Powertrain Trends	<ul style="list-style-type: none"> • Gas and diesel engine will improve • Electric vehicle importance growing • EV's electricity from many sources • Long-term EV will become leader 	<ul style="list-style-type: none"> • Mostly due to electronics advances • EV is a when-question, not if-question • Battery, engine-generator, hydrogen • Is it in 2025 or 2035?
Driver Assist and ADAS Trends	<ul style="list-style-type: none"> • Mostly warning systems • Mostly for luxury cars • Driver error correction emerging • Collision mitigation emerging • Future integrated systems 	<ul style="list-style-type: none"> • Lane, blind spot, speed, parking • Ultrasound park assist is exception • Stability control and others • Improves safety systems effect • Based on ICT
Connected Car Trends	<ul style="list-style-type: none"> • Multiple communication links • Telematics applications and services • Connected navigation systems • Connected auto control systems 	<ul style="list-style-type: none"> • Embedded, driver phone and others • eCall, safety and infotainment functions • Traffic information and others • Remote diagnostics and others
Entertainment Trends	<ul style="list-style-type: none"> • Digital radio receivers • Digital music player interfaces • Internet radio emerging • Premium audio systems 	<ul style="list-style-type: none"> • Satellite radio in some regions • USB, iPod and streaming Bluetooth • High bandwidth communication link • Surround sound music systems

- **Powertrain:** The environmental trend is having a tremendous impact on Powertrain systems. Gasoline and diesel engines will see large improvements in the next decade as they are challenged by electric vehicles. Electronics features will provide much of the needed improvements in fuel efficiency and emissions. Electric motors can get electricity from multiple sources including batteries, engines as generators, and hydrogen. In the next decade most Electric Vehicles (EVs) will use batteries and a small engine-generator to extend the driving range of the vehicle. Electric motor technologies will improve in performance and cost and eventually electric vehicles will become mainstream technology. While the actual timing of this is uncertain, it is likely to happen between 2020 and 2030.
- **Driver assist and ADAS:** Accident avoidance and mitigation is the driving force behind safety systems such as airbags, antilock brakes, electronic stability control and the many driver assist systems. Driver assist products are warning systems that can lower accident rates. ADAS applications are adding features that can mitigate accident impact by calculating that an accident will occur and then performing actions that better protect the driver and passengers. ADAS is also adding functionality that corrects driver errors and avoid accidents.
- **Connected car:** The connected car is expected to have more than one communication link. Currently, both GM OnStar and BMW use an embedded cellular modem for some applications and are also connecting automotive systems to the driver's mobile phone for other applications. At least two more connections are on the way:
 - Cellular communication to an embedded WiFi router that connects any device in the car,
 - V2V-V2I communication systems. These connections will be used by telematics, navigation, car control systems and entertainment systems.

This report claims that the European automotive industry is lagging the USA in telematics deployment. eCall regulation could help the EU to catch-up as it would include the basic functionality of a telematics system, and most automotive manufacturers would include more connected-car functionality.

- **Infotainment:** Infotainment is the combination of entertainment and information systems in cars. Car entertainment is primarily music, which has seen tremendous changes in the last decade. As most music content is moving to a digital format, car systems will need to accommodate digital music formats; including mobile digital music players and digital radio technologies. Infotainment systems also include embedded and mobile navigation systems, telematics systems and video systems that are used by passengers or when the car is parked. Infotainment systems are increasingly using the communication links and are part of the connected car.

Car entertainment systems are following home entertainment products into the digital age. Digital radio receivers are emerging, though currently there are multiple competing digital formats. Satellite radio is available in some regions, with the USA as the clear leader. Car audio systems are adding interfaces that connect to digital music players via USB connections, wireless streaming Bluetooth or a specific interface for the Apple iPod. The next step could be Internet radio via a high bandwidth communication link.

Technological Overview of Automotive Embedded Systems

Automotive ICT product growth has been straining the capacity of the EU automotive industry to design, develop, produce, test and maintain so many different computer-based systems—especially the tremendous growth in embedded software that runs these microcomputers. The next two sections, focused on embedded hardware and software respectively, explain what is being done to manage and deploy the growing number of software-based ICT products.

Automotive Embedded Hardware Summary

Automotive ICT products have become crucial for advancing the automotive industry over the last decade and will become even more important in the next decade and beyond. Today a luxury car has up to 100 microcomputer-based systems that control nearly all aspects of the car's operation. These microcomputer systems are called Electronic Control Units (ECUs) in the automotive industry. ECUs are embedded computer systems because they are part of larger electronic and/or mechanical systems. The ECU is the basic building block for automotive ICT systems. Many ECUs have multiple microcomputers (MCUs). In the last two decades, ECUs have replaced nearly all the mechanical and electromechanical systems in the average car.

- **Powertrain:** The Powertrain domain includes all the ECUs and microcomputers that control the engine, transmission and related systems. For electric vehicles, the Powertrain includes the MCUs that control the battery, electric motors and the power electronics systems that change the battery's DC power to high-voltage AC-power that runs the electric motors.
- **Chassis:** The chassis domain includes all the ECUs and MCUs that control the car's direction, speed, steering, braking, acceleration and suspension. Several advanced systems that enhance the driver's skill have emerged, including anti-lock brakes (ABS) and electronic stability control (ESC). Some chassis systems are being connected to safety systems such as airbag control and driver assist systems.

Table 7 summarizes the many types of ECUs and their basic functionality. ECUs are divided into five domains as shown.

Table 7 - Automotive ICT Product: ECU Domain Description		
Domain	Key Information	ECU Examples
Powertrain: 5-10 ECUs	Controls the car's power and its distribution to the wheels	<ul style="list-style-type: none"> • Engine control • Transmission control
Chassis: 3-5 ECUs	Controls the functions that guides the car's direction, speed, braking and suspension	<ul style="list-style-type: none"> • Steering control • Brake control • Suspension control
Safety, Driver Assist and ADAS 5-10 ECUs	Controls the car's safety systems. Many new systems are emerging	<ul style="list-style-type: none"> • Air bag control • Seat belt control • Driver assist systems-ADAS
Body and Comfort: 10-30 ECUs	Controls the driver and passengers' convenience and comfort systems. Includes dash board and related controls	<ul style="list-style-type: none"> • Heater and air conditioning • Windows and seat control • Window wipers • Instrument cluster display
Infotainment: 5-7 ECUs	Controls the entertainment and information systems used by driver and passengers	<ul style="list-style-type: none"> • Radio and music systems • Navigation systems • Telematics and mobile phone

- **Safety:** The safety systems domain includes all ECUs and MCUs that control airbags, seatbelts and driver assist systems such as park assist, adaptive cruise control, lane departure warning/assist and blind spot detection systems.
- **Body and comfort:** The body and comfort systems domain includes all ECUs and MCUs that control drivers' and passengers' convenience and comfort systems. This domain includes dash board and related controls.
- **Infotainment:** The infotainment systems domain includes all the ECUs and MCUs that control entertainment and information products. The head-unit is the main product and typically includes the radio and audio system, navigation system and connectivity solution for mobile music players and mobile phones. Telematics is usually a separate system, but could also be included in the head-unit. Rear-seat entertainment systems that play videos or receive broadcast TV signals are also included. Some head-units also have video and TV capabilities for front-seat passenger use, but these are usually only active while the car is parked.

Each ECU is a combination of embedded hardware and embedded software components. The embedded software is summarized in the next section. ECU hardware has several main components. The microcomputer is the key part and its capabilities define what functions the ECU can do.

In the early days of ICT development (pre-2000), most MCUs were simple; mostly 8-bit devices that had limited capability. As the computing power needed to control automotive functions increased, more powerful MCUs based on 16-bit processors became common. Today, many of the automotive MCUs have 32-bit processors and can be as complex as the microcomputers that are used in PCs. However, these car grade processors run much more slowly than typical PCs.

The advances in semiconductor technologies have made it possible to include additional devices on the MCU chip. Each MCU generation includes more on-board memory for storing larger programmes and more data. More control functions for electronic buses have also been added with each new generation of MCU chip.

Table 8 – ECU Hardware Overview		
	Key Information	Other Information
Microcomputer (MCU)	<ul style="list-style-type: none"> • Many types, often defined by bit-size • 32-bit are most powerful MCUs now • On-chip memory for many functions • On-chip electronic buses, several types 	<ul style="list-style-type: none"> • 8-bit, 16-bit, 32-bit MCUs • 64-bit used in special cases • Programme and data storage • Connect to other chips/devices
Memory	<ul style="list-style-type: none"> • Extra memory for complex functions 	<ul style="list-style-type: none"> • Additional memory chips
Electronic buses	<ul style="list-style-type: none"> • Multiple buses: low speed to high speed • High-speed use separate control chips 	<ul style="list-style-type: none"> • LIN, CAN, FlexRay, others • Due to higher complexity
Sensors	<ul style="list-style-type: none"> • Measure pressure, temp, speed etc. 	<ul style="list-style-type: none"> • On-chip or separate chip/device
Actuators	<ul style="list-style-type: none"> • Control mechanical devices in car 	<ul style="list-style-type: none"> • Usually separate chip/device
Reliability	<ul style="list-style-type: none"> • Automotive industry requires extra testing • Car-grade more reliable than PC chips 	<ul style="list-style-type: none"> • For better reliability • Higher cost per chip/device

Several electronic buses have been developed for the automotive industry, see Table 8:⁹

- The LIN bus is for slow-speed applications such as window and seat control.
- The CAN bus is the work-horse of the automotive industry and is prevalent in most ECUs.
- The FlexRay bus is just emerging and was developed with the extra features required for safety-related systems that need extra reliability.

Sensors and actuators are the ‘eyes, ears and controllers’ of the MCU. Sensors measure all the key parameters that are needed to control car systems. Examples are air or fluid pressure, temperature, air or fuel flow, linear or rotational speed, position and many others. Actuators transform electrical signals into mechanical work and are used by MCUs to control a car’s mechanical systems such as engine, transmission, brakes and many others.

The reliability requirements of the automotive industry are much stricter than they are in the PC and consumer electronics industries. Car-grade chips and devices require extensive testing and more exacting manufacturing standards than most other industries, resulting in higher prices per chip or electronic device.

The rapid ICT advances in complexity and quantity have been positive for the automotive industry, but have also created many challenges. The management of ECUs for each car model has increased tremendously in the last decade for multiple reasons:

- ECU system complexity has increased because of the higher functionality that is required to control the increasing communication options between ECUs.
- The number and variety of ECUs per car has increased dramatically.
- The number and complexity of MCUs per ECU has grown substantially.

The result is that the development of ECUs per car model has become a significant portion of total car model development costs. ECU embedded software development has become particularly complex over the last five years and is discussed later.

The solution currently implemented by the industry is a layered system architecture, which has been used in other industries such as the PC market. Layered system architecture provides many benefits to ECU hardware and software, the most important of which is the standard interface between MCU hardware and MCU software. In the AUTOSAR standard, as described below, this interface is called the Microcomputer Abstraction Layer. With this standard interface, the number of different ECUs can be lowered by a factor of two or three and maybe even five. This is done by defining a standard ECU with a set of MCU hardware components that can be used

⁹ All acronyms are listed in an Appendix 2.

for multiple applications. The adoption of this architecture means that the same ECU hardware can then be used for multiple functions that previously needed separate and different ECUs. The function tailoring is done by having different embedded software in each ECU.

From a design, manufacturing and logistics viewpoint there are major advantages to having a few standard hardware ECUs that can be used for many automotive control functions. Fewer distinct parts will increase the volume production of the remaining ECUs, which always brings cost savings at most levels, from design to production and life-cycle support. The AUTOSAR standard is starting to provide these advantages to ECU hardware and more will be realized as the standard is widely deployed over the next five years.

More information on layered system architecture is summarized in the next section on embedded software.

Automotive Embedded Software Summary

Embedded software has become a crucial technology for the automotive industry over the last decade. The growth of ECUs evolved one system at a time with no master plan on how to manage the growing amount of embedded software. The result was that many similar versions of embedded software were developed, sometimes in parallel, with little sharing of previously developed software. Each new ECU and its software was tailored for a specific car model or a few car models. Each automotive manufacturer had their own version of embedded software for the same function and often multiple and different versions for different car models. As the volume of software per car grew with the increasing number of ECUs, the difficulty of delivering software on time and on budget and with minimal errors, grew dramatically. By 2000, it became clear that the automotive industry's embedded software development model had failed and a better strategy and implementation plan was needed.

The solution is a layered system architecture that defines standard interfaces between key system components including the main software components. Layered system architecture allows standards to be developed for hardware and software components. The result is 're-usable' software components that can be used for many different ECUs. The European automotive industry formed the AUTOSAR consortium to define and implement a layered system architecture including embedded software standards. Current members include Toyota, General Motors, Volkswagen, Ford, PSA, Daimler, BMW, Bosch and Continental.

Embedded software consists of three types of programmes and every ECU uses each of these three software components:

- Operating System (OS). The OS is the programme that manages all the software used by the ECU and also controls all the hardware devices and connections that are part of the ECU. The OS defines all the key software standards that other programmes must follow. In the PC industry, Windows is the OS that manages most PC hardware and programmes. The equivalent OS in the automotive industry is AUTOSAR, which is now available from multiple software development sources.
- Driver Software. Driver software is a range of specific programmes that control and interface the ECU with all the sensors, digital buses, actuators and other devices that are connected to the ECU. Every ECU hardware component must be controlled by a driver software programme. Each device driver programme is unique, and as the driver layer of software typically changes slowly over time, it is relatively easy to make *standardized* programmes for each of the driver software elements that are used in the system. Since many ECUs use similar hardware components, the same or similar software drivers can be used for multiple ECUs. In the PC world, the programme that runs a printer is an example of driver software, with the same (or similar) software used by many different PC models for the same printer model.

- Application Software. Application programmes are the software that defines what each ECU should do. These programmes can be very simple, such as the ECU that controls and adjusts the driver's seat to its many positions. However, they could also be very complex, like the engine control programme that controls all aspects of running a diesel or gasoline engine. The programme for controlling the engine ECU is typically the most complex embedded software code in the vehicle, and may have up to 500,000 lines of programme code. This area of development is still growing as a result of the addition of new features to improve fuel economy and to lower exhaust emissions.

There are two major embedded software segments in the automotive industry, which have significantly different characteristics: core automotive software and infotainment software:

- Core automotive software: The core automotive software controls all ECUs that manage the operation of the vehicle including comfort functions (such as heating and air conditioning). These control systems have increased in number of features and sophistication since the launch of automotive ICT in the 1990s and will continue to increase in complexity and functionality. Much of the growth in core automotive software is due to the requirement to adhere to exhaust emissions and safety regulations, which require solutions, built from microcomputer-based systems and embedded software. The AUTOSAR¹⁰ software standards are focused on the core automotive software.
- Infotainment software: The infotainment system includes audio and radio systems, navigation systems, telematics and systems that connect to the driver's mobile phone and other mobile devices. For over 60 years, the radio was the only infotainment system in the car, but over the last 15 years the number of new ICT systems has increased. This growth has resulted from advances in consumer electronics, wireless communication, PC and Internet connectivity, which also requires microcomputer-based systems and embedded software solutions. The emerging Genivi¹¹ software standards are focused on automotive infotainment software.

The EU automotive industry has been the leader in developing and implementing the AUTOSAR standard. AUTOSAR has now become a worldwide de-facto standard that is likely to be used by all major automotive companies. Japan has formed its own consortium called JASPAR that will use the AUTOSAR software standards as a base, while GM and Ford in the US are also planning to use the AUTOSAR standards in the future. Other regions such as Korea, India and China are expected to start using AUTOSAR standards in a few years, since most of the AUTOSAR members are doing business in these regions.

EU luxury brands, such as BMW and Mercedes-Benz, have recently started deploying AUTOSAR-compatible embedded software and the EU will continue to lead the implementation of software standards. EU automotive companies will also introduce AUTOSAR software standards to other regions of the world as the preferred way of implementing embedded software for their worldwide operations.

The AUTOSAR software standard is a disruptive technology for the automotive industry. The implications for the EU embedded software industry are both good and bad as summarized in Table 9.

EU companies have led the standard effort and will continue to do so through several more upgrade cycles. EU companies also lead the deployment phase and this creates expertise that can be used to expand the customer base for EU embedded software companies to non-EU automotive manufacturers.

¹⁰ <http://www.autosar.org/>

¹¹ <http://www.genivi.org/>

Table 9 - AUTOSAR Implications		
	Key Information	Other Information
Positive Implications	<ul style="list-style-type: none"> • EU companies lead standard effort • EU companies lead deployment • Standards expand market size • EU company opportunities • Application opportunity last longest 	<ul style="list-style-type: none"> • Multiple upgrades to come • EU luxury brands lead • Early EU expertise gained • OS, driver and applications • Applications need innovation
Negative Implications	<ul style="list-style-type: none"> • Standards increase competition • Standards lead to commodity products • Commodity products has low profit 	<ul style="list-style-type: none"> • Global expertise, not local • Post 2015 for OS and driver • Favours low-cost regions

As the AUTOSAR expertise broadens, there will be much more competition from low-cost countries by 2015. Several Indian software companies are members of AUTOSAR and are likely to be strong competitors in a few years. Other low-cost regions will also offer AUTOSAR-compatible software in the coming years. The result will be increasing competition in AUTOSAR software.

After 2015, some AUTOSAR-compatible software is likely to become commodity software; especially software from the operating system and the driver software segments. OS and driver software will change slowly and will be offered by many companies, which is likely to stimulate competition in the market. Standard applications, that control simple functions such as windows and seat control, are also likely to become commodity software in a few years.

AUTOSAR is focused on embedded software that controls the core functions of the car, but not infotainment software. A new consortium called Genivi, has been formed to develop embedded software standards for infotainment software. Infotainment software includes programmes that run music and entertainment systems, navigation systems and all the telematics and connected car applications. The Genivi group is led by Intel, ST Microelectronics, General Motors, PSA, BMW, Hyundai and other EU and USA-based car component companies.

Clearly, the industry feels infotainment software standards are needed to reduce development costs, and it is likely that these will be beneficial to the automotive industry in terms of re-usable software, improved software productivity and more reliable programmes. The EU is not as strong in infotainment software development as it is in AUTOSAR software development. This is mainly because most infotainment software is related to PC, consumer electronics, digital music, Smartphone and similar software products, which have their core developments in the US and Asian regions.

The Genivi consortium was formed in March 2009, so it is too early to say whether it will achieve the critical mass to succeed. It is unlikely that the Genivi standards will be as dominant as AUTOSAR, because of the widespread use of competing products from proprietary software suppliers such as Microsoft, Harman's QNX and others.

Additionally, several generic trends that impact European embedded software competitiveness must be taken into account:

- The cost of embedded software development is starting to far outweigh the cost of hardware development and this trend will continue.
- As ICT products mature, the authors believe there will be a migration of embedded software development jobs outside the EU to support legacy products.
- In contrast, the development of lower-level hardware (MCU-microprocessor) and first layer embedded software is less easy to separate. As a result, this competence is likely to remain in Europe. Semiconductor suppliers currently prefer to keep their hardware (microprocessor)

and first level software in the same geographical location. For EU semiconductor manufacturers, this product innovation is currently retained in Europe. Beyond 2015, semiconductor suppliers may move their lower level (hardware) design out of Europe (for cost reasons) and it is likely that the required embedded software competence will also move outside Europe.

Future Opportunities and EU Potential Support

The improvements in efficiency and cost savings as a result of the adoption of embedded software standards are good for the EU automotive industry, and especially good for automotive manufacturers who are looking to save money in a competitive market. However, sometime after 2015, embedded software competition will intensify for EU software companies as high-quality, low-cost software products will be available from low-cost countries. As a result of this commoditization of the existing standards, EU embedded software companies will need to move to more advanced embedded software segments in order to maintain their lead in this area. Fortunately, there are several emerging software segments that will provide promising opportunities in the next decade and beyond. These automotive embedded software opportunities are summarized in Table 10.

Table 10 - Future Embedded Software Opportunities		
	Key Information	Other Information
Connected Car Application Software	<ul style="list-style-type: none"> Many applications emerging EU is behind USA in telematics eCall can be basis for telematics apps Multiple communication links emerging 	<ul style="list-style-type: none"> For car, driver and passengers Link to ECUs become important eCall is EU chance to catch up ECU, driver and infotainment links
ADAS Software = Driver error correction	<ul style="list-style-type: none"> Software intensive systems Many applications emerging Builds on driver assist applications EU has ADAS system and sensor expertise 	<ul style="list-style-type: none"> Sensor-based systems Major life and cost saver Warns or corrects driver errors Leverage into software leadership
V2V and V2I Software = Communication vehicle-road	<ul style="list-style-type: none"> Many applications possible EU's CVIS R&D project is important More EU development needed Early EU deployment create expertise 	<ul style="list-style-type: none"> Safety, traffic and fuel-savings Public and private cooperation To complete system architecture Systems and software experience
Autonomous Driving Software	<ul style="list-style-type: none"> Builds on ADAS and V2X systems Progressively more autonomous functions Compute, sensor and software intensive 	<ul style="list-style-type: none"> Deployment likely after 2020 Complex ECUs and software Large software opportunities

- **Connected car:** Connected-car applications are rapidly emerging as drivers and passengers increasingly expect mobile communication services to be available in cars. Currently the USA leads in deploying connected car or 'Telematics' applications, while most of the EU automotive manufacturers have not deployed these systems. Though the EU region has fallen behind other regions of the world in areas of telematics applications, the eCall regulation could improve the EU's position. An eCall product is the minimal functionality for a telematics system. Most automotive manufacturers are likely to build more services on top of their eCall systems, which would provide increased opportunities for telematics hardware and software systems suppliers in Europe.

A key connected-car application is the remote management of ECU software, which can be done with a telematics system. The eCall regulation would provide the impetus for automotive manufacturers to implement remote ECU diagnostics and remote software management. Remote ECU software management is expected to be a key embedded software

technology in the next decade. These connections will tie automotive embedded software with EU-based infrastructure systems, which will in turn require local expertise and presence.

Many of the communication-based functions and applications will need wireless data plans, however high data-plan ‘roaming fees’ in Europe could inhibit or slow the usage of pan-EU connected-car applications and other communication-based services. These high roaming fees will put the EU at a competitive disadvantage versus the USA, which has virtually no wireless roaming fees.

- **ADAS:** ADAS¹² technologies are software intensive systems that can change the driving experience by rectifying driver errors with tremendous savings in terms of accident costs and lives. Much of the ADAS embedded software will be based on pattern recognition technology applied to sensor data sent from cameras, radar and other visual inputs. EU companies are already established in driver assist systems, which are first generation ADAS products. The EU Commission could help by implementing well defined ADAS regulation that would advance the EU’s competitive position.
- **V2V and V2I:** V2X technologies allow vehicles to communicate with roadside infrastructure and also between vehicles. Many V2X applications will be deployed in the next decade. The EU CVIS project is focused on the overall V2X architecture with particular emphasis on networking, software, middleware and location technology that improves GPS accuracy. The EU satellite navigation system Galileo, which will start offering a reduced set of services in 2014, will be one of the elements used for vehicle guidance. V2X systems are very important long-term and will require a substantial amount of embedded software. It is too early to determine which region will lead in V2X software, but the EU is expected to perform well if it continues to invest in V2X research and development and becomes a leader in infrastructure deployment. V2X systems will also need local knowledge of network systems that will in turn require companies to have a local presence. ADAS and V2X systems will be integrated over time, which will add more embedded software.
- **Autonomous Driving:** After V2X deployment, autonomous driving is the next embedded software opportunity for automotive suppliers. Autonomous driving systems will build on ADAS and V2X systems and will add large amounts of computing power and embedded software. Autonomous driving will see a progressive increase in functions that are automated. There are already examples of automated functions in current driver assist systems: adaptive cruise control where the speed and following distance is automated, and self-parking systems.

Among current embedded software segments, the Powertrain domain has the most embedded software code and is the most valuable software segment for the EU automotive industry. The European automotive industry is the clear leader in diesel engines and is also very strong in gasoline engines.

The importance of electric vehicle (EV) Powertrain will grow in the next decade and embedded software that controls EVs will increase in importance. Currently, it seems that Japan and China are ahead in electric vehicle development and the ECUs and software that control the EV Powertrain. China has minimal expertise in diesel and gasoline engines and will focus their software development effort on EV. As electric vehicles increase in importance, the EU will need to be a leader in EV Powertrain embedded software, otherwise the EU automotive industry will risk losing its lead in the largest embedded software segment.

It is always difficult for an entrenched leader to invest in a new technology that will essentially ‘replace’ the technology in which it leads. So, while the EU leads in current diesel and gasoline

¹² http://ec.europa.eu/information_society/activities/intelligentcar/technologies/das/index_en.htm

engines, it will require significant investment to remain the leader in these ‘legacy’ technologies. The key question is whether the EU automotive industry has enough resources to extend the life of its current propulsion systems and also invest enough to gain a leadership role in EV technology. To increase the possibility of this outcome, the EU Commission might need to provide R&D and EV deployment assistance. The period 2010 – 2015 will be the formative stage of EV technology, which is when focused government programmes will be most advantageous.

Current and Future Competitiveness of the European Automotive Embedded Systems Industry

The competitiveness of this EU industry is based on two main factors:

- The strength of EU-based automotive manufacturers and their suppliers—from components to ICT systems.
- Their current technology leadership and the investment they are making in future technologies in order to remain in a strong position in embedded technologies.

Table 11 - EU Automotive Company Strengths		
	Key Information	Other Information
BMW	<ul style="list-style-type: none"> • Leading luxury brand worldwide • Software innovator • Leader in AUTOSAR and Genivi 	<ul style="list-style-type: none"> • USA, Europe and other regions • Crucial to continued EU SW leadership • Understands benefits of SW API
VW	<ul style="list-style-type: none"> • 3rd largest car producer • Leader in EU, China, other regions • Top EU electronics customer 	<ul style="list-style-type: none"> • Gaining share in 2009 recession • Strong presence in most regions • Software, semiconductor and electronics
Other EU Auto OEMs	<ul style="list-style-type: none"> • M-B is another luxury brand leader • M-B: 2nd in SW innovation • Others are average in SW 	<ul style="list-style-type: none"> • USA, Europe and other regions • Strong in driver assist and ADAS • PSA, Renault and Fiat
Tier 1 Companies	<ul style="list-style-type: none"> • Bosch and Continental: World-class • Many other strong companies • EU has strongest Tier 1 companies 	<ul style="list-style-type: none"> • Multiple segments, Strong in SW • Autoliv, Hella, Magneti, Valeo • EU position, but also other regions
Semiconductor Companies	<ul style="list-style-type: none"> • Infineon and ST Micro: World-class • NXP strong in infotainment 	<ul style="list-style-type: none"> • Across multiple automotive segments • Other good companies in automotive

Europe is currently in a strong position in the global automotive market due to its leading position in the development and production of luxury cars. Companies such as BMW are especially important in feature innovation and in forging software standardizations that will provide many future advantages.

Mercedes-Benz, Bosch and Continental have also been important drivers in advancing EU developments. Volkswagen also adds weight as the volume leader and as the third leading luxury brand with Audi.

While the EU industry is generally in a strong market position, there are a few essential weaknesses, particularly in infotainment software and next generation propulsion:

Up-coming technology innovations and technology disruptions will be a key force that will allow the EU to maintain its strong presence in the automotive market for the next 20 years. The authors believe that many ‘hi-tech’ automotive technologies developed in the last decade will increasingly be reduced to ‘commodity status’, and will be increasingly specified, designed and manufactured in a number of non-EU low-cost regions. As a result of this commoditization of current technologies; new automotive technologies must be invented, pioneered and deployed to keep the EU automotive sector in a leadership position.

Currently ICT innovation in the automotive sector is a key-competence in Europe, with very little ICT innovation from outside the EU gaining traction with current EU automotive companies. A major benefit of a strong automotive ICT industry is the resulting large and valuable employment base. But future maintenance of automotive ICT jobs within the EU will only be possible if high levels of product innovation continue within Europe.

Fortunately, there are several technology and market trends that provide significant opportunities for the European automotive embedded software and system industry. However, there are also growing threats that must be considered and counteracted. Table 12 summarizes the key trends and perspectives on how European companies can maintain their lead in the next decade. The summary is organized by the main automotive embedded system categories.

Table 12 - EU Automotive Embedded Systems Competitiveness Summary		
	Key Information	Comments
Core Auto ECUs	<ul style="list-style-type: none"> • EU leadership in multiple domains • AUTOSAR will help retain this leadership • Future AUTOSAR commoditization is a threat 	<ul style="list-style-type: none"> • Engine, chassis, safety and others • EU to lead AUTOSAR updates • Competition from standard systems
EV ECUs	<ul style="list-style-type: none"> • Too focused on combustion engine • EV: when-question, not if-question • EU EV development is behind • EV battery systems need innovation • EV high-voltage electronics is important 	<ul style="list-style-type: none"> • EU strength, but will fade post 2020 • EU has the most to lose • EU effort needed to catch up • EU innovation opportunities • High-voltage chips is EU strength
ADAS and V2X	<ul style="list-style-type: none"> • EU has ADAS leadership • ADAS requires • EU has strong V2X system R&D projects 	<ul style="list-style-type: none"> • ADAS leadership likely to remain • Major future growth market • EU need to lead deployment phase
Infotainment	<ul style="list-style-type: none"> • Strong EU position in current systems • Moving to computer platform architecture • EU software position needs improvement • Genivi software platform is best EU opportunity • Auto App Stores to be important 	<ul style="list-style-type: none"> • Head-unit and navigation strongest • USA leads via QNX and Microsoft • PC and consumer electronics • Auto Android platform is dark horse • EU leadership is needed
Connected Car Applications	<ul style="list-style-type: none"> • EU is behind in connected car applications • eCall regulation would kick-start EU deployment • Multiple communications coming 	<ul style="list-style-type: none"> • USA leads via OnStar and Ford Sync • Software innovation to catch up • V2X is future communication link

New software-intensive automotive features are emerging and will continue to do so in multiple segments. The key for the EU automotive industry is to lead and innovate as these technologies emerge and enter volume production.

The following four examples are key technological advances that will require continued R&D investments from hardware and software manufacturers inside the automotive sector, and infrastructure developers outside the sector:

- The EU's lead in the AUTOSAR will continue as its functionality goes on advancing via regular upgrades. But increasing application software innovation will be needed as some AUTOSAR software become commodity products.
- Electric Vehicle (EV) embedded software has barely started and there are innovation opportunities in battery system architecture. This could be a way for the EU to gain the lead even though battery components are made in low-cost countries.
- Advanced Driver Assist Systems (ADAS) and integrated ADAS are software-intensive systems. The EU leads in ADAS and continued software innovation will retain this position.
- The EU has excellent Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) R&D projects. Leadership in deploying V2X systems will require innovative software development. The combination of ADAS and V2X system will form the basis of future autonomous driving systems, which will require even more innovative software.

In addition, the EU has a strong position in current infotainment systems. However, infotainment systems are becoming computer platforms that have connections to PC, consumer electronics and smartphone software. This opens the door for new suppliers with computer platform design experience that can compete with the traditional automotive Tier suppliers. Several computer platforms are vying for infotainment systems leadership, including the current leaders from QNX and Microsoft. The emerging Genivi platform is Linux-based and EU companies may benefit if it becomes the leader in a few years. The Android platform is being adapted to the automotive industry by Continental and other companies. Android could also be a successful candidate in the automotive infotainment segment.

Also, connected car applications such as telematics systems are emerging and will be a major force in the automotive industry. The EU is behind the USA in deploying these systems, though the EU “ITS Directive”¹³ passed in July 2010 is likely to foster connected car systems during the coming years. If deployment is rapid enough, the EU may catch up in connected car applications in the next decade. After 2015, V2X systems are also likely to be used as links for connected car applications. These advanced communication-based systems connect automotive electronics systems to the local ICT systems deployed in each country and/or along highways. This will require local software and hardware expertise and resources to understand, deploy and support their usage. Such systems favour local and regional companies with an understanding of the local dynamics in each of the European country markets.

Finally, Electric Vehicle (EV) development is the most significant EU weakness. While there is little doubt that EVs will have a significant impact in the future, it is likely that EU companies pursuing current technologies will have the most to lose from the adoption of electric motor technology. As EV Powertrain slowly replaces combustion engines, the Powertrain electronics and software will change dramatically and will require tremendous investment and innovation. Hence, the EU needs to catch up and become an EV leader in the next decade in order to protect its current strong position in Powertrain software and electronics.

Key Conclusions

The EU automotive industry is well positioned in embedded systems, and in particular in embedded software. This leadership position can be extended for a decade or two, but requires considerable investments by all players, including public authorities.

Table 5.1 present a brief SWOT analysis for automotive embedded software. The analysis is from a European software industry perspective. It is a helpful summary to catch some of the essential trends that affect and will affect the future competitiveness of the European Embedded Systems industry.

¹³ Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport”. OJ L 207, 6.8.2010, p. 1–13.

Table 13 – EU Embedded Automotive Software SWOT	
<u>Strengths</u> <ul style="list-style-type: none"> • Luxury car leaders: most software is introduced • AUTOSAR: Standards leadership • AUTOSAR: Software competency & deployment • Diesel and gasoline engine software • Chassis control software (ABS, ESC) • Safety and driver assist software • Software and software tool companies • V2X R&D programmes (CVIS & others) 	<u>Opportunities</u> <ul style="list-style-type: none"> • EV software advances may make EU leaders at EV system level • Automotive apps store leadership • ADAS software and systems and applications • eCall legislation would allow to catch-up in telematics and connected car applications • V2X software and systems (regulation needed) • Autonomous driving (post-2020)
<u>Weaknesses</u> <ul style="list-style-type: none"> • Current EV deployment • Current EV development • Infotainment software OS and API standards • Infotainment application software • Telematics software and deployment 	<u>Threats</u> <ul style="list-style-type: none"> • AUTOSAR commodity software (post-2015) • Infotainment commodity software (post-2015) • EV growth negates powertrain software market leadership (post-2020)

Source: Authors' own elaboration

For the authors, the key conclusions concerning the status and future of embedded software in the European automotive industry are the following:

- EU automotive sales are declining as a share of the world total, with most of the future growth expected to come from non-EU regions. This means the EU-based automotive manufacturers, their EU-based Tier 1, semiconductor and software suppliers must expand outside the EU in order to maintain or grow their worldwide market share.
- The size of the automotive ICT market is difficult to estimate, however it is a growing portion of the value of a vehicle when it is sold. In this study, the authors have estimated that, while ICT value per car depends greatly on what optional electronics are purchased by consumers, it already represents some 10% to 15% of the vehicles purchase price (with minimal optional equipment) and up to 30% of the purchase price (with the purchase of all optional electronics), depending on the type of vehicle.
- The EU leads in embedded software standards due to its role in the formation of the AUTOSAR consortium. AUTOSAR is now a worldwide software standard with EU companies in the best position to benefit from the deployment of the standards that are now underway.
- The EU is in the strongest position in terms of the supply of Powertrain embedded software. However, there is a risk that as electric vehicles begin to replace diesel and gasoline vehicles, EU companies will not have invested enough to be the leaders in Electric Vehicle Powertrain software. EV R&D is needed soon to protect the EU's lead in future Powertrain software.
- Genivi is another embedded software standard effort, underway in the infotainment system domain. The EU is well represented in the GENIVI consortium, but shares leadership with the USA-based companies.

- The EU is behind the USA in connected car applications and software. The impact of eCall regulations has the potential to accelerate EU connected car deployment and allow the EU to catch up in the next decade to 2020.
- To retain leadership in embedded software in the future, the EU automotive industry must invest in emerging and future technologies with software-intensive segments. There are at least three such segments: Advanced Driver Assist systems (ADAS), Vehicle-to-vehicle/Vehicle-to-Infrastructure communication (V2X) and autonomous driving.

Within this context, some political recommendations emerge from the analysis:

- **ICT matters (more than ever):** the present report demonstrates again the importance of taking-up the role of ICT in the transformation of the economy. This general purpose technology, when embedded, becomes one of the major assets for competitiveness. It transforms skills, organisations, processes, products and services, giving them added value and that competitive advantage that makes the difference on the global market. A vision of the Digital Economy reduced to the mere diffusion and impacts of Personal Computers is a major mistake to avoid.
- **Skills: the trends towards a service economy ("from products to services"),** nowadays mainly implemented through software-based solutions, with the creation of integrated systems (bridging often different sectors: transport and health; safety and entertainment; energy and transport; etc.) **call for a highly skilled workforce of software engineers and system integrators, within a multidisciplinary strategy.** All industrial actors insist on the already currently existing skills' gap, and this is particularly true within the Embedded Systems activities to which European engineers appear to be little prepared; the Commission should support the creation of a European network of EU enterprises to advise Universities and training centres in order to adapt e-Skills and Engineering curricula of Universities and permanent training of employees to the needs of EU Automotive and Electronic enterprises.¹⁴
- **Silos:** this trend towards *cross-sector integrated services* **calls for integrated cross-departmental policies.** The vertical silos of most public authorities offer little help, and sometimes add obstacles, to the timely development and implementation of those new skills, organisations, products and services. A priority effort should be put into a firm revision of the vertical organisation of public administrations and diverse policy making agencies;
- **Speed-up the adoption of EU legislation related to the cross-border use of vehicles:** while often seen as impediments to implementation, good regulations are powerful pull/demand factors for innovation to emerge. The eCall case reminds of such public capacity to refrain or

¹⁴ European e-Skills Week 2010: <http://ec.europa.eu/enterprise/sectors/ict/e-skills/support/>
http://ec.europa.eu/enterprise/sectors/ict/e-skills/extended/index_en.htm
 McCORMACK, Ade: "The e-Skills Manifesto - A Call to Arms"
http://eskills-week.ec.europa.eu/web/guest/news/-/journal_content/56_INSTANCE_m7wX/10404/30663/NEWS_MAIN_DISPLAY
http://files.eun.org/eskillsweek/manifesto/e-skills_manifesto.pdf
 INSEAD "eLab" report: <http://www.insead.edu/elab> about best practice to improve e-Skills curricula:
 "Strengthening e-Skills for Innovation in Europe":
http://eskills-week.ec.europa.eu/web/guest/news/-/journal_content/56_INSTANCE_m7wX/10404/27842/NEWS_MAIN_DISPLAY
 Contact point in EU Member States: http://ec.europa.eu/enterprise/sectors/ict/files/e-skillsweek_highlevelcontact_points_15122009_en.pdf

boost innovative capacities. Many other pending issues seem to be related to regulatory aspects (Cross-border Micropayments; Wireless Spectrum management; etc.¹⁵)

- **Global moves:** with advanced and emergent economies competing on one same global market, there is a need for coordinated macro-region initiatives to counterbalance those taken by competitors. The move towards the Electric Vehicle is a good example, where the European legacy with the combustion engine might add a layer of inertia to face the rapid moves observed with our Asian counterparts;
- **No zero-sum games:** the transformation of the economy impacts the economic actors. As new organisations, processes, services emerge, some actors in the value chains emerge as winners, other as losers. And new actors emerge with new roles. These dynamics, partly unpredictable, complicate heavily the role of public authorities when meeting with the industries and their representative organisations to mature the political decisions and implement them. Little can be done about this difficulty. Probably, at a macro-economic level would it be important to ensure Europe's benefits in the overall reshuffling of global value chains, by ensuring that Europe is able to maintain existing actors and nurture those of tomorrow.

When considering the above elements and the detailed analysis presented in this report (on the technological aspects and also those related to the robust and mature industrial context), a striking observation in terms of policy is the absence of a coordinated 'one-stop-shopping' major automotive public agenda at European level. The Smart or Green Car initiatives are claimed to be high on the official agendas of the Commission and of the Member States but they do not seem to deliver any integrated or strong momentum towards a coordinated and efficient action by the industry, public authorities, citizens and probably academia to ensure the rapid development and implementation of such agendas. The above analysis indicates that only action of this type will allow Europe to reap the benefits of the next generation cars, by growing an even stronger automotive sector at OEM and supplier levels, offering the consumer the services and products the market demands and meeting the societal challenges that Europe is confronting in terms of economic growth, employment, environment or well-being.

¹⁵ Interestingly enough, such issues are relevant to the current Digital Agenda, one of the Commission's seven flagships of Europe 2020. In particular, these issues pertain to the Digital Single Market line, aimed at reducing the obstacles for the cross-border trade of digital goods and services.

1. Economic Overview of the Automotive Industry

This chapter introduces briefly to the economic size of the automotive industry in Europe, USA, Japan, China, and worldwide. Information for key European and non-European automotive manufacturers is included, as well as sales and production per regions. Historical data and forecasts are also offered.

1.1 An Essential European Industry

The automotive industry is a major European manufacturing and service industry and is one of the backbones of the European economy. The European Automobile Manufacturers' Association (ACEA)¹⁶ website lists the statistics summarized in Table 1.1.

Table 1.1 - European Automotive Industry: 2007		
	Key Information	Other Information
Employment	<ul style="list-style-type: none">• Direct jobs: 2.2 million• Total jobs: 12.1 million	<ul style="list-style-type: none">• 6.5% of manufacturing jobs• 6% of all jobs
Revenue ¹⁷	<ul style="list-style-type: none">• Worldwide: €551 billion	<ul style="list-style-type: none">• ACEA members
R&D investment	<ul style="list-style-type: none">• Europe: €20 billion• Worldwide: €40 billion	<ul style="list-style-type: none">• 4% of sales (ACEA members)• 7% of sales (ACEA members)
Automotive production	<ul style="list-style-type: none">• 19.7 million vehicles• 17.1 million passenger cars	<ul style="list-style-type: none">• Cars, vans, trucks, buses• 27% of worldwide total
Exports	<ul style="list-style-type: none">• €42.8 billion net trade	<ul style="list-style-type: none">• Leading EU export industry
Vehicle taxes	<ul style="list-style-type: none">• €381 billion in government revenue	<ul style="list-style-type: none">• 3.5% of European GDP
Source: ACEA, www.acea.be		

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

According to ACEA, the European automotive industry provides indirect jobs for 12.1 million workers (2.2 million direct jobs) and is one of the largest private investor in R&D with €20 billion invested in Europe (2007). Worldwide revenue for the ACEA members topped €550 billion in 2007. Automotive manufacturers claim to provide the largest net export of any industry at nearly €43 billion (2007). The governments' tax revenue from the automotive industry would represent some 3.5% of Gross Domestic Product (GDP) or over €380 billion (2007).

Similarly, the European Commission states the following in a recent analysis:¹⁸ "the automotive industry is one of Europe's key industrial sectors, and its importance is largely derived from its linkages within the domestic and international economy and its complex value chain. The automotive sector has a turnover of over €780 billion. Value added in the automotive sector amounts to around €140 billion, representing about 8% of European manufacturing value added. It directly employs more than 2 million people and is responsible in total for more than 12 million jobs across Europe, which is equivalent to about 5.5% of employment in the EU27. In 2007, its best year so far, the European automotive industry produced about 19.7 million vehicles

¹⁶ The European Automobile Manufacturers' Association (ACEA) is composed of the following members: BMW, DAF, DAIMLER, FIAT, FORD OF EUROPE, GENERAL MOTORS EUROPE, JAGUAR LAND ROVER, PORSCHE, PSA PEUGEOT CITROËN, RENAULT, SCANIA, TOYOTA EUROPE, VOLKSWAGEN, VOLVO. From www.acea.be. Last updated: June 2010.

¹⁷ Whenever available, financial data is presented in EUROS. When raw data is in \$ US, as exchange rates have been very volatile during those years and the available data already result usually from calculations based on automotive model prices in local currencies converted to \$ US, the authors have opted to maintain the currency.

¹⁸ European Industry in a changing world: Updated sectoral overview 2009. SEC(2009) 1111 final.

Full document available at: http://ec.europa.eu/enterprise/policies/industrial-competitiveness/files/documents/sectoral-overview_en.pdf. For more, see at: http://ec.europa.eu/enterprise/sectors/automotive/index_en.htm#top

(cars, trucks and buses), equivalent to about 27% of total production worldwide (17.1 million of which were cars - a segment in which the EU holds a global market share of about 30%). Exports of cars from EU27 countries amounted to €125 billion, with imports of €65 billion, giving a trade surplus of €60 billion.

Table 1.2 summarizes key financial data for the top six European-based automotive manufacturers (OEM). Automotive sales and production for 2007 and 2008 are included along with worldwide shares for 2008. PSA is the only EU OEM who made a loss in 2008.

Table 1.2 - European Automotive Manufacturer (OEM)							
	Unit	BMW	VW	M-B	PSA	Renault	Fiat
Car Unit Sales-2007	thousands	1,502	6,192	1,293	3,428	2,484	2,248
Car Unit Sales-2008	thousands	1,436	6,272	1,273	3,260	2,382	2,168
Worldwide Sales Share-2008	%	2.18	9.50	1.93	4.94	3.61	3.28
Car Production-2007	thousands	1,542	6,213	1,300	3,457	2,659	2,410
Car Production-2008	thousands	1,440	6,347	1,338	3,323	2,421	2,365
WW Production Share-2008	%	2.04	9.00	1.90	4.71	3.43	3.35
Revenue-2007	€Bill	56.0	108.9	52.4	44.5	38.7	29.0
Revenue-2008	€Bill	53.2	113.8	47.8	41.6	35.8	29.4
WW Revenue Share-2008	%	2.94	6.19	2.88	2.51	2.16	1.77
Net Profit-2007, share in sales	%	5.59	3.79	9.07	1.94	7.07	3.18
Net Profit-2008, share in sales	%	0.62	4.12	4.43	-0.82	1.68	2.97
R&D/revenues-2007	%	5.61	4.52	5.21	3.95	6.36	3.28
R&D/revenues-2008	%	5.38	5.21	6.16	4.25	6.25	3.59
Employees 2007	thousands	108	329	97.5	208	130	54.1
Employees 2008	thousands	100	370	97.3	202	129	56.4

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Table 1.3 presents similar financial data for the top automotive manufacturers in USA and Asia. Four of the six automotive manufacturers made a loss in 2008. Of the Japanese OEMs only Honda made a profit. Hyundai (including Kia) had a very good year in 2008 and increased their market share as a result of the introduction of new products and substantial investments in marketing in the USA.

Table 1.3 - Non-European Automotive Manufacturer (OEM)							
		GM	Ford	Honda	Nissan	Toyota	Hyundai
Car Unit Sales-2007	thousands	9,370	6,555	3,953	3,700	9,430	2,969
Car Unit Sales-2008	thousands	8,356	5,532	3,517	3,411	8,327	4,215
WW Sales Share-2008	%	12.66	8.38	5.33	5.17	11.46	6.38
Car Production	thousands	9,286	6,350	3,911	3,515	9,045	3,987
Car Production	thousands	8,144	5,410	3,957	2,919	7,810	4,186
WW Production Share	%	11.56	7.67	5.61	4.14	11.07	5.94
Revenue-2007	€Bill	180.0	154.4	83.2	92.9	241.8	72.0
Revenue-2008	€Bill	149.0	129.2	78.1	85.5	185.7	65.0
WW Revenue Share-2008	%	11.95	10.45	6.32	6.76	15.02	5.25
Net Profit-2007, share in sales	%	-21.8	-1.76	6.79	4.45	7.11	4.09
Net Profit-2008, share in sales	%	-20.9	-9.76	0.32	-2.77	-2.35	3.85
R&D-2007: Rev Share	%	4.50	4.86	4.90	4.23	3.39	3.85
R&D-2008: Rev Share	%	5.37	5.65	4.18	5.40	4.67	4.46
Employees 2007	thousands	266	235	130	159	300	77
Employees 2008	thousands	243	203	133	156	320	88

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Again, the European Commission's analysis¹⁹ offers a useful complementary view: "In the European automotive markets competition is intense. A significant decline in real prices for new motor vehicles over the recent years, successful new entries, significant fluctuations in market shares, increased consumer choice within the various market segments combined with shortening of model life-cycles are evidence of a generally dynamic competitive environment. Comparatively modest but fluctuating average profits and constant R&D expenditure are further supportive elements".

Competitive pressure can be expected to increase further as car manufacturers from emerging countries enlarge their presence on the EU markets. The consolidation which has occurred in the global automotive industry over the past few decades is now accelerated by the crisis. The difficulties recently experienced by the main American manufacturers (who have a substantial presence in the European market) have resulted in the sale of Jaguar and Land Rover to Tata Motors. The situation in the US further deteriorated culminating in Chrysler and General Motors undergoing court-supervised bankruptcy with ripple effects on the European markets.

(...) Many manufacturers are already co-operating in both production and R&D (e.g. in form of automotive clusters), which logically could provide a platform for further restructuring or consolidation in the industry. The restructuring process also concerns automotive suppliers who are currently in the process of consolidation accelerated by the recession."

1.2 The Automotive Market

1.2.1 Automotive sales

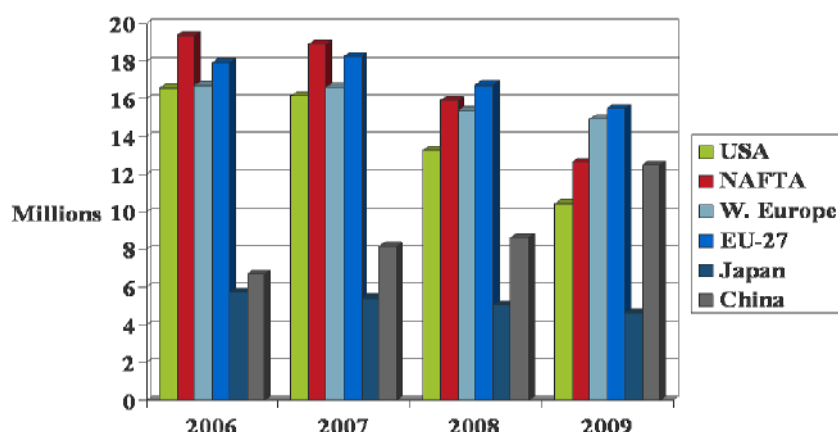
1.2.1.1 Automotive sales per region

Worldwide automotive sales are generally on an upward trend with steady sales increases that are modulated by economic contractions and expansions. The current recession has hit the automotive industry especially hard due to the impact from credit and financial meltdown that hit the world economy in Q4 2008. The impact has been especially severe in the USA where automotive sales have dropped the most.

This global impact of the slow-down in 2009 is summarized in Figure 1.1 which shows automotive sales for key regions of the world from 2006 to 2009. Only China is seeing year-to-year automotive sales growth in 2009. In Europe only Germany has seen automotive sales growth in 2009 due to very aggressive government-based sales incentives.

¹⁹ European Industry in a changing world: Updated sectoral overview 2009. SEC(2009) 1111 final
Full document available at: http://ec.europa.eu/enterprise/policies/industrial-competitiveness/files/documents/sectoral-overview_en.pdf

Figure 1.1 - Regional Automotive Sales Trends



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Worldwide automotive sales were expected to recover in 2010 as summarized in Table 1.4, but not to surpass the 2007 unit sales until after 2012.

Units (000 cars)	2008	2009	2010	2011	2012	2015	2020
W. Europe	15,374	14,941	14,330	14,730	15,250	16,800	17,940
EU27	16,751	15,492	15,110	15,470	16,020	17,620	18,960
USA	13,247	10,432	11,640	12,730	13,870	16,660	17,500
NAFTA	15,911	12,650	13,980	15,200	16,480	19,620	20,820
Japan	5,067	4,597	4,690	4,800	4,930	5,260	5,470
China	8,635	12,491	13,640	14,155	14,735	16,760	19,760
Worldwide	66,019	63,186	65,885	69,130	72,710	83,300	94,280

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

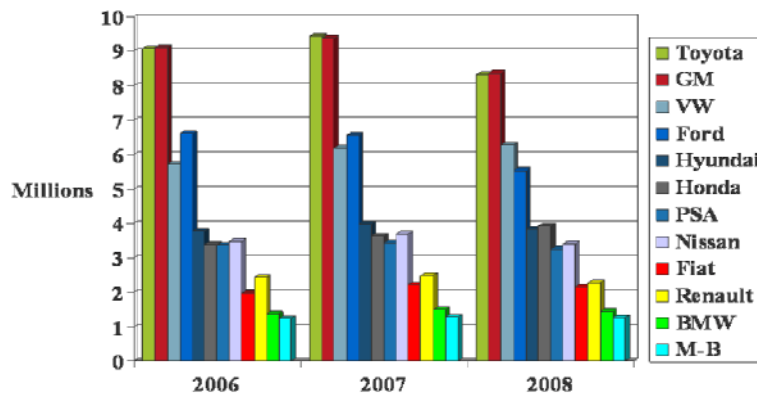
In 2008, the automotive sales share in the EU was around 25% of worldwide sales, but this number will jump to over 26% in 2009 because of the more severe sales drop in USA, Japan and other regions. In the next decade EU automotive sales share will see a steady decline to below 21% by 2020—and could even drop below 20% by 2020 if China and India continue their current strong expansion.

1.2.1.2 Automotive sales per manufacturer (OEM)

Figure 1.2 summarizes for the period 2006-2008 the automotive sales for twelve vehicle OEMs including the six main European-based automotive manufacturers.²⁰

²⁰ None of the Chinese automotive manufactures are in the current top 15 automotive sales list; however it should be noted that all automotive manufacturers must have a partner for automotive production in China, as Chinese law states that non-Chinese automotive manufacturers must have a Chinese partner in order to do business within the country. Consequently, the leading Chinese automotive companies have multiple joint ventures with vehicle OEMs from EU, USA, Japan and Korea.

Figure 1.2 - Automotive Sales by Manufacturer



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

GM has been the leading automotive manufacturer for several decades, but was surpassed by Toyota in 2007. In 2008 GM sold slightly more automobiles than Toyota. Volkswagen became the third largest automotive manufacturer in 2008 when it surpassed Ford.

The six EU-based automotive manufacturers accounted for 26.6% of worldwide automotive sales in 2008. If Opel/Vauxhall, which is included in GM, were added to these figures, the market share increases by nearly 2%. The EU automotive industry is especially strong in the premium automotive segment with the top three suppliers: BMW, Mercedes-Benz and Volkswagen's Audi division.

1.2.1.3 Automotive sales per segment: luxury, mid-range, economy

To better understand the technology trends in the automotive sector, three segments need to be used—luxury, mid-range and economy cars. The segments are defined by price points, but they vary between regions due to purchasing power variations. The price ranges are summarized in Table 1.5 in local currencies for the main regions. For other regions similar price segments are used.

Table 1.5 - Automotive Segment Prices			
Region	Luxury Cars	Mid-Range Cars	Economy Cars
Europe	Over €30K	€15K to €30K	Under €15K
N. America	Over \$35K	\$20K to \$35K	Under \$20K
Japan	Over 3.5M¥	1.5M¥ to 3.5M¥	Under 1.5M¥
China	Over 300K CNY	100K to 300K CNY	Under 100K CNY

Source: iSuppli definitions of segments – generally standard across all analysis produced worldwide

The segments are defined by the suggested retail price for the entry level automotive or the lowest price before taxes and transportation charges. Some models will fall in different categories in some regions. For instance, the BMW 3-series is a mid-range car in EU & USA, but a luxury car in China.

Table 1.6 shows the sales mix for these three automotive segments for the key regions. For each region the percentages add to 100%.

Table 1.6 - Automotive Sales Mix by Segment								
Share: %	Segment	2008	2009	2010	2011	2012	2015	2020
W. Europe	Luxury	8.35	7.80	7.80	7.90	8.10	8.70	9.00
	Mid-range	56.90	57.25	57.15	56.90	56.55	55.50	54.45
	Economy	34.75	34.95	35.05	35.20	35.35	35.80	36.55
EU27	Luxury	8.32	7.77	7.77	7.87	8.07	8.67	8.97
	Mid-range	56.68	57.03	56.93	56.68	56.33	55.31	54.28
	Economy	35.00	35.20	35.30	35.45	35.60	36.02	36.75
USA	Luxury	7.55	7.30	7.40	7.60	7.90	8.50	8.80
	Mid-range	63.55	62.75	62.20	61.65	61.05	59.80	58.85
	Economy	28.90	29.95	30.40	30.75	31.05	31.70	32.35
NAFTA	Luxury	7.49	7.25	7.35	7.55	7.85	8.45	8.75
	Mid-range	63.47	62.65	62.10	61.55	60.95	59.70	58.75
	Economy	29.04	30.10	30.55	30.90	31.20	31.85	32.50
Japan	Luxury	8.11	7.90	7.80	7.75	7.77	7.90	8.15
	Mid-range	63.73	63.79	63.74	63.64	63.47	62.89	61.89
	Economy	28.16	28.31	28.46	28.61	28.76	29.21	29.96
China	Luxury	7.30	6.85	6.75	6.70	6.70	6.80	7.05
	Mid-range	47.25	46.85	46.70	46.55	46.40	46.12	46.00
	Economy	45.45	46.30	46.55	46.75	46.90	47.08	46.95
Worldwide	Luxury	7.33	6.95	6.91	6.95	7.07	7.38	7.61
	Mid-range	53.40	52.58	52.43	52.19	51.91	51.20	50.44
	Economy	39.27	40.47	40.65	40.86	41.03	41.42	41.95

Source: Based on car sales and model prices for 2008-09. Future data is from trend analysis and iSuppli forecast. Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

W. Europe, USA and Japan have the highest proportion of luxury car sales. China and other developing regions have a larger share of economy cars than the developed countries. USA has the smallest portion of economy cars, but the share will increase in the next decade.

1.2.1.4 Automotive sales retail revenue by region

Automotive retail sales are among the largest industries in most countries. Table 1.7 shows the estimated automotive retail sales for key regions including forecasts until 2020. Worldwide automotive retail revenue is projected to grow from \$1,421 billion in 2008 over \$2,050 billion in 2020. This corresponds to an average worldwide car sales price of \$21,530 in 2008 and \$21,830 in 2020.

Table 1.7 - Automotive Retail Revenue by Region ²¹							
In \$ billions	2008	2009	2010	2011	2012	2015	2020
W. Europe	363	351	337	347	361	402	434
EU27	389	359	350	360	374	416	453
USA	324	254	284	312	341	415	444
NAFTA	385	304	337	368	400	482	522
Japan	126	114	116	119	122	131	138
China	168	242	264	274	285	327	393
Worldwide	1,421	1,341	1,400	1,472	1,554	1,799	2,058

Source: Based on automotive sales and model prices for 2008-09. Future data is from trend analysis and iSuppli forecast. Based on Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

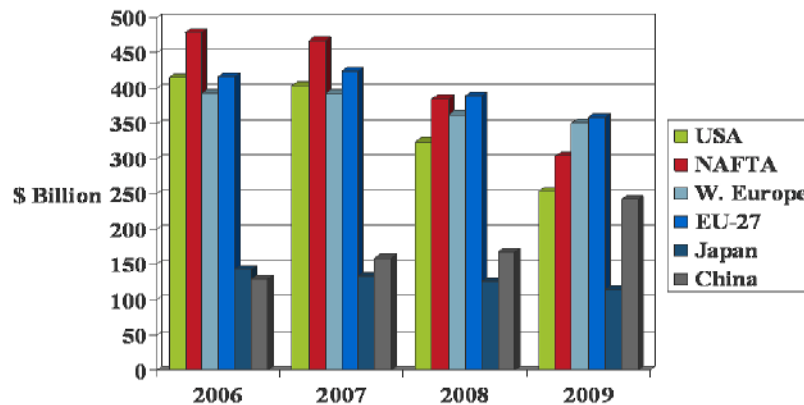
Going forward from 2010, the average price per vehicle (globally) is not set to increase significantly because much of the upcoming automotive sales growth is coming from economy cars in the developing countries. The market-mix shift towards economy vehicles will cancel out

²¹ This data is presented in \$ US as exchange rates have been very volatile during those years and the available data already result usually from calculations based on automotive model prices in local currencies converted to \$ US.

the increases in value per vehicle from the addition of new technologies in other more advanced economies.

Figure 1.3 shows the retail revenue growth for the last three years, plus projections for 2009. N. America (or NAFTA) has been the largest region in automotive retail revenue due to the lower proportion of economy cars sold in this market.

Figure 1.3 - Automotive Retail Revenue Trends



Source: Estimates by authors are created from automotive sales numbers and automotive prices. Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

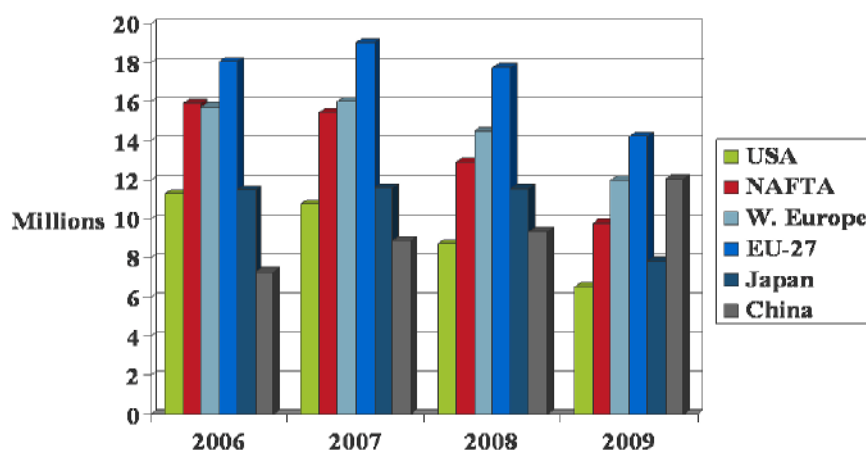
In 2008 the EU region became the largest region in terms of revenue, as automotive sales declined less than in the USA.

1.2.2 Automotive production

1.2.1.1 Automotive production by region

Automotive production temporarily peaked in 2007 and declined in 2008 with further decline continuing in 2009 in most regions as shown in Figure 1.4. Only China will have positive production growth in 2008 and 2009. Volkswagen is the leading automotive brand in China, has joint automotive manufacturing subsidiaries with China companies and benefitted from the Chinese growth.

Figure 1.4 - Automotive Production by Region



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Automotive production in USA has dropped for many years and is not likely to reach 2006-levels in the next decade. NAFTA (Canada, Mexico & USA) will do better and automotive production is forecasted to top 2006-levels in 2019.

Table 1.8 summarizes automotive production by key regions for the next four years and projections for 2015 and 2020. Worldwide automotive production is forecast to grow from 59.5 million in 2009 to over 95.6 million in 2020 or a compound annual growth rate of 4.4%.

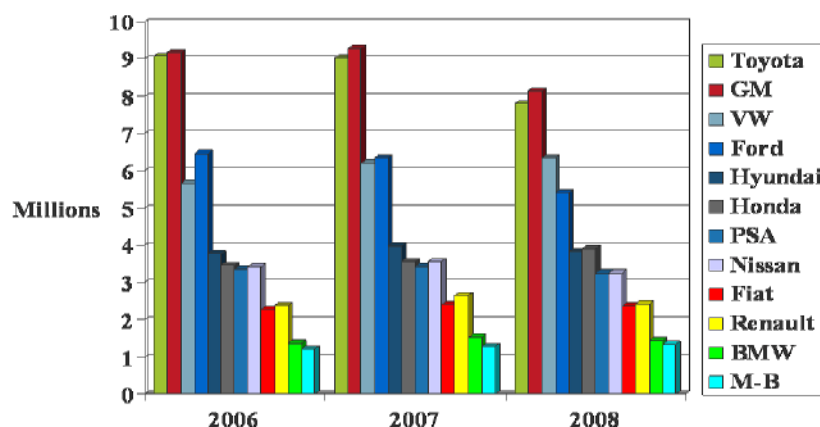
(000 cars)	2008	2009	2010	2011	2012	2015	2020
W. Europe	14,475	11,969	13,020	13,650	14,120	15,250	16,370
EU27	17,718	14,964	16,090	16,770	17,350	18,940	20,540
USA	8,705	6,515	7,170	7,610	8,080	9,640	11,110
NAFTA	12,963	9,825	10,830	11,510	12,230	14,600	16,860
Japan	11,560	7,927	8,910	9,820	10,560	12,970	12,670
China	9,345	12,540	13,570	14,560	15,630	18,230	21,280
Worldwide	70,525	59,452	65,120	69,530	73,700	84,210	95,680

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details). Forecasts estimated by authors.

EU automotive production will not reach 2007-levels until 2017, or possibly a year or two earlier if economic growth is stronger than current forecasts. Automotive production in the EU is forecasted to grow from over 14.9 million in 2009 to 20.5 million in 2020, which is a compound annual growth rate of 3.3%.

Automotive production by the leading automotive manufacturers has followed the general production decline in the last two years as seen in Figure 1.5.

Figure 1.5 - Automotive Production by Manufacturers



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

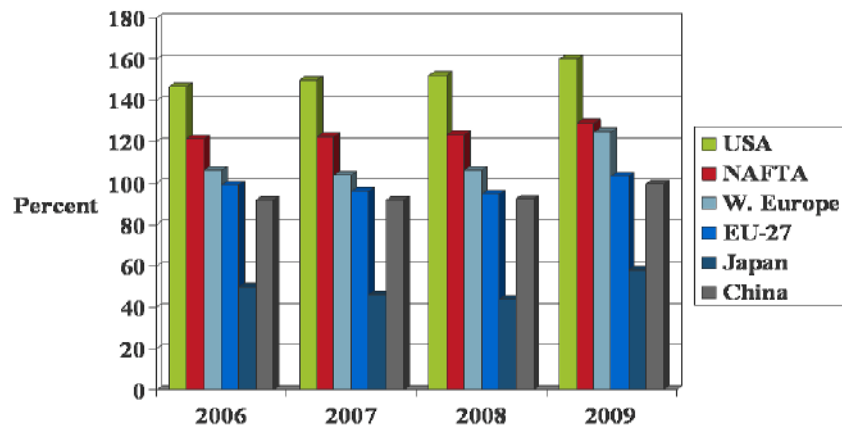
Toyota and GM have been very close in automotive production in the last three years. Volkswagen is #3 after surpassing Ford in 2008. Among other European automotive manufacturers PSA is #7. Fiat, Renault, BMW and Mercedes-Benz are also among the top 14 automotive manufacturers.²²

Figure 1.6 shows the ratio of automotive sales and production, which shows regions with export focused automotive industries. In this figure, when a region is at 100%, sales and production are equal; when numbers are less than 100% the country or region has a net export automotive industry.

Japan has the lowest ratio at less than 50%, showing to be a strong exporter of cars. Japan's ratio increased to 58% in 2009. The EU27 ratio was less than 100%, but went above 100 in 2009, because export to USA and other regions slowed from the economic problems. However, the trend has reversed and the ratio went below 100 in 1H of 2010 as EU export sales increased again—especially for luxury cars. China is already a net exporter at 99%, but more is expected in the next decade. USA has the highest ratio as it is the largest automotive importer. Production in Canada/Mexico lowers the NAFTA ratio as much as the Canadian and Mexican production is sold in the USA.

²² Note that several companies are not shown: Suzuki #9, Chrysler #12.

Figure 1.6 - Automotive Sales to Production Ratio



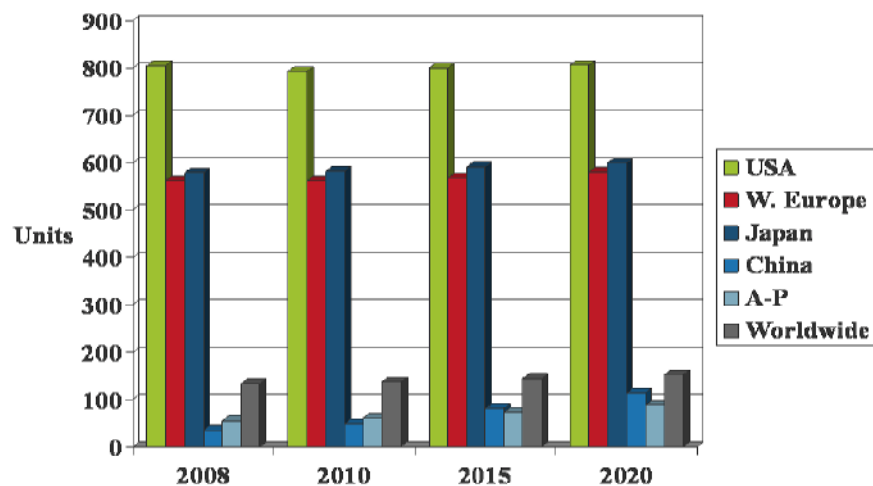
Legend: > 100 = Importing region; <100 = exporting region.

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details). Authors' own calculations.

1.2.3 Automotive in use by region

Cars-in-use per capita is the total number of cars registered divided by a country's population. Cars-in-use per capita is a good indicator of future growth prospects for automotive sales. Countries with high cars-in-use per capita will not see much yearly growth in automotive sales as the market is dominated by replacement sales. USA has the rate at around 800 autos-in-use per 1,000 people and shows to be a rather saturated market. Japan and W.-Europe also have high cars-in-use per 1,000 people at 579 and 562, respectively in 2008.

Figure 1.7 - Cars In-use per 1,000 People



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

These cars-in-use per capita figures show that USA, W.-Europe and Japan are near saturation with little future growth likely. USA will have better growth potential as the population is growing faster than Japan and W. Europe. China, Asia-Pacific and other regions are growing both automotive sales and cars-in-use per capita in the next decade.

1.3 Economic Overview of the Automotive Industry: Summary and Conclusions

The European automotive sector is among the most important industries in Europe. It provides direct and indirect jobs for over 12 million people including 6.5% of all manufacturing jobs. It generates taxes equal to 3.5% of EU GDP and is a leading EU export industry with net trade of nearly €43 billion.

The European automotive industry is also in a leading worldwide position due to its strong automotive manufacturers and suppliers who showed to be, comparatively to their IUS competitors, rather resilient throughout the still on-going financial crisis.

The European automotive manufacturers and suppliers are expanding outside Europe to participate in this sales and production growth. This expansion provides opportunities for the European automotive suppliers. Also, Europe is especially strong in the premium automotive segment with the top three suppliers: BMW, Mercedes-Benz and Volkswagen's Audi division. This luxury automotive segment is the innovator in automotive ICT, which has made the EU the leader in automotive ICT products.

Still, some current and future trends need to be addressed:

- Over 25% of worldwide cars are produced in Europe. But this share is declining as developing countries such as China and India are expanding their automotive production. While major unsaturated markets appear in emerging economies such as China, the rise of competitors and the demand for mid-range and economy segments cars transforms demands and affects the European industry.
- Around 25% of automotive sales are also in Europe—including cars imported from other regions. This percentage is also declining as automotive sales in developing countries are expanding rapidly and European markets are already well served with over 550 cars per 100 inhabitants. In addition, traditional and new Asian OEMs are increasing their market shares in advanced economies, as a result of the introduction of new products (ex.: Toyota) or Mergers and acquisitions (ex.: Tata).

In the following chapters, the report explores how and to what extent product innovation, enabled by automotive ICT, might affect favourably or not the European automotive sector, both on the European market as in terms of market expansion outside of Europe. These ICT-related trends will be explained in more details in the next chapter.

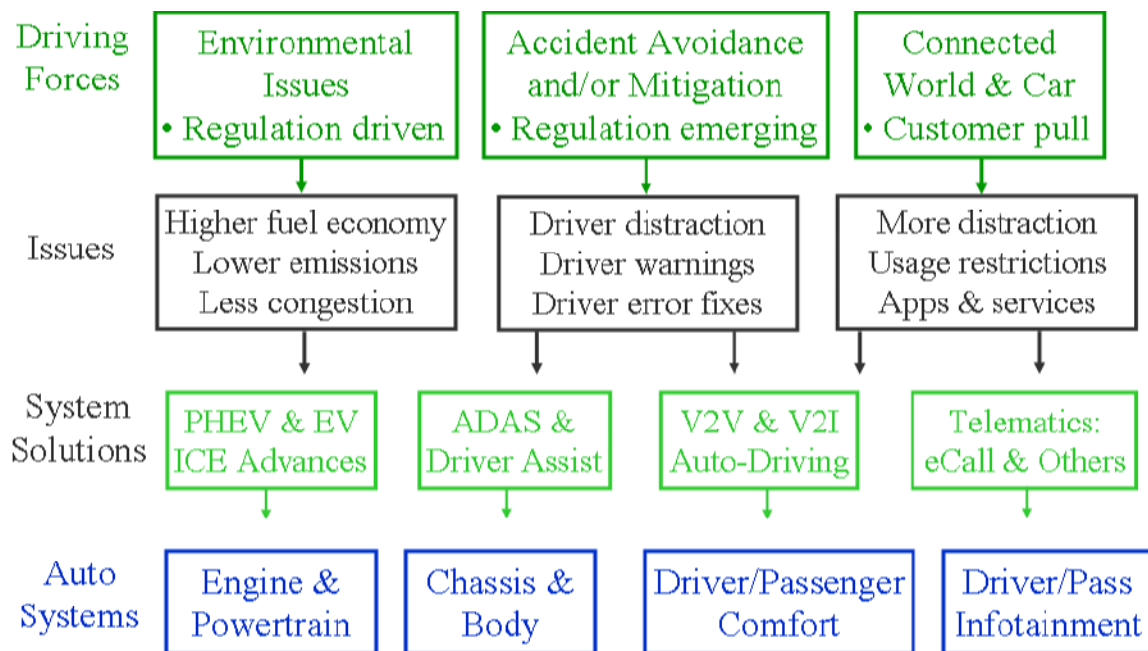
2. Drivers of Change in the Automotive Sector

The car's conversion from **analogue** to **digital** control systems and from mechanical to electrical system has been on-going for over 20 years, with development primarily driven by emission issues. However the ability for the vehicle to be connected and of driving to become more secure have been major new forces that has developed over the last years. This chapter describes the external and internal driving forces impacting the automotive industry, with an emphasis on those that affect most on automotive ICT.²³

2.1 Automotive Industry Driving Forces

Automotive technology has changed considerably in the last two decades and much more is on the way. There are major external forces impacting the automotive industry. These driving forces and their main impacts can be summarized as in Figure 2.1:

Figure 2.1 - Automotive electronics driving forces



ADAS=Advanced Driver Assist Systems; ICE=Internal Combustion Engine; PHEV=Plug-in Hybrid Electric Vehicle
Source: Authors' own elaboration.

Environmental issues: Environmental issues are regulation driven and are having tremendous impact on the automotive industry. Most of the solutions designed to lower emissions and improve fuel-efficiency are dependant on electronics and associated embedded applications to improve the efficiency of the internal combustion engine (ICE) and the development of electric motor based power systems (PHEV, EV, etc.).

Accident Avoidance / Mitigation: Accident avoidance and accident mitigation can be improved with a greater use of electronics and software systems in the vehicle in the form of Advanced

²³ Appendix A2 explains all acronyms used in the report.

Driver Assist Systems (ADAS) and driver assist systems²⁴ that ‘correct’ many of the errors made by drivers.

Future Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) systems will further advance ADAS solution and will eventually lead to Autonomous driving systems, where human intervention will be reduced even further.²⁵

Mobile connectivity requirements / Connected Car: As consumers become used to the convenience of the ‘connected-world’, through their mobile devices, there will be increasing demand for OEM’s to engineer ‘connected cars’. This is particularly the case for a new generation of consumers that have become used to Internet access and mobile phones. However, the connected car will bring more driver distractions, which in turn will need to be managed by more intelligent and advanced electronics systems.

2.2 System Solutions

2.2.1 Environment: hybrid and electric vehicles: just one battery innovation away?

While the EU region is at the forefront of industry solutions for **current generation** propulsion solutions (petrol and diesel), the EU is not seen as being proactive in ‘next generation’ propulsion including the electric drive train and high-voltage battery developments. Table 2.1 summarizes most of the key issues for electric vehicles.

Table 2.1 - Disruptive Technology: Electric Vehicles		
	Likely Events	Impact/Comments
Hybrid Electric	<ul style="list-style-type: none"> • Medium-term importance • Experience for plug-in EV 	<ul style="list-style-type: none"> • Mostly in Asia Pacific and USA • Toyota & Honda leads
Hybrid Generator as	<ul style="list-style-type: none"> • Engine: generator to battery • Long-term importance • Price premium will decline 	<ul style="list-style-type: none"> • Range extender to battery • Much smaller engine needed • Price competitive in 5+ years
Plug-in electric car	<ul style="list-style-type: none"> • Long-term importance • Rapid price declines likely • Growth as oil prices increase • EV limitations will decline 	<ul style="list-style-type: none"> • Electric motor: Up to 80% efficient • Volume production & innovation • Oil price hike: When, how much? • Innovations coming i.e. solar film
Battery Technology	<ul style="list-style-type: none"> • Current AP battery lead • USA R&D investment • EU R&D investment • New battery innovation likely 	<ul style="list-style-type: none"> • China: BYD-battery & car maker • More likely • More needed • 1 innovation away from disruption
High Voltage Electronics	<ul style="list-style-type: none"> • Continued EU leadership • Rapid cost decline likely • Innovation coming 	<ul style="list-style-type: none"> • ST Micro, Infineon • Semiconductor learning curve • Improved battery management

Source: Authors' own elaboration.

Improved efficiency will be one of the primary motives for the development and roll-out of the electric motor in vehicles. Currently the internal combustion engine is only about 20% efficient, while electric motors can be up to 80% efficient. A second motivation is that electronics-based technologies advance at a much higher rate than mechanical technologies. Electrical motors are a mixture of electrical and electronics technologies, and will not move as fast as electronics, but are still likely to move faster than mechanics.

²⁴ ADAS: "Driver assist" were the first systems and Advanced Driver Assist Systems (ADAS) are the more sophisticated products that are now emerging.

²⁵ As it is already the case in Auto-Pilot systems on aircraft and some automatic trains.

Currently it is not clear which systems will be used to generate and run the electric motors in the vehicles of the future. The current hybrid approach that duplicates traditional engines and electric motors is likely to be a short-term solution, while the next generation systems are likely to use electric batteries in conjunction with a small engine as a 'generator' to extend the range of the battery. Most new announcements are using this approach including the Chevrolet Volt, Opel Ampera and Nissan Leaf. There are also battery-only vehicles in development, but these are likely to be very expensive cars such as the Tesla, or 'city-cars' with limited range.

Battery-only cars will require many years of advances in battery technology before they become viable in terms of cost. Current battery technologies are a significant cost adder to current generation electric/hybrid vehicle production. The fuel cell is another technology that can generate electricity as well as drive electric motors. Hence there are multiple technology options that can advance electric vehicles.

2.2.1.1 Obstacles and disruptions

In Europe, the Electric vehicle shows some severe market issues. While there is wide industry consensus that the use of electric vehicles and battery technology will be widespread in the future, the use of Hybrid and electric vehicles is currently not gaining traction inside the EU region (rather mainly in US and Japan). Still, the EU region would need to be at the forefront of developing high-technology next generation electric vehicle technologies as failure to do so will result in the EU moving to follower status in the development of these technologies.

The EV is a threat in terms of lower tax revenues. When electric vehicles come to market in greater volumes, governments will see substantial drops in tax revenues from the automotive sector. In the UK for example, up to 75% of the payment at the pump is tax and fuel duty. With the rise of electric vehicles, governments will need to formulate alternative strategies to make-up for this loss of tax income. Consequently, questions remain as to whether governments will be enthusiastic to support electric vehicle development as it will have a negative effect on tax revenues. Road usage fees based on distance-driven is the likely alternative to fuel taxes. The Netherlands have been at the forefront of testing such systems. Several states in the USA have also tested such systems, with Oregon having done significant testing on a pay-as-you-drive basis.

Reversely, if legislation is introduced EU-wide limiting city centre driving to low (or zero) emissions vehicles, this could have a very positive effect on battery and electric vehicle development. Cities such as London already have high taxation strategies that aim to limit city centre driving to 'Low-emission' vehicles only. The French transport authority recently announced it would be establishing a carbon tax similar to the London low-emission tax, and German transport authorities are in discussion about limiting grams of CO₂ per KM in cities

Other disruptive influences might affect as well the development of the EV.

Electric vehicles will stimulate improvements in current fuel based solutions: The development of battery technologies will have the effect of increasing the competition for the internal combustion engine, which in turn is likely to lead to better and more economical fuel based solutions. This is likely to slow or disrupt the development of electric vehicles. For example, BMW's ED (Efficient Dynamic) technology is breaking new ground in terms of energy efficiency with engines capable of outputting 160+ Horse Power while producing just 104 grams of CO₂ per kilometre

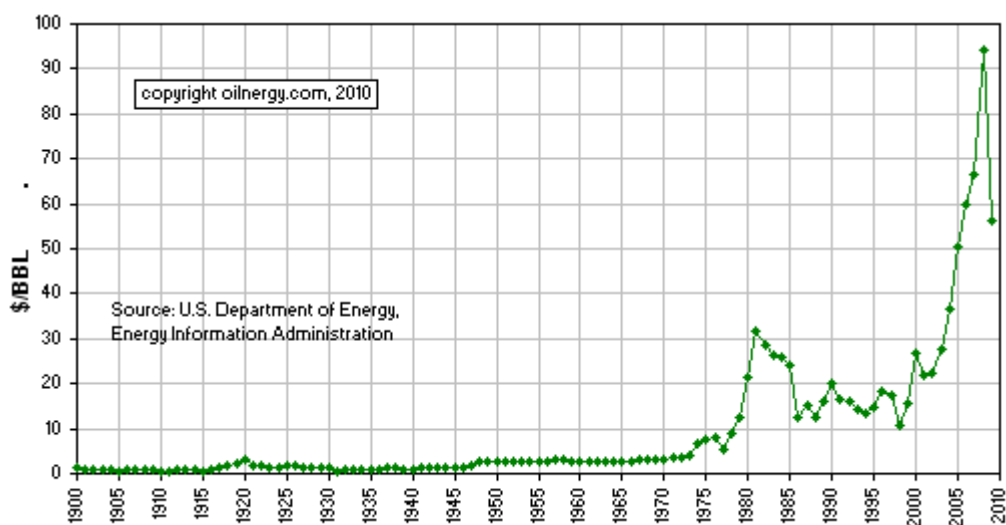
The price of oil could dramatically disrupt the landscape for the development of electric vehicles. The production of cheap to exploit conventional oil fields has already declined in a number of countries (notably USA in 1970 and Mexico in 2004). This is already prompting oil companies to drill more expensive wells in deep ocean water like the Gulf of Mexico and in Arctic areas or to search for heavy oil which is more expensive to exploit and refine. A global decline in the

production of cheap to exploit oil could happen by 2020. Therefore, it is highly likely that the oil price will increase over time as the remaining worldwide supply is more expensive to exploit (particularly over the next 15-20 years).²⁶

Clearly the next 15-20 years will be a critical time in the development of alternatives to fossil fuel based solutions based on electric power.

In July 2008, the oil price reached 147 USD a barrel, but with the global economic crisis, the price plummeted to around 30 USD, lessening the interest in alternative technology development as existing solutions suit the current market conditions. In addition, the depreciation of the USD against the Euro partly cushioned the impact of the oil increase for euro-zone consumers. However, on 7 September 2010 the oil price again rose to 73.8 USD and the Euro has declined against the US Dollar (1 Euro = 1.28 USD), with a barrel at 57.65 Euros.

Figure 2.2 - Price of an Oil Barrel in USD (1900-2010)²⁷



Some put the market tipping point at a sustained oil price above 150 USD/barrel, which will lead to a significant increase of the interest in non-petrol/diesel based solutions, like plugged electric, fuel-cell or hydrogen vehicles (with the hydrogen generated with electricity from renewable energies).

In addition, the world may sharply reduce its use of oil before oil fields are completely exhausted, as soon as the oil energy return on the energy invested to extract it, is equal or lower than 1 ($EROEI \leq 1$).

Some of the limitations of electric vehicles have been played down by the main supporters of this technology. Many industry players believe that as more is learned about the limitations of battery technology, this could have a disruptive effect on the support for development and roll-out of electric propulsion. In practice, electric vehicles are likely to have limited driving ranges unless battery technologies are developed well beyond the current offerings. Still, typical European commutes are less than 80 kilometres per day, which would be in the range of current battery technologies.

Replacing the battery after a year or two of service (battery life) is likely to be a requirement in future vehicles. Currently EV batteries have a high price and are difficult to recycle due to the

²⁶ Report "The world in 2025", by DG Research: [By 2025] oil production will have started to stagnate (peak)". http://ec.europa.eu/research/social-sciences/pdf/the-world-in-2025-report_en.pdf

²⁷ <http://www.oilenergy.com/1opost.htm>

high levels of heavy metals etc. Several companies are planning battery swap stations, which will be the equivalent of a gas station for electric cars. To swap a discharged battery with a charged battery is expected to take the same time as filling the gas tank. Israel is starting a trial project to prove the concept.

Electric vehicles may need to limit (or not install) high-energy use, comfort technologies such as air conditioning, as these technologies could drastically reduce battery performance. The development of low-power solutions for comfort can be seen as a significant opportunity for new technology development in Europe. For example, the use thin film materials that include solar panels is another emerging technology that can be used to generate electricity for comfort systems

The handling of high-voltage batteries requires specialist handling by vehicle manufacturers, as well as secure packaging to ensure vehicle owners are shielded from high-voltage electric shocks. Hybrid and electric vehicle drive trains are based on high-voltage architectures (typically 400-600 volts). Unless handled correctly, these high voltage architectures could be very hazardous not only to vehicle owners but also developers and service technicians. It is likely that non-EU markets (particularly in the developing world) are likely to be less stringent with health and safety requirements, which may lead to an unfair advantage for these regions which will result in a disruptive effect on the development opportunity within the EU.

On 30 July 2010, a Commission report has warned about a possible limited availability for EU manufacturers of a number of raw materials (notably neodymium, nickel, cobalt and lithium), for the manufacturing of high performance batteries and electric magnets for electric engines.²⁸ The report proposed a number of actions to increase their availability, including the improvement of access to and extraction of primary resources, achieving a level playing field in trade and investment in third countries, increasing recycling, and research on substitution and material efficiency.

2.2.1.2 Current European developments

While the EU region has shown progress in developing its own technology base for EV and hybrid vehicles, much of the momentum must be attributed to Asia and Japanese OEMs in particular. The Nissan LEAF will have the greatest effect on the EV market outside of Japan as it begins for deployment in the Netherlands and Portugal at the end of 2010, followed by the UK and Ireland in February 2011. The Mitsubishi i-MiEV will also play a significant role in the European EV market, but not as directly as the LEAF. Mitsubishi has partnered with PSA to share the i-MiEV platform with the Peugeot and Citroen brands, who expect to bring their respective EVs to market around the same time the LEAF begins to make its European impact. Though Mitsubishi will offer the i-MiEV in Europe eventually, it is more likely to make an impact under the Peugeot and Citroen badge.

PSA is not the only French company to make waves in this segment however. From the Renault-Nissan Alliance, Renault has recently introduced several EV concepts that show its commitment towards research efforts in alternative propulsion and the LEAF experience will prove useful for Renault's own deployment plans. As a result, French automotive manufacturers will be the first native European presence, albeit with help from Nissan and Mitsubishi, to push the EV market forward on its home territory. In addition to battery-powered models however, PSA will take more direct steps towards the goal of improving overall fuel efficiency by bringing its diesel HDi hybrid electric technology to market, expected for 2012.

When looking over the list of European OEMs and expected EV deployments however, one notices that European powerhouses BMW and Mercedes-Benz are slightly behind the times.

²⁸ http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm

Though Mercedes-Benz offers a hybrid S-Class, it is more closely related to today's vehicles than the EVs of tomorrow that will soon be available on the European market. Similarly, BMW has only recently introduced its ActiveE concept and has only begun to detail the Mega City Vehicle; these platforms won't be present when the EV market begins to take a more defined shape in Europe in 2011. Both Mercedes-Benz and BMW however have made arguably more realistic progress on their secondary brands, Smart and Mini, respectively. Each has appeared in functioning form and are involved in field tests and fleet deployments to examine real-world use of their technologies. This experience will help ensure a smoother deployment of the EV and hybrid technologies of the parent companies.

Volkswagen and Audi are in a similar position to their German competitors. Audi's eTron concept remains as such and has an expected availability of at least 2012, while Volkswagen's EV platform is scheduled for release in 2013. Volkswagen has taken a similar approach to PSA however by combining already efficient diesel engines with a hybrid electric drivetrain to cover the middle ground between today's technology and full electric propulsion. Rounding out the list is the Toyota Prius, responsible for much of the push for hybrid innovation early on in Japan and the worldwide automotive industry. The only American entry is the Opel Ampera, which is based on the Chevrolet Volt. The Volt is expected to be deployed in the USA in late 2010 but the European Ampera will be forced to wait until Chevrolet tests the waters and the technology embodied by the Volt on the American market.

Table 2.2 – EU-based Hybrid/Electric Vehicle Initiatives			
OEM	Model	Launch	Notes
Nissan	Leaf	December 2010	Full EV, first in Netherlands & Portugal
Mitsubishi	i-MiEV	Early 2011	Full EV, commercial sales in Japan since 2009
Citroen	C-Zero Berlingo, First Electric	Late 2010 2011	Full EV, same platform as i-MiEV Commercial, cooperation with Venturi
Peugeot	iOn BB1 3008 Hybrid RCZ Hybrid	Late 2010 2012 2012 2012	Full EV, same platform as i-MiEV Concept debut at IAA 2009 Diesel HDi plug-in hybrid Diesel HDi plug-in hybrid
Renault	Fluence ZE Kangoo ZE Zoe ZE Twizy ZE DeZir	2011 2011 Late 2011 2012 2012	First model in Renault ZE programme, IAA 2009 Full EV sedan & urban car, commercial Full EV, concept debut at IAA 2009 Full EV, concept debut at IAA 2009 Concept debut in Paris 2010
Mercedes-Benz	S 400 Hybrid F 800 Style	2010 Concept	Plug-in Hybrid, debut at IAA 2009 Fuel cell concept, debut at Geneva 2010
Smart	Smart ed	2012	Full EV, Tesla-supplied electric motor
BMW	ActiveE Mega City Vehicle	2013+ 2013+	Based on 1 Series, debut at NAIAS 2010 Prototype expected in 2012
Mini	Mini-E	TBD	US & EU field testing in 2009-2010
Audi	e-Tron	Concept	Debut at IAA 2009
Volkswagen	Golf E-Up	2013 2013	Diesel plug-in hybrid Full EV or hybrid, concept debut at IAA 2009
Toyota	Prius Plug-in Hybrid	2012	Gas-electric hybrid, debut at IAA 2009
Lexus	LF-ch	Concept	Gas-electric hybrid, debut at IAA 2009
REVA	NXR NXG	2010 2012	Full EV, debut at IAA 2009, telematics Full EV, debut at IAA 2009
Opel	Ampera	Late 2011	Full EV, European Chevy Volt

Source: Authors' own elaboration.

Altogether, environmental issues are having a tremendous impact on Powertrain systems and ECU features will provide much of the needed increase in fuel efficiency and emissions improvements for traditional combustion engines. Table 2.3 lists numerous trends that are taking place and nearly all are dependent on electronics and embedded software.

The wider use of MCUs and embedded software in the Powertrain has already improved the efficiency of the internal combustion engine (ICE), with more advances being introduced into the market all the time. However, we have seen above that the competition from the introduction of the electric motor drive is forcing ICE technologies to improve their efficiency or face greater competition in the future.

Table 2.3 - Powertrain Trends		
	Current Features	Emerging/Future Features
Propulsion System Mix	<ul style="list-style-type: none"> • ICE: Gasoline engine • ICE: Diesel engine • Hybrid: ICE & electric motor 	<ul style="list-style-type: none"> • Hybrid ICE & electric-Serial • Plug-in electric: battery • Electric car: hydrogen
Hybrid-Electric Control	<ul style="list-style-type: none"> • Battery control • Inverter control • Electric motor control 	<ul style="list-style-type: none"> • Battery control innovation • Inverter control innovation • Improved motor control
Internal Combustion Engine Control	<ul style="list-style-type: none"> • Engine management system • Electronic GDI (direct injection) • Electronic turbo control • Cylinder-on-demand 	<ul style="list-style-type: none"> • Electronic valve control-EVC • HCCI (gas injection technology) • Small engine-turbo integration
Transmission Control	<ul style="list-style-type: none"> • Electronic transmission • Transmission-CVT 	<ul style="list-style-type: none"> • MPE road geometry/attributes

Source: Authors' own elaboration.

Over the next ten years to 2020, technology improvements will keep ICE cars in the game due to better engine control by advanced ECUs and embedded software, however, over time, electric motor technologies will improve in performance and cost and eventually electric vehicles will become mainstream technology. While the actual timing of this event is uncertain, there is little doubt that this change will happen between 2020 and 2030.

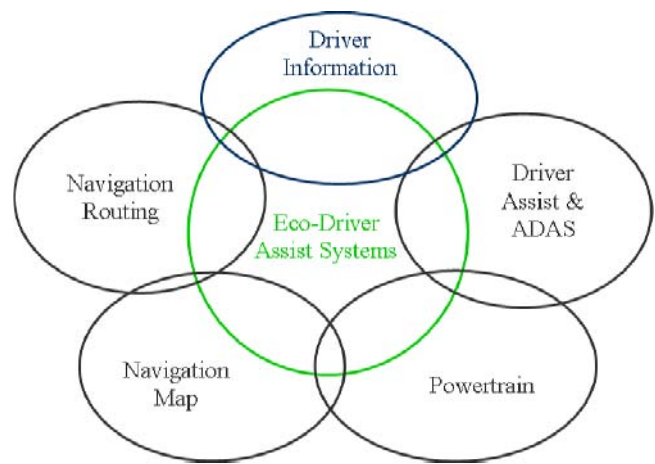
2.2.1.3 Green technologies

Vehicle manufacturers and suppliers continue to improve the performance and efficiency of motor vehicles as they respond to the increased consumer awareness and a general global movement towards 'going-green'. As a result of this raised awareness of green technologies; Eco-Driver Assist Systems (EDAS) have become prominent in the automotive industry and have assumed a role in many driver assist and ADAS products.

Green technologies can vary widely but typically their designs target increased efficiency for the vehicle in some way, (e.g. improved fuel efficiency or lower emissions). Electronic 'green' technologies are typically integrated into the vehicle's systems, gathering information regarding the vehicle's performance or surroundings, and either passively advising the driver to drive more efficiently (often with the use of driver metrics on displays), or actively changing vehicle settings or behaviour in order to achieve more efficient operation.

Figure 2.2 presents a conceptual view of how the Eco/Green driver assist developments touch many aspects of the vehicle's function from human machine interfaces to navigation routing as well and Powertrain monitoring and control.

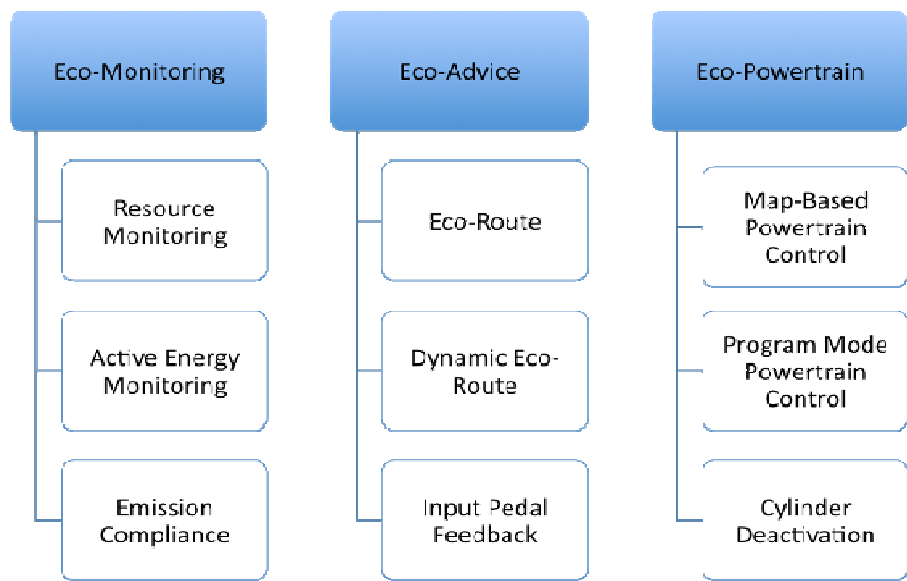
Figure 2.3 - Domains Affected by Green Technology



Source: Authors' own elaboration.

Figure 2.3 presents a breakout of the activities in three key focus areas for making vehicle operation more eco-friendly: Eco-monitoring, Eco-advice and Eco-powertrain.

Figure 2.4 - Focus Areas for Green Technology



Source: Authors' own elaboration.

Eco-monitoring is already available and some functionality is included in vehicle trip computers. Eco-monitoring systems include information on instantaneous and average fuel consumption, and are adding tracking driver patterns for further analysis. Most eco-advice or eco-routing systems use navigation systems to give information on routing that have low fuel usage. Powertrain eco-management includes a variety of engine efficiency technologies. An interesting emerging technology is the Map and Position Engine (MPE) from Navteq that will use map attributes to improve fuel usage. Numerous EDAS products are already available in Europe and other regions.

2.2.1.4 Environmental driver: findings and conclusions

- While the European region has been slow to develop Hybrid and electric vehicles, most EU based car manufactures now have programmes in place to supply vehicles into this market segment
- The challenges of developing electric motor solutions over traditional fuel base solutions, requires innovative thinking and creative problem solving particularly in the area of power usage/efficiency. This 'eco' requirement has lead many of the vehicles listed above to be launched with innovative solutions that are currently not part of the automotive mainstream.

One example is the inclusion of a telematics package with many of the vehicles listed, usually to help with battery management. Although telematics was originally designed for maintenance and other issues related to the electric charge of the vehicle, the inclusion of a telematics system opens up safety and infotainment options as well.

- Acceptance level of Electric vehicles by the public is hard to determine. Many Europeans, value the current 'driving experience' of fuel based systems, which cannot easily be replicated using an EV. However, Europeans typically have shorter commutes to and from work than their American counterparts; meaning the shorter distances per charge on many current electric vehicles, may not be an issue. (Also fuel prices in Europe tend to be much higher than in other countries such as the US, which is likely to provide greater market pull.)
- The EU automotive industry generally believes electric cars will remain a niche market for a decade or more. This belief is based on the price premium from high battery cost and the high voltage electronics cost. The cost of high voltage electronics will likely decline much faster than the norm in the automotive industry. While battery technology development has been moving at slow speed in the past, the automotive industry's interest in battery technology and the government sponsored investments in new battery technology could speed up technological improvements.

The economic rewards of a breakthrough in battery technology are certainly among the largest opportunities available for suppliers of electric vehicles. Hence, a severe disruption for the EU automotive industry could be just one battery innovation away.

2.2.2 Security: driver assist systems, ADAS and V2X: from accident avoidance to autonomous driving

2.2.2.1 Driver assist systems

The total cost of car accidents to society is very high and range from 1.5% to over 2% of a country's gross domestic product (GDP).²⁹ Driver assist system can lower accident rates and future ADAS applications will improve society's typically negative impact of car usage. Hence, accident avoidance and mitigation is the driving force behind safety systems such as airbags, antilock brakes, electronic stability control and the many driver assist systems. Driver assist systems become *advanced* systems (ADAS) as they are integrated with other automotive systems including vehicle-to-vehicle (V2V) communication systems. Table 2.4 shows current trends for six driver assist systems.³⁰

²⁹ This is a conservative estimate based on a major study that was done by the U.S. Department of Transportation, National Highway Traffic Safety Administration. The estimate was that total accident cost was \$231 billion for calendar year 2000 including property costs, medical costs and lost productivity from accident costs. This figure was equal to 2.3% of the USA GDP.

³⁰ For the sake of clarity, it is important to note that the European Commission has already proposed the mandatory introduction of AEBS (Advanced Emergency Braking Systems) and LDWS (Lane Departure Warning Systems) for *commercial* vehicles. It is not directly relevant to the current report to enter such level of details, hence

Table 2.4 – Driver Assist Trends		
	Key Information	Other Information
Ultrasonic Park Assist	<ul style="list-style-type: none"> • Most popular system • Will remain largest segment 	<ul style="list-style-type: none"> • Least costly system • Economy car use
Camera Park Assist	<ul style="list-style-type: none"> • Growing availability in most regions • Aftermarket systems merging 	<ul style="list-style-type: none"> • Add-on to navigation • Mirror or PND-based
Adaptive Cruise Control	<ul style="list-style-type: none"> • Strong growth in US-EU-Japan • Base for collision warning systems • Less congestion waves 	<ul style="list-style-type: none"> • Moving to mid-range cars • 1 or 2 radars • Gas savings potential
Lane Departure Warning	<ul style="list-style-type: none"> • Growing, but low availability • Camera-based systems • Future use: Road sign recognition 	<ul style="list-style-type: none"> • Mostly luxury cars • Recognize lane marks • Other apps likely
Blind Spot Detection	<ul style="list-style-type: none"> • Rapid availability growth • Drivers understand BSD need 	<ul style="list-style-type: none"> • Volvo is a pioneer • Long term success
Night Vision	<ul style="list-style-type: none"> • Remains a niche segment • Awaiting better HUD technology 	<ul style="list-style-type: none"> • Only luxury cars • Post 2010

Source: Authors' own elaboration.

Park assist systems are inexpensive—especially ultrasonic systems, which are inexpensive enough to be included on many economy cars.

- Camera park systems are often combined with navigation systems and use the navigation display to show the camera view.
- Advanced Cruise control (ACC) is expanding to some mid-range cars, while Lane departure warning (LDW) systems remain mostly on luxury cars.
- Blind spot detection (BSD) systems appeared only four years ago and are growing fast. Since most driver have experienced near-collision event from cars hidden in blind spots, most drivers intuitively understand the value of BSD.

ADAS systems are evolving from simple driver assist systems, which were described in the previous paragraph. ADAS technologies are software intensive systems that have the potential to change the driving experience by rectifying driver errors with tremendous savings in terms of accident costs and lives.

Table 2.5 - Disruptive Technologies: ADAS and V2X		
	Likely Events	Impact/Comments
ADAS Technology	<ul style="list-style-type: none"> • Software intensive systems • Sensor-based systems • Pattern recognition SW • Major life and cost saver • Autonomous driving by 2020? 	<ul style="list-style-type: none"> • EU leadership is important • EU has sensor leadership • Leverage robotics software • High ROI to society • EU leadership is important
ADAS integration	<ul style="list-style-type: none"> • Integration among ADAS • Integration with V2X systems • Integration with chassis apps 	<ul style="list-style-type: none"> • Sensor fusion, more functionality • Embedded SW tied to EU system • Improved safety applications
V2V and V2I	<ul style="list-style-type: none"> • CVIS R&D project • CVIS: system architecture • V2V deployment by 2012? • V2V is regulation by 2015? • V2I fully deployed by 2020? 	<ul style="list-style-type: none"> • CVIS project: 2008-2010, €41M+ • Includes mass transit systems • Based on international standards • Network effect needs regulation • Likely advantageous for EU jobs

Source: Authors' own elaboration.

separating commercial vehicles from passenger cars. For further reference on EC Regulation 661/2009 on general safety for motor vehicles:

<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:200:0001:0024:EN:PDF>

Much of the ADAS embedded software will be based on pattern recognition technology applied to sensor data sent from cameras, radar and other visual inputs. These technologies in combination with V2X systems will further advance ADAS products to the point where *autonomous driving* is expected to be feasible in about a decade. V2X technologies are described in the next section.

2.2.2.2 ADAS and V2X

Vehicle-to-Vehicle (V2V) is an automobile technology designed to allow cars to "talk" to each other. V2I is an extension of V2V and allows vehicles to communicate with roadside infrastructure. Collectively they are known as V2V2I or V2X. The V2X connected vehicles vision is extensive and has the following goals:

- All vehicles have communication equipment that allows continuous connection to all nearby vehicles and to all roadway infrastructures.
- Many V2X applications to improve safety, traffic flow, energy usage and others will be developed. Many unforeseen V2X applications are likely to emerge.
- V2X will become an enabling technology for future cruise-assisted highways and autonomous driving.
- The deployment timing of this vision is uncertain, but deployment will start before 2015, will be significant by 2020 and will become prevalent by 2025.

Major V2X projects are ongoing in Europe, USA and Japan. There is coordination among the three regions—especially in terms of standards. Japan is likely to deploy V2X technology first and some early systems are appearing later in 2009.

CVIS or Cooperative Vehicle-Infrastructure Systems is an EU research project managed by the European Intelligent Transport Initiative (ITS) organization ERTICO. Table 2.6 summarizes key data about the CVIS projects. CVIS was started in early 2006 and will last nearly four years. There are 61 organizations participating in CVIS ranging from major OEMs (BMW, Daimler, Renault and Volvo) to map suppliers (Navteq and Tele Atlas) and mobile network operators (Telecom Italy and Vodafone). Among the Tier 1 suppliers only Bosch is participating. The funding is over €41M. Deployment of CVIS-based systems is planned for 2012, but will probably vary by countries.

The CVIS project is focused on the overall V2X architecture with particular emphasis on networking, software middleware and location technology that improves GPS accuracy. DSRC based on IEEE 802.11p is the key communication technology, but CVIS also supports 3G to 4G cellular technologies, WiFi, CALM (Communications Access for Land Mobiles) infrared and legacy DSRC (915 MHz).

Table 2.6 – CVIS Summary		
	Key Data	Comments
CVIS	• Cooperative Vehicle-Infrastructure Systems	• ERTICO project
Time frame	• February 2006 to January 2010	• 61 organizations participating
Funding	• Over €41M; EU funding is nearly €22M	• EU's 6 th Framework Programme
CVIS Programmes	• 3 core technologies and test-beds • 4 reference applications • System testing	• Networking, Middleware, Positioning • V2V and V2I applications • Testing in 7 countries
CVIS Status	• System architecture: Designed, in test • Auto V2X client: Designed and in test • Positioning: New technologies in test • Applications: Some designed and in test • Development tools: Designed and in-use • Testing: Multiple field tests in 2008-2009	• Uses ISO CALM architecture & IPv6 • Based on OSGi • To improve GPS accuracy • More to be developed • More to come • De, Fr, It, NL, Be, Se, UK
Deployment	• Planned for 2012	• May vary by EU countries

Source: Authors' own elaboration.

The CVIS programmes are focused on developing the key elements that are needed to test and prove the viability of V2V and V2I systems. There are three core technology programmes included: networking-communication, software middleware and positioning technologies. CVIS is also implementing four applications that are focused on cooperative systems. Considerable testing is included and started in December 2008 and continued through 2009. The most recent successful tests were done in the Netherlands in May 2009.

The CVIS project is in its last year and has come a long way. The system architecture, which is based on the CALM architecture, has been designed and is in the testing phase. The CALM standards are the new ISO-Standards for car-to-car and car-to-infrastructure communication and are still under development. The CALM standard and CVIS are based on IPv6 networking. This decision was taken based on the needs of the Intelligent Transport (ITS) initiative, and is based on the assumption that IPv6 will take over from IPv4 in the next five years. However, both versions of the IP protocol can cohabit, through the use of some transition mechanisms.

Security Driver: Findings and Conclusions

- Driver assist and systems are already making a positive impact by lowering accident rates for many driving situations. Emerging advanced driver assist systems (ADAS) will further lower the accident rates through sensors and automotive ICT systems.
- Many of the emerging ADAS products take temporary control of selected driving functions to correct driver errors or inexperience. Examples are braking, steering, light dimming and others.
- There is little doubt that V2X systems will happen: most automotive players believe it is a matter of 'when' rather than 'if'. One of the primary reasons for the future success of V2X is the large reduction in accident costs that are feasible as the installed base of V2V cars become a significant share of cars in-use. The benefits of V2X deployment follow the network effect concept.³¹ This means that a rapid growth of V2V deployment creates the most benefit, which favours the option of a legislative deployment strategy a few years after the roll-out has started.
- V2V and V2I systems will become a major market for electronics suppliers and semiconductor manufacturers in the next decade. At some point in the future every car sold will have a V2V system—first in the EU, U.S. and Japan—and later in other regions. The

³¹ Typically summarised as "the benefits are proportional to the square of the numbers in-use" (Metcalfe's law).

V2I infrastructure units sales are much smaller than V2V units—just a fraction of 1% for most years.³²

- There is also future potential for mobile devices to access V2X networks as they are likely to become another wireless network for content access. Some mobile devices may also be used instead of embedded V2V in the aftermarket to give older cars access to V2X system benefits.
- The impact of V2X has the potential to generate a transformative impact on the automotive industry that is similar to what the Internet have done in the last 15 years.
- V2X systems will favour EU-based companies, as well as companies that have a significant presence in Europe. V2V systems will interface and connect to roadside V2I systems in European countries, and this expertise is likely to be developed first in Europe due to extensive testing and research projects that are underway or planned, other regions such as US and Japan showing less research efforts in that domain.
- The combination of ADAS, V2V and V2I systems are likely to add increasing amount of autonomous driving functionality—first to prevent accidents and counteract driver distraction, but eventually as convenience and to lower the amount of driving if so desired.

2.2.3 Connectivity: from eCall to Apps Stores

2.2.3.1 The ‘connected vehicle’ roadmap

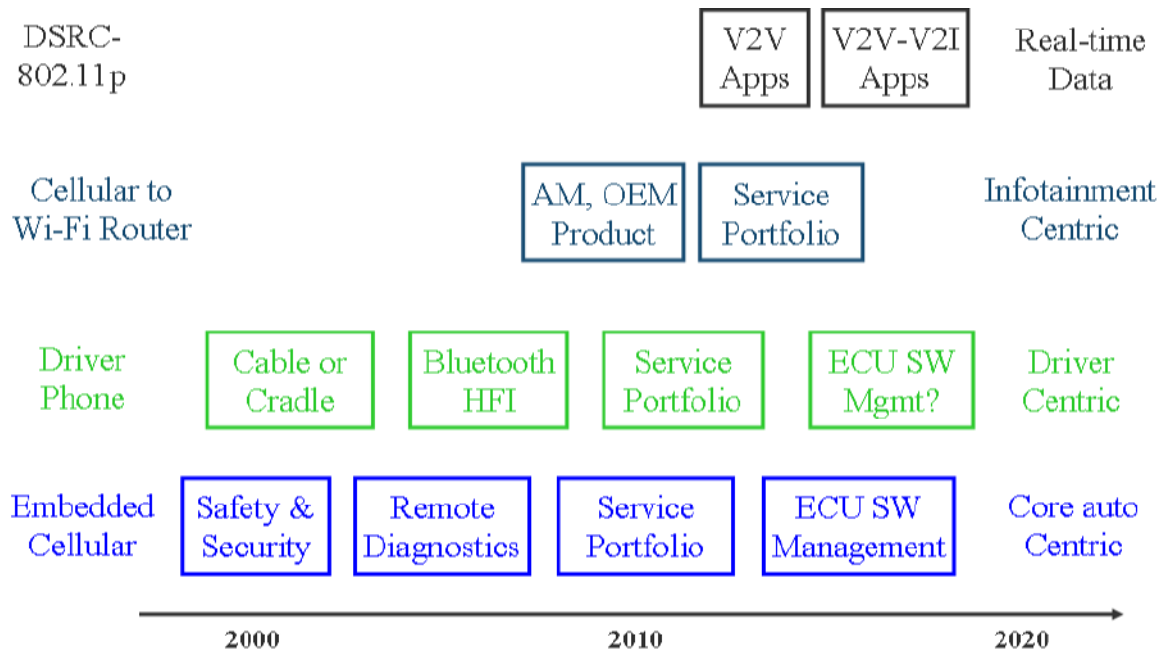
Current connection technologies as well as emerging wireless technologies are linking vehicles to the outside world.

1. **Embedded cellular layer:** The bottom layer of Figure 2.4 presents an embedded communication link, which was the first ‘connected’ approach to be launched into the automotive market. This is exemplified by the BMW Assist system and the GM OnStar system in the USA. This communication link is gaining more services and will eventually become a secure link to connect and upgrade the vehicles’ many ECU software programmes.
2. **Driver phone:** The second to bottom layer in Figure 2.4 is based on leveraging the driver’s mobile phone which was initially connected via a cable or cradle, but is now almost exclusively linked to the vehicle via a wireless Bluetooth Hands-Free Interface (HFI). Nearly every car manufacturer now offers a Bluetooth HFI system. The mobile phone approach was initially only for voice communication, but suppliers are now adding services such as eCall, traffic information and navigation services. The Bluetooth HFI system is driver centric, but will provide some services for the car ECUs in the future.
3. **Cellular to WiFi-Router:** The third approach (second layer from the top in Figure 2.4) is just emerging and is built on a cellular link to a WiFi router that connects to any mobile device in the car that supports WiFi. This link will primarily be for passenger infotainment services or for use by the driver when the car is parked.
4. **DSRC- 802.11p:** The last approach (top layer in Figure 2.4) is called V2X (as already presented above) and is a few years down the road in terms of implementation in the market. However, V2X is likely to become the most important link within a vehicle in a decade or so. V2X systems will be the basis for many advanced safety applications (ADAS) and will eventually become a key technology for autonomous driving. V2X is also likely to add infotainment applications and services that will be better able to filter and manage and reduce

³² Estimating rationale: V2V systems will be included with every car sold (14M+/year plus sales to all autos in use (250M+)). V2I systems are installed at dangerous intersections and maybe 1 every KM or so on highways and such systems last for many years. Adding this up, 60,000+ KM of highways in EU and maybe 200,000 intersections in EU stays far below in volume. If the deployment time is 5-years, only 20% of total V2I will be sold/year. But each V2I system will be much more expensive than a V2V system, so the revenue opportunity will be much closer.

unwanted driver distractions. Since the V2X systems will have situational awareness of the driver's work load, they will be programmable to block communication-based distractions when needed.

Figure 2.5 - Connected Vehicle Technology Evolution



Source: Authors' own elaboration.

The connected car is desirable to drivers and passengers due to the many services and applications that become feasible when the car is connected. Perhaps the most disruptive impact of the connected car is how ECUs and embedded systems can be corrected and updated when there are software errors. As the ECU and software functionality can also be changed and upgraded, this means that the car's efficiency could be improved *after the sales of the vehicle*, with for example lower emissions using better software algorithms for engine management.

Table 2.7 presents a summary of some expected benefits of the connected car:

The left side of the table presents reasons why connectivity is useful to the car maker and the cars electronics systems:

- The car's many electronic systems need a connection to the outside world for diagnostics and software corrections and updates.
- Future ADAS applications will use (Vehicle-2-Vehicle) V2V systems to communicate the cars' directional paths, which can be used to calculate the likelihood of a potential crash.

The right side of the table lists three communication-based application segments for driver and passenger.

- Driving related applications are primarily navigation-centric, but include toll collection and future road usage fee collection.
- Safety applications include eCall and related functions.
- Infotainment applications have the most driver distraction potential and need good HMI to minimize driver distraction.

Table 2.7 – The Connected Vehicle: What is Connected?	
Connected Car	Connected Driver-Passengers
<u>Core Auto Systems</u> <ul style="list-style-type: none"> • Remote diagnostics connection • System problem reporting link • ECU SW correction connection • ECU SW function update link • State regulation compliance link • OEM/Dealer/CRM link 	<u>Driving-related</u> <ul style="list-style-type: none"> • Route-destination download link • Traffic information connection • Mobile search connection • Mobile navigation connection • Electronic toll connection • Road usage fee connection
<u>Safety and Security</u> <ul style="list-style-type: none"> • Car-to-car: driver assist systems • Car-to-roadway: collision avoidance 	<u>Safety & Security</u> <ul style="list-style-type: none"> • eCall/ACN connection • b-Call/road assistance link
<u>Car Infotainment Systems</u> <ul style="list-style-type: none"> • Remote system control • Map update connection • Tracking information connection • Stolen vehicle tracking connection 	<u>Infotainment-related</u> <ul style="list-style-type: none"> • Voice communication link • Information access connection • Entertainment download link • Mobile device connection

Source: Authors' own elaboration.

2.2.3.2 The case for eCall: a market disrupter after regulation?

eCall³³ is an automatic crash notification and SOS calling in the event of an emergency. The system is based on vehicles connecting to the emergency 112 number in the event of an incident. Consequently, it is being analysed whether it should be installed in all new passenger vehicles sold in Europe.

Currently 20 Member States (but not France, United Kingdom or Poland), and 3 other European Countries (Norway, Iceland and Switzerland), have signed the non-binding eCall Memorandum of Understanding.³⁴

It is believed that the adoption of the ITS Directive has been a significant market disruptor.³⁵

The adopted ITS Directive will make compulsory, when a Member State decides to introduce a public eCall, to comply with the European specifications. These European specifications should be adopted by the end of 2010. While some vehicle manufacturers have implementation programmes in place to support eCall services in the future, the current development timelines mean most manufacturers are some years away from implementation of the initiative on all models. eCall legislation, now under consideration in the EU, would require manufacturers to significantly change their development schedules to bring forward eCall specifications compliance.

eCall systems would need to work in all 27 EU countries, plus Iceland, Norway, and Switzerland.³⁶ Currently no vehicle OEM offers services in all 30 country regions, although PSA has announced it will have this facility in place by 2012.

³³ COM (2009) 434 final: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0434:FIN:EN:PDF>
http://ec.europa.eu/information_society/activities/esafety/doc/2009/20091029_eCall_summit/ed_presentation.pdf
http://ec.europa.eu/information_society/doc/factsheets/049-eCall_july10_en.pdf
<http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1346&format=HTML&aged=1&language=EN&guiLanguage=fr>

³⁴ http://ec.europa.eu/information_society/activities/esafety/doc/esafety_library/mou/list_of_signatures.pdf

³⁵ In an interesting analogy, GM's use of an eCall-based telematics system on every car sold has forced every leading OEM to introduce (or soon introduce) their own telematics system with eCall functionality.

³⁶ EU member States have to progressively implement the infrastructure to support eCall. In January 2010 there was still one infringement proceedings against a Member State, the rest having been closed. For more, see:

Automotive OEMs are concerned about *who will bear the cost* of building-up and supporting the system. Current stakeholders include, Countries/States, telecom companies, vehicle OEM's and the consumer. It is estimated that once mass production begins, the cost of manufacturing eCall in-vehicle systems could fall to less than €100. Currently eCall systems typically cost significantly more, and it remains to be seen if this €100 price target can be achieved. Experts believe the EC estimate to be accurate.

On July 7th, 2010 was adopted the Directive 2010/40/EU on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport.³⁷ The adoption of the ITS Directive is expected to create an influx of both hardware and software suppliers.

- Software: Although software solutions already exist, each OEM would be free to create their own system variation.
- Hardware: The passing of the directive should create a significant increase in the requirement for telematics hardware production and support services for this new value chain. This includes semiconductor chip manufacturers, GPS phone module manufacturers, GSM phone chip manufacturers, Tier 1 suppliers of telematics control units, microphone suppliers, GPS antennae suppliers, sensor manufacturers, and Bluetooth chip manufacturers.

As more and more cars become connected to the outside world, the disruptive potential to the supply chain increases dramatically, as we have already seen with connected homes and PCs, and we are starting to see in the mobile phone sector. The next table summarizes the eCall initiative and the connected car potential it can boost.

Table 2.8 - Connected Car and eCall		
	Current/Likely Events	Impact/Comments
eCall	<ul style="list-style-type: none"> • 2010 ITS Directive passed • 2012 public eCall deployment starts • Fully deployed by 2015 	<ul style="list-style-type: none"> • Some OEMs already deploying • Innovative applications likely • eCall accelerates telematics
Telematics	<ul style="list-style-type: none"> • Telematics expansion • Multiple connections to car • Including V2I link post-2012 	<ul style="list-style-type: none"> • Both embedded and driver phone • Cellular WiFi router to devices • V2I as content/Internet link
Driver & Passenger Apps	<ul style="list-style-type: none"> • Safety & security applications • Driving related applications • Infotainment applications • Many innovative application 	<ul style="list-style-type: none"> • Stolen vehicle tracking • Navigation centric apps • Music and video centric • Some based on iPhone/Smartphones
Car-Centric Apps	<ul style="list-style-type: none"> • Remote diagnostics • Remote software upgrades • Emission-centric apps • Road usage fee collection 	<ul style="list-style-type: none"> • In use by BMW, GM, Ford • Embedded SW tied to local EU systems • Embedded SW tied to local EU systems • Embedded SW tied to local EU systems

Source: Authors' own elaboration

The implementation of a public pan European eCall could push forward the development of driver centric services by all members of the value chain from automotive OEMs, to Tier 1 suppliers as well as telematics service providers and telecommunication companies. Each value chain player would target add-on services to the eCall ecosystem, creating an entirely new

http://ec.europa.eu/information_society/activities/112/docs/table_infring.pdf. In addition, currently, three countries (Italy, Lithuania, and the Netherlands) are not yet able to geographically locate 112 mobile callers after an incident. Also, several countries still take too long to geographically locate mobile callers for eCall to be effective.

³⁷ <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:207:0001:0013:EN:PDF>

market of automotive telematics services, much like the current iPhone App Store or Android Market place is doing for Smartphones.

2.2.3.3 The rise of infotainment: the apps battlefield

The car's infotainment system is a major user of embedded software and this trend will continue into the next decade. As most entertainment content is moving to a digital format, the car's systems will need to accommodate to Digital Broadcast technologies as well as mobile digital music and digital music devices.

All of these changes require a greater use of MCUs and embedded software, with most of this ICT being developed initially for the consumer electronics and PC industries.

Table 2.9 - Infotainment Trends		
	Current Features	Emerging/Future Features
Head-Unit	<ul style="list-style-type: none"> • Digital/satellite radio • Mobile music interface (multiple) • Hard disk/solid state disk 	<ul style="list-style-type: none"> • Surround sound music • Mobile TV receiver • Internet radio
Navigation	<ul style="list-style-type: none"> • In-vehicle navigation • Mobile navigation devices 	<ul style="list-style-type: none"> • Connected navigation • Mobile navigation integration
Telematics	<ul style="list-style-type: none"> • Embedded cellular • Bluetooth HFI to cellular • Embedded & Bluetooth 	<ul style="list-style-type: none"> • Cellular to WiFi router • Vehicle-vehicle: V2V2I • Multiple links per car
Telematics Services	<ul style="list-style-type: none"> • Safety and security • Voice communication • Navigation services 	<ul style="list-style-type: none"> • Infotainment services • Internet-based services • LBS services
Human Machine Interface	<ul style="list-style-type: none"> • Speech input • Touch input • Haptic/multifunction control 	<ul style="list-style-type: none"> • Instrument cluster display integration • Multifunction centre display • Distraction management

Source: Authors' own elaboration.

Connected navigation systems and telematics systems require a growing amount of embedded software to manage an increasing number of services including website access, communication management and better human-machine interface (HMI) technologies.

The development of better HMI technologies will require additional software for natural speech recognition, text-to-speech output.

The market for smart phone applications—or “apps”—has emerged as a central battlefield in the global technology industry that is packed with device manufacturers, wireless service providers and software developers fighting it out for a share of this fast-growing market. The competition has now spread to the automotive market with BMW, Nokia and Parrot-SA³⁸ all unveiling different approaches to bring Smartphone applications to vehicles.

For software developers, this opens a whole new domain to sell their apps. For car makers, apps provide new ways to deliver infotainment and telematics services to customers. The ability to access and update infotainment apps is a new paradigm for drivers and passengers, as it not only ensures their systems remain current during the ownership lifecycle of the vehicle, but also they only pay for the applications they use. With apps so critical to the automotive market, an increasing number of companies are pushing approaches that benefit their specific goals.

³⁸ <http://www.parrot.com>

The OEM Automaker approach

BMW recently unveiled the newest aspect of its ConnectedDrive offerings: the Concept BMW Application Store. The store offers several apps for download to the iDrive Multimedia system.³⁹

Benefits of the Auto Application approach:

- The vehicle OEM can control the content (or apps) used in the vehicle.
- This ‘apps’ approach exploits and expands the opportunity of existing infotainment systems, which reduces the requirement to develop new hardware and systems and in so doing reduces the cost of ownership
- Applications can leverage available data from the car or infotainment system

Drawbacks of the Auto Application approach:

- Developers must write new apps using the car’s software platform
- BMW’s customers will need to purchase an expensive infotainment system option to make use of the apps capability
- Customers will more than likely have to purchase an ongoing monthly telematics service commitment.

The Telco Smartphone approach

European cell phone maker Nokia, which bought map provider Navteq in 2008, has recently introduced a method to integrate apps into the vehicle. However Nokia’s approach is focused on mobile device integration with the vehicle rather than introducing applications that can run independently on vehicle systems. The ‘device’ is a cable that integrates the main functionality of the smart phone or other device to the vehicle.⁴⁰ Nokia demonstrated a cable version of this connectivity link, but it is also developing a system that works using Bluetooth (wireless).

Benefits of the Smartphone approach:

- Leverages existing app stores.
- If creating new apps for vehicles, developers will already be familiar with the software development platforms.
- Exploits existing infotainment systems. Only small updates are needed to accommodate the cable or Bluetooth technology.
- Applications can leverage data from the car or infotainment system.
- Users are familiar with the phone’s features and the cars HMI.

Drawbacks of the Smartphone approach:

- OEMs cannot control which apps are accessed via the head-unit which could lead to safety concerns, caused by driver distraction.

³⁹ Apps include; multimedia travel guides from Merian and Geowiki, various games, Web radio, podcasts, Facebook, XING and Twitter. The Concept BMW Application Store also allows users to transfer contact data including addresses to the navigation system or mobile phone. In addition, the installed apps are able to utilize vehicle-related information—for example, taking the car’s location into account when using the social networking tool XING.

⁴⁰ The Nokia Research Center has demonstrated a cable that connects a phone to a vehicle’s head-unit. The connection allows all of the phone’s functions to appear on the vehicle’s head-unit display for control by voice, touch screen etc. Users would be familiar with the user interface as it is similar to the layout on their phone. Also, since the head-unit is usually connected to a car’s Controller Area Network (CAN) BUS, the Nokia concept allows for the exchange of information between the device and the vehicle, enabling the display of fuel levels or map-based ADAS alerts. Nokia’s phone to head-unit connectivity demonstration used a Magneti Marelli head-unit, however Nokia stated it could be used with any head-unit and mobile device combination, with sufficient protocol development. Although more hardware than software, this Nokia approach allows for software apps to be used by the vehicle.

- Cell phone apps are not typically written for in-vehicle use, as a result many applications will not be of any practical use in the vehicle.
- Some car owners may not own a Smartphone.

The Tier 1 supplier approach

Tier 1 Bluetooth supplier Parrot, unveiled a new head-unit that uses the Android-Java-based operating system. The company's FC6100 module offers automotive implementation of all smart phone features. The head-unit itself includes hands-free Bluetooth, A2DP audio streaming, speaker-independent voice recognition, multimedia connectivity, smart track browsing and playlist management, 3G+ web browsing and Wi-Fi and Bluetooth. While all of these features are appealing, it is the Android/Java-based Operating System (OS) that is most intriguing. The Android/Java OS allows for a customizable user interface for OEMs, plus a vast open source community of developers. In fact, applications that are developed for smart phones that use Android can also be used for this module. As developers do not have to develop application separately for the vehicle, hundreds of applications are already available for the module.

Benefits of the supplier approach:

- Leverages existing app stores.
- If creating new apps for cars, developers already know the software platforms.
- Applications can leverage data from the car or infotainment system.
- Multiple connectivity pipes.

Drawbacks of the supplier approach:

- OEMs cannot control which apps are accessed via the head-unit which could lead to safety concerns, caused by driver distraction.
- Cell phone apps are not typically written for in-vehicle use, as a result many applications will not be of any practical use in the vehicle.
- This head-unit is likely to be expensive.

The various apps solutions shown provide something for every interested OEM. For OEMs desiring to control content and not to worry about installing new hardware; BMW's solution is optimal, however if OEMs wish to give the customer freedom plus a hardware solution with multiple-connectivity pipes, Parrot is potential solution. If the OEMs wants to give that same freedom as found in a Parrot system, at a cheaper price with minimal design changes, Nokia's concept may be suitable.

The tremendous success of 'apps' in the consumer space on mobile phones and Smartphones is likely to drive their adoption in the vehicle. Clearly it will be up to the vehicle OEM's to offer sufficient flexibility in design to ensure they stay up to date with this fast moving technology area that is being driven by the consumer electronics industry.

Connectivity driver: findings and conclusions

- Connected car technologies and the resulting applications will have a major long-term impact on the automotive industry and will require an increasing amount of new embedded software in future cars.
- Currently a small portion of cars in Europe are connected, but we will see a tremendous growth as the eCall specifications foreseen in the ITS Directive has been adopted and public eCall will start mass deployment around 2012 in those Member States which decide to implement a public eCall system. Telematics systems based on eCall are expected to flourish and start a connected cars application revolution.

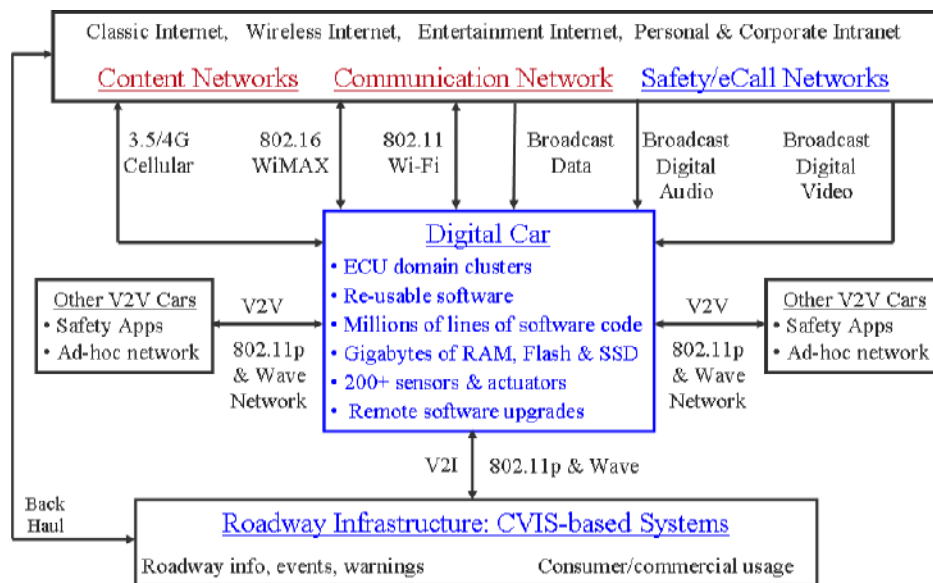
- Multiple wireless communication technologies will be used and in the next decade many cars will have multiple communication links.
- Connected car applications have two main segments—links for the automotive-centric applications to update the automotive control electronics and links for the driver and passengers' applications for driving tasks and entertainment.
- The infotainment systems in the car, head-unit, navigation and telematics systems will see an increasing number of applications that are based on wireless connection. The automotive infotainment software will rely on software that is derived from Smartphone, PC and consumer electronics industries.

2.3 Towards the 2020 Car

Figure 2.5 summarizes project characteristics for a mid-range car around 2020.

- The middle of the figure lists typical electronic characteristics of the 2020 digital car including V2V connections to other cars.
- The top of the figure summarizes the various content networks that the car can connect to and the communications links that are available—including 2-way and broadcast links.
- The bottom part of the figure shows the vehicle-to-infrastructure connections that will be used for safety applications as well as for communication and content access.

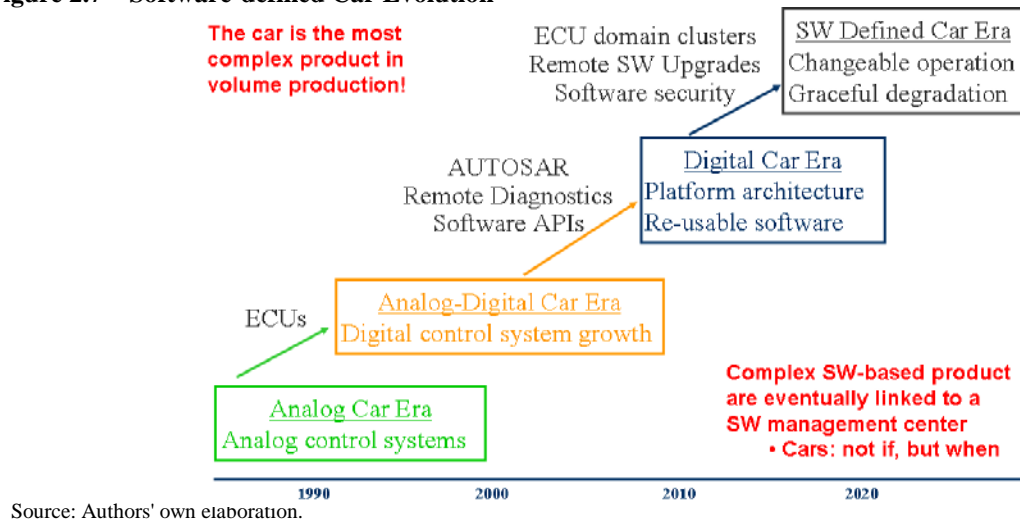
Figure 2.6 - 2020 Car Characteristics



Source: Authors' own elaboration.

Figure 2.6 presents a summary of how important software is becoming to cars. Prior to 1990, most electronic systems in cars involved **Analogue** control, however by the early 2000's, the deployment of **Digital** control systems had grown rapidly.

Figure 2.7 – Software-defined Car Evolution



In the next five years to 2015, nearly all electronics systems will be digital and will be built on ‘fault-tolerant’ system architectures that have graceful degradation characteristics to allow minimal system operation for most component failures. By 2020 most car functions will be defined by software and many operational characteristics will be changeable and will be improved by remote software downloads after the car has been sold.

2.4 Drivers of Change: Summary and Conclusions

There are many external and internal forces that have an impact on automotive ICT products. The following list summarizes the issues and key automotive ICT technology trends:

- Three key external driving forces—environmental issues, society’s accident cost and mobile connectivity—are impacting and shaping automotive technology.
- Economic and environmental issues are forcing the automotive industry to both improve the efficiency of current combustion engines as well as look at electric motors as a next generation propulsion alternative. These electric motors can be powered by batteries, fuel cells or a combination of battery and a small combustion engine that acts as an electric generator.
- The EU automotive industry believes electric cars will remain a niche market for at least a decade due to high battery cost and the high voltage electronics cost. The cost of high voltage electronics will likely decline much faster than the norm in the automotive industry. While battery technology has been moving at slow speed in the past, the growing investments in new battery technologies are likely to speed up the development of this important technology. The economic rewards of a battery breakthrough will create significant opportunities for the automotive supply chain, which could result in severe disruption for the current EU automotive industry, as a battery breakthrough could be just one innovation away.
- The high cost of automotive accidents, both in terms of lives lost and economic loss, require new systems for accident avoidance/mitigation. Current driver assist systems and emerging ADAS or advanced versions show potential to make significant improvements in lowering these negative aspects of automotive mobility.
- The connected car is just emerging, but there is little doubt that all cars sold will eventually have communication links that will foster tremendous innovation in applications and services that benefit drivers/passenger, automotive manufacturers and society in general

- V2V and V2I systems are other connected systems that will lower accident rates and will become a major market for electronics suppliers and software companies in the next decade. Around 2020 it is likely that nearly every car sold will have V2V systems. ADAS, V2X and additional technologies may lead to autonomous driving post 2020.
- The automotive industry is developing many solutions to meet the challenges of these three outside forces, which means that automotive technology will see tremendous changes, innovation and advances for at least two more decades.

3. Technological Overview of Automotive Embedded Systems

The most significant change in the automotive value chain in the last 10-15 years is the introduction of ICT into the vehicle, with systems evolving from mechanical systems to electric/electronic control systems based on microcomputer-based ECUs, generically called ICT embedded systems.

ICT embedded systems refer to computers that are programmed to do specific functions as part of a larger system.⁴¹ These computers are located within the system infrastructure and hence are called embedded computers. The software that runs on these computers is known as embedded software. In contrast to an embedded computer, a general purpose computer (i.e. PC) is designed to be flexible and can do a variety of tasks, with the ability to add new functions without hardware changes and via software updates.

Nearly every electronic-based product in a car is controlled by an embedded computer where the functions are defined by embedded software, this ranges from engine control and airbags to radios and navigation systems.

Table 3.1 summarizes key features of embedded computers and software with a focus on automotive ICT products.

Table 3.1 - Embedded Systems Overview		
	Key Information	Comments/Examples
Embedded System or Computer	<ul style="list-style-type: none"> • Computer system for dedicated functions • With real-time computing constraints • Embedded as part of a larger system • Often controlling mechanical systems • Controlled by embedded software 	<ul style="list-style-type: none"> • Engine control functions • Activate airbag to protect driver • Car has 100+ systems • Brakes, fuel injection, pistons • System & application software
Embedded Software	<ul style="list-style-type: none"> • Operating system: Overall controller • Driver software: Manage peripherals • Application SW: Complete specified tasks 	<ul style="list-style-type: none"> • Manage hardware & software • 1 driver per peripheral or device • Controls all functions

Source: Authors' own elaboration.

There are three 'components' or layers that make up embedded software.

- **Operating System:** The operating system (OS) is the overall manager of all hardware and software aspects of a computer.
- **Driver Software:** To control the many different peripherals and input and output devices, a programme called driver software is used.
- **Application Software:** Each type of peripheral, sensor, actuator or other device connected to a computer needs a software programme that is tailored to the devices' characteristics (or applications) to communicate and control the devices operation.

The automotive industry has a growing number of ICT embedded systems and more such embedded systems are on the way. Table 3.2 summarizes the key building blocks for automotive ICT embedded systems. In this report, we call such systems, ICT systems.

As will be described in details later, the key device of ICT systems is the microcomputer chip or Micro Computer Unit (MCU), which is used in every automotive ICT system. The MCU along with sensors,⁴² actuators and other chips and components are used to build the hardware part of an Electronic Control Unit (ECU). The hardware parts are connected via different types of

⁴¹ Embedded computers and embedded software are used in all industries that have electronics products.

⁴² Sensors: a section dedicated to sensors can be found in Appendix 5.

electronic busses. When embedded software is added, the ECU becomes the main ICT system building block for the automotive industry.

The automotive ICT devices and systems will be explained in more detail in Section 3.1 of this chapter. The software component will be covered in the next section.

Table 3.2 - Automotive ICT Systems Building Blocks		
	Key Information	Comments/Examples
Hardware: Semiconductor Parts and Components	<ul style="list-style-type: none"> • Microcomputer chips: many types • Memory chips: multiple types • Sensor chips and devices: many types • Other chips and components • Actuator devices 	<ul style="list-style-type: none"> • MCU is key ICT device • Stores software • To get auto operational data • Many types • To control automotive systems
Electronic Buses	<ul style="list-style-type: none"> • 5+ electronic bus types • Connects hardware components • Connects MCU to MCU 	<ul style="list-style-type: none"> • Specific to automotive industry • Connects sensors & actuators • New bus types emerging
Embedded Software	<ul style="list-style-type: none"> • Operating system • Driver software • Application software 	<ul style="list-style-type: none"> • OS standards are emerging • Different for each device • Different for each function
Electronic Control Units	<ul style="list-style-type: none"> • Built from hardware and software • ECU is the main ICT building block 	<ul style="list-style-type: none"> • ECU can have multiple MCUs • ECU standard are emerging
• Functional Domains	<ul style="list-style-type: none"> • Domains have multiple ECUs • Domains have related automotive functions • There are 5 main domains 	<ul style="list-style-type: none"> • An emerging trend • ECU connections increasing • Based on functions performed

Source: Authors' own elaboration.

There are five functional domains in automotive. Each functional domain consists of a number of ECU's typically linked by a digital BUS (i.e. CAN, MOST, FlexRay, LIN etc). Each domain is optimised to deal with a specific list of automotive functions ranging from propulsion and safety to comfort and infotainment. Those five domains are:

1. **Powertrain:** Includes all the ECU's and MCUs that control the engine, transmission and related systems. For electric vehicles the Powertrain include the MCUs that control the battery, electric motors and the power electronics systems that change battery's DC power to high-voltage, AC-power that runs the electric motors
2. **Chassis:** Includes all the ECU's and MCUs that control the car's direction, speed, steering, braking, acceleration and suspension. Several advanced systems that enhance the driver's skill have emerged including anti-lock brakes (ABS) and electronic stability control (ESC). Some of the chassis systems are being connected to the safety systems such as airbag control and driver assist systems
3. **Safety:** Includes all ECU's and MCUs that control airbags, seatbelts and driver assist systems (ADAS) such as park assist, adaptive cruise control, lane departure warning/assist and blind spot detection systems.
4. **Body and Comfort:** Includes all ECU's and MCUs that control the driver and passengers' convenience and comfort systems. This domain includes dash board & related controls
5. **Infotainment:** Includes all the ECU's and MCUs that control the entertainment and information products.
 - The head-unit is the main product and it includes the radio and audio system, navigation and connectivity solution to mobile music players and mobile phones.
 - Telematics is usually a separate system, but could also be included in the head-unit.

- Rear-seat entertainment systems that play video or receive broadcast TV signals are also included. Some head-units also have video and TV capabilities for front-seat passenger use, but these are usually only active while the car is parked.

Table 3.3 - Automotive ICT Product: ECU Domain Description		
Domain	Key Information	Comments/Examples
Powertrain: 5-10 ECUs	Controls the car's power and its distribution to the wheels	<ul style="list-style-type: none"> • Engine control • Transmission control
Chassis: 3-5 ECUs	Controls the functions that guides the car's direction and speed	<ul style="list-style-type: none"> • Steering control • Brake control • Suspension control
Safety, Driver Assist and ADAS 5-10 ECUs	Controls the car's safety systems. Many new systems are emerging	<ul style="list-style-type: none"> • Air bag control • Seat belt control • Driver assist systems-ADAS
Body and Comfort: 10-30 ECUs	Controls the driver and passengers' convenience and comfort systems. Includes dash board and related controls	<ul style="list-style-type: none"> • Heater and air conditioning • Windows and seat control • Window wipers • Instrument cluster display
Infotainment: 5-7 ECUs	Controls the entertainment and information systems used by driver and passengers	<ul style="list-style-type: none"> • Radio and music systems • Navigation systems • Telematics and mobile phone

Source: Authors' own elaboration.

3.1 Embedded Hardware in the Automotive Industry

This section introduces to MCU, ECU and hardware technology trends. In particular it details the shift towards ECU and domain interconnection, the emergence of the Domain Controller Architecture, the trade-offs between hardware and software, and the potential future impacts of domains' evolutions on the ECU.

3.1.1 The Micro Computer Unit (MCU)

The Micro Computer Unit (MCU) is the most important hardware component in ICT Automotive systems. The MCU is a computer on a chip which often includes memory to store embedded software. This MCU is typically linked by electronic busses to other hardware in the vehicle. Some MCUs will have additional hardware such as sensors and actuators. Table 3.4 summarizes key information about the MCUs used in the automotive industry.

The MCU word size is the first indicator of its processing power. 8-bit MCUs are used for simple functions and are the least expensive MCUs. The 16-bit MCU is the volume leader and is used for most functions. The 32-bit MCUs are growing rapidly in number and are used for complex functions. The Digital Signal Processor (DSP) is a special MCU that is used for functions that control analog signals such as music, voice and video.

Table 3.4 - MCU Overview		
	Key Information	Comments/Examples
MCU Types: Word Size	<ul style="list-style-type: none"> • 8-bit MCU • 16-bit MCU • 32-bit MCU • 64-bit MCU • Digital Signal Processor (DSP) 	<ul style="list-style-type: none"> • Lowest performance • Most common car MCU • For complex functions • Mostly for future use • DSP often combined with MCU
On-Board Memory	<ul style="list-style-type: none"> • Random Access Memory (RAM) • Read-Only Memory (ROM) • Flash ROM 	<ul style="list-style-type: none"> • Fast, changeable, but expensive • Fixed memory, difficult to change • Programme storage
Electronic Buses	<ul style="list-style-type: none"> • Communicates with other chips • Many types: slow to fast 	<ul style="list-style-type: none"> • Tailored for automotive industry • Simple to complex
MCU Instruction Set	<ul style="list-style-type: none"> • Different for most MCUs • Different for most semiconductor companies 	<ul style="list-style-type: none"> • Software translation between MCUs • ARM MCU used by many companies
Key MCU Families	<ul style="list-style-type: none"> • Freescale PowerPC • Infineon XC23, XC27 and TriCore • Intel Atom • NEC V850 • NXP LPC • Renesas SH-2, SH-3, SH-4 • ST Micro SPC56 and STA 60 	<ul style="list-style-type: none"> • 32-bit MCU • 16- and 32-bit MCUs • Compatible with PC processors • 32-bit MCU • 32-bit; ARM compatible • 16- and 32-bit MCUs • PowerPC and ARM compatible
MCU: System On Chip (SOC)	<ul style="list-style-type: none"> • 1-chip solution • All hardware and software on 1-chip 	<ul style="list-style-type: none"> • Lowest cost solution • Only for simple functions

Source: Authors' own elaboration.

The MCU instruction set defines the basic operations of the MCU. The instruction set is different for most MCUs, which means that any software has to be translated to run on different MCUs.

Most semiconductor companies manufacture MCUs with different instruction sets: MCU families from the leading semiconductor companies are also listed in Table 3.4. The PowerPC is made by both Freescale and ST Micro. The ARM MCU architecture is the closest thing to a standard MCU in the semiconductor industry. The ARM processor is licensed by a British semiconductor design house and is the most popular MCU type. The ARM is dominant in many consumer electronics products including mobile phones and is also growing in the automotive industry.

3.1.2 The Electronic Control Unit (ECU)

The Electronic Control Unit (ECU) is the core building block for making automotive ICT systems. An ECU is an MCU-based ICT hardware tailored by embedded software.

Today, an average car might integrate some 25 to 50 ECUs, controlling up to a hundred different functions. Table 3.5 summarizes the key characteristics of an ECU.

Table 3.5 - ECU Overview		
	Key Information	Comments/Examples
ECU Definition	<ul style="list-style-type: none"> • Embedded computer system • MCU-based hardware • Tailored by embedded software 	<ul style="list-style-type: none"> • Specific to car control functions • An ECU may use multiple MCUs • Large software size variations
ECU Auto Usage	<ul style="list-style-type: none"> • 100+ car control functions • Luxury cars: 60+ ECUs • Economy cars: 25+ ECUs 	<ul style="list-style-type: none"> • Each may use MCU or ECU • Luxury cars: 100+ MCUs • Economy cars: 40+ MCUs
ECU Range	<ul style="list-style-type: none"> • Proprietary ECU • Standard ECU • Networked ECU • Domain ECU 	<ul style="list-style-type: none"> • Designed for only 1 control function • Several function (Autosar standard) • Controls many MCUs • Controls all or part of an automotive domain
ECU Prices	<ul style="list-style-type: none"> • Simple ECUs: \$5 range • Complex ECUs: \$100-\$200 	<ul style="list-style-type: none"> • Example: Window control • Example: Engine control

Source: Authors' own elaboration.

The next sections explain key ECU characteristics including their development history, emerging standards, architecture changes, etc.

3.1.2.1 The ECU development history

The foundation product of ICT development in Automotive is the ECU (Electronic Control Unit) and its digital BUS connectivity network. The introduction of the ECU has been responsible for the evolution of both the embedded software and semiconductor landscapes over the last 15 years.

- Period 1995 → 2000:
 - This period saw the introduction of the ECU into the automotive mass market
 - The period was characterized by a highly diverse project-oriented approach in automotive; where individual Tier 1 suppliers partnered with semiconductor manufacturers to produce a 'customised' set of silicon and embedded software solutions within the developing ECU environment, often for a single vehicle OEM for use on a single car model
 - ECU costs were typically very high, production volumes were low.
- Period 2000 → 2010
 - This period saw the rise of a highly integrated semiconductor and ECU development environment that has allowed Tier 1 suppliers and semiconductor suppliers to leverage their designs for use by many customers.
 - The ability to leverage products to serve multiple markets has not only reduced ECU costs, but also boosted usage rates.
- Period 2010 → 2020
 - This period will be characterised by the increased use of embedded software including Windows Automotive, QNX and GENIVI software platform in Infotainment as well as the AUTOSAR software platform in non-infotainment applications (See also Sections 3.2.2 on AUTOSAR and GENIVI). The adoption of AUTOSAR is allowing systems developers more freedom to 'de-couple' their software coding from specific hardware elements, in much the same way as a PC manufacturer is able to choose between Intel and AMD for their core processors.

The following paragraphs detail further those three periods.

The period 1995-2000 was characterised by the growing importance of ECUs in vehicles. However these ECUs were typically proprietary in nature, with little ‘know-how’ shared between OEM manufacturers and between suppliers:

- On the semiconductor side, this period was characterized by being almost completely hardware/chip dependant with little or no ‘embedded software’ provided to the automotive Tier 1 supplier by the microprocessor supplier.
- Typical processor speeds were 10-20 MIPS (Million instructions per second).
- The operating system of choice was OSEK, with a coding size of just 5-25 KB. OSEK was developed and used by the European automotive industry.
- The semiconductor/ECU architecture was characterised by a fixed data structure, where embedded software instructions were carried out by a single ECU typically on a single microprocessor.
- Software coding was highly optimised for individual functions, offering little flexibility for system reconfiguration.

During the period 2000-2010, the focus of software development shifted for Tier 1 suppliers and vehicle OEM’s from lower level proprietary code writing, to the development of the upper layers in the software stack API.⁴³

For semiconductor suppliers, the lower level hardware (microcontroller) and 1st level of driver software was no longer the focus for product differentiation. Semiconductor manufacturers began to be measured on the success and flexibility of their support for higher level API’s.

Since 2010 and beyond, the latest generation of ECU design has taken on an appearance that is very similar to the PC environment. This approach has allowed ECU manufacturers to interchange their microprocessor (MCU) suppliers in the same way as PC manufacturers can choose Intel over AMD without requiring lower level code restructuring.

The latest ECU structure (detailed in Figure 3.1) is divided into the following layers:

- **Application layer:** All applications use the software and hardware functions at the lower levels. The applications use standard interfaces to communicate with the lower levels. The interface is often called Application Programming Interface (API) or the Run-Time Environment.
- **Services layer:** The service layer provides software services from the operating system software and the device driver software. Each device driver programme controls a specific device. The service layer also has standard interfaces.
- **ECU abstraction layer:** ECUs have different capabilities depending on what functions they are programmed to do. This layer describes the functional capabilities of the ECU.
- **Microcontroller abstraction layer:** Many different microcontrollers (MCUs) are typically used within an ECU. This layer describes the hardware and software characteristics of each type of MCU. The application and system software can then be translated to native software instructions of each MCU.
- **Complex driver:** This represents the non-standard segment in the development. This segment has become the focal point for embedded software code writing by Tier 1 suppliers or vehicle OEMs. This ‘Complex driver’ coding is sometimes called ECU ‘tuning’ and is part

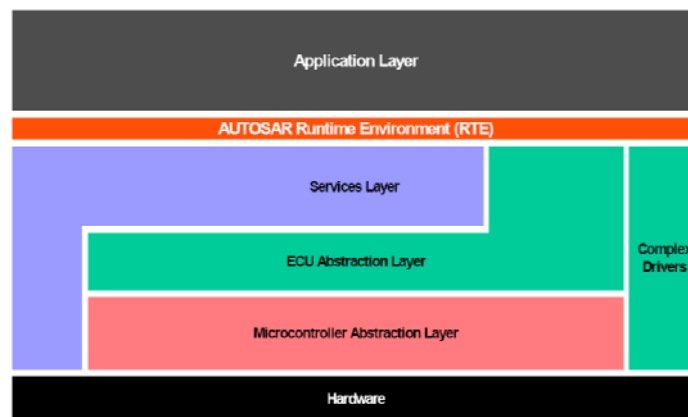
⁴³ Application Programming Interface or API: This layer and library provides developers with the software tools to enable the specific functions of a device.

of the definition of the vehicle brand for some premium manufacturers. i.e. the ‘BMW-ness’ of the brand.

The next generation of ECU architecture moves towards ‘**Object-Oriented programming**’, which allows software programme execution on any relevant ECU.⁴⁴ Pre-2000, the introduction of new features almost always required the introduction of a new ECU and microcontroller (MCU), however with the updated architecture post-2008, the industry has created an architecture that ‘de-couples’ the hardware from the software, which is allowing developers to add new features without the requirement to re-engineer the hardware.

The next generation of ECU system configuration presented in Figure 3.1, has been formalised by several automotive value chain members in Europe, and is now considered to be mature in terms of overall design.

Figure 3.1 - Example ECU from 2010: Electronic Stability Controller (ESC)



Source: AUTOSAR.

⁴⁴ For more details , see for example: http://en.wikibooks.org/wiki/Object_Oriented_Programming

ECU development timeline⁴⁵

- Pre 2000: the cost of a typical single ECU solution (e.g. Airbag from Autoliv) was between €6-7 million:
 - The majority of the cost was associated with hardware development
 - Up to 60% of the relatively simple software stack would be dedicated to internal functionality such as the triggering function of an airbag.
- By 2010: The market has witnessed the launch of ‘smart airbags’, with development costs of €8-10 million:
 - These ‘smart airbags’ are capable of adapting to many complex inputs from the vehicle.
 - Autoliv confirmed that in a typical ‘Smart’ airbag, the internal ‘trigger’ software element has been reduced to less than 20% of the total software stack, with the remaining 80% of the software dedicated to the interface functions with the other vehicle systems.

ECU ‘family’ development methodology

In interviews, leading automotive ECU suppliers highlight the high cost of developing and testing the latest generation of ECUs into the market. In order to reduce costs, the companies try to develop a ‘family’ of similar ECU types, with scaled capability tailored to a number of end market requirements. As a result, a single ECU ‘family’ might have 3-10 sub-ECU developments tailored to different requirements, ranging from entry level vehicles up to cutting edge, high-value premium-sector vehicles.

ECU ‘family’ developments typically have a core set of features that are available on all models of the ECU. Also, the ‘family’ concept is able to leverage and carry over the development costs from one ECU sub-development to the next ECU development. This reduces the risks in the development of 2nd and 3rd generation product lines.

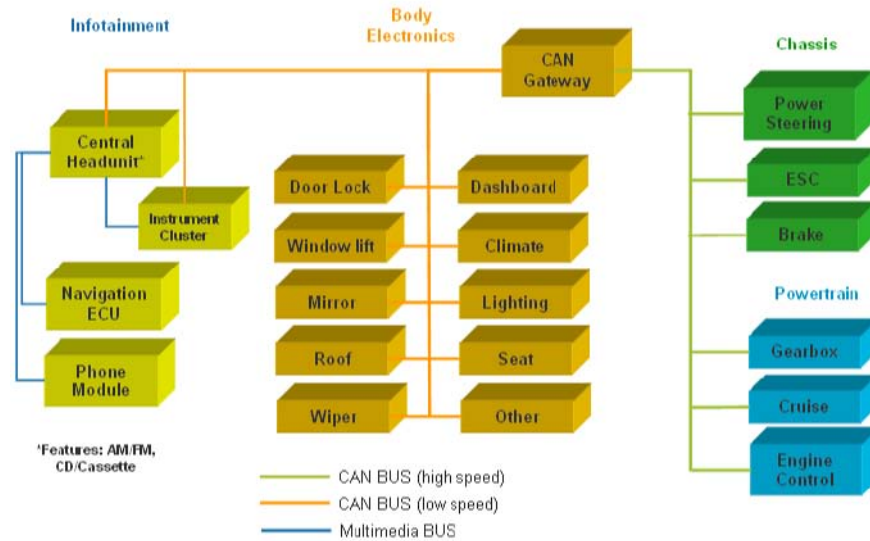
3.1.2.2 The shift towards ECU and/or Functional Domain Interconnection

Prior to 2000, the proprietary hardware and software nature of code and BUS development gave little room for interconnects between individual ECUs or domains within a vehicle. While the ECU’s within a domain such as chassis or infotainment did have very basic levels of connectivity or interaction, these were mostly limited to one-way messaging, or broadcasting onto the Controller Area Network (CAN) digital BUS. For example, a speed pulse sensor/generator inside a Brake ECU could output a simple ‘current-speed’ message onto the CAN BUS, which could be read by a navigation system in the adjacent Infotainment BUS. Vehicle ‘Speed-pulse’ was essential for accurate vehicle positioning in early navigation systems.

However in automotive networks pre-2000 as shown in Figure 3.2, the messaging protocols were still in development. As a result, only very low-level interactions were possible between domains.

⁴⁵ This box is based on interviews run by the authors with Autoliv. We thank the company for accepting to make this data public.

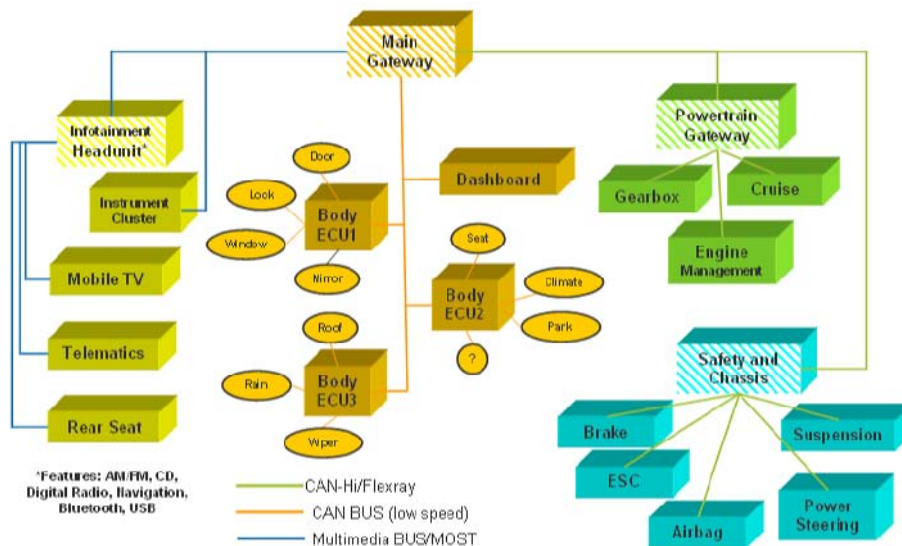
Figure 3.2 – Vehicle ECU Network Pre 2000



Source: Authors' own elaboration.

From 2001, the development of a new 'Gateway' architecture extended the basic concept of the single CAN Gateway as seen in Figure 3.3. This architecture allowed interconnects to build between former disassociated functions. This has enabled the development of cross-functionality such as a speed sensor, (originally designed to update the driver speedometer) that can be used for electronic stability control, tire pressure monitoring algorithms, anti-lock braking or even to aid navigation positioning.

Figure 3.3 – ECU 'Gateway' Architecture 2000 – 2010



Source: Authors' own elaboration.

This broader use of system information has required manufacturers to evolve the vehicle BUS architecture and protocols so that digital data could be encoded and broadcast around the vehicle BUS for use by a broader range of ECU's. This period saw the introduction of new digital BUS protocols:

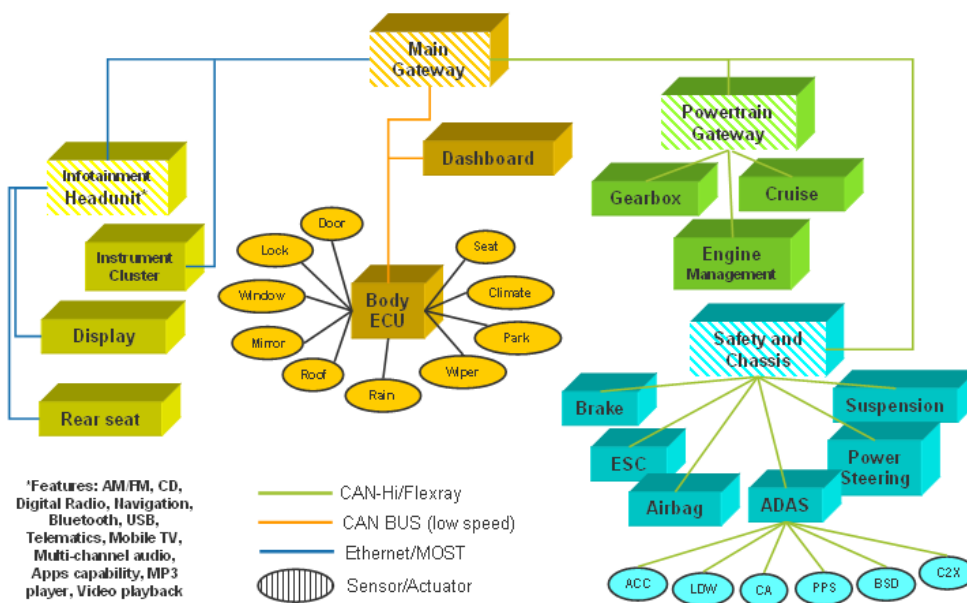
- MOST for Infotainment.
- FlexRay for safety and chassis systems.

3.1.2.3 The emergence of the domain controller architecture⁴⁶

From 2010, a new ECU and digital BUS structure will emerge; based on a smaller number of more powerful ECUs capable of handling multiple tasks on powerful single- or multi-core microprocessors. This 'Domain Controller' architecture will be characterized by a smaller number of ECU's running highly sophisticated, embedded software applications that will allow greater interdependency between domains.

In such context, Tier 1 suppliers and semiconductor suppliers will need to strike the right balance between providing a high level of hardware functionality, while building in sufficient software flexibility to cope with the expanding array of features in a vehicle.

Figure 3.4 – Domain Controller Architecture (From 2010 onwards)



Source: Authors' own elaboration.

- ECU Development pre 2000: Overall hardware costs for typical ECU's were high, however embedded software costs were low; as ECU's typically supported a limited range of features. (Typically unit sales were low, limited to mid-high and feature rich vehicles).
- ECU Development since 2000: Overall hardware development costs for typical ECU's have fallen dramatically, however more complex functionality has meant a much higher proportion of the overall cost of ECU development is spent on embedded software code development.

3.1.2.4 The trade-offs between high-hardware or high-software dependency

Prior to 2000, most automotive semiconductors were relatively simple 8-bit microcomputers or MCUs. These MCUs had highly optimized software instruction sets that were small in size, and capable of performing a limited list of tasks (e.g. electric window up/down). However since 2000, semiconductor vendors have come under increased pressure to engineer solutions that not only provide multi-function capability, but also build sufficient flexibility into the design, to allow automotive systems developers to make changes during the development of their products.

As a result of these new pressures in the market, semiconductor design has shifted from a hardware centric model (pre-2000) to a new model based on building a hardware (silicon) block

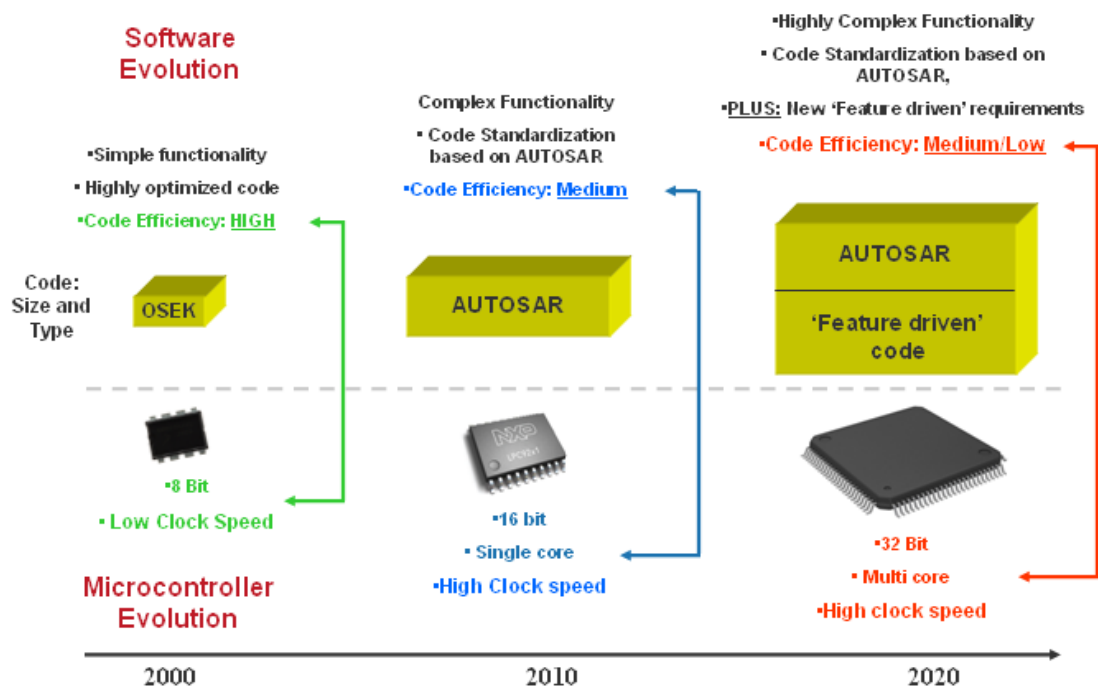
⁴⁶ For more see at: Siemens presentation (Marcus Fehling, Siemens) of 28 April 2010. Available at: <http://is.jrc.ec.europa.eu/pages/ISG/COMPLETE/automotive/index.html>

as well as developing a highly complex software block. This has raised the issue of which features and functions should be enabled in hardware and which in software. These decisions are guided by several technical considerations:

- Does the end device require a dedicated semiconductor technology to function?
- Does the end device have real time execution restraints (this would favour hardware)?
- Is flexibility in design more important (this approach favours software)?
- What is the benchmark price for the development?
- Will the device have the flexibility to be used in multiple ECUs?
- How will the developer protect their core IP technology?

Figure 3.5 presents the evolution of the MCU hardware and software environment from highly optimized software-code running on 8 bit MCUs (pre 2000) to the highly ‘feature-driven’ software running on multi-core 32 bit microcontrollers.⁴⁷

Figure 3.5 – Microcontroller Evolution 2000 to 2020



Source: Authors' own elaboration.

The prioritisation of development between **hardware** and **software** architectures within the ECU is becoming one of the biggest issues facing semiconductor manufacturers and Tier 1 suppliers, particularly as microprocessors become more sophisticated and multifunctional at a lower entry price. As a result of this debate, semiconductor manufacturers and Tier 1 suppliers are in the process of defining the software/hardware split on future ECUs, with options to choose a path of high-hardware or high-software dependency. Both paths of development have their ‘strengths

⁴⁷ Semiconductor supplier Infineon confirmed that the trend towards driving up MCU clock speeds has been replaced by the increasing integration of multiple processor-cores on one chip (so called ‘system-on-chip’ or SOC). The multi-core chip is a trend that started in the PC industry. In the case of automotive compliant semiconductors; clock speeds have stabilized in the 250-300 MHz range, however the transition from single core technologies to multi-core significantly increases the software engineering requirements in a typical product development.

and weaknesses', however choosing the split-point between competences within each ECU is a key task facing current developers.

ECU Development strategy #1: High Hardware (silicon) dependency

- **Strength:** Lower cost, higher system performance. Hardware dependant solutions typically offer more efficient, faster operation on dedicated microcontrollers
- **Weakness:** Low flexibility for re-design during development. This hardware dependant approach ties ECU manufacturers into using a specified array of features implemented into specific ECUs, regardless of the end use-case requirements.
- **Opportunities:** Limited. High dependency on hardware will limit the opportunities for new feature adoption
- **Threat:** Limited scope for new feature development. The lack of flexibility from a high hardware dependant approach is likely to threaten the business opportunities of manufacturers who do not offer flexible design alternatives.

ECU development strategy #2: High Embedded software dependency

- **Strength:** Greater flexibility for designers and end product
- **Weakness:** Higher development cost and lower system performance
- **Opportunity:** This approach will allow developers to separate 1st level software programming from hardware development.
 - However this might not be the most efficient production method, as most value chain players agree that the lowest levels of software programming should be retained geographically near to the hardware development centres. (Currently these are mainly in Europe)
- **Threat:** This approach requires higher development costs; as a result it is likely that EU based companies will need to move their embedded software competence away from current development centres in Europe, towards low-cost regions such as India.

3.1.3 Future trends and their impacts on the ECU

The further evolution from mechanical to electric/electronic ICT systems in the automotive industry is a driving force that will have a major impact on all ECU domains as summarized in Table 3.6. The trends are listed in two time periods—the time period from 2010-2015 and 2015 to 2020.

Table 3.6 - ECU Domain Trends		
	2010-2015	2015-2020
Powertrain	<ul style="list-style-type: none"> • Autosar re-usable software • Combustion engine advances • Hybrid cars • Hybrid and plug-in electric autos 	<ul style="list-style-type: none"> • Autosar re-usable software • Plug-in electric autos • Combustion engine advances • Plug-in and electric cars
Chassis & Safety	<ul style="list-style-type: none"> • Mechanical → Electrical device • Autosar re-usable software • Smart airbag expansion • Drive-by-wire 	<ul style="list-style-type: none"> • Autosar re-usable software • ADAS & Chassis connection • V2X & Chassis connection • Visual event data recorder
Body & Comfort	<ul style="list-style-type: none"> • Mechanical → Electrical device • Autosar re-usable software • Multifunction displays 	<ul style="list-style-type: none"> • Driver workload management • Multifunction displays • ICD & Head-unit connection
ADAS & Driver Assist	<ul style="list-style-type: none"> • Autonomous parking • Collision warning & mitigation • Blind spot detection • ACC & Cooperative ACC • Driver monitoring 	<ul style="list-style-type: none"> • Autonomous driving • Collision avoidance • V2V and V2I⁴⁸ • Sensor fusion • Integrated ADAS
Infotainment	<ul style="list-style-type: none"> • Telematics expansion • Digital entertainment • Navigation to Powertrain link 	<ul style="list-style-type: none"> • Connected infotainment • Content expansion • Workload management

Source: Authors' own elaboration.

Some elements listed in Table 3.6 are worth mentioning. Driver distraction (workload) from mobile devices is a growing problem. So-called workload systems are application software that have situational awareness of the driving load and can prevent interruption from mobile devices when necessary.

The link between the chassis domain and the ADAS systems will improve safety applications by temporarily taking control of some car functions in emergency situations. Examples are emergency braking when a collision is imminent. Such systems are already emerging on the market, and are early examples of partial autonomous driving. Other examples include self-parking systems, where the driver controls the accelerator pedal, but the steering is autonomous. Adaptive cruise control is a further example where the speed is controlled autonomously.

Clearly the feature expansion in ADAS will have a major impact on ECU hardware and software and this impact will be analyzed in later sections.

Future integration between ADAS and infotainment systems are also emerging and will have an impact on the ICT system architecture. The growth of integration between automotive domains are increasing the ECU system complexity and is a driving force to combine individual ECUs into ECU domains that are designed and connected from a top-down architecture perspective.

The next paragraphs of the report detail past trends and likely future trends for ECU hardware characteristics in specific domains. Since the ECUs domains are quite different in terms of hardware capabilities, three separate domain groups are presented, each with its own table of hardware characteristics spanning four time periods from Pre-2000 to 2020.

Domain group 1) Powertrain, Chassis and Body ECUs

Domain group 2) Driver assist, ADAS and V2X ECUs

Domain group 3) Infotainment: Head-unit, navigation and telematics ECUs

⁴⁸ V2V: Vehicle-to-Vehicle communications; V2I: Vehicle-to-Infrastructure communications.

Hardware evolution: Powertrain, chassis and body trends

Table 3.7 summarizes the hardware evolution of Powertrain, chassis and body functions. Comfort and convenience functions are similar to body hardware characteristics.

Table 3.7 - Hardware Evolution: Powertrain, Chassis, Body				
	Pre 2000	2001-2010	2011-2015	2016-2020
ECU architecture:	Single function	Multiple functions	Domain emerging	Domain mature
Specification	Custom/OEM/Tier 1	OEM/Tier 1	OEM/T-1/Ref design	OEM/T-1/Ref design
Design	OEM	OEM/Tier1	Tier 1/Outsource	Commodity
Manufacturing Region	EU	EU/A-P	EU/A-P	EU/A-P
ECU's per vehicle				
Powertrain	3-5	5-10	3-5	2-3
Chassis	1-2	3-5	2-4	2-3
Body	8-12	10-30	4-8	3-5
Semiconductor:				
MCU type: Powertrain	16-bit	32-bit	32-bit	32-bit/Multi-core
MCU type: Chassis	8/16-bit	8/16/32-bit	16/32-bit	16/32-bit/Multi-core
MCU type: Body	8/16-bit	8/16-bit	8/16/32-bit	8/16/32-bit
MCU count: Powertrain	3-8	5-12	6-14	7-13
MCU count: Chassis	1-5	3-8	4-10	5-10
MCU count: Body	7-12	15-30	12-25	10-22
Sensors:				
Sensor total: Powertrain	10-35	30-40	36-45	40-50
Sensor total: Chassis	5-34	18-36	26-38	30-42
Sensor total: Body	9-29	25-50	35-60	40-70
Digital Bus:				
Powertrain	Hi-Speed CAN	Hi-Speed CAN	CAN/FlexRay	CAN/FlexRay/Other
Chassis	Lo-Speed CAN	Hi-Speed CAN	CAN/FlexRay	CAN/FlexRay/Other
Body	CAN/LIN	CAN/LIN	CAN/LIN/Ethernet	CAN/LIN/Ethernet

Source: Authors' own elaboration.

The data for the core car functions shows that the number of ECUs per vehicle has peaked and will decline in the future, while the number of MCUs is still increasing. Sensors will continue to increase through the four time periods.

Hardware evolution: driver assist, ADAS & V2X trends

Table 3.8 summarizes the hardware evolution of driver assist, ADAS and expected future characteristics for Vehicle-to-Vehicle communications (V2V) and Vehicle-to-Infrastructure (V2I) communications systems.

Table 3.8 - Hardware Evolution: Driver Assist, ADAS & V2X				
	Pre 2000	2001-2010	2011-2015	2016-2020
ECU architecture	Single function	Multiple functions	Domain emerging	Domain mature
Specification	Custom/OEM/Tier 1	OEM/Tier1	OEM/Tier1	OEM/Tier1
Design	OEM	OEM/Tier1	OEM/Tier1	Tier 1/Outsource
Manufacturing Region	EU	EU/A-P	Low cost countries	Low cost countries
ECU's per vehicle				
Safety & Driver Assist	3-5	5-10	5-8	4-5
ADAS	0	0	1-2	1-3
V2V & V2I	0	0	0-1	1-2
Semiconductor				
MCU type: Driver Assist	8/16-bit	16/32-bit	16/32-bit	32-bit/Multil-core
MCU type: ADAS			32-bit/Dual-core	32/64-bit/Multi-core
MCU type: V2V2I			16/32-bit	32-bit/Multil-core
MCUs: Driver Assist	0-2	1-8	8-15	5-10
MCU count: ADAS	0	0	7-15	20-30
MCU count: V2V2I	0	0	0-3	3-6
Sensors	Standalone	Standalone	Sensor fusion	Sensor fusion
Sensors: Driver Assist	0-19	5-21	17-18	8-12
Sensor total: ADAS	0	0	5-10	15-20
Sensor total: V2V2I	0	0	0-3	2-10
Digital Bus				
Driver Assist	Lo-Speed CAN	Hi-Speed CAN	CAN/FlexRay/Other	CAN/FlexRay/Other
ADAS	Lo-Speed CAN	Hi-Speed CAN	CAN/FlexRay/Other	CAN/FlexRay/Other
V2V2I	Not available	Not available	NA/Ethernet	Ethernet

Source: Authors' own elaboration.

The data for driver assist, ADAS and V2X functions shows different trends to the core car functions. The number of ECUs per vehicle is still increasing because many new functions will be added in the future. The number of MCUs is also increasing. Sensors will continue to increase through the four time periods.

Hardware evolution: infotainment trends

Table 3.9 summarizes the hardware evolution of Infotainment systems including head-unit (audio and video), Navigation and Telematics systems.

Table 3.9 - Hardware Evolution: Infotainment				
	Pre 2000	2001-2010	2011-2015	2016-2020
ECU architecture	Multiple functions	Multiple functions	Domain emerging	Domain mature
Specification	Custom/OEM/Tier 1	Custom/OEM/Tier 1	Custom/Ref design	Custom/Ref design
Design	OEM	OEM/Tier 1	Tier 1/Outsource	Outsource/Tier 1
Manufacturing region	EU	EU/A-P	A-P/EU	A-P/EU
ECU Total	3-4	5-7	3-5	1-3
Semiconductor				
MCU/MPU: Head-Unit	16-bit	32-bit	32/64-bit	32/64-bit/Dual-core
MCU/MPU: Navigation	16-bit	32-bit	32/64-bit	32/64-bit/Multi-core
MCU/MPU: Telematics	16-bit	32-bit	32-bit	32/64-bit/Multi-core
MCU/MPU #: Head-Unit	1-3	3-5	5-8	5-8
MCU/MPU #: Navi	1	2-3	2-3	2-3
MCU/MPU #: Telematics	1	2-3	3-5	4-6
Sensor				
Sensor total: Head-Unit	0-1	1-3	2-5	0-7
Sensor total: Navigation	0-2	4-4	4-4	4-4
Sensor total: Telematics	1-2	2-4	3-5	4-7
Digital Bus	Proprietary/Custom	MOST	MOST/Ethernet	Ethernet/MOST

Source: Authors' own elaboration.

The data for infotainment systems show trends similar to the core car systems. The number of ECUs per vehicle has peaked and will decline in the future, while the number of MCUs is still increasing. Sensors will continue to increase throughout the four time periods.

3.1.4 Embedded automotive hardware: summary and conclusions

Embedded automotive hardware is impacted by multiple forces. These factors are increasing the system complexity and need better architectures, both at the hardware and software levels, to be able to design systems that are reliable, affordable and flexible.

- Increasing MCU capabilities due to the advances of semiconductor technology. The next step is multiple MCUs on a single chip or so-called multi-core chips. Multi-core MCUs are already common in the PC industry and will grow in the automotive industry in areas such as ADAS where the computing load can be very high. Multi-core MCUs will also be used to merge separate MCUs
- Growth of MCUs because more automotive functions are becoming digital system that requires a microcomputer. The typical car in Europe currently has about 65 MCU-based systems, with high-end luxury vehicles having well over 100 MCUs. The processing power of each individual MCU varies widely, but is typically much lower than current PCs. With future trends, the total MCU processing power in a modern vehicle is likely to exceed the average PC in terms of processing power.
- In the past, each MCU was effectively a simple 'ECU' since it would primarily operate in a stand-alone mode. As the communication load between ECUs grew, system complexity increased, this is particularly the case for software complexity.
- The growing ECU-ECU communication requirements are changing the ECU architecture to a domain structure. The result is fewer ECU systems, with each ECU controlled by multiple MCUs, while the number of MCUs is still growing.

- Advances in software technology and software standards are having a tremendous impact on embedded hardware and are covered in a later section. The AUTOSAR Microcomputer Abstraction Layer facilitates considerable ECU standardization; as a result, the same ECU hardware can be used for different functions, running different software. The result is increased ECU production volume with fewer ECU part types, which will result in lower price per ECU.
- The combination of embedded hardware and software advances are required to lower embedded automotive ICT system complexity. The emergence of computer platforms to design core ECUs and infotainment ECUs is a growing trend—AUTOSAR for core ECUs and GENIVI and others for infotainment.

3.2 Embedded Software in the Automotive Industry

This section looks at the embedded software for the automotive industry. In particular it details the shift towards software standards and the potential future impacts of such software platforms on all automotive embedded systems.

3.2.1 Embedded software overview

As we have seen in Section 3.1, embedded software is becoming the key to automotive ICT products. Nearly every electronics-based product in a car is controlled by an embedded computer, with functions that are defined by embedded software. These products range from airbags to brakes and engine control to music, windows and navigation systems.

Table 3.10 summarizes key features of embedded systems with a focus on embedded software.

Table 3.10 - Embedded Software Overview		
	Key Information	Comments/Examples
Embedded Systems	<ul style="list-style-type: none"> • Computer system for dedicated functions • Often controlling mechanical systems • Controlled by embedded software 	<ul style="list-style-type: none"> • Car has 100+ systems • Seats, windows, brakes, wheels • System and application software
Embedded Software	<ul style="list-style-type: none"> • System SW: Manage computer hardware • Application SW: From simple to complex 	<ul style="list-style-type: none"> • Processor and peripherals • More complexity coming
Embedded System Software	<ul style="list-style-type: none"> • Operating system: Overall controller • Driver software: Manage peripherals 	<ul style="list-style-type: none"> • Key to software standards • 1 driver for each peripheral
Embedded Application Software	<ul style="list-style-type: none"> • Fixed function application: simple tasks • Fixed function application: complex tasks • Multi-MCU applications (single ECU) • Domain applications (multiple ECU) • Upgradable applications (future trend) 	<ul style="list-style-type: none"> • Window, seat control • ABS, ESC • Air bags, engine • Collision avoidance • Functionality and corrections

Source: Authors' own elaboration.

Originally, embedded application software had fixed functions that typically did simple tasks such as window up/down and seat control. However there are a growing number of complex embedded applications as listed in Table 3.10. Emerging embedded automotive systems are adding many applications, with some systems ‘fusing’ to becoming a mixture of embedded and general purpose computer systems.

3.2.2 The emergence of an automotive layered software architecture

Layered system and software architectures have become the most efficient way of designing, implementing and supporting computer systems. A layered computer system—including embedded systems—consists of the following layers:

- Hardware layer with the microcomputer as the defining element
- System software layer that have all the software that interfaces and controls peripherals, input and output devices. In embedded automotive systems, this includes sensors and actuator.
- Operating system software layer which is the overall manager of all hardware and software aspects of a computer. The OS includes the Application Programming Interfaces (APIs), which are used by all software components.
- Application software layer, which must use the APIs to be compatible with the layered system.

The layered system architecture can use open systems or proprietary systems and both approaches have similar advantages. The open system approach happened first in the PC industry. Not all levels in the layered system architecture need to be open, but the application software layer must have standard Application Programming Interfaces (APIs). This allows any company to make application software based on the APIs to be compatible with the computer system. The PC architecture has open software APIs as well as standard buses for connecting peripherals, however the microprocessor is typically proprietary and the operating system is proprietary (Microsoft Windows, Apple OS etc).

If compared to the PC industry, embedded system developers have been slower in embracing layered system architectures. The main approach has been to use standard computer boards in the design of new embedded products, and while this has worked very well in many industrial applications, most computer boards are too big to be used in automotive applications.

Table 3.11 summarizes the advantages of layered systems and gives examples of layered system architectures. The AUTOSAR consortium was started in 2003 to define layered system architecture for the core automotive applications. AUTOSAR is open at all levels of the system architecture, which is an extraordinary achievement in a mature industry with so many established players. More recently, the Genivi alliance has been set-up in March 2009 to standardize API software blocks for the automotive infotainment applications.

Table 3.11 - Layered System and Software Architecture		
	Key Information	Comments
Examples	<ul style="list-style-type: none"> • PC Industry • AUTOSAR • GENIVI • Android • V2V and V2I 	<ul style="list-style-type: none"> • Extremely successful • Deployment stage, success coming • Definition stage; success likely • Deployment stage, success likely • V2X to use layer system architecture
Why?	<ul style="list-style-type: none"> • Tremendous advantages • Cost savings at all levels • Economy of scale • Product re-use • Software APIs most crucial 	<ul style="list-style-type: none"> • Across all system elements • Design, development, deployment • Hardware and software • Across product lines and generations • Standards needed in all industries
Application Innovation	<ul style="list-style-type: none"> • Focus is on application • Focused expertise • Better development tools 	<ul style="list-style-type: none"> • For product differentiation • Deep knowledge of standard platform • Focus on standard systems
Standard Setting	<ul style="list-style-type: none"> • Requires major companies • Requires open systems • Requires software support • Support at all levels 	<ul style="list-style-type: none"> • In established markets • Absolutely required at software level • Application base determine success • Chip, hardware, tools, software

Source: Authors' own elaboration.

Table 3.12 looks at layered system architectures and software standards in the automotive industry in more detail. The AUTOSAR consortium has done a tremendous job of defining and

implementing layered system architectures for the automotive industry. The deployment has started, but future improved versions of AUTOSAR will be available at regular intervals. The EU leadership in AUTOSAR gives the EU automotive industry significant influence and clout in guiding future direction of the automotive industry.

The success of AUTOSAR in the core automotive design has encouraged the launch of a similar consortium called the Genivi alliance to standardize API software blocks for automotive infotainment applications. The EU participation in Genivi is not as strong as in AUTOSAR, however the Genivi alliance is in the early stages of gathering support. Therefore, it is not yet clear whether the alliance's effort will be successful.

Table 3.12 - Software Standard Impact		
	Current/Likely Events	Impact/Comments
Autosar Consortium	<ul style="list-style-type: none"> Continued EU leadership Auto OEMs gain the most Worldwide impact 	<ul style="list-style-type: none"> Core members: BMW, M-B, VW, PSA, Bosch, Continental Cost, reliability, maintenance, features Other core members: GM, Ford, Toyota
Software APIs	<ul style="list-style-type: none"> Autosar is now a standard Deployment starting now Reusable system software 	<ul style="list-style-type: none"> Major automotive cost savings 5+ year deployment cycle Expertise is global, not local
Reusable software	<ul style="list-style-type: none"> Prevalence of standard OS Standard driver software Standard apps software? 	<ul style="list-style-type: none"> Autosar OS commodity by 2015 Driver SW commodity by 2015 Some apps commodity post-2015
Infotainment Software	<ul style="list-style-type: none"> Using PC related SW Genivi impact likely Linux OS impact likely Any Genivi competitors? 	<ul style="list-style-type: none"> Operating system, software drivers Intel-BMW led group may succeed Open source OS for infotainment Windows-based competitor?

Source: Authors' own elaboration.

The creation of AUTOSAR and Genivi, and their probably successful implementation, are tremendously important on the automotive embedded systems industry and its value chain, in Europe and worldwide. Therefore, the next sections enter in more details about those two standards and their potential impacts.

3.2.2.1 AUTOSAR

The AUTOSAR consortium was started in 2002 and has been led by EU automotive companies such as BMW, M-B, VW, PSA, Bosch, Continental, also joined by non-EU ones such as GM, Ford, Toyota.

The AUTOSAR consortium has been very successful in developing a set of software standards. The first deployment of these software standards is now taking place in the market. AUTOSAR has become the standard 'real-time' operating system in the non-infotainment (or "core") automotive domains.⁴⁹

The benefits of standard software are considerable and include:

⁴⁹ Most EU automotive manufacturers have moved towards the standardization of the AUTOSAR operating system for non-infotainment applications. However some semiconductor companies believe the automotive software market is evolving further; towards non-standard 'feature driven' developments that will lead to a decrease in code efficiency. This reduction in code efficiency will put greater pressure on semiconductor vendors to improve silicon hardware to maintain performance levels. However, automotive microcomputers are currently quite slow compared to PC microprocessors; as a result it should be relatively easy to increase the performance to counteract coding inefficiency of higher level object oriented languages.

- Lower development costs, higher reliability, less software maintenance and better functionality.
- Increased scalability and flexibility to integrate and transfer functions between Tier 1 suppliers.
- Higher penetration of COTS (Commercial off the Shelf) software and hardware components across product lines.
- Future proofing technology roll-outs for software upgrades and maintenance.
- Improved containment of product and process complexity and lower risk.
- Cost optimization of scalable systems.

AUTOSAR not only covers pure software functionality but also the broader design methodology for application development. This includes both the signal naming and signal structure that is used by embedded software developers. While some signal naming and signal structures are currently different between OEMs, it is likely the future will see the harmonisation of these requirements into a common standard.

One can expect that such changes will profoundly impact the automotive value chain. On the short to medium-term, the benefits of AUTOSAR-compliance software will benefit EU-based vehicle OEMs, Tier 1 suppliers, and software companies. On the medium to long term, vehicle OEMs will continue to receive benefits of standardization, however EU-based software suppliers will see increasing competition from low-cost regions. Finally, with full standardization, many automotive Tier 1 and Tier 2 (semiconductor) suppliers will (have already) shift some software development to India and other 'low-wage' regions. Clearly, further standardisation of AUTOSAR will increase this trend, which is likely to cause significant disruption to the embedded software employment landscape in high-wage economies.

AUTOSAR Implementation timeline

- Definition and development started in 2004. Testing is ongoing and early deployment started in 2008 and 2009. Each year additional car models will use AUTOSAR.
- EUROPE: By 2013-2014, PSA, BMW, Daimler and AUDI/VW will widely adopt the new AUTOSAR standards across their ranges.
- The broader adoption of the AUTOSAR structure is likely to migrate quickly into mainstream automotive as it is highly scalable once a car manufacturer adopts the standards
- JAPAN: Most Japanese manufacturers are following a Japanese variant of AUTOSAR called JASPAR. This is very similar to AUTOSAR, however for historical reasons the typical network structure in Japanese cars offers less 'interconnects' between ECUs and domains, i.e. the Infotainment ECUs will be separate from Body electronics ECUs and Chassis ECUs.

3.2.2.2 Genivi

With the success of the AUTOSAR consortium, several companies have organized a new group to try to achieve similar benefits in the infotainment software segment. Many of the AUTOSAR players are also participating in Genivi, with BMW being the most prominent. BMW and Intel are the key companies that are leading the technical and marketing efforts. Table 3.13 summarizes the Genivi consortium and its objectives.

Table 3.13 - Genivi Overview		
	Key Information	Comments
GENIVI Focus	<ul style="list-style-type: none"> • IVI: In-vehicle infotainment apps • Non-profit industry alliance • Open source platform 	<ul style="list-style-type: none"> • Audio, navi, telematics, etc. • Any IVI organization can join • Development platform
What Is It?	<ul style="list-style-type: none"> • Linux-based OS core • Middleware • Open application layer interface • Compliance testing • No HMI included 	<ul style="list-style-type: none"> • Common software architecture • Driver software • Application Programme Interface • Simplify system integration • HMI: Key product differentiation
Advantages	<ul style="list-style-type: none"> • Re-usable system software • Re-usable application software • Higher software reliability • Increased SW productivity • Better testing & debugging • Lower SW development costs • Lower development time 	<ul style="list-style-type: none"> • OS & software device drivers • Mostly via recompilation • Via growing experience • Better SW development tools • Better HW and SW tools • Re-usable software • Speeds time to market
Key Members	<ul style="list-style-type: none"> • BMW, GM, PSA, Nissan • Continental, Magneti, Delphi, Visteon 	<ul style="list-style-type: none"> • Intel, Freescale, Texas Instrument • Alpine, XSe (Harman subsidiary)

Source: Authors' own elaboration.

The advantages of Genivi will be similar to the AUTOSAR advantages and are listed in Table 3.13. Most advantages are based on standard application programming interfaces (APIs) and re-usable software.

The structure of AUTOSAR and Genivi are similar. Similarities include layered system architecture, software APIs and a focus on application software.

The main difference between Genivi and AUTOSAR is the Microcontroller abstraction layer, which allows multiple MCUs to be used. Genivi is likely to only use the Intel's PC-based 8086 microprocessor architecture and compatible MCUs.

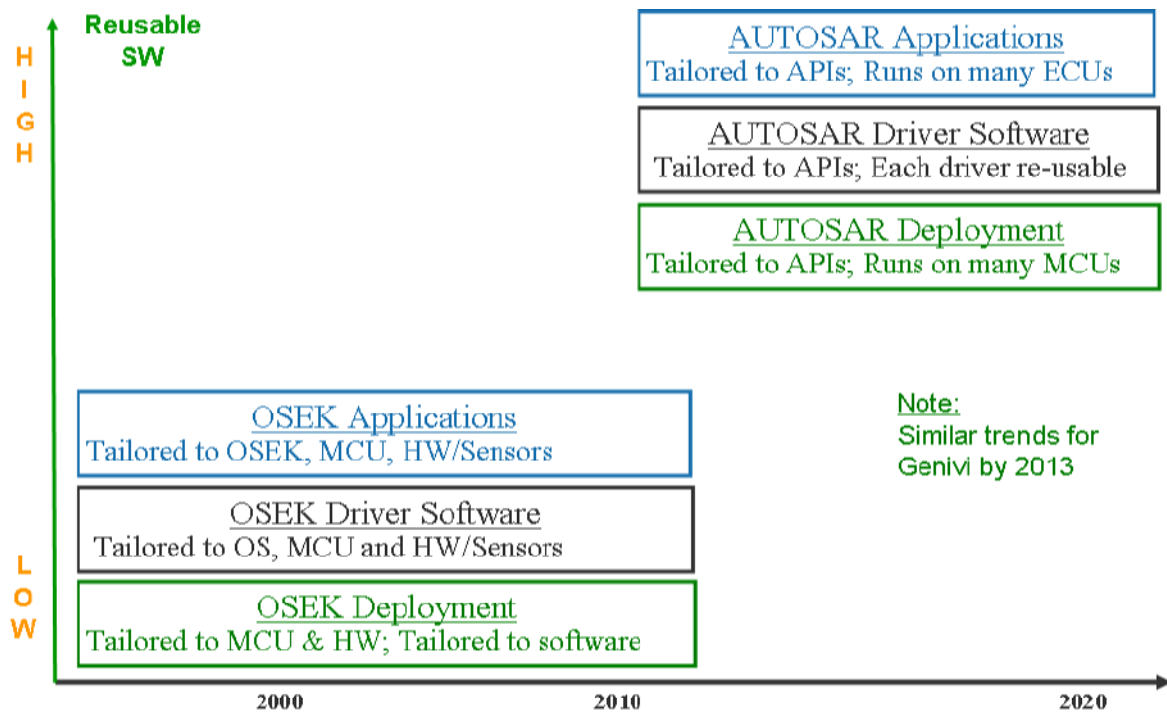
There is no question that API standards for Infotainment software will benefit car manufacturers and Tier suppliers as they will reduce duplication and decrease time to market in Infotainment which is a consumer lead segment. However the key question is whether Genivi will succeed or if another alternative will appear? Genivi probably has the critical mass to succeed, but it will need a few more EU automotive suppliers join the effort to establish the alliance. Most observers estimate that, unless there is a competing consortium to Genivi before the end of 2010, the Genivi alliance is likely to succeed.

3.2.2.3 Embedded software standard trends in a nutshell

Layered system architecture and software standards are new in the automotive industry, but will have a tremendous impact in the next decade. Figure 3.6 summarizes the impact of layered system architecture and embedded software standards. This figure is focused on AUTOSAR benefits, but similar advantages are expected for other API standards such as Genivi.

The key reason for using software API standards is that most of the software becomes re-usable, saving large amounts of software development and bug-fixing efforts, which can then be applied to improve existing applications as well as develop new applications.

Figure 3.6 - Software Standard Advantages



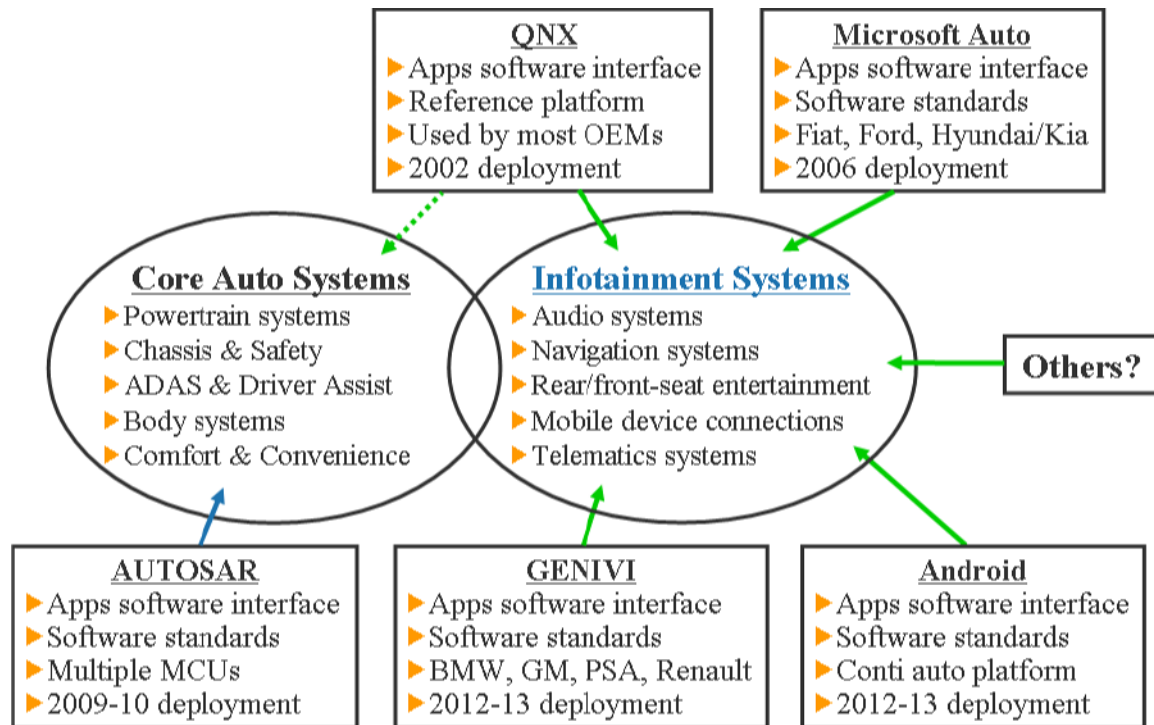
Source: Authors' own elaboration.

The layered system architecture also makes the production of 'standard' ECUs possible, which saves effort on the hardware design of many different ECU types, with resulting lower costs.

Figure 3.7 shows what is likely to happen in automotive embedded software standards in the next five years. There will be some overlaps between AUTOSAR and Genivi as both systems improve in functionality. ADAS software currently looks like an overlap area as pattern recognition applications become prevalent. Most of the pattern recognition software is currently developed for use on PCs—especially industrial PCs. ADAS systems are also likely to overlap with Infotainment systems in the user interface area.

Another potential overlap is V2X systems that will have a great deal of communication and network management software that is likely to come from PC and wireless communication software platforms.

Figure 3.7 - Embedded Software Standard Landscape



Source: Authors' own elaboration.

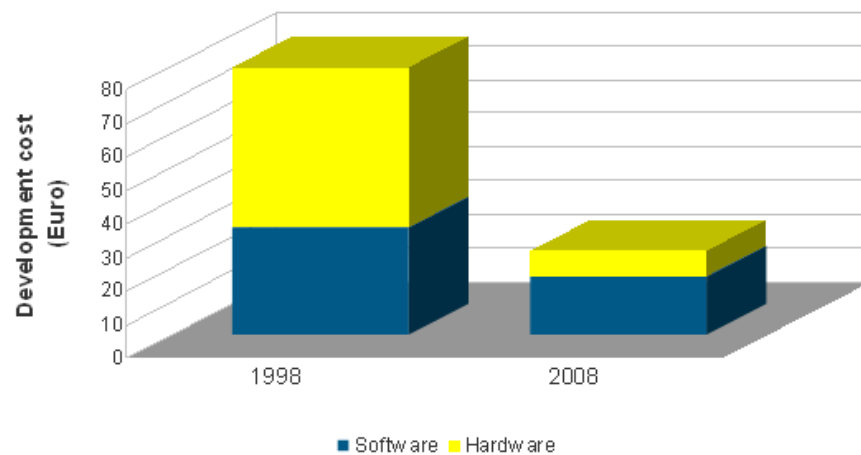
3.2.3 Future trends and their impacts on automotive embedded software

Embedded software has seen tremendous changes in the last two decades and is expected to see continued changes in the future. According to information gathered during interviews with stakeholders in the automotive value chain:

- In 1998, the **hardware** element represented 60%+ of the total cost of developing a typical ECU. Also the number of ECU's in the market was low; mainly to be found in premium sector vehicles
- By 2008, **embedded software** development costs accounted for 70%+ of a typical ECU, with hardware on mature platforms accounting for just 30% of the development costs.
- Also, the number of ECU's and software complexity has increased dramatically since 2000, creating a significant revenue opportunity for embedded software developers.

Figure 3.8 presents the change in the typical ECU development cost and cost split between hardware and software in 1998 and 2008.

Figure 3.8 - ABS ECU: Software/Hardware Development Split: 1998 and 2008



Source: Authors' own elaboration based on semiconductors industry interviews.

To understand the software evolutions, three aspects of embedded software need to be examined:

- Operating system, which manages all the elements of the system.
- Driver software which interfaces MCUs to sensors, actuators and other hardware.
- Application software which implements the MCUs' intended functions.

In addition, Diagnostic software has become an important feature for system testing with the increasing software complexity and deserves therefore some specific attention below.

As already said earlier, the operating system in automotive applications was initially simple proprietary programmes that were tailored to each ECU. Then, in the mid 1990s OSEK was developed as standard operating system by the European automotive industry. Finally, in the last five years, the AUTOSAR consortium has developed a set of Application Programmer Interfaces (APIs) that have become a standard for the automotive industry, replacing OSEK.⁵⁰ AUTOSAR-compliant operating systems are now available from multiple Tier 1 and software companies.

The driver software layer will also become AUTOSAR-compliant in the coming years. The result is that most OS and driver software will be reusable to a large extent, which will provide considerable saving in the development of embedded software.⁵¹

The application software development will also see cost savings because the same functions can be adapted to multiple car models with much lower effort than previously.

Diagnostics software has also increased in complexity—from simple start-up checks (go/no-go) to remote diagnostics checks or remote monitoring. The On-Board Diagnostics (OBD) systems

⁵⁰ The authors consider that OSEK will be used until AUTOSAR eventually replaces it, probably 5-10 years from now depending on automotive OEMs.

⁵¹ It is difficult to estimate the economic impact, in terms of savings that would be due to the AUTOSAR standard. The following analysis gives some indication of the potential. There is little embedded software requirement in sensors if compared to typical ECU software. Typical requirements for sensors are 10KBytes of software code per sensor. The typical car has around 60 sensors, which means the sensors contribute 0.6MBytes of software code to an average car. The average line of software code is around three bytes, which means the average car has 0.2M lines of software code to drive all the sensors. The conservative estimate for typical development costs per line of software code is about \$20. Hence the development cost for sensor software is around \$4 million for the average car. Re-usable software will not save all of this for a new car model development, but 50% savings is probably realistic. Luxury cars typically have twice as many sensors and software code if compared to mid-range vehicles.

that are mandatory in the USA and Europe have added information that is now being used by aftermarket suppliers. There are inexpensive tools that connect to the OBD-bus that can interpret what the OBD-codes mean. The latest trend is OBD devices that can transmit the information to a nearby smartphone so the driver will know the importance of a fault code if such an event happens. Remote diagnostics are expected to grow in the future by using the telematics system as the communication link.

The next paragraphs of the report detail past trends and likely future trends for ECU software characteristics in specific domains. Since the ECUs domains are quite different in terms of application capabilities, three separate domain groups are presented, each with its own table of software characteristics spanning four time periods from Pre-2000, to the 2020 timeframe.

Domain group 1) Powertrain, Chassis and Body ECUs

Domain group 2) Driver assist, ADAS and V2X ECUs

Domain group 3) Infotainment: Head-unit, navigation and telematics ECUs

Powertrain, chassis and body software trends

Table 3.14 summarizes the software evolution of Powertrain, chassis and body functions. Comfort and convenience functions are similar to body software characteristics.

Table 3.14 - Software Evolution: Powertrain, Chassis, Body				
	Pre 2000	2001-2010	2011-2015	2016-2020
Operating System	OSEK emerging	OSEK mature	Autosar emerging	Autosar matures
Specification/Design	OEM	OEM/Tier 1	OEM/Tier 1/SW	OEM/Tier 1/SW
Specification /Design Region	EU	EU	EU	EU
Coding	OEM/Tier 1	OEM/SW/Tier 1	OEM/SW/Tier 1	OEM/SW/Tier 1
Coding Region	EU	EU/India/ Low Cost Countries	India/ Low Cost Countries	Low-cost countries
Driver Layer	Proprietary/Custom	Standards emerging	Updated Standards	Updated Standards
Specification /Design	OEM/Tier 1	Tier 1/OEM	Tier 1/OEM	Multi-source
Specification /Design Region	EU	EU	EU/ Low Cost Countries	Multi-source
Coding	OEM/SW Companies	Tier1/SW/Semiconductor	SW/Semi/Tier 1	Semiconductor/SW/Tier 1
Coding Region	EU	EU/India	Low-cost countries	Low-cost countries
Application Layer	Proprietary/Custom	Proprietary/Custom	Re-usable apps	Re-usable apps
Application Interface	Proprietary/Custom	Autosar emerging	Autosar standard	Autosar updates
Specification /Design	OEM/Tier 1	OEM/Tier 1	OEM/Tier 1	OEM/Tier 1
Specification /Design Region	EU	EU	EU	EU
Coding	OEM/Tier 1	OEM/Tier 1	OEM/Tier 1	OEM/Tier 1
Coding Region	EU	EU/India	EU/India/ Low Cost Countries	EU/India/ Low Cost Countries
Diagnostics SW	OEM	OEM	OEM/Smartphone SW	OEM/Smartphone SW
Diagnostics check	Go/No-Go test	OBD tool/Remote	Remote/Smartphone	Remote/Smartphone
Diagnostics Region	EU	EU	EU/USA/Other	EU/USA/Other
SW upgrades	Dealer service bay	Dealer service bay	Dealer/Remote update	Remote Update
SW upgrades Region	EU	EU	EU	EU

Source: Authors' own elaboration.

The software trends in the Powertrain, Chassis and Body domains are dominated by the emergence of a layered system architecture as well as software standards from the AUTOSAR consortium.

- The software API standard will make the operating system and driver software products into commodity products post 2015.
- The application software will remain the key value-added for the embedded software industry.
- The coding of software including applications will increasingly move simple software to low-cost countries (Low Cost Countries). However, the increasing software productivity of standard-based software development tools will keep complex application coding in Europe.
- The specification and design of applications will mostly remain in Europe for the operating systems and applications.

Driver assist, ADAS and V2X software trends

Table 3.15 summarizes the software evolution of driver assist, ADAS and future V2V and V2I functions.

Table 3.15 - Software Evolution: Driver Assist, ADAS & V2X				
	Pre 2000	2001-2010	2011-2015	2016-2020
Operating System	OSEK emerging	OSEK mature	Autosar emerging	Autosar and/or Genivi
Specification/Design	OEM	OEM/Tier 1	OEM/Tier 1/SW	OEM/Tier 1/SW
Specification/Design Region	EU	EU	EU	EU/USA
Coding	OEM/Tier 1	OEM/SW/Tier 1	OEM/SW/Tier 1	OEM/SW/Tier 1
Coding Region	EU	EU/India	India/ Low Cost Countries	Low-cost countries
Driver Layer	Proprietary/Custom	Standards emerging	Updated Standards	Updated Standards
Specification/Design	OEM/Tier 1	Tier 1/OEM	Tier 1/OEM/Semiconductor	Multiple source
Specification/Design Region	EU	EU	EU/ Low Cost Countries	Multiple source
Coding	OEM/SW Companies	Tier 1/SW/Semiconductor	SW/Semiconductor/Tier 1	Semiconductor/SW/Tier 1
Coding Region	EU	EU/India	Low-cost countries	Low-cost countries
Application Layer	Proprietary/Custom	Proprietary/Custom	Re-usable apps	Re-usable apps
Application Interface	Proprietary/Custom	Standards emerging	Autosar standard	Autosar and/or Genivi
Specification/Design	OEM/Tier 1	OEM/Tier 1	OEM/Tier 1/SW	OEM/Tier 1/SW
Specification/Design Region	EU	EU	EU/USA/Japan	EU/USA/Japan
Coding	OEM/Tier 1	OEM/Tier 1	OEM/Tier 1	OEM/Tier 1
Coding Region	EU	EU/India	EU/USA/India	EU/USA/ Low Cost Countries
Diagnostics SW	OEM	OEM	OEM/Smartphone SW	OEM/Smartphone SW
Diagnostics check	Go/No-Go test	Remote Monitoring	Remote/Smartphone	Remote/Smartphone
Diagnostics Region	EU	EU	EU/USA/Other	EU/USA/Other
SW upgrades	Dealer service bay	Dealer service bay	Dealer/Remote update	Remote Update
SW upgrades Region	EU	EU	EU	EU

Source: Authors' own elaboration.

The software trends for driver assist and ADAS are dominated by the emergence of the layered system architecture and software standards from the AUTOSAR consortium. For some

applications the Genivi APIs may also be used as there is increasing overlap between ADAS and infotainment.

- The software API standard will make the operating system and driver software products into commodity products post 2015. The application software will remain the key value-added for the embedded software industry.
- The coding of commodity software and application will increasingly move to low-cost countries (Low Cost Countries). However, the increasing software productivity of standard-based software development tools will keep complex application coding in Europe.
- The specification and design of applications will mostly remain in Europe for the operating systems and applications.
- V2X software will also have a layered architecture and software API standard. V2X will use Internet Protocol and OSGi standards and may also use Genivi APIs as well as other standards. V2X systems will be tied closely to local systems, which will keep most of the software development in Europe.

Infotainment software trends

Table 3.16 summarizes the software evolution of infotainment systems including head-unit (audio and video), navigation and telematics systems.

Table 3.16 - Software Evolution: Infotainment				
	Pre 2000	2001-2010	2011-2015	2016-2020
Operating System	Proprietary/Custom	QNX, Windows, Linux	Linux, Windows	Linux, Windows
Specification/Design	OEM/Tier 1	SW company	SW company	SW company
Specification/Design Region	EU	N. America/EU	N. America/EU	N. America/EU
Coding	OEM/SW company	SW company	SW company	SW company
Coding Region	EU	N. America/EU	USA/EU	USA/EU/ Low Cost Countries
Driver Layer	Proprietary/Custom	Standard by OS	Standard by OS	Standard by OS
Specification/Design	OEM/Tier1	Tier1/OEM	Multiple Source	Multiple Source
Specification/Design Region	EU	EU	EU/USA	EU/USA
Coding	OEM/SW Companies	Tier 1/SW/Semiconductor	SW/Semiconductor/Tier 1	Semiconductor/SW/Tier 1
Coding Region	EU	EU/A-P	EU/A-P	EU/A-P
Application Layer	Proprietary/Custom	Proprietary/Custom	Re-usable apps	Re-usable apps
Application Interface	Proprietary/Custom	Modified PC/CE	Genivi/O. Standard	Genivi/O. Standard
Specification/Design	OEM/Tier 1	Tier 1	Tier 1	Tier 1
Specification/Design Region	EU	EU/Japan	EU/Japan	EU/Japan
Coding	OEM/Tier 1	Tier 1	Tier 1/Outsource	Tier 1/Outsource
Coding Region	EU	EU/USA/Japan	EU/USA/ Low Cost Countries	EU/USA/ Low Cost Countries

Table 3.16 - Software Evolution: Infotainment				
HMI Layer	Proprietary/Custom	MS AUI, Flash SW	MS AUI, Flash SW	MS AUI, Flash SW
Specification/Design	OEM/Tier 1	OEM/Tier 1	OEM/Tier 1	OEM/Tier 1
Specification/Design Region	EU	EU	EU	EU
Coding	OEM/Tier 1	Tier 1/OEM	Tier 1/Outsource	Tier 1/Outsource
Coding Region	EU	EU/IUSA/A-P	Low Cost Countries /EU	Low-cost countries

Source: Authors' own elaboration.

The software trends for infotainment are currently mostly related to consumer electronics and PC industry software events. The emergence of layered system architecture and software standards from the PC and consumer electronics industries is happening with the Genivi consortium.

- Software API standards will make the operating system and driver software into commodity products post 2015. The infotainment application software will remain the key value-add for the embedded infotainment software industry.
- The coding of infotainment software including applications will increasingly move to low-cost countries; however the increasing software productivity of standard-based software development tools will keep complex application coding in Europe and USA.
- The specification and design of infotainment applications will mostly remain in USA and Europe for the operating systems and applications.

3.2.4 Embedded automotive software: summary and conclusions

The European automotive industry currently has a strong position in embedded software for the many ECUs used in cars. The following are key conclusions from this software chapter:

- Automotive software is going through a revolutionary change that is standardizing the software interfaces between most software components. The EU-led AUTOSAR consortium has brought this project to the deployment phase, which will dramatically change future embedded software development.
- AUTOSAR compliant software will allow most software programmes to be reusable, which will reduce re-development costs when companies migrate their technology from project to project. The software saving will be used to develop more advanced software systems that will be required to meet the pressure from environmental compliance, accident prevention and the connected car.
- Embedded software standards for automotive applications are the right development for the European automotive industry—especially since most of the specifications and design have originated from European companies.
- Some of the EU automotive OEMs are the early adopters of the AUTOSAR standards, as a result they will be able to benefit from re-usable software including lower software development costs, more reliable software as well as higher software functionality.
- The AUTOSAR consortium has a worldwide reach and will be the basis for similar systems in Japan and other regions. Many companies from around the world are participating in this consortium and have (or will) acquire expertise in designing or implementing AUTOSAR-compliant software.
- Software standardization opens the door for non-EU companies to better compete in the automotive embedded software market. AUTOSAR already has members from the Indian

software community. Embedded software expertise for automotive applications is likely to spread to many regions where software expertise exists.

- Long-term AUTOSAR-compliant software will become a competitive market and low-cost regions will gain increased share in this segment.
- Infotainment software has an increasing connection to the PC, Internet and consumer electronics industries. The drivers for these industries are currently non-EU based companies with the USA as the primary innovator for many consumer standards, while lower level coding is being developed in low-cost Asian regions. As a result of the success of the AUTOSAR standard, technology leader BMW is part of an alliance that is attempting to create a new *infotainment* software standard called Genivi. Currently, PSA, Continental and Magneti-Marelli are Genivi participants; however key European OEMs and Tier 1 companies are not currently supporting this effort in large numbers.
- Software standards will enable much more productive software development, thereby increasing software development efficiency. This trend is likely to keep much of the application development in Europe—at least for complex applications and applications that are linked to local ICT systems such as V2X as well as connected car services and autonomous driving.

In order to secure long-term automotive ICT jobs within the EU, it is essential that high levels of product innovation are encouraged within EU. Product innovation will require Embedded software innovation, which needs to be the corner stone of future high value jobs within the EU:

- As the AUTOSAR standard is deployed more widely, upper level ECU embedded software applications are likely to migrate to more commodity level programming complexity, which is in turn likely to lead to a migration of embedded software labour outside the EU towards lower-cost labour regions (Asia-Pacific and Egypt).
- A potential counter-trend is the rapid improvement of software development tools that become possible with the AUTOSAR standard. These software development tools will give much higher software productivity as AUTOSAR experience base grows. Since the AUTOSAR deployment and competence is building first in Europe, this may counteract the high cost structure—at least in the short term.
- Much of the ECU application software programming competence is likely to stay with vehicle OEMs and Tier 1 companies in Europe; especially the specifications and design tasks. However, lower level application software coding has, or will migrate to low-cost regions that have the software coding competency.

4. Economic Overview: Supply Chain and Competitiveness of the European Automotive Embedded Systems Industry

4.1 The Value Chain

4.1.1 A general overview

Until the mid 1990's, car design was typically more focussed on 'mechanical' design (pulleys, pumps and hydraulics) rather than 'electronic' or ICT design (sensors, electric motors, and computer-based device controllers). Advanced electronic developments were typically limited to luxury vehicles rather than the mass market.

In the mid 1990's vehicle manufacturers began to shift their focus away from this 'mechanical' approach towards greater centralised electronic control of vehicle systems. This approach led to the development of the ECU (Electronic Control Units) as well as the introduction of a digital connectivity network architecture (Digital BUS). This design philosophy continues to this day.

As the ECU architecture matured, it evolved from simple control of single functions in the vehicle such as window up/down, to the highly complex ICT systems of today that control almost all the electronic and mechanical systems on modern vehicles. The introduction of the ECU, required an expansion of the value chain to involve embedded software designers and semiconductor suppliers in developing a greater range of advanced features.

As a result of the introduction of the ECU and vehicle BUS architecture, the automotive ICT value chain has become broadly segmented into four layers:

1. Vehicle OEMs (e.g. VW, Renault, BMW)

These companies design, manufacture and market motor vehicles to end customers. They also integrate all their ICT systems from their suppliers.

2. Tier 1 supplier's (e.g. Bosch, Magneti Marrelli)

These companies are typically the primary interface and customer of the Vehicle OEM's. They design, manufacture and develop hardware and software solutions for vehicle OEMs.

3. Tier 2-3 suppliers (e.g. Preh, Parrot, Paragon)

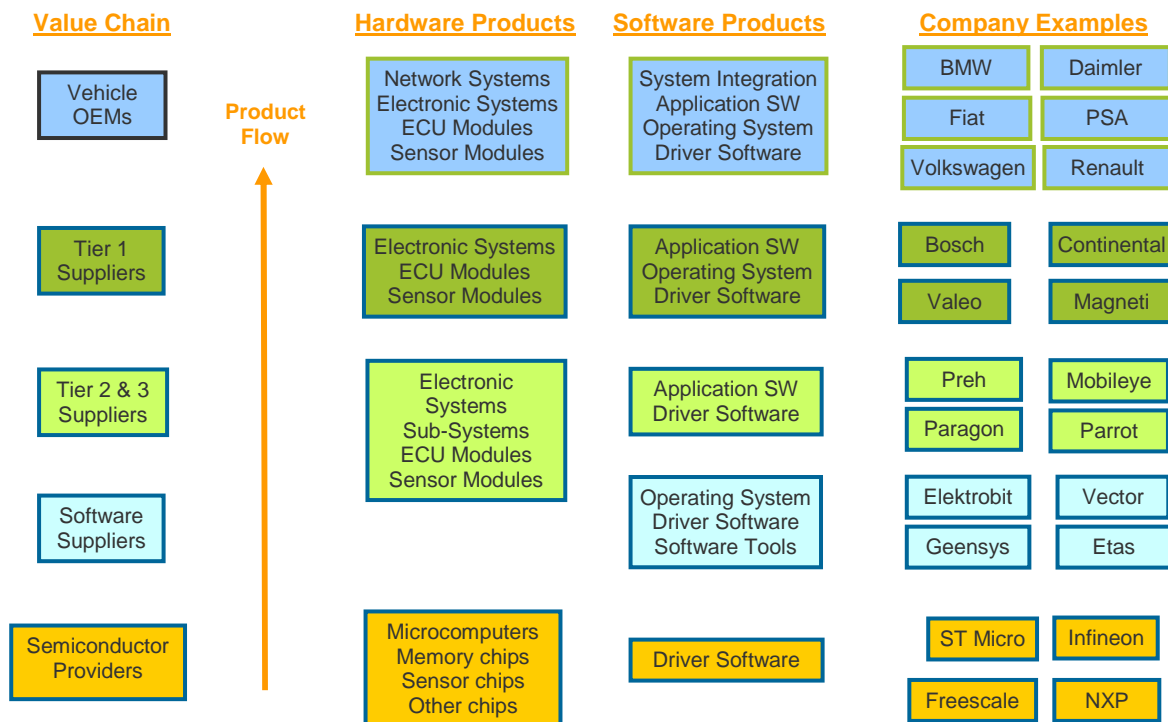
These companies are often used in an outsourcing capacity by Tier 1 suppliers. They also design, manufacture and develop hardware and software solutions for Tier 1 suppliers.

4. Semiconductor suppliers (e.g. ST Micro and Infineon)

These companies design, manufacture and develop semiconductors for Tier 1-3 suppliers.

Figure 4.1 is a 2 dimensional view of the automotive value chain, with examples of products and services, and companies that operate in each layer of the chain.

Figure 4.1 – Automotive ICT Value Chain



Source: Authors' own elaboration.

The hardware product flow is from the bottom up, (i.e. Semiconductor suppliers work with software suppliers, who pass their products onto tier 1s, tier 2s, and then onto the OEMs) Embedded software products can be added at all levels. This value chain is further described in the next sections.

It is nevertheless important to note that the automotive ICT value chain will become attractive to a much wider range of value-chain members as more ICT products and services are offered in vehicles. The car's conversion from analogue to digital control systems and from mechanical to electrical system has been on-going for over 20 years, with development primarily driven by emission issues. However the ability for the vehicle to be connected is one of the major new forces that have developed over the last 3-5 years.

While currently the Automotive Value-chain is mainly made of Vehicle OEM's, Tier 1 suppliers, Semiconductor suppliers and Software suppliers, it is expected that in the short/medium term this will expand to include all of the above, plus:

- Telecoms providers (to establish link to the vehicle for wireless connectivity). Recent examples include joint activities of T-Mobile with BMW, P&T Luxembourg with PSA, WiFi devices now entering the market, enabling a WiFi link in the vehicle using the cell network as the data carrier.
- Location-based service providers (able to offer services to support Telematics, V2V communications and advanced driver assist services).
- In the longer term, Electricity suppliers. They will have an interest in supplying power to electric vehicles as well as tracking car usage patterns for efficiency and using car batteries as temporary power storage for off-loading peak demand.

4.1.2 OEM's supply chain overview: examples

Two European auto OEMs supply chains are presented in some detail in this section: those of BMW and Volkswagen.⁵²

The automotive industry is often secretive about its supplier relationships and it is standard procedure for the car manufacturers to ask its vendors to not publicly disclose their supplier contracts. Hence it is difficult to collect supplier data on most ICT products and supplier relationships. Table 4.1 summarizes the ICT supplier data that the authors have collected for BMW and have been allowed to reveal.

Table 4.1 - BMW ICT Supply Chain Overview			
	System	Tier1/System	Tier2/Components
Infotainment	<ul style="list-style-type: none"> Navigation Head-Unit Premium audio Telematics HMI Bluetooth HFI Rearseat video 	<ul style="list-style-type: none"> Harman-Becker, Conti Harman Kardon, Conti Harman Kardon Continental Preh, Temic & SVOX Paragon Lear (7-Series) 	<ul style="list-style-type: none"> Navteq-map Lear-amplifier NXP, ST Micro Freescall, Wavecom iDrive, Speech-ASR/TTS Parrot in 2010 JCI-RSE display
Powertrain	<ul style="list-style-type: none"> Engine ECU Transmission ECU 	<ul style="list-style-type: none"> Bosch Bosch 	<ul style="list-style-type: none"> Infineon, ST Micro Infineon, ST Micro
Body & Comfort	<ul style="list-style-type: none"> Instrument Cluster Head-up display Rain sensing wipers 	<ul style="list-style-type: none"> Bosch Nippon Seiki Hella 	<ul style="list-style-type: none"> JCI, ST Micro
Safety & Chassis	<ul style="list-style-type: none"> ABS Air bag system Electronic stability 	<ul style="list-style-type: none"> Bosch Autoliv Bosch 	<ul style="list-style-type: none"> Infineon, ST Micro Infineon, Elmos Infineon, ST Micro
Driver Assist & ADAS	<ul style="list-style-type: none"> Adaptive cruise Adaptive lighting Blind spot detection Camera park Lane departure Ultrasonic PA Night vision 	<ul style="list-style-type: none"> Bosch Hella Hella Valeo Continental Valeo Autoliv 	<ul style="list-style-type: none"> Infineon, ST Micro Mobileye-camera Elmos

Source: Authors' own elaboration.

Table 4.1 shows that BMW favours European suppliers in most cases, with Autoliv, Bosch, Continental, Harman-Becker, Hella and Valeo being the most important suppliers. European semiconductor companies such as Infineon and ST Micro are also strongly represented.

Table 4.2 summarizes the ICT supplier data that the authors have collected for Volkswagen and were allowed to reveal. Some of the supplier relations include Audi; the luxury brand of Volkswagen.

⁵² BMW was chosen because it is the worldwide leader in automotive electronics and software technology. BMW sells its luxury and premium autos in most countries of the world. Volkswagen was chosen because it is the sales and production leader in Europe and is the third largest auto manufacturer in the world. Volkswagen has a strong presence in most regions and is the leader in Europe and China. It is also strong in Latin America and other developing regions. Volkswagen has minimal presence in Japan and has the potential to do better in the USA, as it only has a 2.5% market share.

Table 4.2 - Volkswagen ICT Supplier Overview			
	System	Tier 1	Tier2/Comments
Infotainment	<ul style="list-style-type: none"> Navigation Head-Unit Branded audio Rearseat video HMI (Audi) 	<ul style="list-style-type: none"> Bosch, Continental Bosch, Delphi, H-B Bose, B&O, Dynaudio Visteon, Blaupunkt Preh (MMI), Becker 	<ul style="list-style-type: none"> Navteq & Tele Atlas NXP, ST Micro ST Micro, NXP Elmos SVOX (TTS)
Powertrain	<ul style="list-style-type: none"> Engine ECU Transmission ECU 	<ul style="list-style-type: none"> Bosch Bosch, Hella 	<ul style="list-style-type: none"> Infineon, ST Micro Infineon, ST Micro
Body & Comfort	<ul style="list-style-type: none"> Instrument Cluster Rain sensing wipers HVACs 	<ul style="list-style-type: none"> Magneti (Audi & VW) Valeo (Audi) Valeo 	<ul style="list-style-type: none"> ST Micro Infineon, Elmos
Safety & Chassis	<ul style="list-style-type: none"> ABS Adaptive lighting Air bag system Electronic stability 	<ul style="list-style-type: none"> Bosch Hella Autoliv Bosch 	<ul style="list-style-type: none"> Infineon, ST Micro Infineon, Elmos Infineon, ST Micro
Driver Assist & ADAS	<ul style="list-style-type: none"> Adaptive cruise Lane departure Ultrasonic PA Autonomous PA Side object 	<ul style="list-style-type: none"> Bosch Continental (Audi) Valeo Valeo Hella 	<ul style="list-style-type: none"> Infineon, ST Micro Elmos

Source: Authors' own elaboration.

In common with the BMW supplier profile, Table 4.2 shows that Volkswagen is using European suppliers for most electronics systems. Bosch, Continental, Harman-Becker, Hella, Autoliv and Valeo are the prominent suppliers to Volkswagen, while the European semiconductor companies such as Infineon and ST Micro are also strong Volkswagen customers.

Both examples show highly structured and concentrated supply chains, with an obvious dominance of European companies.

4.1.3 Tier 1 supply chain overview

Europe has the strongest line-up of Tier 1 suppliers of any region as already perceived from the examples above and shown again in Table 4.3. Bosch is the largest car supplier in the world in terms of revenue. Continental is now the third largest supplier, while US based Delphi was number two in 2008. Delphi has been scaled down significantly during its bankruptcy proceedings and is now smaller than Continental.

Table 4.3 - Tier 1 Suppliers: EU-based						
		Bosch	Conti	Magneti	Autoliv	Valeo
Total Revenue-2007	€M	46,320	16,619	5,000	6,769	9,689
Total Revenue-2008	€M	45,127	24,239	5,447	6,473	8,815
Net Profit-2007	%	6.15	6.32	4.18	4.25	0.84
Net Profit-2008	%	0.82	-4.45	1.71	2.55	-2.35
R&D-2007: Revenue Share	%	7.74	5.02	4.42	5.85	6.89
R&D-2008: Revenue Share	%	8.62	6.18	4.92	5.67	7.25
WW Employees	#K	268	152	28	35	61
WW Employees	#K	283	139	33	34	51
EU Employees	#K	185	100	NA	NA	NA
EU Employees	#K	189	92	NA	NA	NA
Automotive Revenue	€M	NA	7,296	5,000	6,769	9,689
Automotive Revenue	€M	NA	14,900	5,447	6,473	8,815

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Bosch and Continental are two of the most technologically advanced Tier 1 suppliers and cover a broader electronics product range than any of their competitors. Magneti-Marelli, which is owned by Fiat, is primarily a supplier to Fiat. It also has some business with PSA Citroen Peugeot. Autoliv is a leader in safety systems and has been a pioneer and innovator in seatbelt and airbag systems. Autoliv is also innovating in active safety systems or driver assist products such as lane departure warning, adaptive cruise control and night vision. Valeo's electronics systems are focused on driver assist and ADAS products. Hella is another strong EU-based driver assist and ADAS supplier

The leading non-EU-based Tier 1 suppliers are summarized in Table 4.4. Denso is the second largest automotive supplier and is especially strong in Japan. Since Denso primarily supplies the Japanese car manufacturers, it has been hit hard by the current recession. Alpine is primarily a supplier of infotainment systems and is especially strong in navigation systems; this company has been similarly badly hit by the automotive downturn.

Table 4.4 - Tier 1 Suppliers: Non-EU-based					
		Delphi	Visteon	Denso	Alpine
Total Revenue-2007	\$M	22,283	11,275	31,667	2,211
Total Revenue-2008	\$M	18,060	9,544	40,975	2,005
Net Profit-2007	%	-13.75	-3.30	5.68	1.41
Net Profit-2008	%	-16.82	-7.14	6.06	-5.08
R&D-2007: Revenue Share	%	8.98	4.52	7.76	11.50
R&D-2008: Revenue Share	%	10.52	4.55	7.75	14.21
WW Employees	#K	170	42	112	13
WW Employees	#K	147	34	119	12
Automotive Revenue	\$M	22,283	11,275	31,149	2,211
Automotive Revenue	\$M	18,060	9,544	40,446	2,005
Headquarter Country		USA	USA	Japan	Japan

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

The two major USA-based Tier 1 suppliers (Visteon and Delphi) have gone through tough times over the past few years with both companies filing for bankruptcy protection to continue trading. Delphi was originally a GM subsidiary and was spun off as an independent company in 1999. Similarly Visteon was a Ford subsidiary and was spun off as an independent company in 2000. Visteon filed for bankruptcy protection in May 2009.

An important reason why the EU car suppliers are healthier than their international counterparts is they were typically not 'captive suppliers' to any specific car makers (with the exception of Magneti-Marelli and Fiat). Denso, Delphi and Visteon were at one time subsidiaries of Toyota, GM and Ford respectively, while the EU Tier 1s needed to compete with each other for automotive business, which has made them more innovative, profit-oriented and market savvy.

4.2 Automotive Embedded Hardware

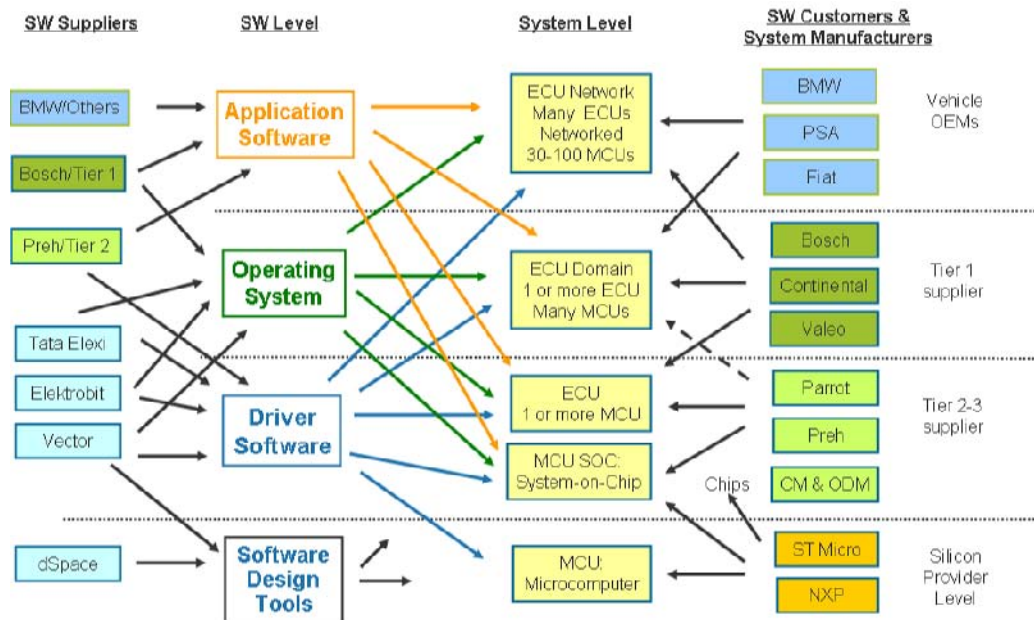
4.2.1 Embedded hardware value chain

This section of the report introduces to the hardware value chain within ICT within the automotive. The software part is covered in the next section. Because of their interdependencies, Figure 4.2 shows the value chain and includes how software and hardware products flow to the various systems at different levels.

The left side of Figure 4.2 shows (examples of) companies that provide software at all levels in value chain, while the arrows points to the type of software each company offers (which is shown in the second column). The right side of the figure shows system manufacturing companies at

each level. At each level the companies make a product that is a system from their view, which then become a sub-system to the next level. These companies are also embedded software customers. The arrows from the system manufacturers point to the types of hardware system they provide. The middle arrows indicate what type of embedded software is used at each hardware system level.

Figure 4.2 - Automotive Embedded Hardware and Software Value Chain



Source: Authors' own elaboration.

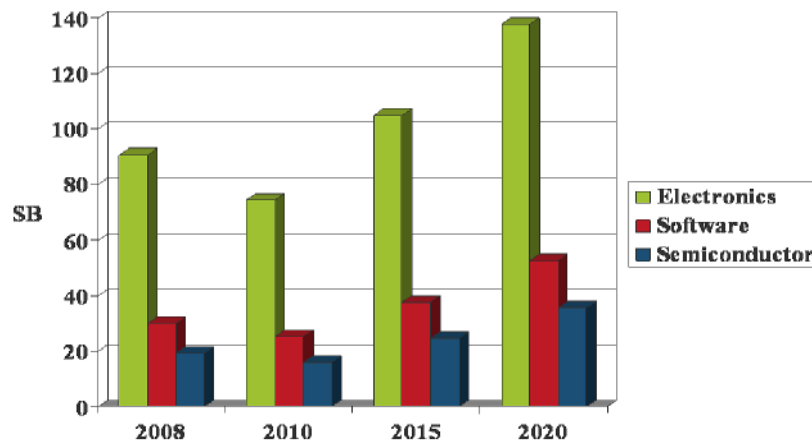
The products tend to flow upwards at the system level and at each step become more complex and has more valuable. Each upward step also adds additional amount of software. These steps happen for each ECU and hence there are 50 to 100+ systems, depending on car type, that follow this flow for every car produced.

4.2.2 Automotive embedded hardware value

4.2.2.1 Setting the scene: total embedded systems value estimates

Figure 4.3 summarizes the estimated value of worldwide automotive electronics, semiconductors and software. The software value will be further discussed in later sections of this chapter.

Figure 4.3 - Worldwide Auto Embedded Systems Value by Segment



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Worldwide automotive electronics value is projected⁵³ to grow from \$90 billion + in 2008 to over \$137 billion in 2020, with a dip in 2010 due to the severe recession in 2009 (iSuppli estimate). The automotive electronics value estimate is factory value or the value that automotive OEMs pay to their electronics suppliers. The electronics value includes semiconductor parts as they are included in the embedded electronics systems. Some of the embedded software value is also included in the electronics value, because the embedded software is part of the electronics systems. However, the automotive manufactures are also adding software as they are integrating the many electronics systems into the car and this software is not included in the electronics value.

Worldwide semiconductor value is forecasted to grow from \$19 billion in 2008 to over \$35 billion in 2020 (iSuppli estimate). The semiconductor value estimate is factory value or the value that automotive suppliers and OEMs pay to their semiconductor suppliers.

The worldwide embedded software value is estimated to grow from \$30 billion in 2008 to over \$52 billion in 2020. The embedded software market value estimate is explained in a later section.

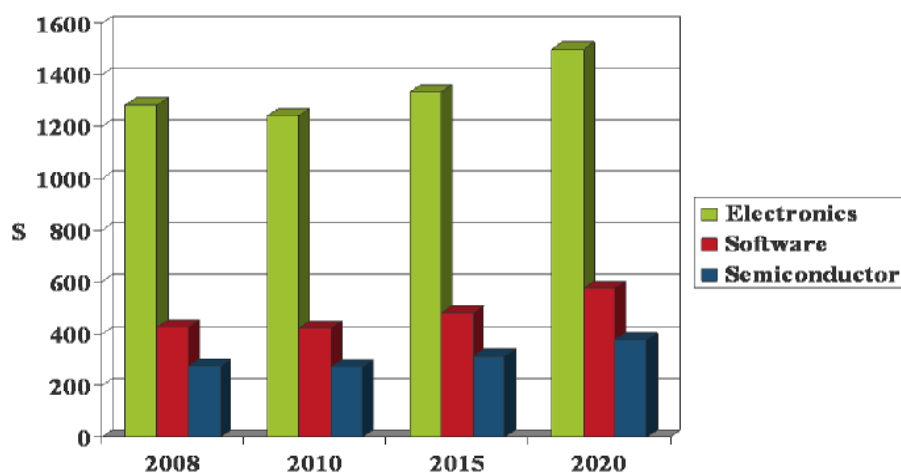
Figure 4.4 summarizes the estimated worldwide automotive electronics, semiconductor and software (also included for comparison) values per average car.⁵⁴

The average electronics value per car is forecast to grow from \$1,284 in 2008 to over \$1,500 in 2020. The average semiconductor value per car is projected to grow from \$273 in 2008 to \$376 in 2020. The average software value per car is estimated to increase from \$425 in 2008 to \$575 in 2020.

⁵³ iSuppli estimates in Q1 2010

⁵⁴ The total market values were divided by the yearly production volume to get the per-car values.

Figure 4.4 - Worldwide Automotive ICT Value per Car by Segment

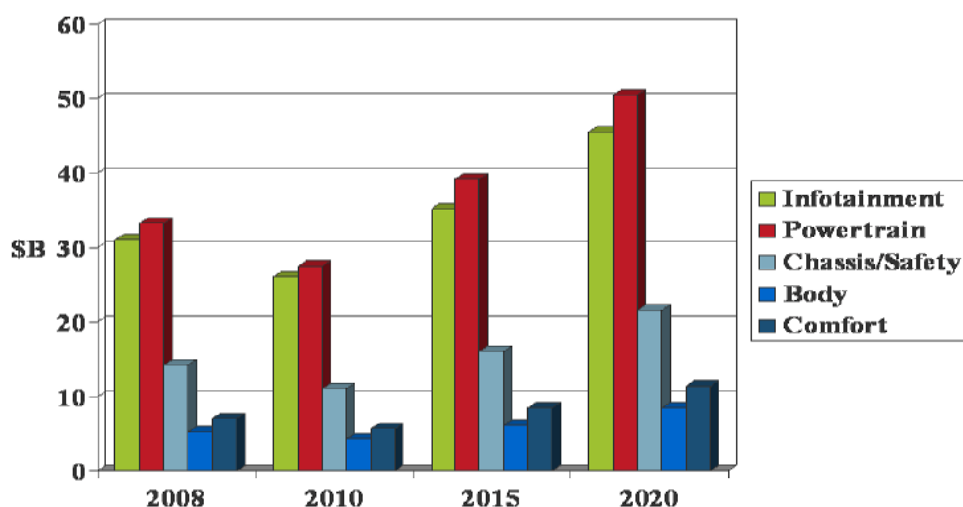


Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

4.2.2.2 Automotive electronics value estimates

Estimates and forecast for Automotive Electronics value have been produced and extended by iSuppli to 2020 as shown in Figure 4.5.⁵⁵

Figure 4.5 - Worldwide Automotive Electronics Value by Domain



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

The Powertrain domain is, in value, the largest automotive electronics consuming segment and is expected to grow from \$33 billion in 2008 to over \$50 billion in 2020. The reason is that every car produced has a significant amount of Powertrain electronics system to run the engine, transmission and related systems. The Infotainment domain is the second largest segment with a projected growth going from \$31 billion in 2008 to \$45 billion in 2020. The third largest segment is Chassis and safety which also includes driver assist and ADAS. This domain is forecast to grow from \$14 billion in 2008 to nearly \$22 billion in 2020.

⁵⁵ The specialized consultancy iSuppli tracks worldwide automotive electronics value by ECU domains. The estimates and forecast are based on the collected data.

4.2.2.3 Automotive semiconductors value estimates

The global market for all semiconductor types was €175 billion in 2008 (iSuppli estimate). While the automotive semiconductor market represents just 7.5% of the 2008 global total, the percentage and revenue opportunity for semiconductors will substantially increase in the future as more ICT products are incorporated into vehicles.

For example, ST Microelectronics estimates⁵⁶ that the average cost of semiconductors needed in a typical engine control ECU in 2009 is in the range of \$25-\$40 per unit for a fuel based vehicle ECU. However in an 'All-electric' vehicle, this requirement will be substantially greater, mainly to support high-power electronics and monitoring systems. ST Microelectronics expects that electric vehicles will boost the semiconductor opportunity for engine control into the \$200 - \$300 range. As a result the company believes that the revenue opportunity for semiconductor manufacturers could increase by as much as a factor 10 in some cases if compared to the current fuel engine equivalent.

In addition, the authors believe the transition to electric power will have a cascading effect on ICT product-design, as traditional belt based motors and pumps will need to be replaced by electronic motor drives and coupled devices for power-steering and climate control etc. This will inevitably increase the requirement for power semiconductors and monitoring systems with more sensors and microcontrollers required to optimize battery efficiency.

Market by semiconductor type (2008)

Table 4.5 presents an overview of the global semiconductor market in 2008, with revenues split by semiconductor type. It shows that while the Automotive industry is not a major customer in most sub-segments, in the area of Microcontrollers, (MCUs), the Automotive Market accounted for 25.7% of the total in 2008.

Table 4.5 – Market Splits by Semiconductor Segments: 2008							
€Millions	Automotive	Wired Comms	Wireless Comms	Computer Peripheral	Consumer	Industrial	Total
MCU	2,723	81	224	706	1728	5,106	10,568
DSP ASSP	180	177	1,034	90	386	0	1,868
DSP ASIC	0	0	1,608	0	0	0	1,608
Logic ASSP	756	4,078	9,389	10,856	6,113	598	31,790
Logic ASIC	330	866	1,176	2,294	4,064	561	9,292
Analog ASSP	2,436	1,061	5,785	1,903	3,110	1,225	15,520
Analog ASIC	942	64	1,002	525	52	237	2,823
Others	5,840	4,206	14,940	48,248	20,298	8,746	102,277
Total	13,208	10,533	35,158	64,622	35,752	16,473	175,746
Others include Microprocessors (MPU), sensors, memory, etc.							

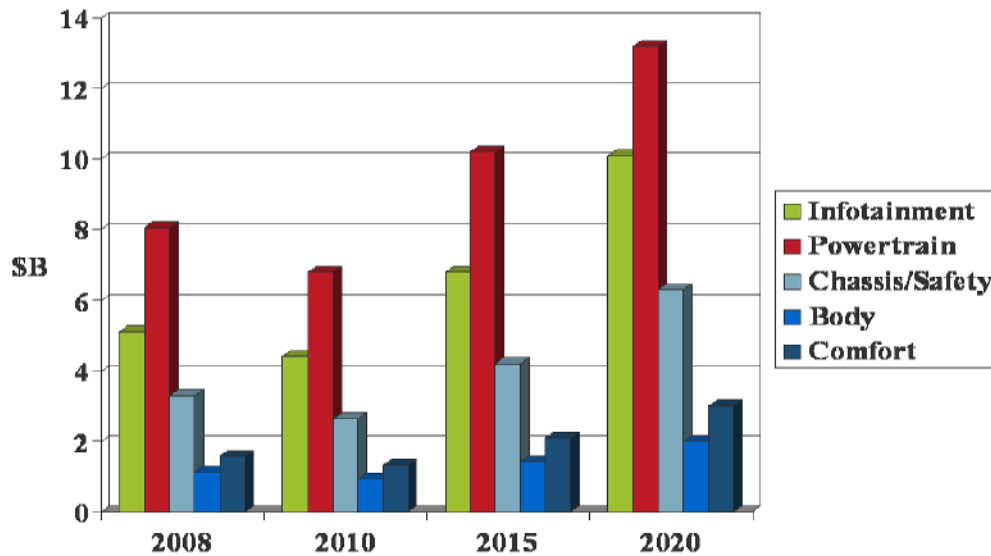
Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

⁵⁶ From interviews conducted throughout this study.

Market by domain (2008 - 2020)

Figure 4.6 presents the worldwide revenue splits for the 5 automotive domains.

Figure 4.6 - Worldwide Automotive Semiconductor Value by Domain



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Powertrain is, in value, the largest domain for the semiconductor industry and is forecasted to grow from \$8 billion in 2008 to over \$13 billion in 2020. Infotainment is the second largest domain is projected to increase from \$5.1 billion in 2008 to \$10.1 billion in 2020. Chassis and safety, including driver assist and ADAS, is the third largest domain and will grow from \$3.3 billion in 2008 to \$6.3 billion in 2020.

Market by company (2008)

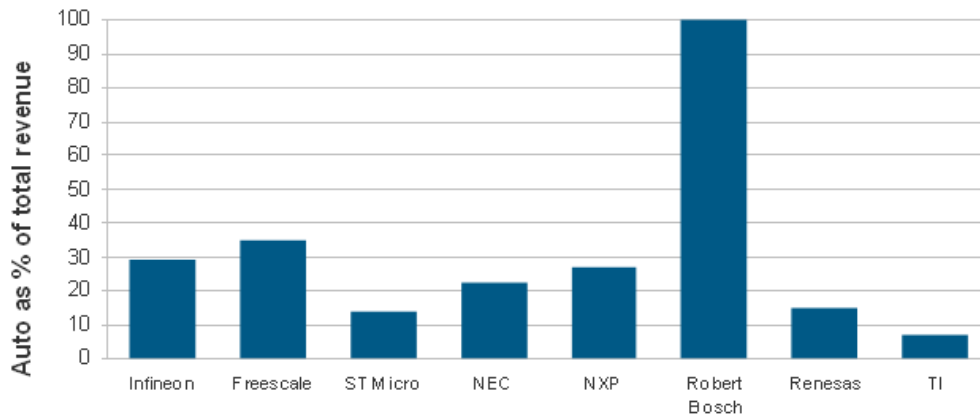
In 2008, the top eight global automotive semiconductor suppliers account for 52% of worldwide revenues, with the EU region dominated by 4 major manufacturers. These EU companies are clearly a leading force in the world market, occupying positions 1, 3, 5 and 6, with combined revenues in 2008 of nearly €4 Billion, or more than 27% of the global share of automotive semiconductors.

€Millions	Infineon	Freescale	ST Micro	NEC	NXP	Bosch	Renesas	TI	Others	Total
Headquarters	EU	USA	EU	Japan	EU	EU	Japan	USA		
Automotive	1,180	1,177	971	877	738	729	722	499	6,314	13,208
Wired Com	414	187	178	116	11	0	107	1,412	8,108	10,533
Wireless Com	1,015	1,329	2,672	282	313	0	1,183	447	27,917	35,158
Consumer	166	254	1,077	1,340	903	0	1,001	3260	27,751	35,752
Data Processing	379	81	1,030	993	346	0	1,078	999	59,716	64,622
Industrial	895	348	1,092	355	447	0	722	910	11,704	16,473
Total	4,049	3,377	7,021	3,962	2,757	729	4,814	7,526	141,511	175,746

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Figure 4.7 presents the percentage share of automotive revenues for the top eight global semiconductor manufacturers.

Figure 4.7 - Top 8 Semiconductor Suppliers: Automotive Revenues as a % of the total



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

For some of the companies listed above, the automotive industry does not represent any significant share of their annual revenues (e.g. Texas instruments 6.6%). However, the requirement to support the vehicle market with automotive-compliant semiconductors means all companies have invested significant resources in providing specialist products that typically require high tolerance levels for use in the vehicle environment.⁵⁷

For other companies, investment and revenue share from the automotive market is significant. As an example, US-based Freescale Semiconductor derived 35% of their revenues from automotive markets, while EU-based Infineon and Robert Bosch receive 30% and 100% of their revenues from their automotive markets respectively.

Table 4.7 presents a snapshot of the top EU Semiconductor suppliers with metrics for: Revenues, Profit and Loss, R&D, Employee and Automotive share in 2007 and 2008.

Table 4.7 - Automotive Industry: Top Semiconductor Suppliers – EU					
		Infineon	ST Micro	NXP	Bosch
Total Revenue-2007	€M	4,533	7,310	4,200	820
Total Revenue-2008	€M	4,049	7,021	2,757	729
Net Profit-2007: %	%	-24.5	-5.4	-12.3	Private
Net Profit-2008: %	%	-5.6	-2.0	-5.6	Private
R&D-2007: %	%	18.9	18	20.7	n/a
R&D-2008: %	%	17.5	20.8	28.6	n/a
Employees-2007	#K	29.5	52.1	37.6	n/a
Employees-2008	#K	29.1	51.8	30.1	n/a
EU Employees-2007	#K	15.6	22.3	n/a	n/a
EU Employees-2008	#K	15.4	18.1	n/a	n/a
Automotive Revenue-2007	€M	1,328	1,115	835	820
Automotive Revenue-2008	€M	1,180	971	783	729
Worldwide Ranking 2008	Rank	#1	#3	#5	#6

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

⁵⁷ Automotive semiconductor suppliers are required to conform to the AEC-Q100 standard. This typically requires semiconductors to perform under extreme stress (e.g. Extreme heat and cold etc) <http://www.aecouncil.com/>

- The EU occupies positions 1, 3, 5 and 6 globally, in terms of revenues from automotive-compliant semiconductors.
- The top 2 EU based manufacturers have significant workforces outside the EU, with 47% of Infineon's and 65% of ST Micro's employee's **non-EU** based.

Table 4.8 presents a snapshot of the top EU Semiconductor suppliers with metrics for: Revenues, Profit and Loss, R&D, Employee and Automotive share in 2007 and 2008.

Table 4.8 – Automotive Industry: Top Semiconductor Suppliers – Non-EU					
		Freescale	NEC	Renesas	TI
Total Revenue-2007	€M	3,848	4,197	5,849	8,973
Total Revenue-2008	€M	3,377	3,962	4,772	7,526
Net Profit-2007: %	%	-29.9	-1.8	Private	28.5
Net Profit-2008: %	%	-149.7	-2.7	Private	22.0
R&D-2007: %	%	21.6	21.8	Private	17.4
R&D-2008: %	%	23.0	19.1	Private	17.5
Employees-2007	#K	n/a	23.1	26.8	26
Employees-2008	#K	n/a	22.5	25.0	25.1
EU Employees-2007	#K	n/a	n/a	n/a	n/a
EU Employees-2008	#K	n/a	n/a	n/a	n/a
Automotive Revenue-2007	€M	1,457	755	896	588
Automotive Revenue-2008	€M	1,177	877	722	499
Worldwide Ranking 2008	Rank	#2	#4	#7	#8
Headquarter Country		USA	Japan	Japan	USA

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

4.2.2.4 OEM's embedded systems value estimates: two examples

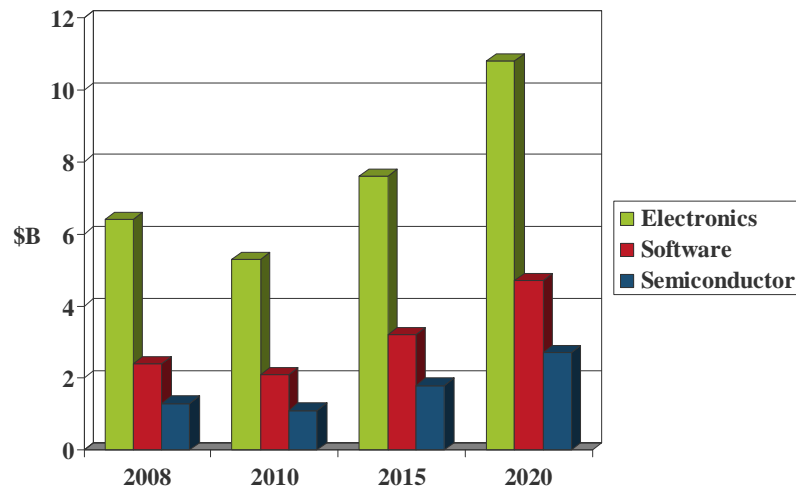
BMW embedded systems total value estimates

Luxury cars encompass the highest electronics and software value due to the specification of a large amount of infotainment, driver assist and other advanced electronics systems. This means BMW typically consumes more electronics, semiconductor and software per car than any other volume automotive manufacturer. Figure 4.8 summarizes the authors' estimates of how much electronics and semiconductor products BMW consumes per year. Software value is also estimated including purchased software and BMW's own software development effort.

BMW's forecast of growth 2008-2020 in:

- purchase of electronics equipment: from \$6.4 billion to \$10.7 billion.
- consumption of semiconductor products: from \$1.3 billion to \$2.7 billion.
- software value: from \$2.4 billion to \$4.7 billion, for a compound annual growth of 5.8%.

Figure 4.8 - BMW Automotive Embedded Systems Value Estimate



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

BMW embedded systems value/car estimates: BMW 7-Series

The BMW 7-Series is one of the most advanced cars on the market—especially in terms of ICT systems. Table 4.9 summarizes most of the infotainment and driver assist systems that are available, as well as their retail price in the USA. Similar systems are available in European countries with some variations.

Table 4.9 - BMW ICT: 7-Series			
	System	Retail Price	Value/Car
Infotainment	<ul style="list-style-type: none"> • Audio Head-Unit • Premium Audio • Navigation System • Telematics • Rear-seat Entertainment • Device interfaces • Total 	<ul style="list-style-type: none"> • \$1,500 • \$1,100 • \$2,500 • \$ 700 • \$2,200 • \$ 800 • \$8,800 	<ul style="list-style-type: none"> • Electronics: \$4,200 • Software: \$1,680 • Semiconductor: \$710
Powertrain	<ul style="list-style-type: none"> • ECUs: 10+ • MCUs: 15+ • Sensors: 35+ 	<ul style="list-style-type: none"> • 2X Electronics • \$2,100 	<ul style="list-style-type: none"> • Electronics: \$1,050 • Software: \$350 • Semiconductor: \$250
Body & Comfort	<ul style="list-style-type: none"> • ECUs: 30+ • MCUs: 35+ • Sensors: 45+ 	<ul style="list-style-type: none"> • 2X Electronics • \$900 	<ul style="list-style-type: none"> • Electronics: \$450 • Software: \$110 • Semiconductor: \$100
Safety & Chassis	<ul style="list-style-type: none"> • ECUs: 10+ • MCUs: 20+ • Sensors: 40+ 	<ul style="list-style-type: none"> • 2X Electronics • \$1,260 	<ul style="list-style-type: none"> • Electronics: \$630 • Software: \$190 • Semiconductor: \$140
Driver Assist & ADAS	<ul style="list-style-type: none"> • Adaptive cruise • Adaptive lighting • Blind spot detection • Camera park • Head-up display • Night vision • Lane departure warning • Total 	<ul style="list-style-type: none"> • \$2,400 • \$ 250 • \$ 500 • \$ 750 • \$1,300 • \$2,600 • \$ 650 • \$8,450 	<ul style="list-style-type: none"> • Electronics: \$4,450 • Software: \$1,330 • Semiconductor: \$890
Total	<ul style="list-style-type: none"> • Infotainment and ADAS • Core electronics • Total 	<ul style="list-style-type: none"> • \$ 17,250 • \$ 4,260 • \$21,510 	<ul style="list-style-type: none"> • Electronics: \$10,780 • Software: \$3,660 • Semiconductor: \$2,090

Source: Authors' own elaboration.

The authors used the retail prices for the electronics by domain to create an estimation of the software value and the semiconductor value for the current BMW 7-Series. As the core automotive systems (non-infotainment systems) have no published retail price, the electronics value of the BMW core automotive systems was assumed to be 210% of the average for the industry. The semiconductor value can be estimated from the electronics value based on iSuppli's automotive research data. The software value is the most difficult value to access, as there is little published market data available for this segment. Later sections of the report offer estimates for embedded software value.

The electronics and semiconductor values in Table 4.9 are the factory value, or the price that BMW pays its suppliers when the products are purchased. The software value includes the embedded software products that are part of the semiconductor and electronics systems, but also includes an estimate of BMW's own –in-house' software development effort.

The estimates in Table 4.9 show that the infotainment and driver assist functions have a retail price of \$17,250 if all of these options are purchased with the car. The core automotive electronics are standard with the car and are included in the car's base price; as a result the prices for these products are more difficult to estimate. A reasonable assumption is that the retail price would be twice the electronics purchase price, which adds to \$4,260 for the core automotive electronics. The total electronics value of the BMW 7-Series is \$21,510. The base price of the BMW 7-Series is around \$74,000, which gives a total purchase price of over \$91,000 with all the optional infotainment and driver assist equipment.

Based on these calculations, the electronics value is more than 23% of the purchase price (but only 6% of the purchase price if no optional equipment is purchased):

- The total electronics value of a fully equipped BMW 7-Series is \$10,780 at BMW's manufacturing cost level,
- The semiconductor sub-segment value is \$2,090,
- The software value of a BMW 7-Series is \$3,660 including purchased software and BMW's own in-house software development.

Volkswagen embedded systems total value estimates

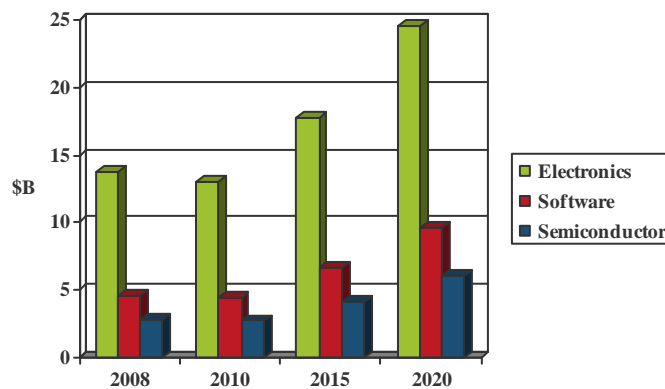
Volkswagen produces a wide range of vehicles including luxury cars such as the Audi range, through to mid-range cars such as the Golf and economy cars such as the Fox. Volkswagen's Skoda and Seat brands also sell mid-range and economy cars. Volkswagen is the third largest automotive producer in the world, and while the company is not the leader in *per-car* ICT consumption, it is among the top three consumers of electronics, semiconductor and software products due to its substantial vehicle production volumes.

Figure 4.9 summarizes the authors' estimates of Volkswagens' annual consumption of electronics and semiconductor products. Software value is also estimated including purchased software and Volkswagen's own 'in-house' software development effort.

Volkswagen's forecast of growth 2008-2020 in:

- purchase of electronics equipment: from \$13.7 billion to \$24.5 billion.
- consumption of semiconductor products: from \$2.8 billion to \$6 billion.
- software value: from \$4.6 billion to \$9.6 billion.

Figure 4.9 - Volkswagen Automotive Embedded Systems Value Estimate



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Volkswagen embedded systems value/car estimates: Volkswagen Golf

The Volkswagen Golf is the top seller in most European countries and a leader in many countries of the world. It does not have as much optional equipment if compared to BMW's 7 Series; however it is a good example of the typical car sold in developed countries.

As the estimates⁵⁸ in Table 4.10 show, infotainment and driver assist functions have a retail price of \$6,370 if all of the options are purchased with the car. The core automotive electronics are standard with the car and so are included in the car's base price. A reasonable assumption is that the retail price would be twice the electronics purchase price, which adds \$3,240 for the core automotive electronics.

Table 4.10 - Volkswagen ICT: Golf			
	System	Retail Price	Value/Car
Infotainment	<ul style="list-style-type: none"> Audio Head-Unit Premium Audio Navigation System Bluetooth HFI Device interfaces Total 	<ul style="list-style-type: none"> \$ 475 \$ 325 \$1,750 \$ 700 \$ 400 \$3,650 	<ul style="list-style-type: none"> Electronics: \$1,825 Software: \$730 Semiconductor: \$275
Powertrain	<ul style="list-style-type: none"> ECUs: 5+ MCUs: 7+ Sensors: 25+ 	<ul style="list-style-type: none"> 2X Electronics \$1,600 	<ul style="list-style-type: none"> Electronics: \$800 Software: \$270 Semiconductor: \$190
Body and Comfort	<ul style="list-style-type: none"> ECUs: 15+ MCUs: 20+ Sensors: 30+ 	<ul style="list-style-type: none"> 2X Electronics \$720 	<ul style="list-style-type: none"> Electronics: \$360 Software: \$90 Semiconductor: \$80
Safety and Chassis	<ul style="list-style-type: none"> ECUs: 5+ MCUs: 7+ Sensors: 20+ 	<ul style="list-style-type: none"> 2X Electronics \$920 	<ul style="list-style-type: none"> Electronics: \$460 Software: \$140 Semiconductor: \$100
Driver Assist & ADAS	<ul style="list-style-type: none"> Ultrasonic park Camera park Autonomous Park Total 	<ul style="list-style-type: none"> \$ 750 \$ 900 \$1,070 \$2,720 	<ul style="list-style-type: none"> Electronics: \$1,510 Software: \$485 Semiconductor: \$300
Total	<ul style="list-style-type: none"> Infotainment & ADAS Core electronics Total 	<ul style="list-style-type: none"> \$6,370 \$3,240 \$9,610 	<ul style="list-style-type: none"> Electronics: \$4,955 Software: \$1,715 Semiconductor: \$945

Source: Authors' own elaboration.

⁵⁸ The methodology used to create the Volkswagen Golf ICT table is explained in the BMW 7-Series ICT **section**.

The total electronics value of the VW Golf is \$9,610. The base price of the VW Golf is around \$23,000, which gives a total purchase price of over \$29,000 with all the optional infotainment and driver assist equipment. The electronics value is then over 33% of the purchase price, but only 14% if no optional equipment is purchased.

4.2.3 Automotive embedded hardware current and future competitiveness

The assessment of the competitiveness of each segment presented below is based on data time series analysis, on experts' opinions gathered during interviews of major stakeholders, as well as factual aspects such as the observation of the actors in the value chain or their respective positioning in terms of technologies.

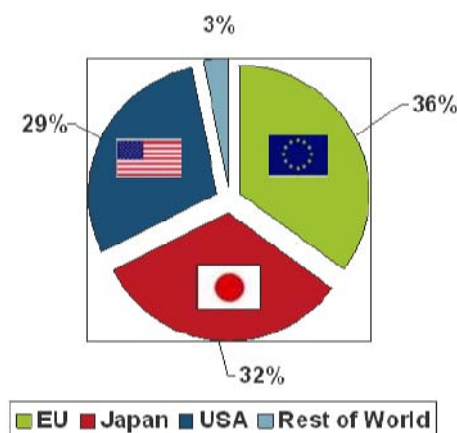
4.2.3.1 Automotive semiconductors

In 2008, the European region was the largest supplier of semiconductors to the global automotive market. Based on quarterly survey data,⁵⁹ the EU region supplied 36% of the global total (iSuppli estimate) as shown in Figure 4.10. Japan was in second place with 32% market share and the USA followed with 29% market share. The rest of the world represented just 3% of the global total in 2008 (mainly Korea).

In summary, Europe has a strong position in automotive semiconductors and is expected to continue to lead in supplying the worldwide automotive manufacturers. The lead is due to three main factors:

- Europe has three top automotive semiconductor suppliers—ST Micro, NXP and Infineon and many smaller suppliers in specific market segments.
- Luxury automotive manufacturers lead in introducing new technology and Europe has three of the five leading luxury automotive manufacturers, BMW, Audi and Mercedes-Benz. The EU semiconductor manufacturers have excellent relations with the EU luxury brands and benefit from being involved with new automotive technology development. EU also has multiple high-volume automotive manufacturers and again the semiconductor companies benefit as the advanced technologies are transferred from luxury cars to the volume automotive brands.
- Europe also has two top Tier 1 suppliers, Bosch and Continental, and several other major embedded system suppliers that are major semiconductor customers. These Tier 1 companies are focused on EU automotive OEMs, but are also strong suppliers to automotive OEMs in USA, China and Japan.

Figure 4.10 - Automotive Semiconductors Revenue splits (Worldwide – 2008)



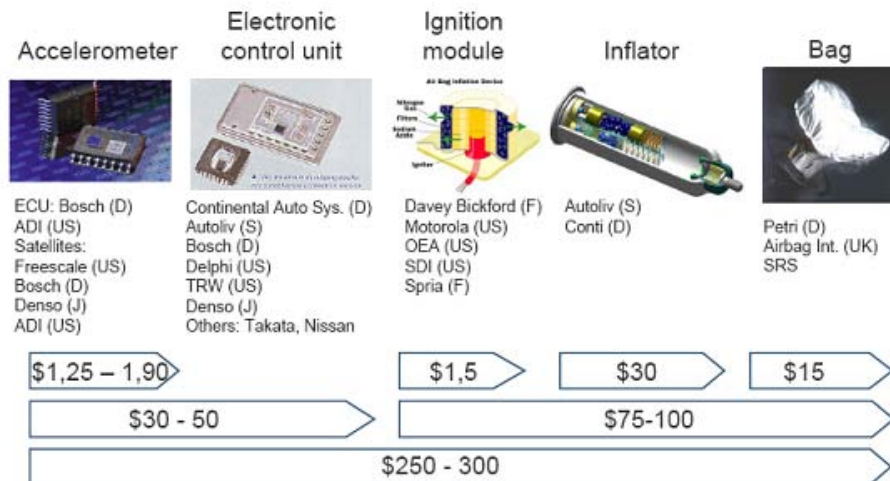
Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

⁵⁹ iSuppli sources and databases (See Appendix 1 for details).

4.2.3.2 Airbags

Air bag systems are dependent on microcomputers for their control and to make a decision on when to inflate. A basic airbag system consists of the following hardware: acceleration sensor, ignition module, inflator, airbag and electronic control unit as seen in Figure 4.11. Of the total \$300 for a complete system, the electronic control unit or ECU is worth about 10-20% or \$30-50 depending on the complexity of its tasks.

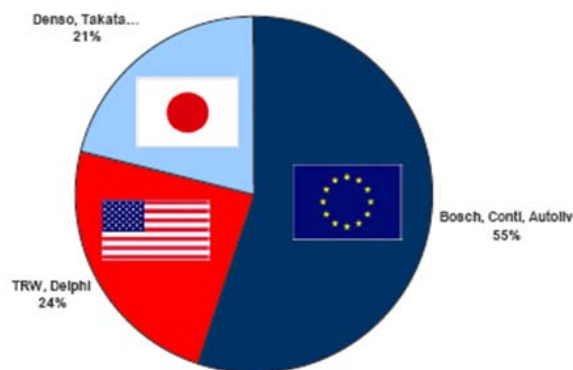
Figure 4.11 - Airbag Hardware Supply Chain



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

The main benefactors of the airbag application are European Tier 1 suppliers and their associated supply chain, which account for around 55% of the market (iSuppli estimate) as shown in Figure 4.12. Continental, Autoliv and Bosch are the leading suppliers of airbag ECUs. Software suppliers, mostly in Europe, provide the intelligence to manage these functions.

Figure 4.12 - Tier 1 Suppliers Market Shares- Airbag (2008, World)

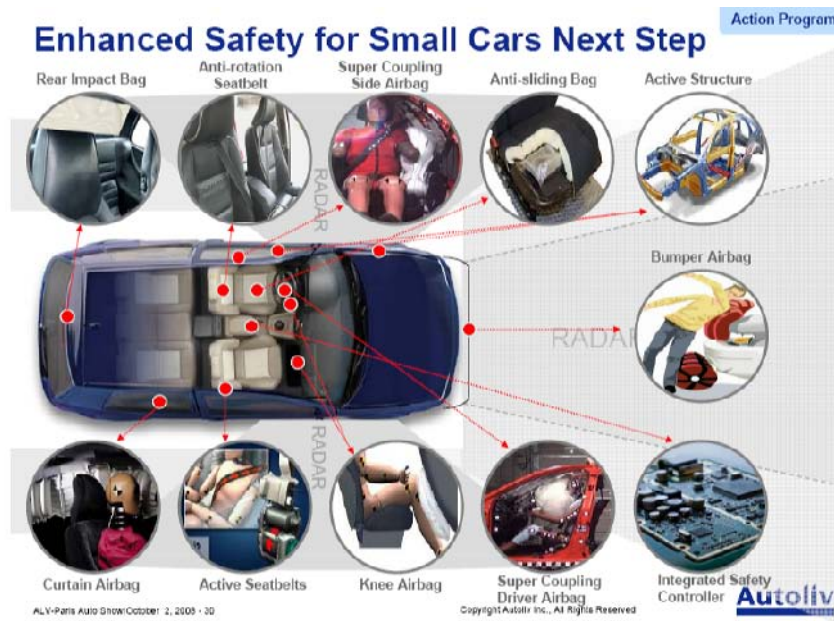


Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Leading EU airbag manufacturers forecast that as new kinds of airbags and advanced safety developments were brought to market, many of the newly introduced features would fuse together, creating a combination of passive and active protection for the driver (e.g. seat belt restraint systems will be combined with active safety systems). Managing all of this functionality - especially the fusion of active and passive systems will increase software requirements considerably.

As the airbag system increases in sophistication, it will become a “hub” for additional safety features. Figure 4.13, from Autoliv, illustrates their vision of the next step in airbag implementation in the vehicle.

Figure 4.13 - Autoliv: Enhanced Safety for Small Cars



Source: Courtesy of Autoliv.

Currently, the active and passive safety systems have individual sensors and separate electronic control units (ECUs). These ECUs are typically separate stability control and airbag ‘black-boxes’. Both systems are typically located in the middle of the vehicle; close to the vehicle’s centre of gravity and contain not only back-up sensors but also redundant/back-up microprocessors, circuit boards, power supplies and housings, etc.

As system functions fuse together, many redundant components and back-up systems can be removed which will reduce material costs. In addition, vehicle OEMs can reduce manufacturing costs for wiring and installation as a result of less complicated ‘single-box’ architectures created by systems integration. EU Tier 1 suppliers are currently leading these advancements, with companies such as Continental developing integrated systems, while Bosch has un-veiled its ABPlus airbag units.

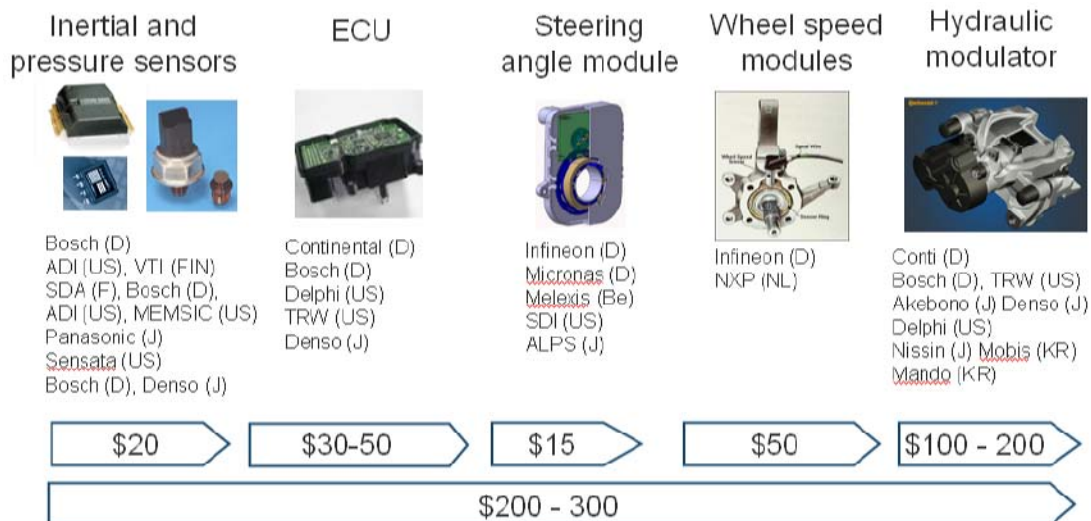
Ultimately the airbag will morph into an integrated safety domain controller, perhaps in as little as 4-5 years, particularly in high end luxury vehicles such as the 5 and 7 series from BMW. Bosch and Autoliv have already participated in the first steps of this integration; with airbags combined with ESC sensors.

In summary, Europe leads the airbag ECU market with about 55% market share. The European software companies that are shaping the AUTOSAR standards have a significant position in Europe and alliances with key semiconductor suppliers such as Infineon and Bosch. Airbag companies compete in developing countries by supplying systems compliant to local conditions, as well as full hardware with all interfaces and processors, etc. This modular design allows local Tier 1 or OEM to write their own application layer to tailor the functionality to the local requirements.

4.2.3.3 Electronic Stability Control System (ESC)

The Electronic Stability Control (ESC) system is basically an Anti-lock Braking system (ABS) that takes inputs from wheel speed sensors and pressure sensors, as well as sensors that detect vehicle behaviour (acceleration sensor and turn rate or yaw). These inputs are compared to the drivers real driving intentions, based on steering wheel angle. The system then modifies the braking at each wheel using precise pressure sensors, which in turn feedback the effect of the vehicles track, based on inputs calculated by the software algorithms in the ESC ECU. Figure 4.14 presents the ESC supply chain:

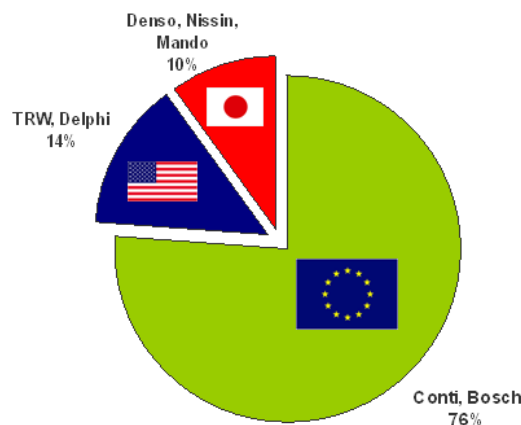
Figure 4.14 - ESC Supply Chain



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

In 2008 Europe had about 75% of the world market for ESC systems and ECUs (iSuppli estimate) with the two top Tier 1 suppliers, Bosch and Continental. Figure 4.15 presents the market share splits for suppliers of ESC systems worldwide.

Figure 4.15 - ESC Tier 1 Supplier: Regional Market Shares (2008, World)



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

The value of a typical ESC-ECU is \$30-50. The breakout of the components of an ESC ECU looks similar to the airbag, but the ESC system is typically connected to a higher number of sensors than a standard airbag unit, which can add considerably to overall cost of the total system. Tier 1 suppliers and technology leading OEMs such as BMW, develop their own proprietary software algorithms in order to distinguish themselves from their competitors. Software is

therefore a key element in this differentiation and in common with airbag development will account for up to 70% of the cost of the overall ECU development.

In common with airbag development, the EU is in a leading position worldwide in terms of system development. This is again partly stimulated by the AUTOSAR initiative. Leading companies are Bosch and Continental, each with over one third of the market.

The companies that work on ECU software development, modelling and testing include Elektrobit, Vector, and ETAS, among others. These European companies benefit from the strong position of European Tier ones and especially their involvement in AUTOSAR.

In summary, Europe lead the ESC ECU market with over 70% market share and is expected to maintain their advantage even if the market share may decline in the coming years. It shows the advantage of pioneering a market, which usually results in leadership when production volume increases and eventually becomes a volume market. The ESC market is rapidly growing as both the USA and Europe have regulation to make ESC a compulsory requirement by 2012. Other regions are likely to follow due to improved safety. The European ECS suppliers are expected to be leaders as the deployment moves to other regions even if they don't get the dominant position they have in Europe and USA.

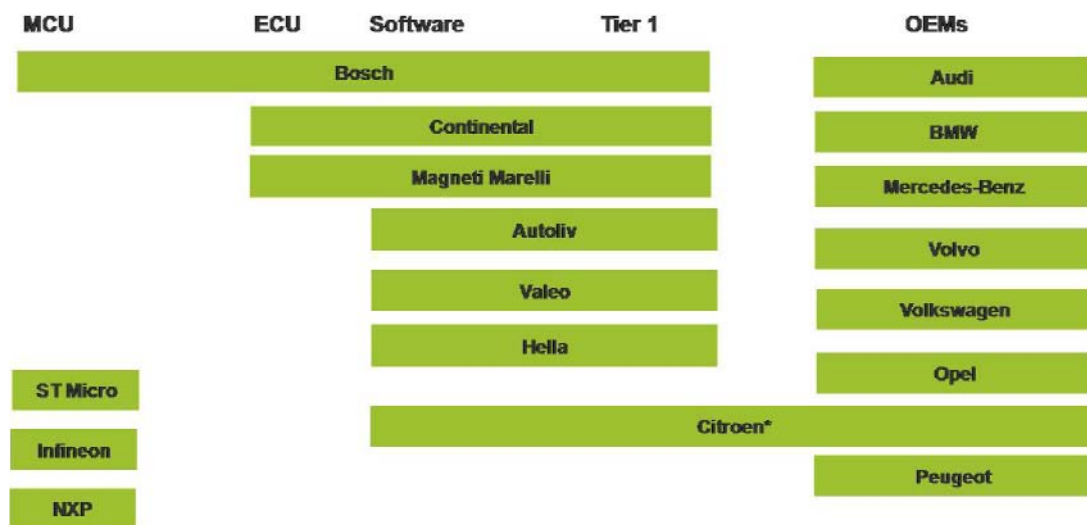
4.2.3.4 ADAS

Advanced Driver Assistance Systems (ADAS) comprise a wide variety of vehicle-based solutions designed to aid the driver in operating the motor vehicle. ADAS solutions are heavily dependent on sensors that constantly monitor the vehicle's surroundings. While ADAS is dependent on information from various sensors mounted in or around the vehicle, processing that information quickly and accurately is most important. ADAS solutions constantly gather information from vehicle-based sensors, processes the raw data in an ECU and function-specific logic, and then provide an output for the driver in the form of an audible or visual warning or suggestion or autonomously actuates vehicle systems to correct or prevent behaviour.

In the area of ADAS development, more systems are being purposed for multiple operations. As an example, a camera mounted on the windscreen can be used in image recognition as well as enabling lane departure warning, pre-collision warning, adaptive lighting or night vision. This 'clustering' of features surrounding a variation of one system is called "sensor fusion".

Sensor fusion is important to the embedded software industry because one ADAS system can utilize multiple software programmes to create different features for vehicle OEMs. This means that OEMs can re-purpose one hardware system but are able to offer multiple ADAS options to their customers, all due to embedded software. This software is generally written by the Tier 1 Company that is supplying the ADAS system.

Figure 4.16 - European ADAS Supply Chain



*Citroen has a proprietary lane departure warning system that is supplied by Valeo.

Bosch is #1 in ultrasonic parking.

All Tier 1s develop their own software for advanced driver assist systems. Bosch, Continental, and Magneti also produce ECUs.

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Figure 4.16 shows the European ADAS supply chain. The European companies were pioneers in developing ADAS and had to develop the application software along with the hardware. Since the European Tier 1 companies supply their own software for their own systems, they offer complete solutions that are proven in the market and can be deployed in any region.

ADAS has been present in the automotive segment for at least a decade in the form of anti-lock brakes and electronic stability control. Ultrasonic park assist has been available since the early 1990s with Bosch recently announcing the production of its 100 millionth ultrasonic range sensor. Park assist ADAS is one of the few applications that has entered a mature phase of its product lifespan.

Most other ADAS functions, based on radar or vision, are still in a growth phase after being introduced to market within the last five years. Production costs are reducing for radar sensors and their versatility is nearly unparalleled. Similarly, vision-based ADAS will experience growth due to both advances in hardware technology as well as innovation in image-recognition software. Both radar- and vision-based ADAS will experience significant growth in availability as prices and technology improve and they are offered on a greater number of vehicles and by a greater number of OEMs. Autonomy within ADAS will also expand, particularly with regards to safety applications such as collision warning systems.

In summary, the European companies have a strong position in the various ADAS product segments and are likely to continue in this leading position. The reasons are similar to previous market dynamics—market development pioneers, need from the European luxury automotive manufacturers to get products started and moving to volume automotive manufacturers as each of the ADAS segments become affordable. This trend has at least a decade to play out as only park assist is in the volume stage while the other ADAS segments will follow. Hence the European ADAS suppliers have strong future growth opportunities.

4.2.3.5 A summary: European strengths and weaknesses in automotive hardware

The European automotive hardware industry has been in a leadership position for several decades and is likely to retain a strong market position. However, the automotive embedded hardware market is becoming much more competitive as new players are entering automotive electronics.

The hardware competition will intensify for two main reasons—regional shift in auto buying and emerging hardware platform standards.

Automotive sales growth is primarily happening outside Europe and North America with Asia seeing the most growth. Regional automotive production always follows sales when the volumes are high enough and this is well on its way in China, India and other countries. This creates new Asian electronics suppliers that are increasingly competing with European suppliers—first in Asia including European automotive OEMs in Asia, and eventually in Europe. This has already happened to some degree with electronics suppliers supporting the Japanese and Korean automotive manufacturers.

The emerging hardware platform standards will make it easier for non-European electronics companies to compete in Europe in a few years. Since most of the embedded electronics hardware are small enough for economical shipping between continents, some of the hardware production is likely to move to low-cost regions in Asia or other areas. The impact will vary between the various embedded hardware segments.

- The component segments that includes semiconductor chips and sensors, is used to compete on a worldwide basis. The automotive component sector will continue to do well as explained in earlier sections.
- The core automotive ECU hardware segment is strong in Europe—especially for internal combustion engines and the EU supplier will likely retain its leadership in the next decade. However, the emerging electric vehicle ECUs is another story and is wide open in terms which companies and regions will become leaders. **Currently the EU EV industry is behind and needs significant investments to catch up and even higher investment for future leadership.**
- The ADAS hardware ECUs is expected to remain a leadership area for the European suppliers. Selected safety-related legislation such as the recent Intelligent Transport System (ITS) Directive,⁶⁰ can strengthen the EU position. Also, the future implementation of eCall⁶¹ could be supportive to European technological and industrial developments. ADAS combination with V2X systems will be even better for the European hardware suppliers.
- The Infotainment ECU hardware has been a strong segment for European-based suppliers, but is likely to become a mixed bag. The infotainment ECUs are moving towards hardware platform standards such as the GENIVI platform, which is under development. The infotainment systems have strong connection to the PC and consumer electronics industry where Europe is weak compared to the core automotive ECUs. The growing importance of Smartphone platforms is now led by the Apple iPhone and Google's Android platform. Unfortunately, the early Smartphone leader, Nokia, has lost its influence, even though it remains the volume leader and may retain this for a few years.

4.3 Automotive Embedded Software

4.3.1 Embedded software value chain

4.3.1.1 An overview

The embedded software industry spans all of the industries that use computer controlled products—ranging from toys and phones to elevators and industrial control equipment.

⁶⁰ ITS Directive 2010/40/EU, July 2010

⁶¹ The ITS Directive refers to eCall but does not mandate it. Only when all the specifications for an EU eCall will be adopted, the Commission will be able to issue legislation that will impose compliance with the specification for any future voluntary new public eCall system in the EU.

Automotive is a growing segment of the embedded software industry, particularly as the number and complexity of embedded computers per car continues to increase. Automotive embedded software is used at every hardware level—from MCUs and sensor interfaces to every ECU and networks of ECUs. Each level adds additional embedded software.

The embedded software industry consists of many small and mostly regional companies. Most automotive embedded software companies also participate in embedded software segments outside the automotive industry. Nearly all embedded software companies are privately held and only a few are public-owned. There are currently no ‘dominant’ embedded software companies.

Table 4.11 present some of the key characteristics of the embedded software industry. The industry is characterized by having relatively few, large customers, with only the automotive manufacturers and Tier 1 companies buying software in large volumes. These customers are conservative and demanding, which makes for a loyal customer as product cycles are very long. These characteristics also make it hard to enter the automotive embedded software market.

Embedded software development has the image of being an ‘unglamorous industry’ with most software vendors unknown outside the automotive industry. There are no famous embedded software programmers like there are in the PC or Internet software. However their contribution to the automotive industry will become increasingly significant as the percentage of ICT per vehicle increases in the future.

Table 4.11 - Embedded Software Industry Characteristics		
	Key Information	Other Information
Industry Characteristics	<ul style="list-style-type: none"> • Unglamorous business • Few potential customers • Defensible business • Hard to enter business 	<ul style="list-style-type: none"> • Little publicity and fame • Car manufacturers and Tier 1-3 • Loyal customers; high switching cost • Long initial sales cycle
Business Characteristics	<ul style="list-style-type: none"> • Primarily small companies • Mostly private companies • Mostly regional car customers • Participates in standards: OSEK, AUTOSAR, GENIVI 	<ul style="list-style-type: none"> • 30% to 70% from car software • Minimal or no financial data released • Supported on a worldwide basis • To get early access to information • Expands their product portfolio
Business Focus	<ul style="list-style-type: none"> • Multiple business segments: Automotive and non-automotive • Driver software and software tools • Key auto OEMs and Tier 1s 	<ul style="list-style-type: none"> • Embedded software focus • 2+ embedded software segments • SW tools often a second segment • First Germany, then EU and so on
Business Growth	<ul style="list-style-type: none"> • Steady growth is the norm • Growth follows automotive R&D cycle • New standards expand market 	<ul style="list-style-type: none"> • Rapid growth is rare • R&D continues in bad times • More customers and more competition

Source: Authors' own elaboration.

Most embedded software companies are relatively small with annual revenues less than €150Million. These companies are typically highly specialized, often with the specialized skills needed to develop many different ECU requirements. However, the wider deployment of AUTOSAR is likely to change this characteristic, as it will be easier for companies to serve multiple ECU types with similar standard-based software.

Figure 4.17 presents again the supply chain, with a focus on those embedded software activities and companies.

Pure Software development companies are at the bottom of the table. These companies provide operating systems, driver software and software design tools, but typically do not develop application software. The software products these companies develop are used by all suppliers at

the higher levels in the table; from semiconductor manufacturers to Tier 1-3 suppliers as well as car manufacturers.

Embedded software products are also made by all other levels in the system hierarchy. Silicon suppliers may develop driver software. Tier 1-3 suppliers and vehicle OEMs may develop driver software, operating system and application software.

The complexity of this supply chain makes it very difficult to estimate the size of the automotive embedded software industry, particularly as there are a large number of companies that provide 'niche' embedded software services at different levels, as well as companies that provide embedded software services to multiple sectors

Figure 4.17 - Embedded Software Industry Structure

	<u>Software Products</u>	<u>Company Examples</u>			<u>Company Focus</u>
Vehicle OEMs	<ul style="list-style-type: none"> • SW Integration • Application SW • Operating System 	BMW	Daimler	Fiat	<ul style="list-style-type: none"> • Auto production • System design • System integration
Tier 1 suppliers	<ul style="list-style-type: none"> • Application SW • Operating System • Driver Software 	Bosch	Continental	Magneti	<ul style="list-style-type: none"> • Supplier to OEMs • Sub-system design • ECU production
Tier 2-3 suppliers	<ul style="list-style-type: none"> • Application SW • Operating System • Driver Software 	TRW	JCI	Preh	<ul style="list-style-type: none"> • Supplier to Tier 1 • ECU design • ECU production
Silicon Suppliers	<ul style="list-style-type: none"> • Driver Software • SW design tools 	ST Micro	Infineon	NXP	<ul style="list-style-type: none"> • Supplier to Tier 1-3 • Chip production
Software Suppliers	<ul style="list-style-type: none"> • Operating System • Driver Software • SW design tools 	Elektrobit	Vector	dSpace	<ul style="list-style-type: none"> • Supplier: All levels • Software products

Source: Authors' own elaboration.

4.3.1.2 Embedded software companies: core automotive software

Table 4.12 lists over 20 companies that supply embedded software to support core (non-infotainment) automotive ICT products. They range from Tier 1 suppliers such as Bosch and Continental to companies that primarily supply software development tools such as dSpace and MathWorks. Many of the companies also provide embedded software to industries other than automotive. The middle column Table 4.12 lists ownership status: Public, Private or Subsidiary.

Table 4.12 - Embedded Software Companies: Core (Non-Infotainment)		
Company, HQ		Other Information
<ul style="list-style-type: none"> • Artisan Software Tools, USA • Axe, Japan • Bosch, Germany • Continental, Germany • dSpace, Germany • Elektrobit, Finland 	<ul style="list-style-type: none"> • PVT • PVT • PVT • Pub • PVT • Pub 	<ul style="list-style-type: none"> • Autosar software, software tools • Autosar, Jaspar, embedded software • Autosar OS & OSEK OS, applications • Applications • Autosar SW development tools; 800 people • Autosar OS, Driver SW & Design Tools; 2008: €172M
<ul style="list-style-type: none"> • ESG Automotive, Germany • Etas, Germany • Geensys, France • Gigatronik, Germany • IAV, Germany (VW & Conti) 	<ul style="list-style-type: none"> • PVT • PVT • PVT • PVT • Sub 	<ul style="list-style-type: none"> • Embedded system and software consulting • Autosar and ECU software, hardware, 680 people • Autosar software and development tools • Autosar and software tools; 400 people; €36M • Auto systems and SW; 3,850 people; €380M
<ul style="list-style-type: none"> • Ihr, Germany • Inchron, Germany • Intecs, Italy • MathWorks, USA • MB Tech, Germany • Mentor Graphics, USA • Softing, Germany 	<ul style="list-style-type: none"> • PVT • PVT • PVT • PVT • Sub • Pub • Pub 	<ul style="list-style-type: none"> • Software and bus emulation tools • Autosar and embedded software development tools • Osek, Autosar and embedded software tools; 400 people • Embedded software tools; 2,000+ people • Osek, Autosar, embedded SW; 2,700 people, €360M • Autosar and other software tools; 4,400 people, \$800M • Autosar OS; 235 people; €33M
<ul style="list-style-type: none"> • Symtavision, Germany • Tata Ellexi, India • TTech, Austria • Vector, Germany 	<ul style="list-style-type: none"> • PVT • Sub • PVT • PVT 	<ul style="list-style-type: none"> • ECU software design tools • Autosar and development software • Autosar and OSEK OS; '06 Rev: €100M+ • Autosar software and tools

Source: Authors' own elaboration.

Table 4.12 shows many of the key automotive embedded software companies. For most of these companies, automotive software is just one of their business segments.

The AUTOSAR standard will make it easier to enter the automotive software market. This means there will new market entrants in the embedded software industry—including Asian software companies. A large percentage of embedded software companies are already offering AUTOSAR-compatible software, development tools, testing software and other productivity software.

An example: Elektrobit

Table 4.13 presents a typical embedded software company—Elektrobit.

Elektrobit is a publically owned company, based in Finland, that serves two main software segments; wireless communication and automotive. The automotive segment accounted for 37% of 2008 revenue at €63M. Nearly 67% of its revenue came from Europe in 2008. Elektrobit spent over 21% of its revenue on R&D in 2008.⁶²

⁶² A ratio which declined substantially in 1H 2009 for obvious reasons of crisis in the automotive sector.

Table 4.13 - Embedded Software Example: Elektrobit		
	Key Information	Other Information
Product Focus	<ul style="list-style-type: none"> Automotive software Wireless industry software 	<ul style="list-style-type: none"> Autosar focus; Supports Windows Auto SW tools: LTE, WiMax; MID ref design
Revenue: €M	<ul style="list-style-type: none"> 2008: 172.3 (+19.4%) 1H'09: 80.2 (-9.2%) 	<ul style="list-style-type: none"> Automotive Software: 63.3 (+20.3%) Automotive Software: 29.9 (+4.1%)
Regional Revenue	<ul style="list-style-type: none"> 2008 EU: 66.7% Americas: 28.6%; Asia: 4.7% 	<ul style="list-style-type: none"> 2007 EU: 70.4% 2007: Americas: 23.1%; Asia: 6.6%
R&D €M	<ul style="list-style-type: none"> 2008: 37.9 (38.3 in 2007) 	<ul style="list-style-type: none"> 1H'09: 6.9 (21.6 in 1H08); 2H08 decline
Automotive Software	<ul style="list-style-type: none"> EB Treos AutoCore EB Treos Designer EB Treos Studio EB Treos Inspector EB Treos Busmirror EB Assist ADTF 	<ul style="list-style-type: none"> Production-ready Autosar system software System/network design tool (FlexRay) Software design & coding Network analysis: CAN, LIN, FlexRay FlexRay simulation Driver assist software development
Automotive SW Customers	<ul style="list-style-type: none"> EU: BMW, Audi EU: Infineon, ST Micro Japan: Fujitsu, NEC EL USA: Freescale China 	<ul style="list-style-type: none"> Audi joint-venture: Infotainment SW Supports Infineon TriCore MCU Jaspar members use AutoCore Supports Freescale PowerPC MCU Unknown customers

Source: Authors' own elaboration.

Elektrobit has multiple products that are focused on Autosar software design, including development, simulation and network analysis. The company also has a focus on the development of the major automotive BUS systems such as CAN, LIN and FlexRay. Its main customers are in Europe and include BMW, Audi, Infineon and ST Micro. It is interesting to note that Elektrobit has also picked up customers from the Jaspar alliance, the Japanese version of AUTOSAR.

4.3.1.3 Embedded software companies: infotainment automotive software

Infotainment software has considerable commonality with PC and consumer electronics software. Most communication software has roots in the PC industry or mobile phone industry. Most music software is based on programmes used on PCs and digital music player such as MP3 and iPod players. Emerging software for telematics services and Internet content will also come from the PC and mobile phone industries.

The result of the use of standardization borrowed from consumer electronics, means that European companies are not as strong in embedded infotainment software as they are in the AUTOSAR-based core segments. The USA is probably strongest in infotainment software currently, but European and Asian companies are also competing well—depending on the segment. Many Indian software companies are entering the infotainment software market and a few are members of Genivi (and AUTOSAR).

Table 4.14 shows embedded software companies that provide infotainment software to the automotive industry. The middle column lists ownership status: Public, Private or Subsidiary.

Table 4.14 - Embedded Software Companies: Infotainment		
Company, HQ		Other Information
<ul style="list-style-type: none"> • Allgo Embedded, India • eSOL, Japan • Euros Embedded, Germany • Fujisoft, Japan • Gaio Technology, Japan • ICT, Netherlands 	<ul style="list-style-type: none"> • PVT • PVT • PVT • Pub • PVT • Pub 	<ul style="list-style-type: none"> • Embedded infotainment software; Genivi • Operating system, middleware, driver software • Embedded OS and software • Infotainment, ECU and embedded SW; 2008: \$265M • Embedded, ECU and software tools • Infotainment and embedded SW; 900 people; €97M
<ul style="list-style-type: none"> • KPIT Cummins, India • Larsen & Toubro Emsys, India • Microsoft, USA • MontaVista, USA • OpenSynergy, Germany 	<ul style="list-style-type: none"> • Pub • Sub • Pub • PVT • PVT 	<ul style="list-style-type: none"> • Embedded software; Genivi and Autosar • Infotainment, Autosar, embedded systems • Windows (several automotive versions) • Linux OS; Genivi member • Embedded OS; Genivi and Autosar member
<ul style="list-style-type: none"> • Patni, India • QNX, Canada (Sub Harman) • Scaleo Chip, France • SVOX, Switzerland • Tieto, Finland • TomTom, Netherlands • Wind River/Intel, USA 	<ul style="list-style-type: none"> • Pub • Sub • PVT • PVT • Pub • Pub • Pub 	<ul style="list-style-type: none"> • Infotainment and embedded SW; \$719M • OS and embedded software tools • 32-bit MCU and embedded software; Linux, WinCE • Embedded speech software • Embedded infotainment software; Genivi • Navigation software • Linux and own OS/system software

Source: Authors' own elaboration.

Table 4.14 shows some of the key infotainment software companies. For most of these companies, the automotive segment is a small part of their business. The Genivi standard will make it easier to enter the automotive infotainment software market. The Genivi consortium is eager to get many more software participants because then more application programmes will become available and Genivi will become a stronger competitor versus other infotainment software platforms.

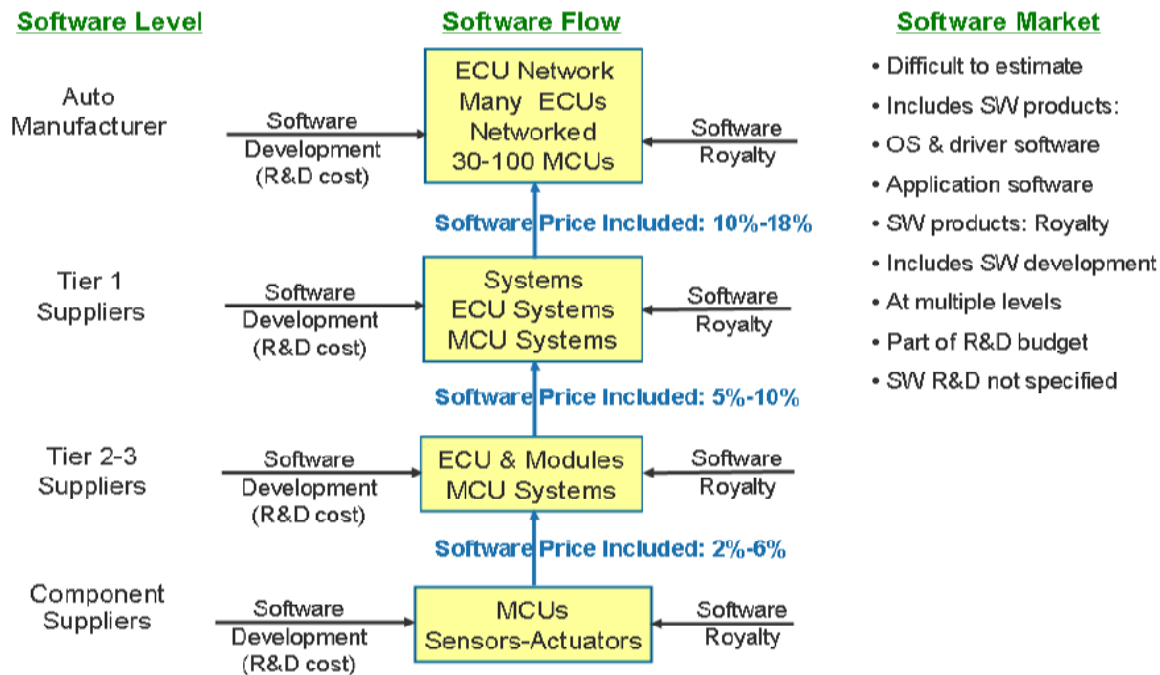
4.3.2 Automotive embedded software value

4.3.2.1 Setting the scene

As explained earlier, the size of the automotive embedded software market is very difficult to estimate due to the complexity of the product flows and the mixture of products at multiple levels, as well as the 'in-house' software development value by the car manufacturers.

The next figure shows that there are two elements of software at every level in the product flow. The first element is the software that is incorporated in the product, but from another company, which is normally paid a software royalty for each copy used. The second element is the software development effort that is done to complete the product functionality. This development is usually application software, but could also be system software (such as specialized driver software).

Figure 4.18 - Software Market Value Flow



This research project confirms that there is less than minimal data publicly available on software development investments, as none of the car manufacturers or Tier 1-3 companies provide any significant information on their software development expenditures. Figure 4.18 presents the authors' best estimate of software value at the various levels as the products move up the value chain. The estimate includes a broad range of values, as different products have varied amount of software—depending mostly on the ECU domains deployed in the system.

4.3.2.2 'In-house' OEM software value estimates⁶³

The embedded software value cannot be estimated from a product sale since the software is included with a system product. Instead the software value was estimated as portion of the electronics value plus the embedded software development that are done by the car manufacturers.

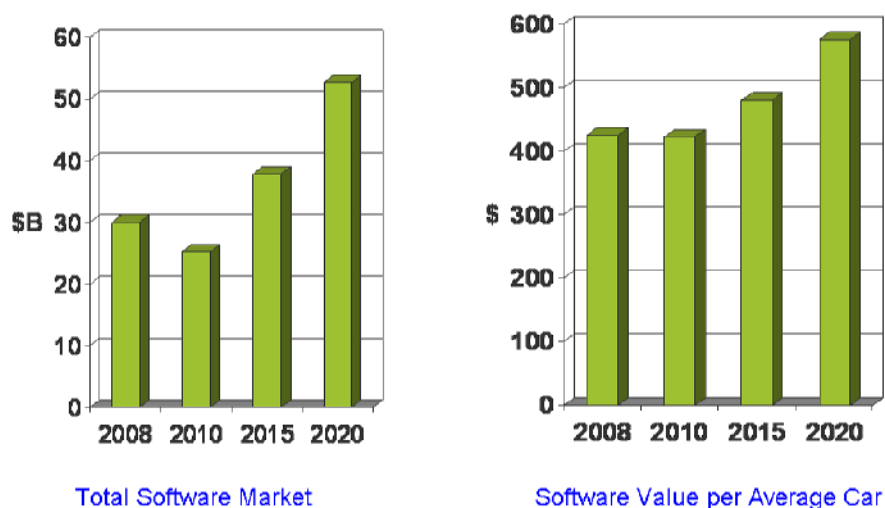
The biggest uncertainty when attempting to estimate software value is at the top level or 'in-house' level. This is the 'in-house' software R&D that is done by the car manufacturers. The car manufacturers' R&D expenses were over \$80 billion in 2008, with the European, Japanese and USA-based OEMs accounting for over 75% of the total. The authors' best estimate is that 15-20% of the R&D expenditure is for software development. This gives a software value of \$12-16 billion for 2008. Our 2008 estimate for total embedded software is \$30 billion, which would mean the car manufacturers account for about half of the total.

Figure 4.19 shows estimates and forecasts for worldwide embedded software market from 2008 to 2020. The worldwide embedded software value is estimated by the authors to grow from \$30 billion in 2008 to over \$52 billion in 2020, sustaining a compound annual growth rate of 4.7%.

⁶³ The authors acknowledge explicitly that the embedded software value estimates in this report are not as accurate as those offered for electronics and semiconductors. Unfortunately, there is simply not enough publically available data available to make accurate embedded software estimates.

Figure 4.19 also shows estimates and forecasts for the average software value per car. The average software value per car is forecasted to increase from \$425 in 2008 to \$575 in 2020, sustaining a compound annual growth rate of 1.6%. This slow growth is probably a conservative forecast. The total market values were divided by the (estimated) yearly production volume to get the per-car values.

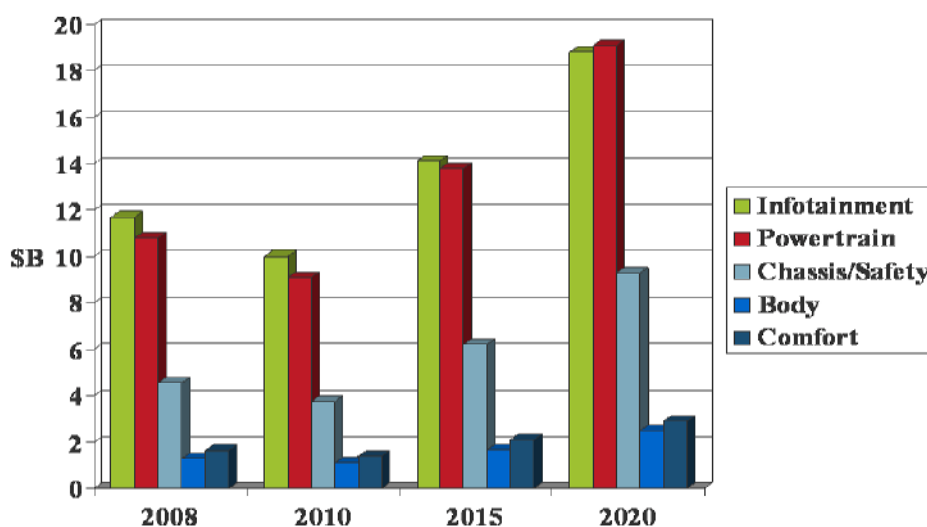
Figure 4.19 - Worldwide Automotive Software Value by Domain



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

In the light of the assumptions above, the authors has created embedded software estimates by ECU domain as shown in Figure 4.20.

Figure 4.20 - Worldwide Automotive Software Value by Domain



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

As from today, the Infotainment domain is currently the largest automotive embedded software segment and is forecasted to grow from \$11.7 billion in 2008 to \$18.8 billion in 2020.

Powertrain embedded software is projected to become the largest segment by 2020 at \$19.1 billion, up from \$10.8 billion in 2008. The reason Powertrain is expected to grow more than

Infotainment is due to increasingly stringent emissions regulation. To meet these requirements, systems will require more computing power and sensor data as well as software to implement new and improved algorithms. Electric cars will also need increasing computing power to manage the batteries, energy recovery from brakes and other innovative technologies.

The Chassis, Safety and ADAS areas are the third largest segment and the embedded software value would grow from \$4.5 billion in 2008 to \$9.3 billion in 2020.

4.3.3 Automotive embedded software current and future competitiveness

4.3.3.1 Current European leadership

As illustrated several times above, Europe is currently very competitive in embedded automotive software and is the leader in many segments. Table 4.15 summarizes the EU competitiveness for embedded software.

Table 4.15 - EU Embedded Software Competitiveness		
	Key Information	Comments
Software Standards Activities	<ul style="list-style-type: none"> • EU Autosar leadership • Infotainment: participation • EU will make/break standards 	<ul style="list-style-type: none"> • For core automotive software • Mostly USA leadership • EU luxury OEMs play key role
Operating System Software	<ul style="list-style-type: none"> • EU has lead OSEK software • EU leads Autosar OS • EU Linux participation 	<ul style="list-style-type: none"> • Importance will fade by 2015 • EU and Indian suppliers, more later • USA leads Windows and QNX
Driver software	<ul style="list-style-type: none"> • EU has lead OSEK driver SW • EU leads Autosar driver SW 	<ul style="list-style-type: none"> • Importance will fade by 2015 • Driver SW commodity by 2015
Application Software	<ul style="list-style-type: none"> • EU API leadership • EU core auto apps leadership • Infotainment apps: competitive 	<ul style="list-style-type: none"> • Leadership from Autosar • Some commodity apps by 2015 • Leaders from PC/CE industries
Genivi Standard	<ul style="list-style-type: none"> • Joint USA & EU leadership • Led by Intel and BMW • May expand past infotainment 	<ul style="list-style-type: none"> • Japan participation from Nissan • EU needs more participation • ADAS, V2X and other apps

Source: Authors' own elaboration.

The EU has leadership in core automotive software because of its pioneering effort in the AUTOSAR consortium. This effort has put EU companies at the head of the pack in gaining experience in deploying core automotive software; however EU automotive companies do not enjoy a similar position in infotainment software development.

In order to address the issues of software standards in infotainment, the Genivi Alliance has been set-up to fulfil this need and iSuppli believes that the Genivi standard will begin to be accepted more widely if there is no credible alternative to this alliance before the end of 2010.

Note: Europe has the power to copy the success of the AUTOSAR consortium and make the Genivi platform successful in the market; particularly if a few more of the leading OEMs and Tier 1s join the alliance. This would give the EU automotive industry a stronger voice in how the Genivi software standards evolve.

4.3.2.2 Future competitiveness: the next steps for Europe

The overall picture

While Europe enjoys leadership in the current embedded software development landscape, it is not guaranteed that it will retain its position in the future. The following table summarizes perspectives on what the authors and the industry believe Europe should do to maintain its position as a key embedded software actor.

Table 4.16 – EU Embedded Software competitiveness: Future		
	Key Information	Comments
Software Standards Activities	<ul style="list-style-type: none"> • EU Autosar leadership • Infotainment: participation • EU will make/break standards 	<ul style="list-style-type: none"> • Autosar updates are planned • Mostly USA leadership • EU luxury OEMs play key role
Operating System Software	<ul style="list-style-type: none"> • EU to lead Autosar OS specs • Autosar OS product: not leader • Infotainment OS: not leader 	<ul style="list-style-type: none"> • Autosar OS updates planned • Autosar OS product → commodity • Leaders from PC/CE industries
Driver SW	<ul style="list-style-type: none"> • EU leads Autosar driver SW • Leadership not needed 	<ul style="list-style-type: none"> • Driver SW commodity by 2015 • Product from many suppliers
SW Apps: Powertrain	<ul style="list-style-type: none"> • Diesel: Clear EU leadership • Gasoline: EU leadership • Current Hybrid EV: Behind • PEV/engine generator: OK • Battery-only EV: OK/behind • Fuel cell EV: OK/good 	<ul style="list-style-type: none"> • Importance: 10-15 more years • Importance: 10-15 more years • Parallel engine/battery may fade • EU needs to improve • EU needs to improve • EU/USA is ahead of A-P

Source: Authors'own elaboration

- **Innovation:** The overriding motivation needs to focus on evolving and upgrading the AUTOSAR operating system; particularly as the current AUTOSAR operating system and driver software is expected to be reduced to commodity status in a few years time. This shift from code innovation to commodity means many entrants from low-cost countries will be offering AUTOSAR-compatible software. To counter this competition **EU software companies must focus their effort on improving their application software skills - especially in the areas of application specification and new software product design.**
- **Setting a new standard in infotainment:** The successful creation of an infotainment software standard (such as Genivi) remains a substantial unknown in the market, as discussed previously in this report. Clearly, automotive infotainment software is strongly linked to consumer electronics and PC software, which is currently being championed in the USA. As a result it will be important for the European automotive industry to be a strong participant in **setting infotainment software standards**, if it is to emulate the success of AUTOSAR in core automotive software.
- **Next generation propulsion:** Powertrain application software will see major changes in the next decade and the previous table looks at some of these issues. While the EU is very strong in embedded software for diesel and gasoline engines, there is less assurance that EU companies will lead in ECU software for the various types of electric Powertrain. As the AUTOSAR software standards are likely to be used for electric vehicle ECU software, this is clearly an advantage that EU companies can leverage, but **more effort is needed within the European automotive industry in the area of Electric vehicles**, for this to happen.
- **The specific case of Vehicle to Vehicle/Infrastructure (V2X).**

The following table looks at EU competitiveness in V2V and V2I software design and manufacture. There are currently three geographic regions with major V2X R&D projects; USA, Japan and EU. There is also considerable joint effort to set V2X standards between these regions.

The key standards are IEEE 802.11p and IEEE 1609 WAVE, which are now in testing in the three regions. The following table presents an overview of the V2X software development.

Table 4.17 - Future EU Competitiveness: V2X Software		
	Key Information	Comments
V2X R&D Projects	<ul style="list-style-type: none"> • CVIS is a leading project • USA project: IntelliDrive/VII • Japan: SmartWay and DSSS 	<ul style="list-style-type: none"> • System-architecture focus • IEEE 802.11p/1609/WAVE focus • Upgrade from VICS
V2X Standards	<ul style="list-style-type: none"> • EU lead: system architecture • EU/USA/Japan lead standards • IEEE 802.11p and 1609/WAVE 	<ul style="list-style-type: none"> • Both automotive and mass transit • Coordination with USA and Japan • Likely V2X standards
V2X Deployment	<ul style="list-style-type: none"> • 2012 EU deployment plan • USA deployment is similar • Japan is leading 	<ul style="list-style-type: none"> • Mandate would be leadership • Regulation likely in USA • 2009 SmartWay deployment
V2X Software	<ul style="list-style-type: none"> • V2X is software intensive • Layered software architecture • Some from PC and CE software 	<ul style="list-style-type: none"> • EU need to lead in V2X software • CVIS is defining architecture • EU need to invest more
Autonomous Driving SW	<ul style="list-style-type: none"> • Mature V2X application • Who will lead these apps? 	<ul style="list-style-type: none"> • Emerging post-2020 • EU need to invest in this field

Source: Authors'own elaboration

V2X software is three to five years away from deployment and it is too early to determine which region will lead in V2X software, but the EU should perform well if it **continues to invest in V2X R&D and infrastructure deployment**. V2X software follows the 'layered' system architecture as seen in other automotive systems, however several additional layers of communication software need has to be added to complete the stack.

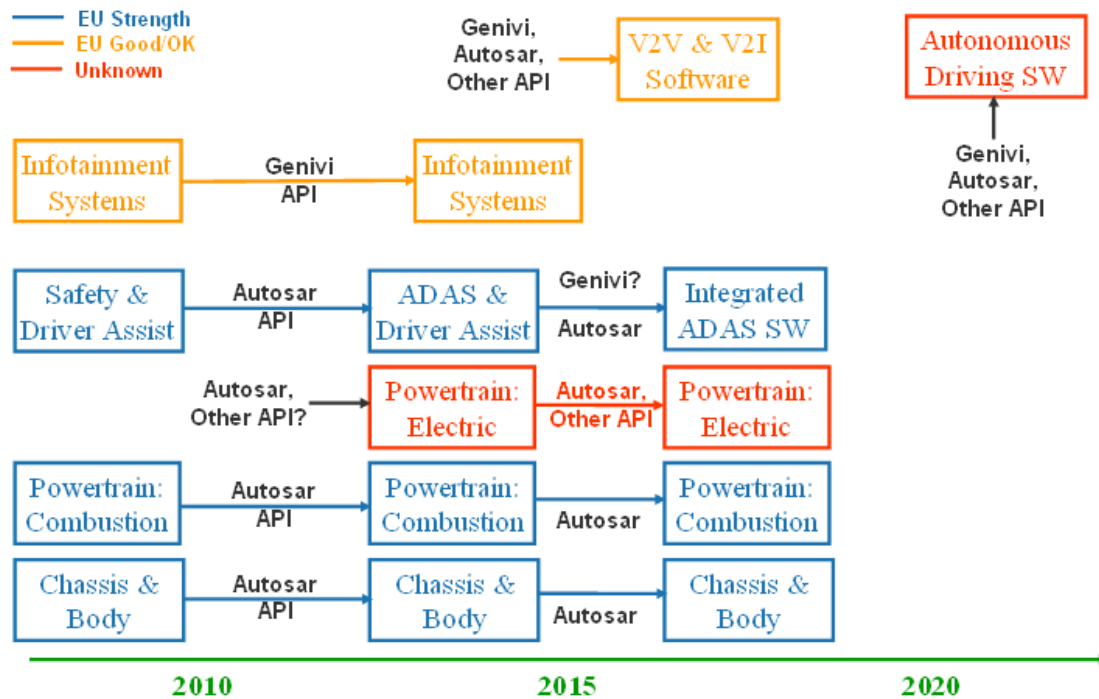
It will be important for the EU region to lead in V2X software development, as this will make it easier to retain its leadership in ECU software development. The next generation of V2X will include autonomous driving systems which should be another important technology target for the EU.

4.3.3.3 A summary: Europe's automotive software strengths and weaknesses

Figure 4.21 summarizes the likely evolution in terms of software standards and European position.

The Blue blocks indicate where the EU is currently in a **Strong** position or will retain such a lead. The Orange blocks indicate where the EU is currently in a **Good** (or **OK**) position. The Red blocks indicate unknown/uncertain positions. Clearly major efforts are needed in these areas in the next few years.

Figure 4.21 - Embedded Software Evolution



Source: Authors' own elaboration.

The European automotive industry currently has a strong position in embedded software for the many ECUs used in cars. The following are key conclusions for Europe's competitiveness in automotive embedded software.

- Automotive software is going through a revolutionary change that is standardizing the software interfaces between most software components. The EU-led AUTOSAR consortium has brought this project to the deployment phase, which will dramatically change future embedded software development.
- AUTOSAR compliant software will allow most software programmes to be reusable, which will reduce re-development costs when companies migrate their technology from project to project. The software saving will be used to develop more advanced software systems that will be required to meet the pressure from environmental compliance, accident prevention and the connected car.
- Embedded software standards for automotive applications are the right development for the European automotive industry—especially since most of the specifications and design have originated from European companies.
- The EU automotive OEMs are the early adopters of the AUTOSAR standards, and will be able to benefit from re-usable software including lower software development costs, more reliable software as well as higher software functionality
- The AUTOSAR consortium has a worldwide reach and will be the basis for similar systems in Japan and other regions. Many companies from around the world are participating in this consortium and have (or will) acquire expertise in designing or implementing AUTOSAR-compliant software.
- Software standardization opens the door for non-EU companies to better compete in the automotive embedded software market. AUTOSAR already has members from the Indian

software community. Embedded software expertise for automotive applications is likely to spread to many regions where software expertise exists.

- Long-term AUTOSAR-compliant software will become a competitive market and low-cost regions will gain increased share in this segment.
- Infotainment software has an increasing connection to the PC, Internet and consumer electronics industries. The drivers for these industries are currently non-EU based companies with the USA as the primary innovator for many consumer standards, while lower level coding is being developed in low-cost Asian regions. As a result of the success of the AUTOSAR standard, technology leader; BMW is part of an alliance that is attempting to create a new *infotainment* software standard called Genivi. Currently, PSA, Continental and Magneti-Marelli are Genivi participants; however key European OEMs and Tier 1 companies are not currently supporting this effort in large numbers. Genivi may be the best option for the European infotainment companies to gain more strength in infotainment software and hardware systems
- Software standards will enable much more productive software development, thereby increasing software development efficiency. This trend is likely to keep much of the application development in Europe—at least for complex applications and applications that are linked to local ICT systems such as V2X as well as connected car services and autonomous driving.
- **There are several future embedded software segments where the European software industry must have strong participation and preferably gain a leadership position. These emerging and future embedded software segments include EV software, ADAS software, V2X software and autonomous driving software.** The emerging connected car applications and especially the so-called auto app stores segment needs strong European participation.
- In order to secure long-term European leadership in automotive embedded software, and more generally the European automotive sector, **it is essential that high levels of product innovation are encouraged. As a consequence, public authorities, and in particular the European Commission have an active role to play in the support to research, innovation and deployment of those technologies, through a variety of instruments including in particular the adoption of legislation mandating the introduction of next generation automotive technologies for environmental (including the EU objective to reduce CO2 emissions by 20% by 2020, and more stringent objectives down the line), and road safety aims.**

5. Some Policy-related Conclusions

The EU automotive industry is well positioned in embedded systems, and in particular in embedded software. This leadership position can be extended for a decade or two, but requires considerable investments by all players including public authorities.

Table 5.1 present a brief SWOT analysis for automotive embedded software. The analysis is from a European software industry perspective. It is a helpful summary to catch some of the essential trends that affect and will affect the future competitiveness of the European Embedded Systems industry.

Table 5.1 – EU Embedded Automotive Software SWOT	
<u>Strengths</u> <ul style="list-style-type: none"> • Luxury car leaders: most software is introduced • AUTOSAR: Standards leadership • AUTOSAR: Software competency & deployment • Diesel and gasoline engine software • Chassis control software (ABS, ESC) • Safety and driver assist software • Software and software tool companies • V2X R&D programmes (CVIS & others) 	<u>Opportunities</u> <ul style="list-style-type: none"> • EV software advances may make EU leaders at EV system level • Automotive apps store leadership • ADAS software and systems and applications • eCall legislation would allow to catch-up in telematics and connected car applications • V2X software and systems (regulation needed) • Autonomous driving (post-2020)
<u>Weaknesses</u> <ul style="list-style-type: none"> • Current EV deployment • Current EV development • Infotainment software OS and API standards • Infotainment application software • Telematics software and deployment 	<u>Threats</u> <ul style="list-style-type: none"> • AUTOSAR commodity software (post-2015) • Infotainment commodity software (post-2015) • Electric Vehicle growth negates powertrain software market leadership (post-2020)

Source: Authors' own elaboration.

For the authors, the key conclusions concerning the status and future of Embedded systems, and in particular Embedded software in the European automotive industry are the following:

- EU automotive sales are declining as a share of the world total, with most of the future growth expected to come from non-EU regions. This means the EU-based automotive manufacturers, their EU-based Tier 1, semiconductor and software suppliers must expand outside the EU in order to maintain or grow their worldwide market share.
- The automotive ICT market size is difficult to estimate, however it is a growing portion of value of a vehicle when it is sold. In this study, the authors have estimated that, while ICT value per car depends greatly on what optional electronics are purchased by consumers, it still represents already some 10% to 15% of the vehicles purchase price (With minimal optional equipment) up to 30% of the purchase price (With the purchase of all optional electronics) depending on the type of vehicle.
- The EU has a leadership role in embedded software standards due to its role in the formation of the AUTOSAR consortium. AUTOSAR is now a worldwide software standard with EU companies in the best position to benefit from the deployment of the standards that are now underway.

The EU is in the strongest position in terms of the supply of Powertrain embedded software. However, there is a risk that, as electric vehicles begin to replace diesel and gasoline vehicles, EU companies will not have invested enough to be the leaders in Electric Vehicle Powertrain software. Public support to private investment in **Electric Vehicle R&D is needed soon to protect the EU's lead in future Powertrain software** in the form of Venture-Capital, Pre-financing of Launch, 100% deductibility of R&D investment from Company Tax.

- Genivi is another embedded software standard effort that is under way in the infotainment system domain. The EU is well represented in the GENIVI consortium, but shares the leadership role with the USA-based companies.
- EU is behind USA in connected car applications and software. The impact of eCall Directive has the potential to accelerate EU connected car deployment and allow the EU to catch-up in the next decade to 2020.
- To retain future leadership in embedded software, **the EU automotive industry must invest in emerging and future technologies with software-intensive segments: Advanced Driver Assist systems (ADAS), Vehicle-to-vehicle/Vehicle-to-Infrastructure communication (V2X) and autonomous driving.**

Within this context, some political recommendations emerge from the analysis:

- **ICT matters (more than ever):** the present report demonstrates again the importance of taking-up the role of ICT in the transformation of the economy. This general purpose technology, when embedded, becomes one of the major assets for competitiveness. It transforms skills, organisations, processes, products and services, giving them added value and that competitive advantage that makes the difference on the global market. A vision of the Digital Economy reduced to the mere diffusion and impacts of Personal Computers is a major mistake to avoid.
- **Skills: the trends towards a service economy** ("*from products to services*"), nowadays mainly implemented through software-based solutions, with the creation of integrated systems (bridging often different sectors: transport and health; safety and entertainment; energy and transport; etc.) **call for a highly skilled workforce of software engineers and system integrators, within a multidisciplinary strategy.** All industrial actors insist on the already currently existing skills' gap, and this is particularly true within the Embedded Systems activities to which European engineers appear to be little prepared; the Commission should support the creation of a European network of EU enterprises to advise Universities and training centres in order to adapt e-Skills and Engineering curricula of Universities and permanent training of employees to the needs of EU Automotive and Electronic enterprises.⁶⁴
- **Silos:** this trend towards *cross-sector integrated services* **calls for integrated cross-departmental policies.** The vertical silos of most public authorities offer little help, and

⁶⁴ European e-Skills Week 2010: <http://ec.europa.eu/enterprise/sectors/ict/e-skills/support/>
http://ec.europa.eu/enterprise/sectors/ict/e-skills/extended/index_en.htm
 McCORMACK, Ade: "The e-Skills Manifesto - A Call to Arms"
http://eskills-week.ec.europa.eu/web/guest/news/-/journal_content/56_INSTANCE_m7wX/10404/30663/NEWS_MAIN_DISPLAY
http://files.eun.org/eskillsweek/manifesto/e-skills_manifesto.pdf
 INSEAD "eLab" report: <http://www.insead.edu/elab> about best practice to improve e-Skills curricula:
 "Strengthening e-Skills for Innovation in Europe":
http://eskills-week.ec.europa.eu/web/guest/news/-/journal_content/56_INSTANCE_m7wX/10404/27842/NEWS_MAIN_DISPLAY
 Contact point in EU Member States: http://ec.europa.eu/enterprise/sectors/ict/files/e-skillsweek_highlevelcontact_points_15122009_en.pdf

sometimes add obstacles, to the timely development and implementation of those new skills, organisations, products and services. A priority effort should be put into a firm revision of the vertical organisation of public administrations and diverse policy making agencies;

- **Speed-up the adoption of EU legislation related to the cross-border use of vehicles:** while often seen as impediments to implementation, good regulations are powerful pull/demand factors for innovation to emerge. The eCall case reminds of such public capacity to refrain or boost innovative capacities. Many other pending issues seem to be related to regulatory aspects (Cross-border Micropayments; Wireless Spectrum management; etc.⁶⁵)

- **Global moves:** with advanced and emergent economies competing on one same global market, there is a need for coordinated macro-region initiatives to counterbalance those taken by competitors. The move towards the Electric Vehicle is a good example, where the European legacy with the combustion engine might add a layer of inertia to face the rapid moves observed with our Asian counterparts;

- **No zero-sum games:** the transformation of the economy impacts the economic actors. As new organisations, processes, services emerge, some actors in the value chains emerge as winners, other as losers. And new actors emerge with new roles. These dynamics, partly unpredictable, complicate heavily the role of public authorities when meeting with the industries and their representative organisations to mature the political decisions and implement them. Little can be done about this difficulty. Probably, at a macro-economic level would it be important to ensure Europe's benefits in the overall reshuffling of global value chains, by ensuring that Europe is able to maintain existing actors and nurture those of tomorrow.

When considering the above elements and the detailed analysis presented in this report, both on the technological aspects as those related to the robust and mature industrial context, a striking observation in terms of policy is the absence of a coordinated "one-stop-shopping" major automotive public agenda at European level. The Smart or Green Car initiatives are claimed to be high on the official agendas of the Commission and of the Member States but they do not seem to deliver any integrated and strong momentum towards a coordinated and efficient move of the industry, public authorities, citizens and probably academia to ensure the rapid development and implementation of such agendas. The above analysis shows that only such move will allow Europe to reap the benefits of the next generation cars, by growing an even stronger automotive sector, at OEMs and at suppliers level, offering the consumer the services and products the market demands and meeting the societal challenges that Europe is confronting in terms of economic growth, employment, environment or well-being.

⁶⁵ Interestingly enough, such issues are relevant to the current Digital Agenda, one of the Commission's seven flagships of Europe 2020. In particular, these issues pertain to the Digital Single Market line, aimed at reducing the obstacles for the cross-border trade of digital goods and services.

Appendix 1. Data Sources

A variety of sources were used for automotive sales and production data, financial data and market statistics. The sources are summarized in Table A1.1:

Table A1.1 - Data Sources		
	Sources	Comments
Automotive sales and production	<ul style="list-style-type: none"> Automotive manufacturer financial reports Automotive manufacturers websites Auto organizations 	<ul style="list-style-type: none"> Annual and quarterly reports Monthly sales data are common Example: ACEA, JAMA, KAMA
Financial data	<ul style="list-style-type: none"> Automotive manufacturer financial reports ICT companies financial reports 	<ul style="list-style-type: none"> Annual and quarterly reports Annual and quarterly reports
Market statistics	<ul style="list-style-type: none"> iSuppli historical data iSuppli forecast data 	<ul style="list-style-type: none"> Extensive data on ICT industries Extensive ICT forecasts

ACEA is the European automobile manufacturers' association.

JAMA is the Japan automobile manufacturers' association.

KAMA is the Korean automobile manufacturers' association.

This report used data, estimates and content from numerous iSuppli reports and services. The key report titles and services that were used are listed in Table A1.2:

Table A1.2 – iSuppli Research Reports and Services		
Segments	Report/Service Name	Publication Date
Semiconductor Industry	<ul style="list-style-type: none"> Electronics Equipment and Semiconductor Forecast Automotive Infotainment Competitive Landscape Tool Automotive Sensors: A Look Back at 2009, and Forward Power Management Market Tracker Semiconductor Design Activity Tool Digital Radio and Mobile TV in Automotive Automotive Infotainment Semiconductor Market Tracker Automotive Research Portal: Components and Devices 	<ul style="list-style-type: none"> 2010 – Q2 2010 – Q1 2010 – Q1 2009 - Q4 2009 - Q4 2009 - Q4 2009 - Q4 Updated daily
Infotainment Industry	<ul style="list-style-type: none"> Premium Audio: Music to Everyone's Ears Chinese Telematics Market Telematics Systems: Here to Stay Internet in the Car: Future of In-Vehicle Connectivity Next-Gen Navigation: Is it all About Apps and Map? Next Generation Head-unit Design: Beyond Just Hardware Automotive Research Portal: Infotainment 	<ul style="list-style-type: none"> 2010 - Q1 2010 - Q1 2009 - Q4 2009 - Q4 2009 - Q3 2009 - Q2 Updated daily
Portable and LBS	<ul style="list-style-type: none"> Smartphones: The New LBS Battleground Navigation, Traffic and Telematics Service Opportunities Automotive Research Portal: Portable and LBS 	<ul style="list-style-type: none"> 2010 - Q2 2009 – Q2 Updated daily
ADAS Industry	<ul style="list-style-type: none"> V2V and V2I Market Trends (To be published) Eco-technologies Gain Speed in Automotive Industry Automotive Research Portal: ADAS ADAS Offers Big Opportunities for Auto Manufacturers Eco-Telematics: Using Technology to Go Green 	<ul style="list-style-type: none"> 2010 - Q3 2010 - Q1 Updated daily 2009 - Q2 2008 - Q4

Appendix 2. Industry Acronyms

As in most industries, there are many acronyms used in the automotive business. Table A2.1 defines the meaning of 50+acronyms used in this report. Additional information is also included in the third column.

Table A2.1 - Acronyms		
Acronym	Meaning	Other Information
ABS	Anti-lock Braking System	Improves brake performance
ACC	Adaptive Cruise Control	Radar modulates speed and follow-distance
ACN	Automatic Collision Notification	eCall in Europe
ADAS	Advanced Driver Assist System	Systems that counteracts driver errors
API	Application Programming Interface	Allows re-usable software
ASIC	Application Specific Integrated Circuit	Custom chip for a specific application
ASSP	Application Specific Standard Part	Generic ASIC for a specific market
AUTOSAR	Automotive Open System Architecture	Consortium, started in EU, now WW
BSD	Blind Spot Detection	Warning to avoid side collision
CALM	Communications Access for Land Mobiles	Communication standards defined by ISO
CAN	Controller Area Network	Electronic bus for core automotive systems
CVT	Continuous Variable Transmission	More gears than you can count
DSP	Digital Signal Processor	MCU for processing analog signals
ECU	Electronic Control Unit	Standard term for microcomputer control
EDAS	Eco-Driver Assist System	Products for improving fuel economy
ESC	Electronic Stability Control	Improves driver's emergency steering
EV	Electric Vehicle	Usually means battery-powered only vehicle
EVC	Electronic Valve Control	MCU controls engine valves
GDI	Gasoline Direct Injection	Improved fuel injection, better fuel efficiency
GENIVI	GENeva and In-Vehicle Infotainment	Consortium, infotainment software standard
HCCI	Homogeneous Charge Compression Ignition	Gasoline injection tech, similar to diesel
HEV	Hybrid Electric Vehicle	Battery is only charged from engine
HFI	Hands-Free Interface	Head-unit interface for mobile devices
HMI	Human Machine Interface	Also called Man-Machine Interface (MMI)
H-U	Head-Unit	Car radio, music, navigation and video system
HUD	Head-Up Display	Display info projected on windshield
IC	Integrated Circuit	Up to billions of transistors on a chip
ICD	Instrument Cluster Display	Car's cockpit display
ICE	Internal Combustion Engine	Gasoline and diesel engines
ICT	Information & Communication Technology	
JASPAR	Japan Automotive Software Platform and Architecture	Japan's AUTOSAR version
LCC	Low Cost Countries	
LDW	Lane Departure Warning	Warning for unintended lane change
LIN	Local Interconnect Network	Low-speed bus for body and comfort systems
MCU	Micro Computer Unit	Computer processor and peripherals on a chip
MEMS	Micro Electro Mechanical Systems	Sensors manufactured by IC technology
MPG	Miles per gallon	Km per litre in Europe
MIPS	Millions Instruction Per Second	Computer speed measurement
MOST	Media Orientated System Transport	Electronic bus for infotainment systems
MPE	Map and Positioning Engine	Use map data to improve fuel efficiency
MPU	Micro Processor Unit	Computer processor on a chip
NCAP	New Car Assessment Programme	
OBD, OBDII	On Board Diagnostics, OBD2	Standard bus for automotive diagnostics, USA, EU
OEM	Original Equipment Manufacturer	Means automotive manufacturer
OSEK	Offene Systeme und Deren Schnittstellen für die Elektronik im Kraftfahrzeug	Open Systems and the Corresponding Interfaces for Automotive Electronics
OSGi	Open Services Gateway initiative	Defines open Java-based service platform

Table A2.1 - Acronyms		
Acronym	Meaning	Other Information
PHEV	Plug-in Hybrid Electric Vehicle	Hybrid with batteries that can be charged
PND	Portable Navigation Device	Handheld GPS navigation device
SOC	System On Chip	MCU, sensors, actuators on single chip
TPMS	Tire Pressure Monitor System	USA regulation; soon in Europe
V2I	Vehicle-to-Infrastructure (communication)	Future com link for safety application
V2V	Vehicle-to-Vehicle (communication)	Future com link for safety application
WAVE	Wireless Access in Vehicular Environment	V2V and V2I wireless standard
WiFi	Wireless Fidelity (IEEE 802.11 standard)	Wireless local area network technology
X-by-Wire	X=steering, gas-pedal, brake	Wire instead of mechanical link

Source: Authors' own elaboration.

Appendix 3. Automotive Manufacturers' Brands

The leading automotive manufacturers have multiple car brands that are sold worldwide or are sold in some geographic regions. Table A3.1 lists the car brands of the leading automotive manufacturers.

Table A3.1 - Car Brands			
	Car Brands	Automotive Segment	Comments
BMW	<ul style="list-style-type: none"> • BMW • Mini • Rolls-Royce 	<ul style="list-style-type: none"> • Luxury • Mid-range • Super-luxury 	<ul style="list-style-type: none"> • Worldwide sales • Worldwide sales • Worldwide sales
Daimler	<ul style="list-style-type: none"> • Mercedes-Benz • Smart 	<ul style="list-style-type: none"> • Luxury • Economy 	<ul style="list-style-type: none"> • Worldwide sales • Sales in most regions
Fiat	<ul style="list-style-type: none"> • Alfa Romeo • Fiat • Ferrari • Lancia • Maserati 	<ul style="list-style-type: none"> • Mid-range • Economy to Mid-range • Luxury sports cars • Mid-range • Luxury sports cars 	<ul style="list-style-type: none"> • Primarily European sales • Sales in most regions • Sales in many regions • Primarily European sales • Sales in many regions
Ford	<ul style="list-style-type: none"> • Ford • Lincoln • Mercury • Volvo 	<ul style="list-style-type: none"> • Economy to Mid-range • Luxury • Economy to Mid-range • Mid-range 	<ul style="list-style-type: none"> • Worldwide sales • N. America only • N. America only; to be shut down • Sold to Geely, China (Aug 2010)
General Motors	<ul style="list-style-type: none"> • Buick • Cadillac • Chevrolet • Daewoo • GMC • Hummer • Opel/Vauxhall • Pontiac • Saab • Saturn 	<ul style="list-style-type: none"> • Economy to Mid-range • Luxury • Economy to Mid-range • Economy • Economy to Mid-range • Luxury SUV • Economy to Mid-range • Economy to Mid-range • Mid-range • Economy to Mid-range 	<ul style="list-style-type: none"> • N. America & China • Worldwide sales • Worldwide sales • Korea, Chevrolet other regions • N. America mostly • To be shut down • Primarily European sales • To be shut down • Sold to Spyker Cars NV (Feb 2010) • To be shut down
Honda	<ul style="list-style-type: none"> • Acura • Honda 	<ul style="list-style-type: none"> • Luxury • Economy to Mid-range 	<ul style="list-style-type: none"> • Mostly N. America • Worldwide sales
Hyundai	<ul style="list-style-type: none"> • Hyundai • Kia 	<ul style="list-style-type: none"> • Economy to Mid-range • Economy to Mid-range 	<ul style="list-style-type: none"> • Worldwide sales • Sales in most regions
Nissan	<ul style="list-style-type: none"> • Infiniti • Nissan 	<ul style="list-style-type: none"> • Luxury • Economy to Luxury 	<ul style="list-style-type: none"> • Mostly N. America • Worldwide sales
PSA	<ul style="list-style-type: none"> • Citroen • Peugeot 	<ul style="list-style-type: none"> • Economy to Mid-range • Economy to Mid-range 	<ul style="list-style-type: none"> • Sales in most regions • Sales in most regions
Renault	<ul style="list-style-type: none"> • Dacia • Renault 	<ul style="list-style-type: none"> • Economy • Economy to Mid-range 	<ul style="list-style-type: none"> • Mostly Europe • Sales in most regions
Toyota	<ul style="list-style-type: none"> • Daihatsu • Lexus • Toyota 	<ul style="list-style-type: none"> • Mostly economy • Luxury • Economy to Luxury 	<ul style="list-style-type: none"> • Sales in many regions • Sales in many regions • Worldwide sales
VW	<ul style="list-style-type: none"> • Audi • Bentley • Lamborghini • Seat • Skoda • Volkswagen 	<ul style="list-style-type: none"> • Luxury • Super-luxury • Luxury sports cars • Economy to Mid-range • Economy to Mid-range • Economy to Luxury 	<ul style="list-style-type: none"> • Worldwide sales • Sales in many regions • Sales in many regions • Sales in many regions • Sales in many regions • Worldwide sales

Source: Authors' own elaboration.

Appendix 4- List of participants in the Experts Workshop

The competitiveness of the European industry in Embedded software in the automotive industry, Brussels, 28 April 2010.

Enrique de Aresti Gutierrez

DG ENTR D.3
ICT for Competitiveness and Industrial Innovation
Belgium

Marc Bogdanowicz

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Carol de Vries

NXP
The Netherlands

Hans Dominik

Autoliv
Germany

Marcus Fehling

Siemens
Germany

Antonis Galetsas

DG INFSO G1
Belgium

Andres Gavira

Sr. Engineer
ICT & e-Economy - Projects Division
European Investment Bank
Luxembourg

Dr. Gerd Gottwald

Bosch
Germany

Olivier Guetta

Renault
France

Brent Hobson

EMEA - iSuppli Corporation
UK

Egil Juliussen

iSuppli Corporation
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Merten Koolen

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The Netherlands

Franck Lesbroussart

Autoliv
France

Sven Lindmark

Independent expert
Spain

Eric Luttermann

Elektrobit
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Alain Puissechet

Alain Puissechet Expertises
France

Richard Robinson

iSuppli Corporation
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Helmut Schelling

Vector
Germany

Nikolaus Steininger

DG ENTR F1
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Geomina Turlea

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Claudio Valesani

STMicroelectronics
Switzerland

Sandrine Wattraint

IPTS JRC J4
Spain

Appendix 5 - Sensors: Overview, Value Estimate and EU Competitiveness

A. Overview

Sensors are devices that measure physical or electrical inputs, which are then converted into a digital signal. These signals can then be interpreted by a MCU for actuation of a function. Sensors are used in a wide range of applications in automotive from simple speedometers to precise angular position of a camshaft or even trajectory and acceleration of a vehicle. There are many types of sensors monitoring; speed, rotation, position, pressure, inertia, yaw rate, temperature and gas composition.

In the case of a simple pressure sensor, a circular membrane of thin material (silicon, metal, ceramic) ‘deforms’ in the presence of a pressure (air, oil, transmission fluid, etc). This ‘deformation’ is recorded typically by either a change in capacitance (effectively the distance between two plates within the device) or by a resistance change, achieved by depositing strain gages on top of the device that detect deformation on the surface of the membrane. In both cases the output is converted to a voltage.

In some instances algorithmic approaches are used. This ‘synthetic’ approach aims to model, reproduce and measure the physical changes. Mostly these approaches by-pass the use of sensor arrays, as a result they are usually considered as inferior or low cost solutions that still require some sensor input to ensure quality of output. Examples of algorithm-based solutions include tire pressure monitors that use wheel speed sensors instead of tire pressure sensors to monitor tire performance.

The enabling nature of MEMS Sensors

Micro Electro Mechanical Systems or **MEMS** sensor technology production is essentially an IC processing method based on highly advanced silicon manufacturing. This approach extends to surface micromachining of silicon (and other materials) to make extremely small silicon chip based sensor devices. Essentially, these devices are like integrated circuits however they are also capable of experiencing mechanical deflection.⁶⁶

MEMS sensors have been responsible for the mass adoption of many applications first in luxury cars, and more recently in middle-segment and smaller cars. Best known among these applications is the airbag, but other examples include the manifold air pressure sensor; a device that acts as a feedback loop for engine control which is used to lower emissions. MEMS technology has essentially allowed precise, compact, inexpensive and highly robust monitoring devices to revolutionize the electronics and functionality of the average car in the last decade.

MEMS sensors are increasing in importance due to their low price and small physical size, which is due to their semiconductor-like manufacturing technology.

MEMS Developments Pre-2000

The majority of the sensors (non-MEMS) in current production were already developed prior to 2000. Powertrain sensors such as pressure devices for manifold air intake to measure and control the fuel-air mix pressure were already standard on many vehicles, as were ABS systems and airbags. Emissions and safety regulations accelerated this adoption.

⁶⁶ Best know examples of the use of MEMS in the consumer device world can be seen in the Nintendo-Wii; were gamers can swing their handset around to play golf or tennis.

Meanwhile many advanced applications such as vehicle stability systems and radar-based Adaptive Cruise Control (ACC) were introduced. These intelligent speed control systems automatically maintain a pre-defined distance from the vehicle in front.

MEMS Developments 2000-2009

In the decade since 2000, the automotive market saw a rapid uptake of sensors in the mid range segment, with vehicle stability systems (ESC) to be found increasingly deployed in, for example, VW Golf class cars. The adoption of sensors was accelerated by safety-related regulations in the United States, which introduced tire pressure monitoring (TREAD Act, mandatory for U.S. vehicles in 2007) and ESC (a legal requirement from 2012).⁶⁷

Increasingly stringent emissions regulations and CO2 targets (e.g. OBDII, EURO 1-6) are the current drivers for sensor implementation in Powertrain applications.

Many other body sensors including magnetic sensors and switches, thermal / infrared sensors for climate control and occupant detection, etc. have proliferated to aid comfort and convenience.

MEMS Projections 2010-2020

The key feature from 2010 will be the growing importance of sensor fusion, which has been accelerated by more complex networks in vehicles.

Existing measurements and inputs will be combined to create more 'intelligent' systems, particularly in the area of safety applications such as intelligent airbag systems that will use inputs from several sources (ESC system, radar systems, cameras etc) in order to make decisions on how to fire the airbags. Regulations are likely to continue to drive commoditization, product innovation and price reductions. New regulations will focus on advanced driver-assist technology (ADAS).

Generally, the number of new sensors will not grow significantly. Most adoption will be seen in body electronics applications; for example to improve the efficiency of Air Conditioning systems. These sensors continuously sample the air/CO2 quality and manage the input flaps intelligently.

⁶⁷ For more see at: <http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.012c081c5966f0ca3253ab10cba046a0/http://www.nhtsa.dot.gov/cars/rules/rulings/TPMSnprmPost2Cir/TPMSnprmPost2Cir.html>
Europe is now following this trend with similar regulations, due in 2012.
<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:200:0001:01:EN:HTML>

Table A5.1 - Sensor Trends		
	Number of Sensors	Comments
Powertrain	Pre-2000: 10-35 2000-10: 30-40 2020: 40-50	<ul style="list-style-type: none"> • First wave of sensors pre-2000 • Luxury segment saturated by 2010 • Mid-range adoption increases 2000-201 • Slow growth post-2010 due to sensor fusion • EV disruption; eliminate some sensors, add others • High software dependence
Chassis & Safety	Pre-2000: 5-34 2000-10: 18-36 2020: 30-42	<ul style="list-style-type: none"> • Pre-2000 mostly in luxury segment. • Adoption in mid range post-2000 • Accelerated by regulations: TPMS, ESC (2007-12) • Slow growth post-2010 due to sensor fusion • High software dependence
Body & Comfort	Pre-2000: 9-29 2000-10: 25-50 2020: 35-60	<ul style="list-style-type: none"> • Most important is airbag sensors • Will merge with chassis safety sensors • Sensors still growing post-2010 • New comfort applications; most non-safety critical • Low software dependence

Source: Authors' own elaboration.

Sensor fusion has implications for software:

- Software coding requirements of sensor based systems will rise as a result of sensor fusion; however this will happen mostly at the ECU-to-ECU level, with some additional intelligence also moving into the sensors and actuators at the semiconductor level.
- At the architectural level, the number of ECUs will be rationalized into a few domain or zone controllers. The contribution of sensors to this trend; will be to reduce sensor size and power consumption while consolidating related sensors into fewer packages.

Note: Examples of sensor fusion include the airbag and ESC sensors, which will be co-located in a central domain controller in the future.

Conclusions:

- Many MEMS sensors are well established in the market and adoption of these devices in mid-range vehicles increasing at a rapid pace.
- New functionalities will be enabled as a result of sensor fusion rather than the introduction of new types of sensors. This is particularly the case in the area of safety.
- Some intelligence will filter down from the ECU level to the semiconductor or component level in an effort to reduce the number of ECUs required by the vehicle.
- The amount of software code will increase, mostly at system (ECU to ECU) level, although sensors will become more intelligent.
- New architectures will limit the number of ECUs considerably, as a result sensors will need to accommodate this trend by being smaller, smarter and consume less power.

B. Sensor Value Estimates

The relative positions of the major sensor suppliers are shown in Table A5.2. Europe has 5 suppliers in the top 10, including first and second place. Typically, vertically integrated companies such as Bosch or Denso have an advantage particularly at times of architectural shift, as they are both Tier 1 suppliers to the car manufacturers as well as sensor manufacturers.

Table A5.2 – Top 10 Worldwide Sensor Suppliers: 2008			
Rank	Company	Revenue \$M	Headquarters
1	Bosch	429	EU
2	Infineon	249	EU
3	Denso	198	Japan
4	Freescale	191	USA
5	Sensata	142	USA
6	Micronas	125	EU
7	Schneider Electric	112	EU
8	Melexis	95	EU
9	Analog Devices	87	USA
10	Allegro (Sanken)	86	USA
	Total Sensor Market	2,255	

Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

This early knowledge of market shifts has allowed Bosch in particular to not only influence the current technology roadmaps for integration of full passive and active safety technology for sensors, but also influence the future of safety and Powertrain domain controllers.

C. Competitiveness of European Sensors industry

Europe has a dominant position in the global supply of sensors to automotive market and is especially innovative in bringing advanced technologies into vehicles. Calculations of the market shares for the major sensor applications,⁶⁸ places Europe in the lead with 55% market share (in revenue terms) in 2008. North America is second with 25% and Asia-Pacific third with 20%. European tier 2 sensor companies have a leading position in the supply of 20 types of sensors serving automotive applications mostly in Powertrain, chassis and safety domains.

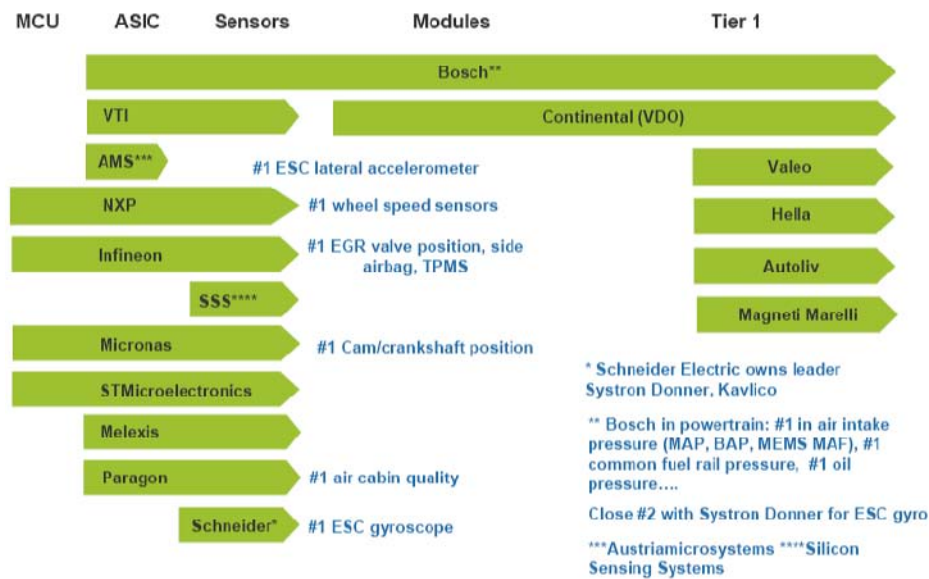
Most significant in Europe is the strong position of Bosch and Continental who are major international suppliers working with OEMs worldwide. Autoliv is also a significant safety systems supplier—especially for airbags. Bosch is vertically integrated, and Continental worked closely with Siemens VDO on many sensor related systems before it acquired Siemens VDO in mid-2007. Continental gained key airbag and ADAS market share from the acquisition of Siemens VDO in the areas of radar systems, navigation and collision avoidance systems.

Figure A5.1 presents an overview and value chain position of the key EU sensor manufacturers to the automotive sector.

Most companies are active at the semiconductor level only, while companies such as Continental manufacture sensor modules and sell these modules as a Tier 1 supplier, while Bosch is active in the entire value chain, manufacturing semiconductors, modules and systems.

⁶⁸ Based on calculations of major sensor types and their applications, and amounting to 70% of the total sensor market.

Figure A5.1 - European Sensor Supply Chain 2008



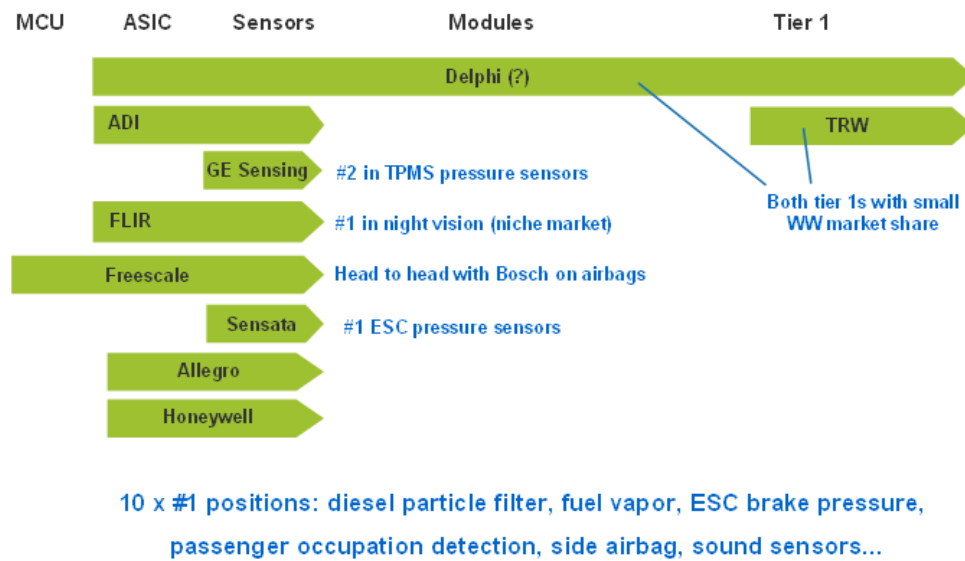
Source: Authors' own elaboration.

Bosch has a powerful position in Powertrain and safety applications. The company not only pioneered, but also has a strong IP position in common fuel rail injection systems, which revolutionized “dirty” diesels and improved efficiency in gasoline powered vehicles. The combined forces of Bosch and Continental have the biggest market share in vehicle dynamics systems, a revolutionary safety system that corrects for over- or under-steer and is based on a suite of MEMS and magnetic sensors. This system is soon to be legislated in Europe. The dominance of the sensor suppliers in Europe is expected to continue in future.

North America has two relatively small tier 1 system suppliers on the world stage, TRW and Delphi, however these two sensor suppliers have a large portion of the world market, delivering 20% of the value of sensors. There is strong domestic focus for both TRW and Delphi, both of whom are vertically integrated as Tier suppliers.

North America has a leading position for suppliers of 10 types of sensors in applications supporting Powertrain, chassis and safety as well as body applications. This region has a significant presence in supply the market for pressure sensors for vehicle dynamics systems (electronic stability control systems or ESC), front and side airbags, air conditioning sensors, and night vision (currently a niche market).

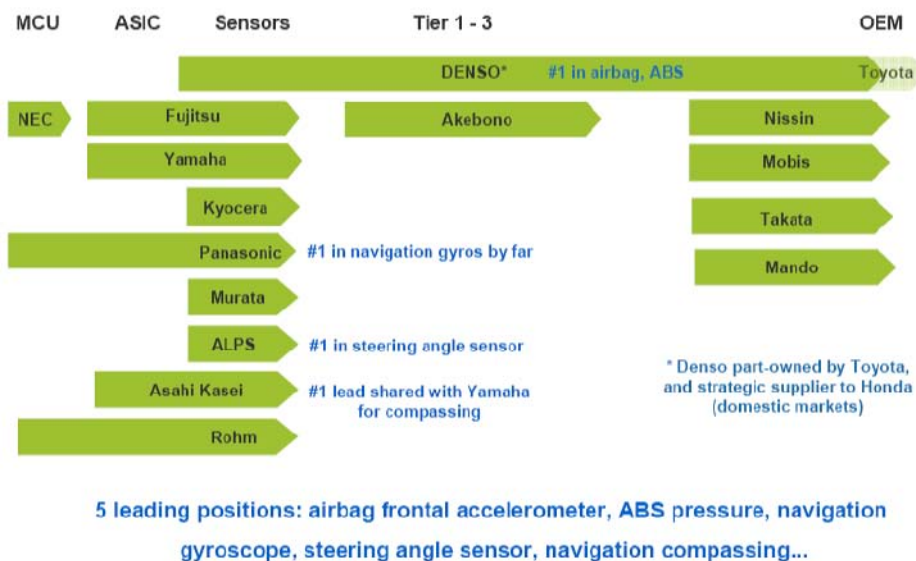
Figure A5.2 - North American Sensor Supply Chain 2008



Source: Authors' own elaboration.

In the Asia-Pacific region, Japanese giant Denso (part-owned by Toyota) is currently the only major Tier 1 of the same magnitude as Continental and Bosch, however Denso has a strong domestic market focus. Asia-Pacific sensor supply chain is shown in Figure A5.3.

Figure A5.3 - Asia Pacific Sensor Supply Chain 2008



Source: Authors' own elaboration.

Denso is vertically integrated as a major supplier for Toyota and Honda. The company is notably in a tight race with Bosch and Freescale, in the supply of frontal airbags as well as ABS pressure sensors. Navigation is an important market in Japan, and three local suppliers lead in this supplying this space.

China will be an important area of expansion in the future. The authors believe the current European suppliers will take an active role, in this market. Currently there are only 4 market leading companies for sensor applications among the Asia-Pacific companies.

Appendix 6: Green Technology and European Automotive Embedded Systems Companies: Examples and Market Forecasts

Audi: EDAS

Audi EDAS is included in the newest generation of their Multi Media Interface (MMI). It includes a new map database incorporating road characteristics and terrain in three dimensions. The map data includes characteristics of roadways that can be used to more accurately reflect the real distance travelled (e.g. when driving over hilly terrain).

By providing more data on roadways, the vehicles navigation software is able to calculate an 'eco-friendly' route in addition to the traditional choices of shortest and fastest route.

In this case the routing software algorithms consider advanced road characteristics such as slope as well as the presence of traffic signals or dense urban centres, when calculating the eco-friendly route. By minimising hills and slopes or other impediments to smooth driving, the software can determine the route that reduces fuel consumption and potential vehicle standstills with the aim of lowering vehicle emissions

Fiat - eco:Drive

The Fiat Group introduced a software application at the Paris Motor Show in October 2008 named eco:Drive. The application is designed to run on the Blue&Me multimedia platform. Blue&Me integrates hands-free Bluetooth and USB connectivity into the vehicle and is primarily an infotainment solution, however eco:Drive has expanded this functionality into an eco-friendly EDAS.

The eco:Drive software can be downloaded from the Fiat website to any USB drive. When this USB is connected to the Blue&Me in-vehicle system, the application is installed to enable eco:Drive to gather and store information via the CAN BUS regarding vehicle performance. The eco:Drive application collects data from four driver-controlled domains: acceleration, deceleration, gear shifting and speed. This data is stored onto the USB drive, which can be interpreted on a PC, giving drivers' feedback on their driving patterns.

The driver sees no signs of operation or feedback while driving. The eco:Drive computer programme is used to manage and interpret the data after driving. The user creates a profile which specifies the model and engine type, as accurate parameters are required for efficiency and performance metrics gathered by eco:Drive. Five individual trips are needed to calibrate the individual driver and vehicle, and the driver is then presented with a profile of their typical driving behaviour within the four driver-controlled domains: acceleration, deceleration, gear shifting, and speed. Through the computer programme, the user can create goals and take lessons in vehicle efficiency. During the ownership cycle, additional trip data can be uploaded to measure improvements in driving behaviour.

Harman: Green edge

Harman International has a new line of products under its 'Green Edge' label. All of the technology under the Green Edge label target lower power consumption thus creating more fuel efficiency in the car. Harman's next generation platform for infotainment and navigation is based on the Intel's Automotive Architecture. The 1.3GHz Intel Atom processor consumes 25% less energy and doubles the processor performance. The system includes eco-routing options as well as sending remote software updates via 3G/3G+ mobile networks. Currently these technologies are not available on the market, however BMW and Daimler (Mercedes-Benz) have signed deals to include the Harman Green Edge infotainment and navigation platform in their new vehicles that will be launched in 2010.

Navteq and STMicroelectronics: MPE

Navteq and STMicroelectronics have collaborated on an ECU called the Map and Positioning Engine (MPE) that includes map data with advanced road characteristics. The MPE is installed in the vehicle and then interfaced with in-vehicle systems that can utilise map data to tune driving parameters based on road configurations (i.e. tighter suspension when travelling on winding road etc)

The MPE hardware includes 1 GB flash memory which contains Navteq's maps and ST Micro's GPS technology. No visual representation of maps is required, which reduces the cost of the MPE as no additional in-vehicle hardware or interface is needed. Navteq has enriched its map database to include various road characteristics such as topography and curvature in addition to the location of traffic signals, highway lanes and exits as well as limited speed areas. This type of information can then be provided to in-vehicle systems, to allow these systems to make more informed decisions in advance of potentially dangerous circumstances, or to alert the driver if current driving behaviour will cause potential risks, such as accelerating while approaching a traffic signal that cannot be seen.

Road characteristics can be laid out to create an 'electronic horizon' for vehicle systems. Safety systems such as electronic stability control can use these road characteristics to anticipate changes in the road and prepare the vehicle for the changing environment. In contrast, most current systems use real-time sensors to determine changes in road status, for example when a vehicle enters a curve at high speeds. The data from the MPE can also be used for dangerous curve warnings and adaptive lighting systems. Having the data available ahead of time gives the vehicles systems more time to prepare, thereby increasing safety.

Continental: eHorizon

Continental has developed an ADAS concept that utilizes road attributes to better optimize fuel economy. The system is called eHorizon and blends geo-coded road attributes with vehicle location to optimize the vehicle for a range of road conditions. According to Continental, eHorizon is able to communicate with various systems within the vehicle. For example, gear changes can be optimized as eHorizon can recognize a curve or slope and react accordingly (e.g. advancing a gear shift to a higher gear). eHorizon can be applied to fuel based engine management by adjusting air and fuel intake parameters, however the system can also be applied to the power management of hybrid electric vehicles where slope will impact electrical charging characteristics.

When combined with GPS location data, the eHorizon acts as a sensor for safety applications that can optimize Powertrain control to improve efficiency. This solution is similar in principle to Navteq's MPE where information on road topography can be applied to safety applications and Powertrain control.

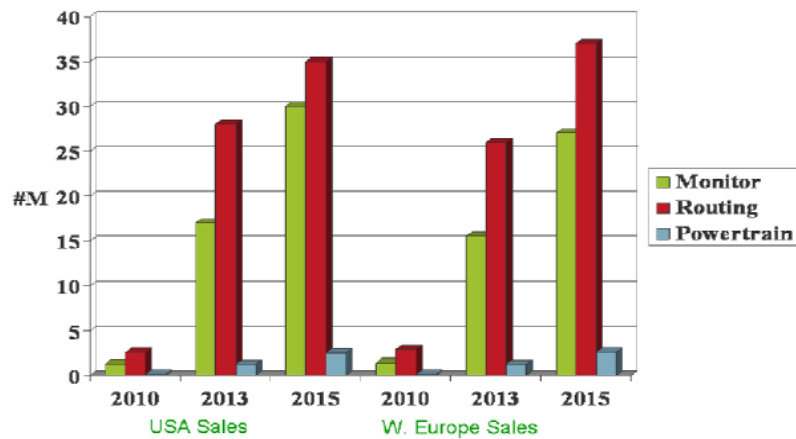
Continental says its eHorizon technology can also better manage a vehicles electrical load. For example, some in-vehicle electronic systems (such as HVAC cycles) can be actively controlled to manage electrical resources. The eHorizon concept from Continental is a modular ECU containing GPS, gyroscope, and wheel sensors while the navigation system provides the external eHorizon data.

Continental has also developed the Accelerator Force Feedback Pedal (AFFP), which makes use of the adaptive cruise control and gives warning of dangerous situations by vibrating and exerting counter pressure in the pedal. This informs the driver to release the gas pedal, prepare to brake and prevent a possible rear-end collision. The AFFP also helps with keeping a more constant speed, which reduces fuel consumption and CO₂ emissions.

Green Technology and EDAS are becoming more prevalent in the automotive industry. The examples listed above have all been introduced since the start of 2008.

Figure A5.4 shows the projected sales figures for green technologies relating to eco-monitoring, eco-routing and eco-Powertrain. Eco-Routing has the largest growth potential in the market sector both in the U.S. and Europe.

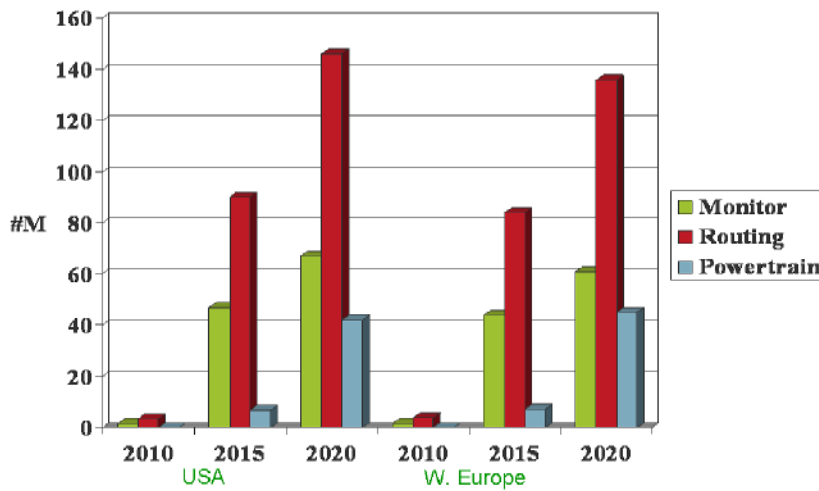
Figure A5.4 - Green Technology Forecasted Sales



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

Figure A5.5 shows the forecasted number of users of green technology in the areas of eco-Monitoring, eco-Routing, and eco-Powertrain. Again eco-Routing appears to be the technology with the most significant growth potential.

Figure A5.5 - Green Technology Forecasted Users



Source: Compiled by the authors from public and iSuppli sources and databases (See Appendix 1 for details).

European Commission

EUR 24601 EN – Joint Research Centre – Institute for Prospective Technological Studies

Title: Is Europe in the driver's seat? The future Competitiveness of the European Automotive Embedded Software Industry

Authors: Richard Robinson and Egil Juliussen (iSuppli)

Luxembourg: Office for Official Publications of the European Communities
2010

EUR – Scientific and Technical Research series – ISSN 1018-5593

ISBN 978-92-79-17658-6

doi:10.2791/49525

Abstract:

This report is one of a series resulting from a project entitled 'Competitiveness by Leveraging Emerging Technologies Economically' (COMPLETE), carried out by JRC-IPTS.

Each of the COMPLETE studies illustrates in its own right that European companies are active on many fronts of emerging and disruptive ICT technologies and are supplying the market with relevant products and services. Nevertheless, the studies also show that the creation and growth of high tech companies is still very complex and difficult in Europe, and too many economic opportunities seem to escape European initiatives and ownership. COMPLETE helps to illustrate some of the difficulties experienced in different segments of the ICT industry and by growing potential global players.

This report reflects the findings of a study conducted by Egil Juliussen and Richard Robinson, two senior experts from iSuppli Corporation⁶⁹ on the Competitiveness of the European Automotive Embedded Software industry. The report starts by introducing the market, its trends, the technologies, their characteristics and their potential economic impact, before moving to an analysis of the competitiveness of the corresponding European industry. It concludes by suggesting policy options. The research, initially based on internal expertise and literature reviews, was complemented with further desk research, expert interviews, expert workshops and company visits. The results were ultimately reviewed by experts and also in a dedicated workshop.⁷⁰

The report concludes that currently ICT innovation in the automotive industry is a key competence in Europe, with very little ICT innovation from outside the EU finding its way into EU automotive companies. A major benefit of a strong automotive ICT industry is the resulting large and valuable employment base. But future maintenance of automotive ICT jobs within the EU will only be possible if the EU continues to have high levels of product innovation.

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⁶⁹ For more about iSuppli Corporation, see at: <http://www.isuppli.com/Pages/Home.aspx>

⁷⁰ See Appendix 4

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