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Study of Worldwide Trends and R&D Programmes in Embedded Systems in View of Maximising the Impact of a Technology Platform in the Area

Final Report
18.11.2005

for the
European Commission
Brussels, Belgium

Information Society Technologies

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Foreword

Digital information technology has revolutionized the world within less than four decades. It has taken the step from mainframe computers, mainly operated as hosts in computing centres, to desktops and laptops, connected by networks and found nearly on all office desks and tables today. Our everyday life in business and at home is deeply affected by an extensive digital infrastructure. Today we communicate over computer networks, store and process our information on network servers connected to our personal computers and support and control technical and administrative processes by computers. Thus, computers have become every day tools deeply integrated into all kinds of activities of our life.

More remarkable, however, is the invisible revolution of digital technology embedded in all kinds of devices that are more and more connected by networks. In fact, not only the devices that we explicitly see as digital technology are part of the digital revolution.

According to the World Semiconductor Trade Statistics today about 98 percent of programmable digital devices are actually embedded. Embedded computers are found in nearly all more elaborate technical devices today and these embedded computers are the basis to provide the sophisticated functionalities of such devices. More and more innovative functionalities are added to existing technical devices and even completely new types of gadgets emerge. There are numerous examples. They start by simple everyday appliances in facilities and facility management such as heating, air conditioning, elevators, escalators, and mission control systems and many more. We find them in production units from robotics to production automation systems, in medicine where many technical devices for diagnostics and medical support are enhanced by computers as well as in the administration of hospitals closely connected with the medical treatment of the patients. In medicine, more and more devices are implanted into the human body and allow completely new solutions to cure diseases. Most remarkable is the existence of Embedded Systems in transportation, be it cars, trucks, ships, trains or airplanes. So, for example, about 5 percent of the world semiconductor market, which will reach about $227 billion (approx. €179 billion[1]) in 2005, is spent in the fast growing automotive sector.

Another important area of application is communication industry where the revolution of mobile phones, handhelds for communication and various forms of new networks are only due to the advances in computer systems and Embedded Systems. Examples for the ubiquitous use of digital technology are numerous. For instance, infotainment is heavily based on digital technology and the possibilities for Embedded Systems are literally unbounded, be it toys, computer games, music players, movie players or all kind of multimedia devices. Often, we do not even realize any more the digital technology in all the kinds of handhelds and mobiles we use.

The rapid development and the introduction of Embedded Systems in new application domains and new fields of technology introduce, of course, many technical and scientific

[1] Throughout the document for values expressed in US$, the approximated value in € (EUR) is given in brackets. The values in € were calculated on the basis of the median exchange rate of 2005 (1,27 US$ /€) [CBQ2005]. However, note that chapter 5 considered for conversion the purchasing party power (PPP) factor of the countries and year.

challenges. Especially the increasing number of connected Embedded Systems results in quite complex, technical solutions and, in addition, the networking of Embedded Systems brings new problems.

For most Embedded Systems it will be unacceptable if the quite high failure rates of classical computer systems will apply for them. So for example the Gartner Group discovered that there was a failure rate of 25 percent for notebook computers used in large American corporations. In analysing repair histories of 13 kinds of products gathered by Consumer Union’s Consumer Reports, PC World found that roughly 22 percent of computers break down every year. That makes them significantly worse on average than VCRs (9 percent), big-screen TVs (7 percent), clothes dryers (7 percent), and refrigerators (8 percent).

So, one of the big challenges is to manage the complexity and reliability of the development, operation, and maintenance of Embedded Systems. We have to understand much better how to capture the requirements for systems with embedded devices and how to be able to find out the user demands. For such systems, ways to create adequate human machine interfaces are needed, which are addressing the needs and capabilities of the typical users and to improve the systems’ usability and reliability.

Nevertheless, the ability to build up complex systems with embedded digital technology becomes one of the critical abilities for industry in modern technology. Since Embedded Systems are the driving forces of innovation and innovative products, they are the key to be successful in the global economical competition. The ability to build up technical devices with adequate embedded digital technology becomes one of the key competencies in modern technology.

In this field we can observe a number of important trends that have to be supported for the European industry to stay competitive. An important trend is the context awareness of embedded applications: Devices become multifunctional and mobile, are deeply integrated into mechanical systems, are connected by networks, including wireless nets, have adequate man-machine interfaces and adapt their functionalities to technical and personal situations.

Another trend is that systems are integrated within networks of devices. More and more data are carried by such devices, some of them being highly security critical such that security becomes one of the main issues. Second, it gets difficult to manage the data input to all the different devices. Thus, one of the main issues is to find ways to exchange data between different devices and to integrate their functionalities within a larger network.

What is proposed at the moment in industry is to set up initiatives that try to standardize the platforms and architecture for the Embedded Systems such that solutions can be exchanged and re-used between different devices. Another trend is to improve the development methods and tools, so that one can produce appropriate functionality for low costs and with high reliability.

A special application domain and a very important aspect of the future of Embedded Systems is ecology. Embedded devices will help to take care of ecological issues; in particular we can strongly improve the efficiency of many technologies by appropriate technologies, controlled by embedded devices. Examples are hybrid engine vehicles, which use a mixture of electrical and gas driven engines or electrical engines with several forms of energy supply including battery devices and also fuel cells. This of course needs sophisticated and well-designed control devices. These devices are embedded computer systems that monitor the overall system and control the engine respectively the power supply accordingly.

It is obvious that the current development increasing the quantity and quality of Embedded Systems will continue in the future. As a result we will get even a higher number of products and processes based on Embedded Systems, even more connected and deeper integrated into the everyday life of the population in Europe. Nearly all technical systems will critically depend on the reliability of their embedded system parts. Human beings will use embedded devices and will rely on them in their everyday life in a very deep and incomprehensive way. Devices from different areas like traffic, telecommunication, but also general information services or medical services will be integrated. Products will be enhanced by techniques like radio frequency identification (RFID) and as a result the logistics and the controlling over products will be more and more done within digital networks.

Taking all that into account we have to improve our abilities to invent, specify, implement and use technical devices based on Embedded Systems. We will, in particular, be depending on our abilities to build up large software applications for embedded devices. Therefore, this study is an important step to a comprehensive view of the future of Embedded Systems. By the various angles it offers, different groups of readers with distinct interests and backgrounds can gather valuable information.

Manfred Broy
Technische Universität München

Executive Summary

The nature of things tends to hide.

Heraklitos of Ephesos
about 500 B.C.

Embedded Systems (ES) are everywhere, even if not noticed at first sight. They are tiny computers that control the functionality of everyday life devices like mobile phones and cameras, elevators and vending machines, cars and manufacturing robots, and will even be integrated into our clothes. They help to increase the ease and safety of our life and make our work interesting and varied.

Embedded Systems imply economical power. They easily outnumber the entire human world population. With the constant evolution of electronic devices and software technologies, there will be more and more Embedded Systems integrated into any kind of equipment. Today more than 90% of computing hardware is built in ES and not in PCs or servers [ASAR2005].

Embedded Systems' importance is undisputed. The ES market size is about 100 times the desktop market [ROADNL2002]. Current forecasts predict a worldwide ES market volume of € 71 billion by 2009 [RG_229R] and a market penetration of over 40 billion of such devices by 2020 [ASAR2005].

But the domain of Embedded Systems is lacking of a comprehensive view of its sectorial, technological and market related aspects. Furthermore, analyses so far do not take into consideration the ongoing R&D programmes and initiatives.

The aim of the new "Study of Worldwide Trends and R&D Programmes in Embedded Systems in View of Maximising the Impact of a Technology Platform in the Area" is to provide an **assessment of the current state of the Embedded Systems** area as a whole and also to provide a better understanding of the basic drivers and effects of the ES market.

Methodology

The study focuses on six relevant sectors for Embedded Systems: automotive, avionics/aerospace, industrial automation, telecommunications, consumer electronics/ intelligent homes, and health/medical equipment. Trends in each sector and their impact on market development were analysed. The analysis is based on quantitative and qualitative data collected from reference studies, interviews with experts and the answers to a worldwide questionnaire [Quest2005] performed within the scope of this study (Annex A.4 and C).

Using data on top 700 companies for private R&D investments

Moreover the business R&D expenditures allocated to ICT and ES of the six sectors were estimated using the data of the worldwide top 700 enterprises published by the British Department of Trade and Industry [Dti2004]. Their general R&D expenditures were split into research for ES and ICT using R&D factors for the sectors and extrapolated to provide a view on the worldwide expenditures. The R&D factors were calculated on basis of data provided by the questionnaire, judged by the opinion of experts and applied using a well-founded methodology.

Detailed analysis of funding programmes for direct public funding

The analysis of the public funding for ICT and ES is based on data of the OECD Economic Outlook Database [ODB2005], IDATE reports [IDATE2002],[CSTI2003] and a detailed examination of the funding programmes of the most relevant countries of Europe, America and Asia. The complete computational method for both business and public funding is described in detail in section A.2.

Sector-based projection for 2009

Forecasts for 2009 have been developed based on past evolution of sectors and countries, and on growth market factors for Embedded Systems in the sectors.

The **outcomes of this study** are the result of a deep **methodological analysis** of the Embedded Domain **by sectors and worldwide regions** covering the **private investments and public funding programmes**.

Importance of ES for Europe

Europe is today a major player in the **field of Embedded Systems**. While the US is the worldwide leader in the area of traditional computing and data processing, Europe has driven the revolution in ES.

Europe is a major ES-player

Embedded Systems play a growing role in research and development (R&D) and in the economy of modern states as well. Its share in the overall R&D activities in Europe was 9% in 2003 and would reach 14% in 2009. And Europe, although being a major ES-player, may lose its leading position to the US due to the imbalance of money invested during the last decades. That might even threaten the competitiveness of European industries, where innovation is deeply influenced by Embedded Systems. **This is the most outstanding result of this study.**

ES support Europe's competitiveness

Embedded Systems have become a key factor in domains like automotive, industrial automation and medical devices. In these domains – at the same time – the European industry is currently leading the market. Therefore, Embedded Systems are already **a massive economic factor** that can help to maintain European competitiveness in these and other high-technological areas. The value added by embedded electronics of a car will increase from now 20% to 35-40% by 2015 [ASAR2005].

ES´ economic power for Europe

The enormous potential **of Embedded Systems for Europe's economic development** is documented by the comparison of the world market's estimated **growth-rate in ES of 14%** p.a. between 2004 and 2009 [RG_229R] and the average annual growth rate of the gross domestic product (GDP) of 4% between 1999 and 2002 [ODB2005].

The importance of Embedded Systems is evidenced even more by comparison of the electronics and the ES market [MEDEA2003]. The number of microprocessors, for example, is estimated to double between 2000 and 2010, which would result in nearly 3 embedded devices per person on earth [BuildAR2004]. Today 98% of all processors produced are used in Embedded Systems [EmbC2005]. Figure 1 shows how the market growth in Embedded Systems outpaces the growth of the electronics market.

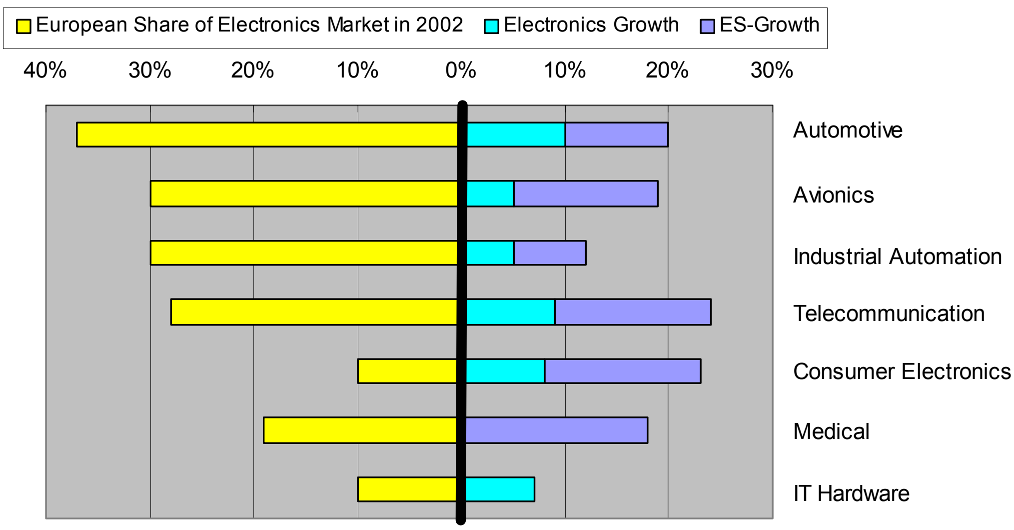

Figure 1: European share in the electronics market and market growth of electronics compared with growth of ES [MEDEA2003], [EmTe2005]

Embedded Systems are relevant for nearly every sector. The relevance is shown in Figure 2, where a great share of the costs of Embedded Systems' development and implementation in the final products' price is represented.

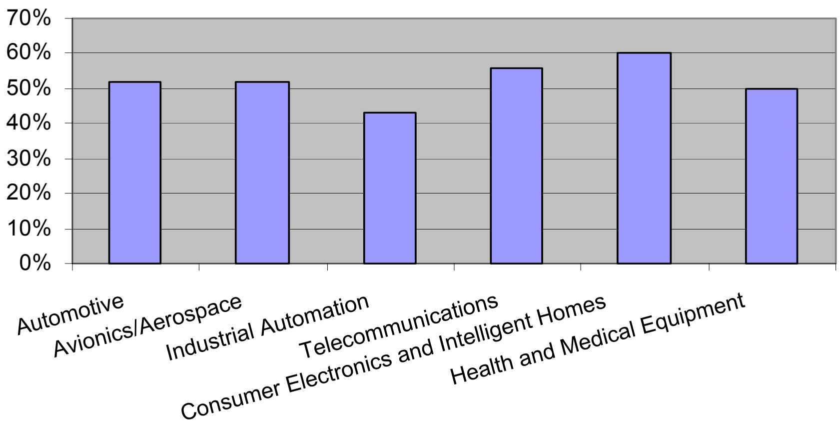

Figure 2: ES costs in final product in 2003 [Quest2005]

Europe's competitors

But Europe's current market position in ES is endangered by the US and challenged by some Asian countries. The **US** are keen on using results of ES in military and industrial applications. **Asian countries** have large home markets, an army of scientists and the technological know-how of manufacturing. The favourable conditions of cheap labour and a prospering domestic market in **China** together with nearby high tech production centres in **Taiwan** and **Singapore** allow rapid and continuing growth. Europe on the other hand has highly skilled labour, developed markets and a good infrastructure.

Current situation of R&D investments in Europe in ES area

An additional worrying fact is that the industry expenditures for research have been too low for the last two decades. As shown in Table 1 the private sector in Europe has invested only 17% of all R&D expenditures into ICT-related research compared with 36% in US. Another important difference is that in Europe almost 50% of all research in ICT is performed by industries in the secondary sectors, whereas in the US this percentage goes down to a 30%. This difference in participation of the secondary industry (where a high percentage of the developed software is embedded) explains that the share of R&D for ES in Europe (56%) is significantly higher than in the US (42%).

However, as shown in Table 2 in absolute numbers European investments in Embedded Systems R&D are only PPP[2] € 12.1 billion compared to PPP € 28.3 billion in the US. Even Asia, mainly Japan, is investing more in ES research than Europe. On the other hand, it must be stressed that in some sectors such as avionics and consumer electronics the European industry invests more in R&D for ES than its American counterparts.

Table 1: Estimates for 2003 of worldwide R&D efforts

2003	ICT R&D business expenses/ total business expenses	ES R&D business expenses/ total business expenses	Ratio of business expenditures for R&D in ES/ICT	Ratio of public funding programmes budgets in ES/ICT
EU25	17%	9%	56%	11%
US	36%	15%	42%	48%
JP	30%	19%	62%	5%
Rest of Asia	19%	10%	54%	10%
World	27%	13%	49%	19%

The importance of Embedded Systems in the European research performed by the industry (56%) is not at all reflected in the ratio of direct public funding in research programmes, where only 11% of the ICT budget is reserved for ES, whilst 48% is invested in the US. It is essential that these investments in ICT have to be maintained to assure the competitiveness of Europe.

Growing Market

Europe has to express its will for leadership in advanced ES. The will has to be shown by concrete actions that will demonstrate the **competence of Europe** in the area of Embedded Systems.

Leadership in new segments within traditional sectors

Europe has **the potential to gain market shares** in all sectors only if the efficiency of the development processes and – at the same time – the quality of the product can be increased. An exception is the consumer electronics industry as the market domination of Asian countries is expected to remain stable. Nevertheless Europe has to exploit the chance to become the leader in some new segments within sectors traditionally lead by Europe (e.g. telematics as part of automotive, remote maintenance as part of automation) as well as sectors not dominated by Europe (e.g. intelligent homes as part of consumer electronics).

Expected situation in the sectors

A prominent example is the **automotive sector**: the share of electronic components in the total value of a passenger vehicle is currently estimated at about 25%, with an expected increase to 33-40% in 2010 and up to 50% for the time after 2010 [Han2004a][Ele2003] [Mer2001]. But the largest consuming market for embedded software solutions seems to remain the telecom/datacom industry with an estimated CAGR of shipments of software products of over 12% [VDC04].

[2] PPP: Purchasing Power Parities

Europe lies behind in **consumer electronics**, which is the fastest-growing category of applying embedded software technology with an expected CAGR of over 15% [VDC04]. And Europe needs to keep pace in innovation in the **health and medical equipment** sector as well because this market will continue to grow rapidly due to demographic reasons. In 2003 350,000 employees worked in Europe in this sector [COMM2005]. ES will also drive the health market since it makes up approximately 25% of the total production value of medical technology [DGBMT2005].

The strong need for increasing R&D in embedded software is illustrated by the sector of **avionics** in which already 85% of the cost for design is software-related [Pri2003].

Market opportunity for ES engineering

In order to bridge the productivity gap, Europe needs to invest in ES specific **processes, method and tools** that help to develop more complex systems faster and more efficiently. For example, shipments of embedded operating systems, bundled tools, and related services increased by 21% during years 2003 to 2004. In the same period, the market for ES specific test automation tools grew by 20%.

Industry in Europe is not investing enough in innovation, especially for ICT

The industry in **Europe is investing substantially less in R&D than industry in US.** That is true for overall R&D level as well as for the ICT segment and also for the ES domain. The absolute differences for R&D expenses in ICT and ES are almost PPP€ 40 and PPP€ 16 billion as observed in Table 2.

On the other hand Europe has to increase their investments if **new market segments should be gained**. The size of the future market can be understood by looking at a forecast of the R&D expenditures in ICT and ES of the private industry. Based on the estimated market growth factors of ES sectors shown in Figure 1 the share of R&D for ES related to ICT will grow from an average 49% in 2003 to over 60% in 2009. The data in Table 2 is derived following our methodology for estimating private R&D expenses.

Table 2: R&D expenses by Business in 2003 and for 2009. Extrapolated data from 700 enterprises in PPP [Dti2004]

2003-2009	ICT R&D Business Expenses	ES R&D Business Expenses	ICT R&D Business Expenses	ES R&D Business Expenses
in PPP	2003		2009	
EU25	21.7 b€	12.1 b€	34.6 b€	22.9 b€
US	68.0 b€	28.3 b€	103.2 b€	54.9 b€
JP	24.8 b€	15.4 b€	40.7 b€	29.3 b€
Rest of Asia	14.2 b€	7.6 b€	23.1 b€	15.2 b€
World	128.7 b€	63.4 b€	201.6 b€	122.3 b€

Weakness of Europe for R&D in ES due to weak IT-sector

The **European weakness of R&D in ES is** mainly a **result of the weak** performance of Europe in the primary **sector of IT.** Therefore the strong position in the secondary sector has to be kept and improved.

ES expert's market

It is reasonable to assume that the need for experts in ES should grow with the same pace. Europe has therefore to take measures to offer an attractive environment for local and foreign ES experts.

The authors believe – underlined by the key findings of this study – that the **next years will be decisive** for the long-term competitiveness of some industrial sectors. Therefore, private and direct public funding has to be increased. For some sectors the expected R&D expenses are only about 1% of the sector's market for electronics components. This ratio is far too low to guarantee Europe's good market position.

Innovations and Trends in ES

Europe focus on innovation

Embedded Systems are the key to innovation. Innovative products might become a commodity, as everyone in the global market can produce them. The consumer will no longer select by quality or functionality, but by price. Alone **Europe cannot compete for commodity products** but has to look into **innovation** constantly, and bring new products into the market in shorter and shorter time.

ES relevant for almost every market sector

There is almost no industrial sector not integrating Embedded Systems: **automotive** or **aerospace**, **industrial automation** or **medical/healthcare**, **telecommunication** or **consumer electronics**, or many others. Embedded Systems have a deep impact on these industries and on the final consumer of their products as well.

Innovations in the various sectors

Some examples in the different sectors of innovation that will be enabled by ES are: energy-efficient, safe cars with near-zero emissions; car-to-car communication as a means to enhance safety; customisable, time-efficient air transport for passengers and unmanned aerial vehicles (UAV) for efficient freight transport; flexible, individualised and remotely controlled manufacturing; ubiquitous secure instant wireless connection; global and narrow-range sensor networks; ultra-low power processors; portable medical care equipment; intelligent buildings and vending machines.

Application trends in ES

The new generations of ES will show increasing complexity and a high demand of functional **safety** and **security**. On the one hand ES includes improved **autonomy** granting intelligent assistance for higher efficiency (e.g., regenerative braking devices in road and rail vehicles), improved **usability** (e.g., mobile devices switch to optimal available carriers), or higher **reliability** (e.g., drive-by-wire); collaboration facilitating **interaction** between systems to improve controlled processes (e.g., in-flight monitoring, telematics); **individualisation** and **customisation** support to strengthen economic adaptation of user-specific products (e.g., product lines of mobile phones, fast commissioning of assembly lines). On the other hand, they are no longer operating stand-alone but **networked** in various ways using wired or wireless (radio or optical) connections. The trend is **interoperability** of ES in networks.

Technology trends in ES

More **computational power** of embedded controllers combined with increased efficiency in terms of space and energy support **more flexible ES.** Due to engineering achievements new possibilities in process control have opened up. Improved sensor and actuator technology and additional integrated system capabilities provided on-chip increase the range of observable and controllable process parameters. Connectivity and network infrastructure increase the manageable complexity of controlled processes. Finally improvements in operating platforms and middleware support efficient development of reliable systems.

HW-SW productivity gap

The capabilities of hardware governed by the well-known Moore’s law are already out-pacing the productivity improvement of the designers. In the “System on a Chip” domain, the annual growth rate of number of transistors per chip is 58% while the ability to design gates by engineers grows only by 21%. The productivity challenge puts pressure on the software engineers asking for **new approaches to improve software productivity** and to match the speed of HW innovation.

Changes in the market

Application sectors are starting to merge, like electronics and IT or telecommunication and consumer electronics. For this reason ES **devices become multi-functional**. Repairing a TV has dramatically changed in the past years. Sony for instance claims to sell more digital cameras within a mobile phone than stand alone cameras.

Complex ES of the future

While touching all areas of human existence, from children’s toys to space probes, Embedded Systems become more and more a commodity. The added value of those artefacts of life will come from their **embedded intelligence**. Furthermore ES anticipate to evolve from present-day single or fixed-function multiprocessor systems to standard-based multiprocessor platforms and to ad hoc, opportunistic, adaptive, self-organising "processor eco-systems", probably starting in the year 2010.

Need for Actions

Converge on innovation on software

The continuous progress of innovation must become a key goal of European industry. All arguments of the study show that requirements in embedded software are more important than those in hardware, and that the market of the future will be largely software driven. In short, **software is the key to innovation**. We need brand-new ways of creating software systems that are **self-configuring, self-adapting and self-healing** based on loosely coupled, independently working components from numerous suppliers around the world [ITEA2004].

Concentrate on main research topics

To obtain multi-domain, re-usable innovations based on fundamental R&D results, Europe has to concentrate on topics as: reference designs and architectures, product line development, middleware and seamless connectivity, system design methods and tools.

ES engineering approach

To overcome complexity inherent to Embedded Systems and to meet the demand for innovative, high-quality solutions, a **systems engineering** approach must be applied. This approach has to integrate domain engineering, electrical/hardware engineering, and software engineering in order to cope with the multidisciplinary character of ES solutions. On the one hand, for developing embedded hardware/software systems on a large scale, a **higher level of abstraction** is needed to manage the new complexity of networked ES. On the other hand does the inherent heterogeneity of ES still require a detailed understanding of platforms, such as HW architecture and protocols.

Verification at design level

Software requirements have never been higher than in the field of ES, because often our life will depend on it. **Theoretical foundations** for ES and its composition and orchestration are required to tackle the issues mentioned above to deliver correct and seamless models, methods and tools. Research has to focus on **verification**, which has to be an integrated part of design to create a label **"correct-by-construction".**

ES reference architecture

A reference architecture for ES could support improved product development in a wide variety of application domains. It should be developed in cooperation of the experts of the involved industrial domains and of the basic researchers of universities and other institutes and it should support the interoperability of compatible components.

Broader use of standards and Open Source

The use of standards makes it much easier to split the production process between various participants. Wherever possible, **standardised operating systems** should be used for ES, particularly regarding the emerging needs of network capabilities in ES. To weaken the monopolies of non-European key players in the area of operating systems for ES, the idea of Open Source should be promoted. Concerning the **real time capabilities** of such systems research is still needed.

Standardisation efforts

For the production of ES the establishment of standards is essential. That is why a major interest of Europe must be to push the use of standards middleware platforms, like J2ME (Java 2 Microcontroller Edition) or the OSGi (Open Service Gateway Initiative) framework, and the fast development and adoption of **new (European) standards**. Special attention has to be given to a broader use of existing standards like ethernet technology, and Internet protocols. In connection with the use of standards problems like timeliness and reliability have to be addressed by further research.

High-level and domain specific languages

Research activities in the ES context should also concentrate on designing appropriate **high-level and domain specific modelling and programming languages**. Those languages should support reliability, efficiency, and portability aspects. Predictable run-times require further research to improve the reliability of hard real-time systems. Such programming language should have a precise, well-defined semantics, in order to use appropriate verification, validation and test techniques of the programs. A profound theoretical foundation is required for such new languages and methods to guarantee their scalability and appropriateness for implementing Embedded Systems.

Appropriate tools and tool chains

The introduction of domain specific programming techniques must be supported by the introduction of appropriate tools for using these techniques. With the shift from implementation towards design, the use of different programming languages and different software platforms, it becomes important to intensify the research for dedicated **tool chains** supporting **a seamless model driven development process**. This seems to be one of the most important points for Europe to succeed in the global competition.

Changes need in education

Regarding the multidisciplinary character of the ES domain it is necessary that a **technological transfer** between these different disciplines happens already **at university level.** This can be achieved by **special Embedded Systems courses** or by **institutes**, which focus on the field of ES. An integrating view requires interdisciplinary knowledge as well as a deep theoretical foundation. A related relevant aspect is the education **at school**, where the technical and mathematical comprehension has to be encouraged. Also an organised knowledge transfer should be developed to **re-school and train experts** to become certified developers of ES.

Promoting an ES engineering discipline

We are witnessing how a **new discipline of Embedded Systems Engineering is born**, mainly driven by the need of research and expertise. In the coming ten years according to EC Commissioner for Research Philippe Busquin [ELS2001], Europe stands to be short of up to half a million scientists, researchers and engineers.

Europe's current pivotal position in education

Due to its strong background both in **basic research** and in **industrial engineering**, Europe is well positioned to meet the challenges by acquiring a leading position in the discipline of ES engineering and to provide a labour force of ES engineers. They will become knowledgeable in ICT and the specific domain fields. This requires new ways of educating future ES experts. Today university education fails to connect the different perspectives like computer science, physics and the respective domain knowledge.

Monitoring EU's progress by specific key indicators

New measures for the new discipline are required. The key indicators that are currently used by OECD or the European Information System (EIS) are not enough to monitor the impact of ES on the competitiveness of Europe. Additional indicators that are more oriented towards European competitiveness in ES could be:

- number of experts trained in ES,
- number of patents related to ES extracted from existing patent databases (for example with a method proposed in the study),
- revenues per employee in the market for components and end products, and
- relationship between penetration with ES and average productivity in industry.

Joining Efforts

Focusing research and development

It is essential to coordinate activities and resources in Europe in order to keep technological leadership in ES and to redress the present imbalance in productivity growth in comparison to the US and Asia. This can only be done by significant **investment in research and development** in the ES sector. European efforts must at least match, if not exceed, comparable investments made in the rest of the world. This investment should be strongly encouraged.

Doubling European effort in ES

Keeping up the current pace of the expenditures of European industry for research in Embedded Systems will increase from PPP€ 12 billion in 2003 to PPP€ 22 billion in 2009. The worldwide Embedded Systems **population of scientists and engineers** is also expected **to double over the next 6 years**.

Higher private investment in R&D is needed

Embedded Systems is not only the key to innovation but also the **key to growth** as it provides the competitive edge to products. Hence it is the **natural interest of all enterprises** to invest in R&D for innovation. However, currently private industry in Europe is investing with 1.2% of GDP far less than other countries like Israel with 3.6%, Japan with 2.4% and US with 1.8%. Huge efforts in R&D are needed by the private industry, as entire production processes need to be changed radically. It is recommended that the private industry should at least **double its investments** in this area.

Combining LE's and SME's efforts

In the private industry **combined efforts** of large enterprises (LEs), and small and medium enterprises (SMEs) promise to achieve essential advances in Embedded Systems. These technological advances together with the use of a systematic engineering approach for ES help to establish a **leadership in functionality, quality** and **innovation**, while maintaining competitive pricing. LEs should centre on basic research and SMEs on domain-specific development. Furthermore a proactive stimulation is needed to guarantee the emergence of a new supply industry for new components, tools and design methodologies supporting ES.

Increased funding for basic research

In addition, **public funding** can alleviate the R&D costs by supporting the basic research for common techniques, tools, architectures and designs that can be used by all sectors and are needed to satisfy the urgent requirements. However, the public funding from commission and member states will leverage the private investment in R&D significantly.

Advances of PPPs

Public-private partnerships can help to manage public and private investments and R&D activities and transform innovations in mature products that can be introduced into the market. The acceleration of the product development lifecycle from the idea to a final product will have positive **impacts on productivity** and **competitiveness** and therefore on the **economic growth** of the region.

Support of an ES eco-system

Such a public-private partnership (PPP) in the area of ES in Europe demands a strong **commitment of the public and private sector,** an operational programme and systematic evaluations of the results. The public sector supporting the initiative has to include regional and local governmental organisations. LEs, SMEs, research institutes and universities form an integrated eco-system, which is ready to master the challenges of advanced ES and would become **a key factor for the development of all technical devices and products**.

Consolidating Europe as the centre of the ES world

Like the Malaysian political vision to make their country the centre of the multimedia world, the goal should be to make Europe **the world-leading region of Embedded Systems** with a well-known reputation of concentrating the know-how and the production for this trend-setting technology. Differences in culture, environmental context and technologies impose the need of different strategies to achieve similar goals.

Creating world's leading ES centres of excellence

Even if the technology to cooperate efficiently in remote locations is there, that's why a research environment is best implemented in physical proximity. It is important to create an infrastructure that supports innovation in form of multidisciplinary Centres of Excellence (CoEs). In these CoEs a staff of researchers from both academic and industrial areas can co-operate and compete in an enhanced technological environment. CoEs will attract **scientists and experts from abroad** and all major players.

Stopping the European brain drain

Today many scholars in Europe have to look for academic employment in universities elsewhere. Europe has to make an effort to **keep the experts in Europe**. The value of research in universities needs to be re-emphasised. New financial models must be discussed allowing a co-financing of the research activities by private industry. At the same time a better integration of researchers in the labour force has to be achieved to cover the industry needs for experts. Assuming average costs for a researcher of PPP€ 130 thousand the estimated R&D expenditures of PPP€ 63 billion by industry reflect a need for 488,000 experts.

Using the diversity of Europe for our benefit

Last but not least, we must **integrate the new "tiger countries"** from Central and South-East Europe, like Poland and Bulgaria into our efforts. Looking at the fast growing markets in Asia it can be noted that even in Taiwan the growth is realised by employing people from areas that can still benefit economically. For old Europe this means to **employ scientists from the new member states**. Making use of the creative potential and the courage of innovation that exists and is developing in these countries would encourage "traditional engineering" Europe and strengthen the community in a number of areas.

Recommendations at a Glance

Europe needs to take a remarkable step forward in developing and deploying ES technology in order to **keep its overall economical competitiveness** with respect to other regions of the world.

In order to maximise the impact of joint efforts we recommend to focus on the following topics:

1. significant increase of public and private investments for R&D in the ES domain,
2. set up a public-private partnership in the area of ES in Europe,
3. creation of Centres of Excellence (CoEs) in ES for interdisciplinary working of industries and academia,
4. support of new industrial eco-systems by specific policies, processes and action plans,
5. keep researchers in Europe and integrate them in the labour force,
6. strengthen international cooperation attracting scientists from abroad,
7. intensive research on software development methods and tools,
8. use of standard technologies, protocols and operating systems, mainly Open Source software,
9. promotion of Embedded Systems Engineering as a new discipline,
10. ease access to venture capital for the Europe's high tech industry,
11. regular measurement of ES impact on market development, productivity and competitiveness,
12. integration of the Central and South-Eastern European "tiger countries".

Going that way Europe has a good chance to **overcome present shortcomings**, to gain ground in the **worldwide competition**, to **increase the number of jobs** and to grant prosperity and welfare to the European people.

1 Introduction

ES all around us

Computers are all around us. We merely don't notice them. They hide themselves in mobile phones, cameras and motorcars, in elevators and vending machines, aeroplanes and assembly lines. They do their work without direct human interaction and are integral parts of the respective visible devices and machines. These Embedded Systems (ES) have become the main application area of information technology hardware now. More than 98 percent of all processors produced worldwide work in ES today [EmbC2005]. **This means on the other hand that today** the volume of the ES market is about 50 times as large as the desktop market **– an economic factor that cannot be over-estimated.** In 2000 the number of ES microprocessors had already surpassed the entire population of the earth, and the number continues to grow rapidly [Bies2005].

ES: An area of strategic importance for Europe

The field of Embedded Systems has been recognised to be of strategic importance for Europe. The advances in this field can be applied to potentially all sectors. ES add value to the products and are more and more responsible for the innovation and competitiveness of entire sectors like automotive, avionics, manufacturing, consumer electronics, telecommunications and health. The increased functionality, the networking and the engineering tools that will be developed in due course will create new markets.

Call for tender to gather information

In order to decide on the best strategies to support the competitiveness of the European industry, the Embedded Systems Unit of the Information Society at the Commission has launched a "Study of Worldwide Trends and R&D Programmes in Embedded Systems in view of Maximising the Impact of a Technology Platform in the Area" [EUCfT2004].

1.1 Background Information

In the sixties began the IT-Revolution

In the sixties the Information Technology (IT) revolution began with the establishment of an IT-industry as a new sector and the transfer of know-how from university into products of the IT-industry. Later products, such as operating systems (OS), databases (DB), programming languages, CASE tools and applications were introduced and transferred to other industry sectors. Today IT is well established in all sectors.

The silent embedded revolution today

As Embedded Systems by nature were not visible and their functionality for a long time was rather limited, they remained almost unnoticed. However, with the advances in hardware (HW) and the trends to make devices smaller and cheaper, Embedded Systems have become omni-present and another revolution started quietly across all sectors - a revolution that was initiated by industry rather than the universities.

Lack of coordination leads to exploding costs

However, common systems engineering problems have not been properly and thoroughly addressed on a scientific basis. Thus applications in the sectors often lack in quality, are designed bottom-up, and are developed from scratch for each new generation of HW. This leads to exploding development costs. In addition, the move from micro- to nano-technology in chip production is becoming so expensive that the private IT-industry alone cannot afford the costs. Hence the IT industry tends to cut costs by moving the production facilities to other regions of the world, or by leaving the field that is then monopolised by a few market leaders.

Fatal effects on the European economy

The loss of the innovative edge in the areas of nano-technology and Embedded Systems would have fatal consequences for many key sectors of the European economy [ENIAC2004].

Previous initiatives

In recognition of the above consequences, the common challenges and research topics for Embedded Systems have been addressed by several European and national initiatives and programmes. Well known examples are the EUREKA initiatives of ITEA and MEDEA, specific projects within the 6th Framework Programme (FP6) such as ARTIST and multiple national programmes, like PROGRESS and FIT-IT.

Vision for Europe

In March 2003 the European Commission presented to the European Council an action plan to “make Europe the most competitive and dynamic knowledge-based economy by 2010” [COM2003]. The action plan aimed at co-ordinating and focusing the research efforts of all member countries. To give weight to the vision the members have committed themselves to increase the overall expenditure for research and development (R&D) efforts to 3% of the Gross Domestic Product (GDP) by 2010.

Technology Platforms are to coordinate and focus research efforts in Europe

The ambitious goal of the European Commission, however, can only be reached by a common effort of the private and public sector. Hence “Technology Platforms” were introduced to integrate research efforts for strategic sectors, technology or engineering areas. The Technology Platforms have to overcome the structural challenges such as

(1) co-ordinating multiple funding programmes and

(2) integrating different initiatives across all
  - European nations and
  - multiple sectors.

In the future all research efforts related to the field of Embedded Systems will be co-ordinated and integrated along a common roadmap specified by the Technology Platform for Embedded Systems “Advanced Research and Technology for Embedded Intelligence & Systems” (ARTEMIS).

The strategy for technology platforms

The European Commission follows a fourfold strategy with the establishment of Technology Platforms

- to step up public and private investments in leading-edge technologies to stimulate economic growth (3% of GDP),
- to create a coherent approach on research priorities using the platform as a common forum,
- to mobilise research and innovation efforts also within SMEs,
- to propagate the use of technology within the framework of societal policies.

1.2 Objectives of the Study

A lack of a common view

Currently there is a lack of a comprehensive view of the Embedded Systems domain addressing technological aspects (software, hardware and design process), sectorial (impact on different processes, products and services), market related and funding (R&D initiatives and programmes and public-private partnerships).

Overall aim of the study

The overall aim of this study is the assessment of the current state of the Embedded Systems area as a whole that takes into account these technological, sectorial, market related and funding aspects.

Objectives of the study in detail

The objectives of this study are:

(1) to get a holistic view on the fragmented domain of Embedded Systems, which is given by

   a. an assessment of the impact of embedded technologies on market development of industry and services, and the analysis of the enabling effects of embedded technologies in the different application sectors (see chapter 3).

   b. technological trends in the area focusing on the most used and most promising technologies. These trends are accompanied by background information on the different application sectors and standards of the different technological fields as well as by the underlying market trends (see chapter 4).

(2) to get an overview about public and private R&D investments of countries outside Europe related to the development and adoption of embedded technologies. The study provides a general comparative picture of the public R&D expenditure of the EU with respect to public expenditure in other relevant non-EU countries (see chapter 5).

(3) to collect best practices from other similar initiatives to technology platforms carried out by public-private undertakings in high-tech areas related to information and communication technologies. The study provides good hints for the operation, coordination activities and transfer of results for the technology platform in Embedded Systems (see chapter 6).

Maximising the impact of ARTEMIS

This study intends to provide a basis for the work of ARTEMIS to maximise the impact of their work. The current trends and their impact on the competitiveness are analysed and the basis for the recommendations formulated.

Awareness for the embedded revolution

The aim of the study is also to raise the awareness of the importance of the embedded revolution that is currently taking place (see chapter 2).

1.3 Scope of the Study

Mapping trends to the globe

The scope of the study includes Embedded Systems, their software and hardware components, and processes and tools to design and develop them. Given the above objectives the study analyses current and future trends in the field of Embedded Systems in terms of their impact on regional markets and competitiveness of industries. Trends, however, are not analysed in technical depth, nor does the study take a stand on competing technical de facto standards.

Patent research and online questionnaire

A systematic analysis of patents was performed and an online questionnaire was compiled. More than 250 experts in the field chose to participate in the survey. The results of the survey have been integrated into the study.

Comparison of R&D programmes

R&D programmes and initiatives for the development and adoption of Embedded Systems abroad were compared with the situation in Europe. The programmes will be compared in terms of their funding instruments, their focus and the way they have been implemented. A quantitative comparison of public funding for research in Embedded Systems can only be used as a rough indicator, as the amounts can often only be estimated. This is due to the fact that in most countries the field of Embedded Systems is not yet a category for reporting/auditing expenditures in R&D.

Best practice report

Finally similar ICT-initiatives inside and outside of Europe not restricted to Embedded Systems were investigated to provide best practice recommendations for the Technology

Platform ARTEMIS in terms of governance, way of working and effectiveness. It is not within the scope of the study to give a complete list of similar initiatives worldwide.

Intended audience

Policy makers, stakeholders and managers in the field of Embedded Systems, can use the study as it provides a non-technical overview of the perceived importance in Europe and in the rest of the world.

1.4 Structure of the Study

Chapter 1: Introduction

In the introduction the motivation for this study, its objectives and the scope of the study are presented.

Chapter 2: Definition and characteristics of ES

The revolution of Embedded Systems is a silent one. Without being conspicuous it has already affected every sector of the industry and today it will be difficult to find an appliance or device, which does not have an embedded system on board.

Chapter 3: Impact on market development and competitiveness

In order to assess the importance of Embedded Systems the direct and indirect economical impact of their development and deployment is analysed. The direct economical value can be derived from the current and future market potential. The indirect value is related to the increase in productivity and competitiveness of entire industries.

Chapter 4:Trends in ES

A more detailed view on how the embedded world penetrates the various sectors and technologies is obtained by studying the trends. Some of these trends still pose challenging problems and are topics of research, others, however, have already resulted in new technologies and standards. The trends are listed in three dimensions – along the general market trends, the market sectors (industries), and the technology fields. Since these trends interact with policies and environmental issues, the influence of these factors is considered too.

Chapter 5: R&D Programmes and initiatives for ES

Research programmes and initiatives outside Europe are investigated and compared to provide a consolidated picture on the worldwide awareness of the importance of Embedded Systems. Using the available information and educated guesses, an estimation on the overall public funding in the area of Embedded Systems is compiled.

Chapter 6: Worldwide initiatives

Technology Platforms are not only a new initiative to streamline the research efforts and to establish a truly European Research Area (ERA), but also a form of a public-private partnership to raise additional funds. Similar types of initiatives will be analysed and best practices will be recommended for ARTEMIS.

Annex: List of references and method used in the study

In order to focus the study on its core objectives, all supportive documentation, references to publications, along with a description of the methodology used, will be listed in the annex.

Short descriptions at the margin are provided to give a synoptic view of the paragraphs, whilst the more relevant concerns within the paragraphs are highlighted.

2 Characteristics of Embedded Systems

Trade in high-technology goods accounted for over 25% of total trade in 2000 and 2001, up from less than 20% in the early 1990s [OECDST2003]. And such high-tech goods like industrial machines, automobiles, medical equipment, cameras, household appliances, airplanes, vending machines, and toys (as well as the more obvious cellular phone and PDA) are among the manifold possible hosts of an embedded system.

Content of this chapter

In this chapter, an introduction to the world of Embedded Systems is given. After defining and explaining the most important terms and concepts[3], today's broad usage of Embedded Systems will be shown. Although ES have gained high relevance in practically all sectors, there are unsolved problems and major challenges for the future research and development. This is mainly due to the increasing complexity, the rise in functionalities, the demand to limit costs, and the need for autonomous and networked systems.

2.1 Definitions and Characteristics

ES are programmable electronic sub-systems

Formerly, Embedded Systems often have been described as being "not directly visible to the user", i.e. the user does not necessarily realize that he is using a computer. To give a more precise definition, we characterise Embedded Systems as **"electronic programmable sub-systems that are generally an integral part of a larger heterogeneous system"** [ART2005].

Software aspect of ES: Main topic of this study

The improvement and miniaturisation of the hardware is a research topic of immense complexity in its own right and is the topic of the Technology Platform of ENIAC. Hence, we will only give an introduction to the current hardware trends, but else and in line with ARTEMIS we will focus on the software aspect of Embedded Systems.

ES vs. "classical" IT

The software of Embedded Systems differs from conventional SW for a general-purpose PC in a number of characteristics that justify the declaration of **Embedded Systems as a new field of research** parallel to the classical information technology.

Embedded Systems often:

Autonomy

- are required to function without maintenance, which leads to more complex requirements concerning autonomous functioning, for example for building automation or their use in military or environmental research, where systems are set adrift and required to run for several years.

Flexible networking

- are autonomous components that are more and more intended to work together in spontaneous ad-hoc networks leading to flexible, spontaneous "processor eco-systems" [Schu2005]. They have an emphasis on machine to machine communication in spontaneous networks, which will be used in automated highways, advanced air traffic control, or next-generation factory automation as well as for military use in unmanned vehicles.

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[3] For a comprehensive list of terms and abbreviations, please see the glossary in the annex

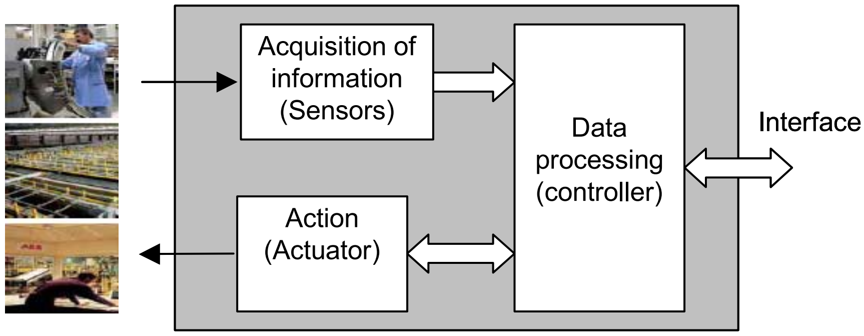
Fault tolerance
- have a higher emphasis on fault tolerance (example: if the software had an error rate of 0.1% this would lead to 500 exceptions in surgeries per week and 18 airplane crashes per day [Lehr2000]). We call an embedded system "safety critical" if human lives or the intactness of facilities or equipment directly depend on its correct operation, as it is the case in domains like avionic, medical or automotive devices.

Restrictions on user interfaces
- have stronger restrictions regarding the user interface, e.g. limited size of displays, limited attention of the user and/or extreme conditions of use.

Real time operation
- operate in a "real" time frame. Time critical systems control and react to physical processes taking place in a timed fashion, i.e. those systems have (and need to have) a definitely restricted period of time between the input signal and their correct reaction. We distinguish between hard real time systems that have to show reactions within hard time bounds and soft real time systems that should react also in some time bound, but where a moderate delay is not catastrophic. Medical devices, brake control in cars or power plant control systems are examples for hard real time.

Reactivity
- are reactive as to continuously respond to incoming events and state changes. In all of the industries considered, most Embedded Systems are used for surveying and controlling physical processes. A typical setup is shown in Figure 2-1: physical measurements from the system's environment are continuously taken by dedicated sensors, and provided to the embedded system as state variables. The controller calculates, based on the sensor data and its previous state, a number of updated values for associated actuators, which influence the process in turn.

Figure 2-1: Diagram of a discrete automation solution



- are often heavily based on control theory, i.e.. the mathematical theory of how to manipulate the parameters affecting the behaviour of a system to produce the desired or optimal outcome.

Restricted resources
- have strong restrictions regarding "resource management", i.e. the use of memory, energy, space and processing time.

Redundancy
- will have to compensate for failures in the underlying HW by using redundant components and a coordination effect between the components.

2.2 Penetration of Embedded Systems

History of ES

The first mass-produced embedded system was the guidance computer for the Minuteman missile that had been in service since 1960 [Jour1996]. In 1968, the Volkswagen 1600 used a microprocessor in its fuel injection system, launching the very first embedded system in the automotive industry [Emb2005].

Current market volume

Today, a car's electronics cost more than the steel used to build it. In fact, Embedded Systems are also spread in all other sectors of the economy and in all areas of our private life. In 2000, there were around 10 billion microprocessors (see Figure 2-2). The number of microprocessors is estimated to double until 2010, which would result in nearly

3 embedded devices per person on earth [BuildAR2004]. Today, 98% of all processors produced are used in Embedded Systems [EmbC2005].

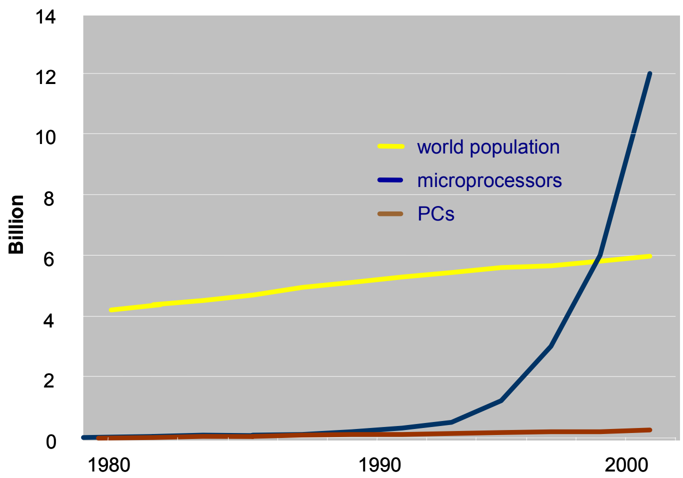


Figure 2-2: The worldwide number of microprocessors [Bies2005] as an indicator for the penetration of ES

Electronic components market

The worldwide market for electronic components, including display components, sensors, semiconductors, etc. reached a volume of € 257 billion in 2004 [EECA2005]. Europe, Japan and the Americas have a market share of 19% each, whereas the Asia-Pacific region is still the largest and largest growing market registering a 43% market share. Currently, the component industry in Europe, which grew by around 7% between 2003 and 2004, supports over 226,000 direct jobs.

ES drive the electronics market

The volume of "the worldwide Embedded Systems market" was estimated at € 37 billion in 2004 and is expected to reach € 71 billion until 2009 with an **estimated growth-rate of 14% p.a.** between 2004 and 2009 [RG_229R]. In contrast, the worldwide hardware and software market including PCs and servers etc. is expected to grow by 8% p.a. [RG-229R]. Thus, Embedded Systems are the main driver for the whole electronics industry. The comparison with the growth of the gross domestic product (GDP) which reached an average of 2.15% p.a. in Europe between 1999 and 2002 [GDP2005] also shows the enormous potential and the **relevance of Embedded Systems for Europe's economic development**.

Specific software related segments

Within the ES market, "shipments of embedded operating systems, bundled tools, and related services reached over € 1.13 billion" in 2003 which represents an **increase of 20.9% year over year** and "the market for SW development tools and related services reached over € 312 million" [RG_229R]. Slightly different numbers are presented in Software market

But the **real value share of software, tools and services is by far greater** than the numbers presented here since the numbers presented above only concern the market for packaged products or COTS components, which is concentrated primarily on hardware. Therefore the shown numbers must not be misinterpreted because software usually is not bundled and sold like hardware modules, i.e. standard software modules for electronics components – and so for ES – do not exist on a broad scale. Instead, the software (application software and very often even for operating software and middleware) is realised and added by the OEM and thus is not included in these numbers that explicitly and solely show the trade volume. An analysis of the total value creation would result in a completely different picture with much higher numbers for embedded software, making it the most important position.

Table 2-1 is based on [VDC2005], [VDC2005a], [VDC2005b], [VDC2005c] and shows the figures for 2004; the growth rates are calculated based on comparisons between 2003 and 2004 data. Both sources have two implications: on the one hand, growth rates are constantly high; on the other hand, the Americas' market is still the largest consumer of tools and services for Embedded Systems design, development and testing with around half of the overall revenues coming from there.

Software market

But the **real value share of software, tools and services is by far greater** than the numbers presented here since the numbers presented above only concern the market for packaged products or COTS components, which is concentrated primarily on hardware. Therefore the shown numbers must not be misinterpreted because software usually is not bundled and sold like hardware modules, i.e. standard software modules for electronics components – and so for ES – do not exist on a broad scale. Instead, the software (application software and very often even for operating software and middleware) is realised and added by the OEM and thus is not included in these numbers that explicitly and solely show the trade volume. An analysis of the total value creation would result in a completely different picture with much higher numbers for embedded software, making it the most important position.

Table 2-1: Market data for 2004 on tools and services

Characteristics Market (2004)	Market volume in million €	Market growth	Largest consuming region and its share	Largest consuming sector and its share
Embedded OSs, bundled tools, related services	712.6	20.9%	Americas 52.7%	Consumer Electronics 41.7%
SW development tools, related services	195.1	1.8%	Americas 48.2%	n.a.
Design automation tools, related services	275.6	n.a.	Americas n.a.	Military / Aerospace, n.a.
Test automation tools, related services	65.7	19.8%	Americas 50.8%	Military / Aerospace, 27.6%
	1,249.0	17.0% (weighted average)		

Highest growth rate for embedded software

However, software shows the highest growth rate within Embedded Systems: the **estimated AAGR between 2004 and 2009 are 16% for embedded software**, 14.2% for embedded hardware (integrated circuits, IC), and 10% for embedded boards [RG_229R]. This is in line with the general trend across all industries since software has been the fastest-growing component of ICT investment. In many countries, its share in total investment "multiplied several times between 1980 and 2000" [OECDST2003].

Conclusion: Crucial relevance of the ES industry

Comparing for example the Average Annual Growth Rate (AAGR) of the market for embedded software (14%) with the estimated growth rates of GDP (about 2%) shows the crucial relevance of the Embedded Systems industry for Europe's economic development. In all sectors, a **strong increase in the value of Embedded Systems is expected**; the most prominent examples are telecommunications (with the number of mobile phones rising and added functionalities), logistics, automation, or automotive where **further "softwareization" is predicted**.

2.3 Challenges in Research and Development and Education

Knowledge push – an important factor of technological progress

Technological progress never results solely from the existence of new technologies, since technological innovations are only one driver of advancement (technology-push). The second force is new market and user needs (market-pull). The application of new technologies continuously catalyses further technical innovations. This cycle, combined with the rocketing growth of technologies, leads to a spiral effect [Kond2001]. But this cycle can only keep its positive strength if the ability of the market exists to build up knowledge, exchange it between all market participants and transfer it into new products, processes and services. As shown in Figure 2-3 we call this force “knowledge-push” to underline its strong effect.

Technological challenges specific to ES

The specific technological challenges in the domain of Embedded Systems, compared with Software Engineering in general, arise

- from the restrictions mentioned in section 2.1, for instance the strong influence of physical restrictions of the hardware that have to be considered and need to be compensated by software design,
- from the increase in functionalities, which an embedded system has to provide,
- from the rising complexity of functionalities, e.g., the number of lines of code per functionality in aircraft systems has increased from 10 to 10^5 between 1970 and 2007 [Vern2005], and
- from the rising number of single Embedded Systems that are networked and establish a higher-order system (miniaturisation enables the integration of several Embedded Systems in one device, which increases its complexity).
- from the heterogeneity of involved domains, such as mechanical/electrical/control engineering, and computer science

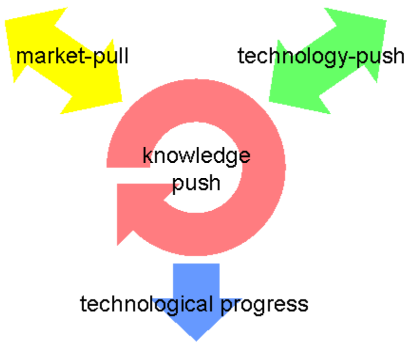


Figure 2-3: Driving forces of technological progress

Increasing complexity requires new approaches

These aspects are often subsumed under the term “real-world constraints” [ART2005] and induce severe challenges for research, development, and education within Embedded Systems. Those challenges, among them the trend towards higher relevance of software, require new ways of designing, developing and using Embedded Systems. In fact, with the many multidisciplinary challenges inherent to the field, **design and validation of ES is a proper discipline of its own**, a fact that has long been neglected. The challenges in detail, and the possible elements constituting the ES discipline, are described in the following paragraphs.

Challenge 1: Softwareization

The increasing functionality per system can only be realised by a **shift from hardware to software**, often referred to as **“Softwareization”** [Dorm2005]. This is because software and programmable units offer more options. Also, it is more difficult and more time-consuming to develop and to change a printed circuit board than software code. Through this focus on software, also more variants can be built, the production of Embedded Systems gains flexibility and costs can be reduced.

Sub-challenge: Productivity gap

At the same time, we observe a growing gap between the size of software developed and the developers' productivity, which indicates a strong need for better methods, processes and tools [Dorm2005].

ES discipline: need skills from software engineering

To meet the softwareization challenge, the ES discipline therefore will have to consider those elements of software engineering that are vital for ES design, such as programming languages and compilers, modelling notations with good understanding of semantics, testing methods, and software design processes, to name a few topics.

Challenge 2: Multifunctionality and flexibility

Figure 2-1 is typical for embedded controllers that measure, control and operate in many specific domains. As long as the "smooth" functioning of a single purpose embedded system is concerned, control theory is the appropriate discipline. Control theory in particular ensures that systems' reactions are smooth and stable, i.e. that the systems do not overshoot or stay behind their reactions. However, more and more of today's systems are multifunctional and are required to react in a very flexible way to events, as for example in mobile devices.

Sub-challenge: Integrating different fields of knowledge
Sub-challenge: Integrating hard- and software engineering

Designing such electronics- and software-dominated controllers involves continuous control and modelling of the physical environment on the one hand ("**real world aspect**" – [RTES2003][Poss2004]) and developing hardware and software for the controller on the other. The challenge for an embedded engineering discipline is that each of these two aspects involves a large body of knowledge of its own, and specialists are required for both disciplines. This implies that different stakeholders with different backgrounds are involved, and integrating all concerns to an optimised hardware/software package with optimised performance vs. cost ratio is notoriously difficult.

In projects with tight time-to-market constraints, engineers cannot evolve hardware and software sequentially, but need to develop both aspects in parallel, leading to complications in the process, and sub optimal hardware/software tradeoffs. Thus, the challenge for the embedded engineering field is to integrate aspects of both hardware and software engineering into an integrated understanding of Embedded Systems as a whole. Hardware engineers need to understand the demands of software developers, while software engineers need a good knowledge of hardware issues on the other hand.

Sub-challenge: Knowledge transfer in enterprises

As a consequence of the multidisciplinary challenge, it is a central demand within an enterprise process to optimally organise the concrete information exchange as well as the long-term knowledge transfer between the heterogeneous specialist areas.

Knowledge transfer between organisations

A second dimension of technology transfer in the field of Embedded Systems is the knowledge transfer between different organisations as enterprises, universities and research institutions. **Single enterprises are not able to acquire each base technology and basic application used in an embedded system as a result of the complex structure of such systems.** Hence, enterprises become more specialised and depend on expertise, which is available from other specialised enterprises, universities or research institutes.

ES discipline: need to integrate different aspects in common curriculum

For tackling the multifunctionality and flexibility challenge, ES engineers **need to have an in-depth understanding** of **at least one of the constituting mono-disciplines**, and needs to be acquainted with the basic foundations of related disciplines. For instance,

- an **"ES real-time systems engineer"** needs to have a deep understanding of both performance programming, and quantitative analysis methods for typical platforms [ART2005]. But in order to be effective in the ES domain, such engineers also need basic HW courses, control theory, and software/systems engineering know-how.

- an **"ES verification & validation engineer"** needs good skills in the application of formal methods, as applied in domains such as avionics [ART2005], along with a deep background on testing methods and tools, and specification models. Again, such an engineer would profit much from related ES-specific knowledge such as HW/SW engineering, real-time systems programming, and control engineering.

Challenge 3: Change in innovation drivers

As the third major challenge, innovation has become more market-driven, more rapid and intense as well as more closely linked to scientific progress [NewE2000]. That means that market-pull and knowledge-push became more important in comparison with technology-push. This implies a strong need for a profound education and creative business environments. But education is still very traditional to date.

Sub-challenge: Knowledge exchange, collaboration, standardization

The combination and integration of the different disciplines has to happen in research institutions, too. The multidisciplinary exchange between groups working on different aspects of Embedded Systems has to be improved, as outlined in chapter 6. In general, collaboration is an important factor for the discovery, appliance and diffusion of technologies. Often, de facto standards arise from supranational collaborations: GSM (Global System for Mobile Communications) is a prominent example.

ES discipline: ability to communicate, understand markets, develop products, lifelong learning

For the ES discipline, the innovation challenge means that **business aspects and soft skills** strongly have to be taken into account as well. ES engineers need to be able to **communicate with stakeholders from other disciplines**, and **quickly learn** about advances in their own field. An **understanding of markets** and market opportunities can be strengthened by hands-on education at universities, such as entrepreneurship seminars, and business plan contests. Engineers need to combine strong foundational know-how with a **strong customer- and product-orientation** in their activities. Similar to tendencies in other parts of the world, Europe's ES stakeholders have to adapt a **lifelong learning perspective**: Engineers need to constantly educate themselves on ES technology innovation.

2.4 Conclusions

Importance of ES for Europe

As a truly new discipline in research, development, and education, parallel to the classical IT technology, **Embedded Systems require special attention** by the different stakeholders such as industry, universities, and policymakers. Because of its strong record in the engineering field, Europe has a unique chance of attaining a world-leading position in ES if the necessary steps are taken and the existing chances are not easily given away. The market opportunities for ES are already very significant, and are projected to grow steadily over the next years. For more details about market impact of ES see chapter 3.

Focus of the study: ES software

This study is focused on the software aspects of ES research and development, because **in this field the greatest impact on industry, market and everyday life is to be expected, especially for Europe**.

Investment and advances in design capabilities needed

Making this impact come true requires significant investment in R&D on the one and organisational efforts on the other hand. **The widening design productivity gap has to be addressed by radical advances in design capabilities**. This is a matter not only of ES developing and deploying industries but also of fundamental research and education.

HW/SW integration is critical

For example, methodologies to enable early integration of HW and SW in the process of designing ES, with early evaluation of HW vs. SW realization for those system parts that can be implemented either way, are an important cornerstone of this engineering discipline. Deepening communication and cooperation between different stakeholders and experts as well as widening education profiles in this direction **will lead to decisive progress in the area of ES design**.

Multiple perspectives required

Another challenge for software developed for ES is the multidisciplinary character of the embedded domain. Therefore **it is necessary in software development for ES to consider several aspects and disciplines together**. Just like in the HW/SW field, technological progress and economic success highly profit from abilities of communicating and cooperating and the social environment supporting them.

Highly important: Communication and cooperation

In addition, the **innovations of different systems components have to be transferred to a large number of varying domains for developing new products** [Poss2004]. For example a mobile phone consists of several technologies, e.g. wireless, display, accumulator, low power concept and manifold software applications. An OECD study on information technology [NewE2000] states that "[...] many key developments draw on a wide range of scientific and commercial knowledge, so that **the need for co-operation among participants in different fields of expertise has become greater** in order to reduce uncertainty, share costs and knowledge and bring innovative products and services to the market." This statement once more underlines the need for a more intense and more efficient knowledge transfer, which needs to be supported by public bodies.

New ways of education needed

Furthermore, as a basic postulation, the combination of different engineering fields in the domain of Embedded Systems demands an adapted education of all persons participating in design, development and integration of Embedded Systems [ESC2002].

3 Impact on Market Development, Productivity and Competitiveness

Embedded technology – a great chance for Europe's economy

The major potential of embedded technology to foster the competitive development of systems with innovative and high-quality functionality is the integration of highly specialized domain-specific technology and know-how with flexible, general-purpose IT solutions and methods. However, **this integration also poses the major challenge of embedded technology**. Therefore, to understand why embedded technology especially offers chances for Economic growth in Europe, the specific strengths and weaknesses of Europe must be taken into consideration. To that end, we argue for the use of embedded technology **to obtain or maintain leadership in quality, innovation and functionality** and illustrate the current potential concerning the necessary know-how to meet that challenge.

3.1 General Overview

High market volume, growing fast

Keeping in mind that the volume of "the worldwide Embedded Systems market" is expected to reach € 71 billion until 2009 [RG_229R], embedded technologies are becoming an important part of the economic competitiveness of Europe. However, to assess the impact of embedded technologies on the market development and the competitiveness factors, the influence of embedded technology on the functionality of produced systems must be taken into consideration as well.

3.1.1 Embedded Systems: A Source of Wealth

Embedded technology: Key to improvement of existing as well as introduction of new functionalities

Embedded technology is influencing the functionality of currently produced systems in two ways:

- Improvement of existing functionality: To improve the efficiency of the controlled system, e.g., in terms of used resources, time, or quality of outcome, embedded IT has become the driving factor. Typical examples are improved performance rates achieved by embedded control (e.g., increase of placed components per hour (cph) in surface mount technology (SMT) from about 1,000 cph in 1980 to 100,000 cph in 2005 [Kun2005][SMD2000]) as well as higher efficiency of the controlled process (**20% reduction of average fuel consumption** in new automotive vehicles from 1990 to 2003, **95% reduction of carbon monoxide**).
- Introduction of new functionality: Functionalities offered by newly introduced systems increasingly depend on sophisticated control mechanisms, made possible by a wider range of available sensors and actuators. Here, the complexity of the controlling tasks is increasingly only manageable using embedded IT; e.g., in domains like automotive industry, **Embedded Systems are expected to account for 90% of the expected innovations** [Pat2004]. Typical examples are new forms of advanced control of physical processes (e.g., the fly-by-wire paradigm introduced by Airbus in the A320 in 1984; Electronic Stability Program introduced by Bosch in 1995, reducing the number of car accidents by 35% [NHTSA]).

Embedded technology can improve production in terms of cost and time to market

Embedded Systems increasingly profit from the integration of highly specialized interfacing and signal processing capabilities with the flexibility and computational power of general-purpose computing. By combining techniques from domain engineering and computer engineering, Embedded Systems can improve the production of solutions both concerning cost and time:

- Reduction of production cost: Today, even in domains like automotive, electronics already account for **more than 23% of the production costs**. At the same time, specific hardware becomes an increasing cost factor in production; e.g., the costs of the design of a specific SoC are in the order € 10 million, while the costs of the production of a single SoC are in the order of € 10 [Kop2002]. By moving from specific hardware to commodity hardware (like a PowerPC-based ECU) and combining specific (software) solutions with more general-purpose hardware, thus production costs can be drastically reduced.
- Reduction of time to market: By using general-purpose hard- or middleware abstracting from the domain-specific platform, the development of new (and especially customised) solutions can be drastically reduced. This is especially influential in domains requiring a wide range of individualised products as, e.g., in mobile communication. For example, by using the P2002/APOXI platform, the **development time for vendor-specific version of mobile phones can be reduced by 25% to 50%** [Büt2005] compared to traditional development with vendor-specific hardware.

Embedded technology supports leadership in innovative, high-quality functionality systems

This possibility to deliver systems with new functionality or improved quality within a competitive time frame **has ensured substantial market shares for the European economy** in domains like automotive (37% in 2002), industry and energy (30% in 2002), or defence and space (30% in 2002), as shown in Figure 3-2. Here, especially the leadership achieved by innovative functionality or high-quality functionality contributed essentially to market dominance; e.g., innovative technologies like fly-by-wire introduced by Airbus made its main competitor Boeing loose about 30% of its market share within the last 30 years; similarly, by leading the market concerning efficiency and accuracy in SMT placement, Siemens SIPLACE could achieve a more-than-average growth in the SMT placement market, holding, e.g., 40% of the market in the automotive sector.

To assess the possible impact of embedded technology for the European economy in more detail, its influence on specific domains is discussed in more detail in section 3.2 of this chapter.

3.1.2 Embedded Technology: Europe's Challenge

Differentiation to increase competitiveness

To maintain the economic competitiveness of European products in the domains illustrated above and gain prominence in those Embedded Systems sectors that are currently dominated by other regions, like consumer electronics, differentiation with respect to competitors is crucial. This can be achieved via

- delivering premium quality ("**leading by quality**"),
- supplying the product at the earliest possible time ("**leading by innovation**"),
- offering better functionality ("**leading by functionality**"),
- providing a competitive price ("**leading by price**").

Europe should be leading by quality, innovation and functionality

To assess the best possibilities for European leadership, her specific capabilities must be taken into consideration. To ensure competitiveness, Europe must be leading in some of these aspects visibly, like through the quality attribute "Made in Europe", without falling behind too much in others, predominantly concerning price. With respect to the specifics of Europe, we suggest leadership by innovation, quality, and functionality, rather than by price. The major challenge for Europe hence will be to gain competitiveness even if the labour costs are higher than in most other countries. Only if European countries manage to step up in the value chain, they will be able to keep their market position.

In the following we suggest approaches to achieve leadership in innovation, quality, and functionality, while maintaining competitiveness by price; furthermore, we also explain how the remainder of this study supports these approaches.

Europe should be quality leader

To deliver premium quality embedded products, it is increasingly important to conquer the complexity of Embedded Systems. This requires an integrated view of Embedded Systems. Europe has a well-established engineering domain. Furthermore, there is a long tradition of integrating different application domains in industry. To that end, the study suggests the integration of different engineering disciplines (mechanical, electrical, electronic, software engineering) into a common discipline of **embedded system engineering** taught in universities and brought to practitioners through programs dedicated to executives and developers. With 3.2 (on a scale between 1 and 4), practitioners rank workshops as the most efficient transfer of knowledge between the university and the industry [Quest2005].

Europe should be innovation leader

To ensure that innovative products are put to the market as soon as possible, it is important to either be a leading supplier of technologies (e.g., concerning sensor, actors, bus systems, etc) or to cooperate closely with leading suppliers (e.g., chip manufacturers). In either case, research of basic technologies is essential to get an early understanding of possible innovations; here, Europe still has a well-established tradition in basic research. To address the issue of innovation, the study explicitly identifies major trends crosscutting individual technological domains and addresses their relation to trends in the application domains (to be an enabling technology). Furthermore, the study addresses the importance of technological know-how for the system engineering discipline (e.g., curricula for **real-time systems engineering**).

Europe should be functionality leader

To deliver the right functionality, it is necessary to have a deep understanding of the trends in the possible application domains. Through the traditionally well-established engineering disciplines in different application domains (mechanical, chemical, electrical, computer engineering), compared to the US European industry has the potential to set early trends in this domain (e.g., by supporting a quick transfer of technological possibilities to domain experts). To that end, the study explicitly identifies major trends crosscutting specific application domains and addresses their relation to technological and engineering trends. Furthermore, the study addresses the importance for application-specific know-how (e.g., establishing an **automotive systems engineering** discipline).

Europe will unlikely be price leader

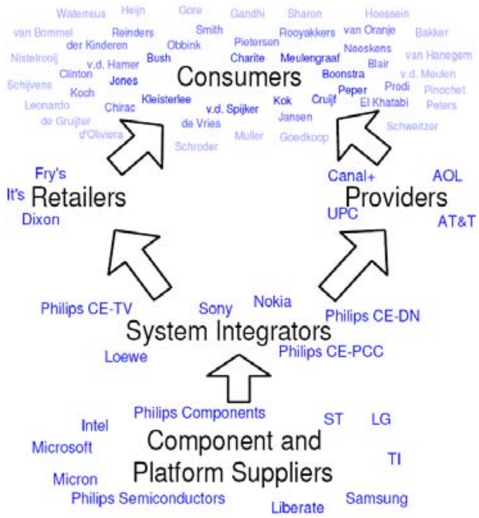
Human resource costs are too high in Europe to compete, especially with Asian industry, in manufacturing. With the US hourly compensation costs being standardised to 100, the EU has 110, Canada 88, Japan 91 and Korea 47 [Inte2005]. Price is therefore an unlikely factor for competitiveness. However, we must avoid widening the gap by improving the efficiency of the engineering process. The current **shift from hardware to software**, i.e. the higher software/hardware ratio of the value of Embedded Systems, **is a big chance** to narrow this gap. Hardware costs are mainly costs for buying and assembling material. But developing and integrating software requires high-skilled staff and is not driven by unit cost calculations. Widespread adoption of best engineering practices for systems development as well as increased development and deployment of advanced engineering tools are good examples for ways to achieve such improvements. To that end, the study explicitly addresses the importance of a well-defined engineering process including engineering support (e.g., **CASE infrastructure**).

3.1.3 Embedded Know-How: Europe's Potential

Differentiation of competitiveness

Production of Embedded Systems is split up into the production of components and platforms, and the integration of these components and platforms – together with application-specific (hardware or software) parts – to the final product. As an example, the value chain from the viewpoint of Philips Semiconductors is shown in [Oppo2004]. Typically, single electronic components, such as single chip TV's, are used by system integrators that build consumer electronics appliances such as televisions. These appliances can be distributed via retail channels or via service providers to end consumers.

Figure 3-1: Value chain for semiconductor and platform providers



ES production is fragmented

As the functionality of Embedded Systems is largely driven by the characteristics of the environment the system is embedded in, the integration part of the production process is generally extremely application-domain specific. Therefore, unlike with management information systems, desktop software, or operating software, the production of Embedded Systems is fragmented analogously to the fragmentation of the application domains.

European market structure: Fragmentation, differentiation, cooperation

The market for embedded platforms and their components in Europe is **based on** "a few big rocks" [Jour2005], i.e. on **a small number of major enterprises** supplying hardware. Another characteristic of the European market is that these large-size companies are complemented with a **high number of small and medium enterprises** (SME's) that serve smaller and more specific shares in the software markets by developing **domain and enterprise specific solutions**. This also holds for large-size Original Equipment Manufacturers (OEMs) and their SME suppliers. At the same time, there are tool suppliers and consulting firms mostly with a focus on specific domains or on single components. These characteristics indicate the high fragmentation of the market for Embedded Systems. Often, the combination of a big player and many SMEs leads to the emergence of clusters that grow around the big enterprises that fosters the diffusion of knowledge.

Trend to standard software solutions

Both with this platform suppliers as well as OEMs, we see a strong trend towards integration with "**platform software**" (operating systems, middleware etc.) and even **standard software modules**.

Europe's initial situation is promising

Obviously, Europe's capability to provide this domain-specific **integration know-how** has granted the EU a large fraction of the market in domains like automotive, industrial and energy, or defence and space. Figure 3-2 shows the European share of the world market and the compound annual growth rate (CAGR) between 2002 and 2007 [MEDEA2003]. However, Japan dominates the market of consumer electronics and America is continuing the domination in PCs.

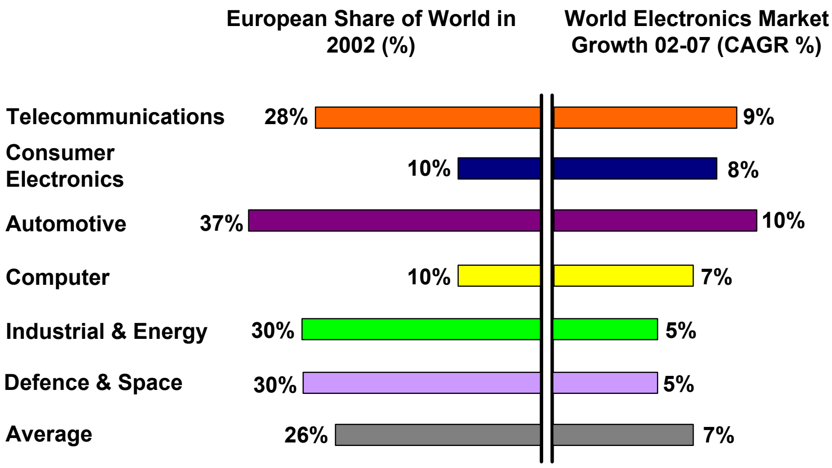


Figure 3-2: European electronics industry well positioned to capitalise on future growth [MEDEA2003]

Across all sectors, the US has a share of 35% of the world electronics market compared to Europe with 26%. **But the European microelectronics industry is weak in IT but well positioned for the secondary sectors.**

3.2 Impact on Industries

The market for electronic components is a good indication of the impact of Embedded Systems on different industries.

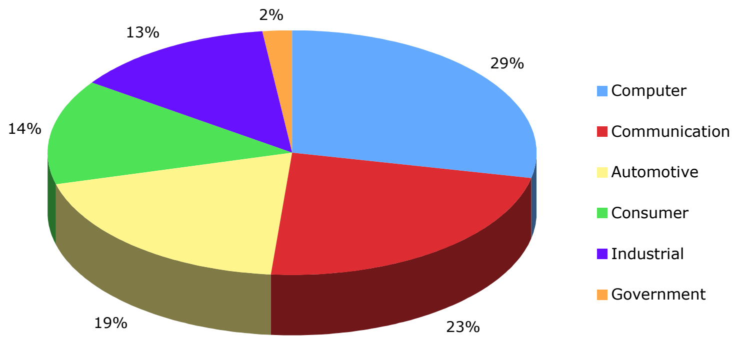


Figure 3-3: Electronic components market in Europe in 2004 [EECA2005]

The industry sectors for our study are selected on the basis of the relevant industrial domains of the electronics industry. As shown in Figure 3-3, the major markets are communication, automotive, consumer electronics, and industrial automation. In addition, the domains health/medical equipment and avionics/aerospace are included. In Table 3-1 detailed descriptions of the industry domains are provided.

Table 3-1: Definition of industry domains

Industry domains	Definition
Automotive	It includes electronic control units in chassis systems power train electronics, body electronics/security systems, information and computing systems, e.g. for traffic control.
Avionics/ Aerospace	It includes commercial aircraft, military aircraft, and satellite systems.
Industrial Automation	It includes manufacturing and process controls, motion controllers, Intelligent Homes, operator interfaces, robotics, HVAC and other controls, e.g. for energy distribution.
Telecommunications	It includes infrastructure, services and end devices.
Consumer Electronics and Intelligent Homes	It includes set-top boxes, Internet access devices, home audio/video, and white goods.
Health and Medical Equipment	It includes patient monitoring equipment, medical therapy equipment, diagnostic equipment, imaging equipment, and surgical systems.

Some basic technologies like Smart Cards or RFID are covered in several sections. Where appropriate, we reference such sectors and point to the interrelations and overlaps.

Overall picture of the worldwide market per sector

The still increasing relevance of Embedded Systems for some of the most promising sectors is shown in Table 3-2, where we present the shares of the end product's total cost that can be attributed to Embedded Systems including hardware. These numbers were collected through a questionnaire filled out by experts in the respective domains and from more than 30 countries; details of the survey [Quest2005] can be found in A.1. The numbers show a slight increase for all sectors, except of the telecommunications domain.

Table 3-2: Share of ES in the cost of the final product or service [Quest2005]

Industry domains	2003	2009
Automotive	52%	56%
Avionics/ Aerospace	52%	54%
Industrial Automation	43%	48%
Telecommunications	56%	58%
Consumer Electronics and Intelligent Homes	60%	62%
Health and Medical Equipment	50%	52%
Weighted average	51%	53%

Using the market for electronics as an indication for ES

Another indicator to determine the relevance of Embedded Systems is the market for electronics (including semiconductors, micro controllers, microprocessors and memory products, and passive, electromechanical, power and discrete components) and the respective European market share. With the exception of health the numbers in Table 3-3 are based on [MEDEA2003]. There, the 2002 world market volume for electronics in these sectors (excluding health) was estimated at $ 800 billion (€ 630 billion) and the share of Europe on the total market and the sectors (displayed in Figure 3-2), was used to calculate the world market volumes in electronics.

Table 3-3: Electronic market per sector in 2002 [MEDEA2003] and for health from [EmTe2005] and growth rates for electronics and ES

2002-2004 Industry domains	Size of world market for electronics in billion € [a]	European market share in electronics [a]	Average annual growth rate for electronics market [a]	Average annual growth rate for ES market
Automotive	30.1 b€	37%	10%	10%[a]
Avionics/ Aerospace	29.6 b€	30%	5%	14%[b]
Industrial automation	88.9 b€	30%	5%	7%[a]
Telecommunications	83.2 b€	28%	9%	15%[a]
Consumer electronics and intelligent homes	182.9 b€	10%	8%	15%[c]
Health & medical equipment [d]	193.0 b€	24%		18%
IT hardware	215.2 b€	10%	7%	

The market for electronics used in medical equipment is calculated based on numbers from [EmTe2005], with the 46.6 billion being the lower border since this is the value of semiconductors used in the domain. The European market share for health and medical equipment is based on the assumption that the market share in final products (€ 45 billion being the European market [COMM2005], compared to the world market of e 193 billion) is as the same in the components market.

The estimation for industrial automation is slightly too high, as the source used included “transport”, which is not part of our definition of the sector “Industrial Automation”.

The growth rates for the electronic market in Table 3-3 are also taken from [MEDEA2003] and are generally lower than the growth rates found for Embedded Systems. As no source for the growth rate of ES in the avionics sector was available, the average annual growth rate (AAGR) of 14% was used, as forecasted over the next five years for the worldwide ES market by [RG_229R]. The growth in Embedded Systems is based on the increasing value of ES for the final product. The drivers behind these growth projections are described in detail in chapter 4 where we show trends and market developments in the different domains as well as in basic technologies and Systems Engineering.

Table 3-4 shows today’s shares of ES in the value of the final product. Based on interviews [Rei2005], [Büt2005], [Tim2005], different studies and reports [ASAR2005] [DGBMT2005]. The values for Industrial Automation, Telecommunications and Consumer Electronics do not represent Embedded Systems, but the share of the value of electronics components of the value of the final product. Thus, these numbers are the minimum of the real value of ES since they exclude all the value-added by in-house development.

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[a] [MEDEA2003], the sector defense and space has been allocated to avionics and aerospace, data on world market has been calculated using the data on European market and share of European market. We used the weighted average of the European market share of 17% to extrapolate the data onto the world market. Data refers to 2002

[b] [RG_229R] (refers to 2004)

[c] [VDC04] (refers to 2003)

[d] [EmTe2005], [COMM2005] (refers to 2004)

Table 3-4: Share of ES or electronic components in the value of the final product or service

Industry domains	2004	2009
Automotive	20%	36%
Avionics/ Aerospace	n.a.	n.a.
Industrial Automation	>13%	22%
Telecommunications	>23%	37%
Consumer Electronics and Intelligent Homes	>14%	41%
Health and Medical Equipment	25%	33%

This high relevance of Embedded Systems for the industry motivates the need for research in that area. In Table 3-5 we present the private expenditures (BERD) in the different sectors in 2003. The details of the calculation are explained in section 5.2 and in Annex A.2.2. Unfortunately, the sectors in Table 3-5 differ from the industry domains used in this section, as the data used to calculate the data [Dti2004] did not differentiate between hardware for telecommunication and IT.

Table 3-5: BERD for ICT and ES in 2003 [ODB2005]

2003 Industry sectors	R&D factor used for ICT	R&D factor used for ES	BERD in ICT in billion €	BERD in ES in billion €	Share of R&D for ES in R&D for ICT
Automotive	40%	30%	11.9 b€	9.0 b€	75%
Avionics/ Aerospace	60%	35%	2.8 b€	1.7 b€	58%
Industrial automation	70%	30%	2.3 b€	1.0 b€	43%
ICT hardware	58%	43%	50.7 b€	37.5 b€	74%
Consumer electronics	60%	40%	17.0 b€	11.3 b€	67%
Medical equipment	45%	10%	1.6 b€	0.3 b€	22%
ICT services	100%	10%	26.2 b€	2.6 b€	10%

The first two columns show the relative R&D factors intensity of ICT and ES respectively that were used to calculate the R&D expenditures (BERD). The methodology to derive at these factors is described in the Annex A.2.2.

Current and future funding and R&D activities in Europe as well as in other relevant areas are worked out in great detail in chapter 5. On the basis of the data presented there, we estimated the numbers for BERD in ICT and ES for 2009, as shown in Table 3-6. The third column shows the share of BERD investments that are dedicated to Embedded Systems as well as the change of that ratio compared to the values of 2003.

2009 Industry sectors	BERD in ICT in billion €	BERD in ES in billion €	Share of R&D for ES in overall ICT R&D
Automotive	18.1 b€	14.4 b€	80% (+ 5)
Avionics/ Aerospace	4.6 b€	3.2 b€	69% (+ 11)
Industrial automation	3.0 b€	1.4 b€	46% (+ 4)
ICT hardware	91.6 b€	75.4 b€	82% (+ 8)
Consumer electronics	29.7 b€	22.8 b€	77% (+ 10)
Medical equipment	2.3 b€	0.8 b€	35% (+ 13)
ICT services	32.9 b€	4.2 b€	13% (+ 3)

Table 3-6: BERD for ICT and ES in 2009

We forecast business R&D expenditures by assuming that ES grow by the factors displayed in Table 3-3 whereas the overall R&D expenditures increase by 4% - a value that is in line with the average growth of GDP during the years of 1999 to 2002 as calculated by using data from OECD [ODB2005]. Due to the faster growth of Embedded Systems the ratio of R&D for Embedded Systems within R&D for ICT will increase in the future. Embedded Systems play a vital role in these sectors and are crucial for future position in the world market for the respective final product or service.

3.2.1 Automotive

3.2.1.1 Market Situation

Core industry of high importance for Europe

The European automotive industry continues to be one of the most important industries in the European Union. The automotive manufacturing sector provides direct employment to **more than 1.1 million people** [ACEA2005], and component suppliers contribute another estimated 3 to 3.5 million jobs **[EMCC2004]**. The overall indirect employment through the automotive sector is estimated at another **11 to 12 million jobs.** The sector is accounting for **3% of the EU GDP** and 7.5% of total EU manufacturing [ACEA2005]. This industry therefore forms a **strong economic backbone of Europe** due to its own contribution to the overall economy. In the Embedded Systems field, the automotive industry generates significant activity for other industries, such as components, electronics, informatics, and telecom.

Production: Old EU-members stagnating, new EU-members prospering

For the European automotive manufacturers, the picture of passenger car production growth is divided (Table 3-7): The old member states, whose automotive industry still accounts for roughly a third of the global passenger car production, are experiencing a stagnation in overall vehicle production, while some of the new member states, which have joined the EU in 2004, and some other Eastern European countries, do experience a healthy yearly growth. The worldwide picture yields that in certain countries in Asia, such as China, India, and South Korea, production continues to grow in the double-digit range, with particularly interesting numbers such as a growth of 83% in the 2003 vs. 2002 Chinese production figures.

Table 3-7: Passenger car production figures in Europe and worldwide [OICA2004]

Continents vs. production	Production increase 2002-2003	Production increase 2003-2004	Production 2004 (Millions of cars)
Worldwide	+1.6%	+5.4%	44.2
EU (old members)	-1%	0%	14.7
EU (new members)	+2%	18%	1.4
America: Nafta	-10%	-4%	6.4
Asia/Oceania	+9%	+10%	17.8
Single countries			
Poland	+7%	+68%	0.5
Romania	+16%	+31%	0.1
China	+83%	+15%	2.3
India	+29%	30%	1.2
South Korea	+4%	13%	3.1

3.2.1.2 Impact of ES on Market

ES: Big share in total value

The share of electronic components in the total value of a passenger vehicle is currently estimated at about 25%, with an expected increase to 33-40% in 2010 and up to 50% for the time beyond 2010 [Han2004a][Ele2003][Mer2001]. In 1990, the share of electronics in a car's value was 16% [PFH2005].

ES innovations govern market developments for electronics-related features

As today's automobiles change from a largely mechanical product for transportation to a combination of transportation equipment and versatile electronics platform, an increasing number of features, and therefore the **market for vehicles as a whole, is driven by ES innovations**. As stated in [Pat2004], a vast majority (90%) of present and future innovations in the automotive sector are expected to be driven by electronics and software in the future.

Example: Positive expected impact of ADAS systems

As an example for a market driving technology, innovation in the area of advanced driver assistance systems (ADAS) certainly has the potential to both improve road safety, yielding a positive macroeconomic impact, and strengthening European carmakers' competitive position. For the macroeconomic side, the current European efforts to prevent road accidents are estimated less than 5 % of the total cost of those accidents [Eur2001]. At the same time, figures from Toyota suggest that widespread deployment of passive safety facilities (e.g. airbags), active safety systems (e.g. ADAS), and cooperative driving systems together can contribute to a 20% reduction in road fatalities each [SBD2004][Res2004]. It is expected that the European market for ADAS will reach € 3.5 billion in 2010 [PFH2005].

Telematics promises strong growth, country-dependent

As an especially vital automotive electronics market, the telematics market promises large growth opportunities for Embedded Systems (Figure 3-2). However, this market is quite heterogeneous across the world: Certain telematics services, such as navigation systems, have particularly high market shares of Europe in Japan (80%), while this market share is below 2% for the US market [Mar2005].

Telematics for commercial vehicles is forecast to be incorporated in 1.3 million new vehicles per annum, with the total market expected to have crossed the billion Euro mark in 2005. By 2009, the installed base of telematics-enabled vehicles is set to touch 5.4 million commercial vehicles with a revenue potential of **€ 4.7 billion** [Fro2004]. **Two-thirds of these revenues are projected to derive from telematics services**, with systems accounting for the remaining amount. By 2010, the total number of commercial and non-commercial vehicles with telematics equipment will have reached $28 million (approx. € 22 million), according to Figure 3-4. The figure shows that automotive telematics has the highest growth rate of all comparable automotive electronics fields.

Commercial vehicle telematics: Four- to five-fold growth until 2009

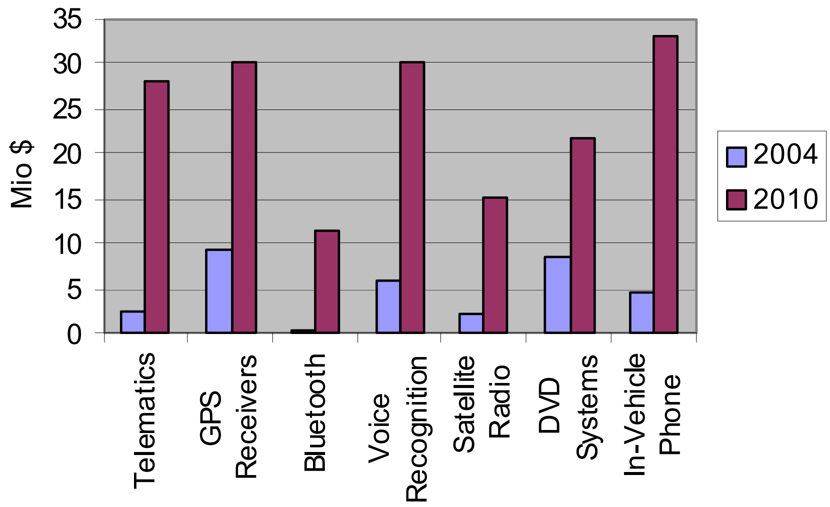


Figure 3-4: Worldwide growth of vehicle electronics applications between 2004 and 2010 [Int2004]

3.2.1.3 Impact of ES on Competitiveness

As indicated in section 3.2.1.2, the **share of electronic components will increase to up to 50%** for the time beyond 2010. The electronics features that are available in low-volume premium cars today will appear in the high-volume segments tomorrow. A carmaker that is among the first in the market to introduce a particular electronics feature will have a competitive advantage in terms of cost and quality once the feature is ready for the high-volume mass market. If quality issues are under control, innovation leadership in automotive can have **a positive radiance towards the brand image**, exemplified by those European premium-car companies that have become known as electronics innovation leaders worldwide. It is therefore fair to conclude that competitiveness in the automotive electronics field, especially with respect to innovations and functionality leadership, is vital for future competitiveness of the European automotive industry as a whole.

ES technology leadership is vital for competitiveness

The European automotive industry is well-positioned in the electronics field: this is both acknowledged by interview sources [Tes2005], and indicated by the fact that around **40% of global automotive ICs are currently consumed by European carmakers** [Mar2005].

European carmakers in good competitive position

The increase of the electronic components in the total value added comes at a price, from a quality perspective: already 30-40% of all warranty incidents in the automotive field are related to Embedded Systems [Ewee2004]. A nontrivial number of car owners do experience **quality problems**: In 2004, 17 percent of German car users had problems with electronic components in their car [CART2004]. This puts a **high pressure on OEMs and suppliers to improve quality issues in electronic components**. The

Growing complexity results in quality problems, strongly affecting European technology leaders pressure is highest for those European vendors that are worldwide innovation leaders in automotive electronics, and whose image has suffered much from highly publicised quality flaws in recent years. This is exemplified by some European premium-car companies that recently went from former quality leaders to companies known for massive recalls in connection with electronics features [Aut2005]. Quality problems in automotive electronics mainly result from the integration challenge for increasingly complex and distributed functionality.

3.2.2 Avionics/Aerospace

3.2.2.1 Market Situation

Commercial aviation recovers, low-cost carriers increase market share, fuel efficiency is critical

After three years of decreasing activity, commercial aviation is experiencing a healthy growth. Traffic has already exceeded the levels from the previous peak in 2000, and airlines are ordering increasing numbers of aircrafts. However, high fuel prices are intensifying the pressure on airlines caused by fierce competition, with the result that many are sustaining heavy losses. In this difficult environment, the **demand for aircraft with the greatest operational and fuel efficiencies is very high**. At the same time, the low-cost carrier business model is increasingly successful. Airlines are becoming more efficient through improving their operational environments, and rationalising their fleets around cost-efficient and larger aircrafts. Low-cost carriers are continuing to take market share, particularly on the short-to-medium haul routes, where **cost-efficient and medium-sized aircraft are required**.

Commercial aviation: International traffic shows strongest increase

According to the International Civil Aviation Organisation (ICAO), air traffic, as measured by revenue passenger kilometres, increased by approximately 14% in the 2003-2004 comparison. International traffic experienced the greatest recovery. The International Air Transport Association (IATA) reports a 15.3% rebound after 2003, when Asia's SARS epidemic and the war in Iraq suppressed activity. The last available figures (1998) show a **total value of production in the aerospace sector of € 133 billion in the US, and € 59 billion in Europe**. The worldwide market for civil aircraft for the summation of years 1999 to 2008 is estimated at $ 810 billion (approx. € 638 billion). The total worldwide aeronautics market, including military aircraft, is expected to exceed $ 1 trillion (approx. € 0.8 trillion) in the 2000-2010 timeframe [JACG2000].

Defence and civil space: USA leading

In 1999, OECD governments to civil space R&D programmes allocated more than € 10 billion, more than half of this by the United States [OECDST2003]. And with by far the biggest defence procurement budget, the United States also dominates global defence spending. It is estimated [EADS2005] that in 2004, the United States spent $125 billion (approx. € 98 billion) on procurement and research, compared with Europe's $55 billion (approx. € 43 billion) and the rest of the world's approximately $135 billion (approx. € 106 billion). Looking only at the budget for R&D in defence, the United States accounted for more than three-quarters of the overall OECD-area budget, or more than four times the EU total [OECDST2003]. In terms of growth, EADS expects US defence spending to expand by an average of approximately 5% per annum for the next five years. According to [EADS2005], defence expenditure in Europe and the rest of the world will move roughly in line with growth of Gross Domestic Product (GDP), with Asian expenditure increasing the most.

Consolidation wave in European defence industry

Europe's defence companies are currently in the middle of a wave of consolidation as they build the scale needed to match their US peers in 2004. Examples are Sagem/Snecma (France), BAE Systems/Alvis (UK), Finmeccanica (Italy)/AgustaWestland (UK). In 2005, Finmeccanica (Italy) and BAE Systems (UK) have agreed to combine and restructure their avionics, communications, and system integration businesses to form three new companies/divisions. Worldwide, the **defence industry is currently repositioning itself** to provide simultaneously the underlying technology for systems and electronics. **Information technology companies will play an increasing role in providing key capabilities.**

As an especially interesting segment, **the market for unmanned aerial vehicles (UAVs) is estimated at $23.7 billion (approx. € 18.7 billion) accumulated from 2001-2010**, with revenues more than doubling between 2001 and 2010 [Jen2005].

UAV market growing fast

3.2.2.2 Impact of ES on Market

Embedded Systems in the form of aviation electronics (avionics) forms a major share of the total value added of modern aircraft, with the after-sales avionics market alone at roughly 7% in relation to the market for new aircraft [JACG2000][Jen2005], and an unknown share of Embedded Systems parts in the total value added of every new aircraft sold. The participants of the online survey from the avionics industry have **estimated this share as high as 51% for 2005, with a slight growth for the future** [Quest2005].

ES form major share of modern aircraft

The example of electronically controlled UAVs, advanced control systems, on-board/off-board communications systems in commercial aviation, or upcoming command-and-control infrastructures in military applications all show that there is virtually **no upcoming application in aerospace that is not heavily dependent on innovation in the Embedded Systems field**.

Modern-day aviation chiefly dependent on electronics innovations

3.2.2.3 Impact of ES on Competitiveness

Due to the **traditionally high importance of ES innovations for the aerospace market**, the successful mastery of the complexity and connectivity challenge in avionics will play a crucial role for competitiveness of companies in the aerospace sector. This observation can be expected to parallel similar developments for the European Airbus consortium in the 1990s. Airbus's superior competence in fly-by-wire technology, which simplifies both the architecture of control systems and the cockpit, had enabled both efficiency gains and standardized human-machine interfaces, resulting in a competitive advantage for the company [EADS2005].

Meeting complexity and connectivity challenge crucial for competitiveness

Those companies that pick up improved engineering and platform solutions will also be future innovation leaders, as these solutions are crucial for mastering the complex networked functionality. As a promising example, an avionics case study showed that the introduction of a middleware solution could bring productivity increases of up to 50%, with a **cost savings** for the task of re-targeting of **up to 90%** [FLV2000].

Example: Advance middleware has potential for productivity increase

3.2.3 Industrial Automation

3.2.3.1 Market Situation

The automation technology (AT) sector is an important industry for Europe. It supports the manufacturing industry, which **employs about 45 million people** in Europe [AWMP2005]. This industry depends on new innovations in automation technology to maintain competitiveness opposite to low-wage countries.

Importance of automation technology

The field of automation technology is wide. There are a lot of small and medium enterprises worldwide, which offer solutions for plant automation. These enterprises are important as producers of automation equipment because they are more innovative than big enterprises [LIU2004]. Some of the big key players in the area of automation solutions are **ABB** with total revenue of $8.5 billion (approx. € 6.7 billion) in automation technology

Key players in the field of automation solutions

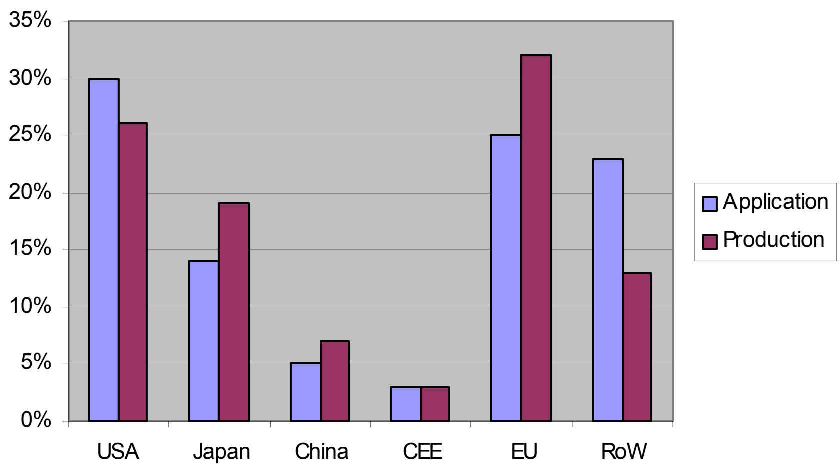
[ATA2003], Kuka Robot Group (total revenue of € 420 million [KRG2003]), Schneider Electric (total revenue of € 2.72 billion in the domain of industrial automation technology [Schn2003]), and **Siemens** (total revenue of € 17.1 billion in automation and control [ESSA2005]). Of special interest is that Siemens spends more than 4% of the revenue for software development [ESSA2005].

Europe leads the automation market

The worldwide automation **market volume in 2004** (building automation included) **amounted to € 203 billion** according to [ISTVAN2005]. ABB estimates the annual growth rate of the automation market being 5%. This leads to a market volume of **€ 272 billion in 2010**. The market is divided in process industry, as the fabrication of chemical products, in manufacturing industries, for example the production of cars, and in building automation. The European market share was 25% with regard to application, whereas it was 32% with regard to production of automation equipment, see Figure 3-5. This shows an exported surplus of European automation products of 7%. This clearly marks **Europe's current leadership in the global automation market**.

With regard to production of automation products **Europe is losing ground** compared to North America and Asia. The annual growth rate in Europe is only between three and four percent whereas the market in Asia is expected to have double-digit growth rates [AWMP2005]. To prevent that Europe loses its leadership, the **implementation of new technological trends has to be encouraged**. These trends result mostly in an increasing use of Embedded Systems in automation products.

Figure 3-5: Automation market shares in 2004 [ISTVAN2005]



Europe leading in the market for machine tools

The machine tool market is a representative sub-segment in the domain of industrial automation. World production of machine tools will grow by 8% in 2005 to **total revenue of € 39 billion**. **Europe is the biggest producer of machine tools with a share of 46%** followed by Asia with 44%. The US has a share of only 9%. In contrast, Asia is the leading consumer of machine tools with a share of 45%. China is worldwide the biggest consumer country and ranks third as a producer. **36% of machine tools were sold in Europe.** Europe is different from other regions with respect to the needs of high technology products [EFH2005].

Europe leading in innovation in future technologies

In a study of the German association of electro technology (VDE), its members were asked, which region has the highest innovation in future technologies [VDEIM2005]. Figure 3-6 shows that actually **76% of respondents ranked Europe highest in innovation** compared to the US and Japan/ Asia. **Up to 2010, they suspect Europe to remain the leading player in this domain**. However, according to Figure 3-6, Japan will gain shares at the expense of Europe, which is ranked top only by 65% of all survey participants.

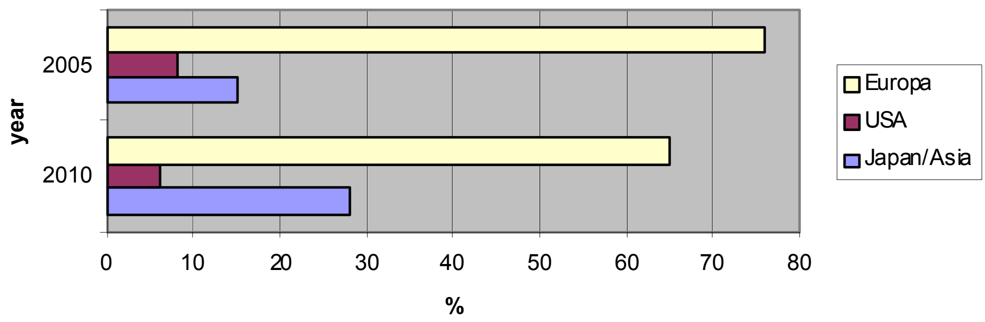


Figure 3-6: Future technologies: Comparison of the innovation in the automation technology of different regions [VDEIM2005]

Europe leading in R&D expenditure of machinery industry

The evaluation above is supported by the comparison of the investments in R&D in Europe, US, and Japan. The **European machinery industry has the highest expenditure for R&D compared to the US and Japan** as Figure 3-7 shows [ITI2004]. The annual growth in the nineties averaged 3.8% in Europe. The USA had in the same time an annual growth of 8.7% and Japan of 4.7%.

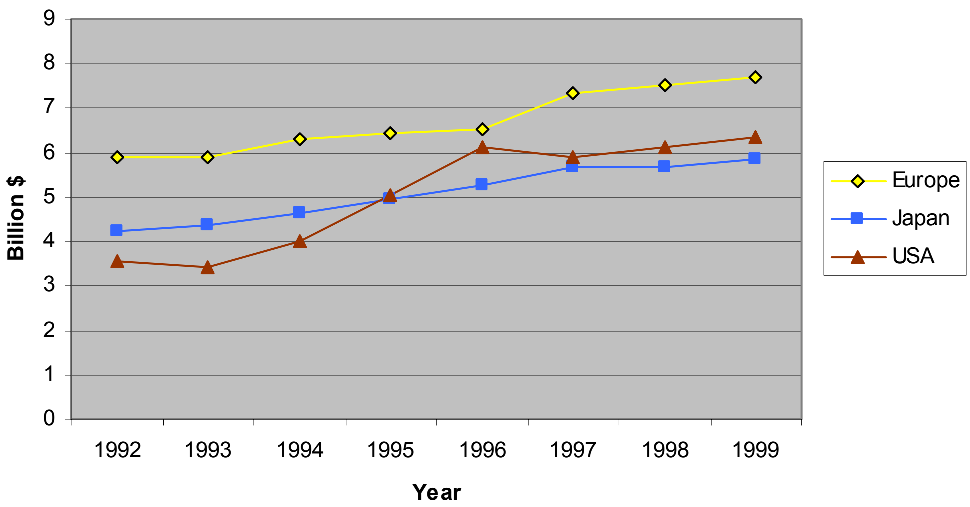


Figure 3-7: R&D investments of the machinery industry [ITI2004]

3.2.3.2 Impact of ES on Market

Great ES market in automation

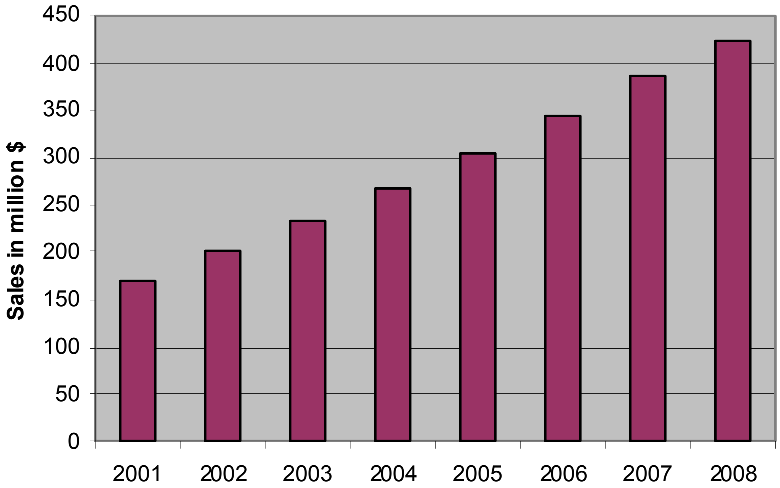
Embedded Systems have a large share in the added value of industrial automation products. According to the online survey [Quest2005], the **Embedded Systems portion of the industrial product/service costs was estimated by 45%.** It is estimated that the part of Embedded Systems will increase by 1% annually. The comparison with the automation market volume results in the estimation that Embedded Systems in the domain of automation will reach a volume of around **€ 122 billion in 2010**.

Fieldbus market growth rapidly

The realisation of networking automation solutions depends significantly on Embedded Systems as shown in section 4.2.3.2. The increasing demand for such solutions results in a **growth rate for the European fieldbus market of around 15%.** According to an analysis of Frost & Sullivan, the European market of fieldbus systems had a sales volume of $170 million (approx. € 134 million) in 2001 and is estimated to grow up to **$425**

million (approx. € 335 million) in 2008, Figure 3-8. The comparison of these numbers with the European automation market share, Figure 3-5, results in a world fieldbus market of **€ 1.41 billion in 2008**.

Figure 3-8: European fieldbus market [UAS2004]



3.2.3.3 Impact of ES on Competitiveness

Productivity, quality, flexibility, resource economy

Industrial automation raises the productivity of machines and plants and decreases the throughput time of production [PRS05][VPO05]. The move from manual work to automation enhances the product quality, whereas industrial automation increases the flexibility of production lines. The integration of machines, sensors and actuators facilitate the monitoring of plants. And last but not least, the use of automation technology enhances the efficient usage of existing resources. All these topics **require an increasing use of Embedded Systems**, e.g. for networking sensors. In [KIT2003], some of the effects are described, e.g. it is expected that “flexible value creation networks” will be “widely spread” until 2009, meaning that **networks of firms and corporations interact for a limited time to deliver specific products**.

Remote control for better and faster maintenance of production lines

The requirements of the market regarding stable production processes rise continuously. The remote control is one instrument to meet these challenges. As described in section 4.2.3.2, failure of a plant will be detected earlier and eliminated faster. This will **reduce downtime and raise productivity**. Also the service interval will be stretched, which reduces maintenance costs. Additionally, **remote service** is a market on its own. In 2010 this **market will reach a volume of € 30 billion.** 20% of this sum goes to the hardware and software [PFF2005].

Distributed systems reduce facility costs

The requirements of the market of production facilities rise continuously. Distributed systems have the potential to meet these challenges. In section 4.2.3.2 we explain that distributed systems are built by single modules. The production of such modules makes use of mass-produced silicon chips [DCCS1998]. Thus the price of distributed systems decreases compared to standard systems and **assembly lines can be produced in a cheaper way**.

Wireless technologies just at their beginning

According to a study of Frost & Sullivan [DTA2004], the rising need for productivity and cost reduction are the main impetus for future growth of wireless technologies for industrial applications. Figure 3-9 shows that, for the time frame between 2002 and 2006, a **quadruplicating of the revenues is estimated** for wireless technologies in Europe.

Until now the market for wireless technologies is at the beginning. First of all security and reliability have to be improved and standards have to be created. When these hurdles are overcome, the wireless technology will be an important factor to encourage the competitiveness of the producers of industrial automation equipments.

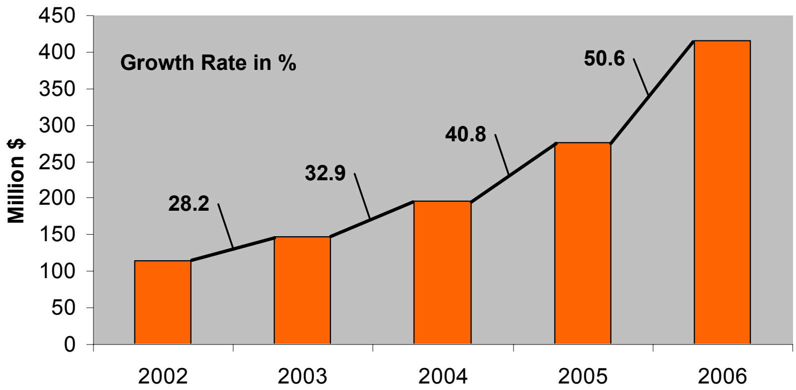


Figure 3-9: Market for wireless technologies for Industrial application in Europe [DTA2004]

ES help to fulfil actual an emerging customers' needs

Customer requirements for individualised products increase steadily. Products have to be manufactured faster, cheaper, and more reliably. To fulfil these requirements the penetration of plants with information and communication technology has to be enhanced and the construction of distributed systems has to be pushed. All these demands are based on broader use of Embedded Systems. Therefore the **significance of software** in the development of automating products **increases** and consequently the importance of using software engineering methodology in the development process enhances. Currently, the most challenging topics are distributed networks and wireless technologies; both are **only realisable by using Embedded Systems**, and, as a higher-ranking topic, the improvement of engineering processes to develop complex systems.

3.2.4 Telecommunications

3.2.4.1 Market Situation

In the European Union most operators will no longer be able to rely on growth in fixed-line voice telephony to sustain high returns. End customers often are only interested in getting a fashionable and convenient mobile connection.

Mobile market growing fast

The mobile telecommunications market in contrast is a growing sector with an increasing number of customers and a steady spreading throughout the world. Until 2007, the **penetration of mobile phones in Western Europe will increase to more than 100 percent** [WEM2005]. In the countries of Middle and Eastern Europe, the penetration rate reached over 66 percent at the end of 2004, which is an increase by 13 percent in 2004. Until 2009, penetration is expected to reach 94 percent [CEE2005].

Revenue shares change drastically and will differ between regions

Whereas the revenues from speech transmission are expected to stagnate, data services will lead to an increase of total revenues by nine percent p.a. until 2007 in Western Europe [WEM2005]. Since new mobile users in Eastern Europe will mainly come from low-income groups, the average revenue per user (ARPU) will decrease in these countries [CEE2005]. But there are chances to leverage revenues by enhanced functionalities. One example of those new services are mobile full-track downloads that are seen as **one of the most promising future market drivers**. „Wireless full-track downloads present an opportunity that is arguably one of the largest in the wireless data industry" since US suppliers alone will reach a **turnover of nearly € 1 billion** by 2009 with more than **50 million subscribers**. One of the key near-term constraints is the lack of available handsets and 3G networks [USWi2005].

Market potential for the European telecommunication industry

The market potential for European telecommunications enterprises in some parts of the world is enormous. In India, as an example, less than six in 100 people use mobile services. By 2007, **India** is expected to have about **250 million phone connections**. The Taiwanese Industrial Technology Research Institute expects that **89 millions of mobile phones** will be bought this year in **China**, which is 14,1 % more than 2004. At the end of 2005, there will be 395 million mobile customers in China. Most of China's mobile market growth can be accounted to Dual-Mode-Services, which support traditional services like GSM or TD-SCDMA as well as PHS (Personal Handyphone System). And in **Africa**, today's fastest growing market for wireless telecommunication, the number of users will double to reach **140 million** within the year 2009 [Afr2005]. Around the world, 730 million mobile phones will be bought in 2005, which leads to a market growth of 8 % [Mark2005]. Europe today is in a very good position; e.g., **Nokia's market share** in India in terms of units sold has grown to **74%** in March 2005 from 61.5% in October 2004 [Cell2005].

Wireless broadband market still developing

A new trend coming up is wireless broadband. The greatest potential for wireless broadband is in China. There is significant potential in Eastern Europe and Latin America. Japan is perceived to have medium attractiveness, as well as Europe. The US have medium to low prospects for wireless broadband. Africa has completely different characteristics, but reaches the same level.

Wireless broadband: Market looks different in industrial and developing countries

At the end of 2003, 100 million fixed-line broadband subscribers were facing only 2.7 million wireless broadband subscribers. This underlines the present dominance of wireline broadband: **DSL and Cable have a market share of 97% of world broadband subscribers.** Both technologies will remain dominant in industrialized countries [MAR2004]. However, even in these countries wireless broadband will become a cost-effective alternative. Currently, the growth of wired broadband is still greater than the growth of wireless broadband, but this will have changed by the end of 2009 [Wim2004]. **The emerging markets and developing countries will generate a major share of the wireless broadband growth.**

Market penetration of UMTS and DVB-T still weak

An indicator for rather low interest in mobile or portable broadband is the low diffusion rate of UMTS. Today, 78 mobile communication providers offer UMTS in 36 countries. The number of subscribers rose by 68% between December 2004 and June 2005 to reach 28.34 million. These users can choose between 26 producers offering 179 different UMTS devices. This number quadrupled since June 2004 [GSA2005]. But in 2008, still only 16% of the Europeans will have an UMTS cell phone [For2003]. In contrast, a fast diffusion of DVB-T in Europe is expected.

Mobile handsets

The development and the presence of mobile handsets have played a central role in the rollout of services in the past. They assured not only success but contributed to the failures, latest experienced within the 3G market.

Mobile handset market Europe

In Western Europe, the use of multi-SIM devices will decrease according to Strategy Analytics, while the multi-device segment will show an increase with nearly 10% of users having a second handset by the end of 2008. Strategy Analytics expect approximately **45% of all users in Western Europe to have UMTS-enabled handsets by the end of 2008** [Tele04].

Mobile handset market Asia/Pacific

In 2002, the Asia/Pacific region was the world's largest handset market, growing 16.4% to 174 million. Growth in the region is expected to increase dramatically over the next five years since penetration remains low.

In contrast, **Europe lost sales** last year owing to the stalling of the Western European market, being ever reliant on the replacement market, and growth is expected to be slow up to 2008 [Arc03].

3.2.4.2 Impact of ES on Market

The importance of Embedded Systems for the mobile market is indisputable. Without ES there would be no mobile telecommunication at all.

Market for embedded software solutions

Telecom/datacom industry was the largest consuming market for embedded software solutions in 2002, and is expected to remain over the forecast period. VDC estimates that telecom/datacom accounted for € 276.8 million in shipments in 2002 and is forecast to reach over € 504 million in 2007, a CAGR of over 12.0% [VDC04].

Market driver convergence

Convergence of telecommunications systems and devices is enabled and **driven by the expansion of broadband Internet**. It is opening new markets and creating new challenges, not the least of which are interoperability at the network, device and content levels, the efficient management of spectrum to facilitate the emergence of new wireless technologies, and the availability of content. All this places demands on **new embedded system solutions to realise these concepts.**

Handsets with camera and video capabilities will force UMTS use

Leading the videophone market is Japan where it is estimated that 40 per cent of camera-phones sold in the second half of 2003 will have video recording capabilities. However, the deployment of mobile video in both Europe and America will not rise until at least 2004/2005 with the launch of UMTS networks. Widespread availability of such services will not occur much before 2006 when large quantities of video-capable handsets are expected to be available. The **development and improvement of new Embedded Systems can help to secure a sustainable market growth**.

Next generation handsets

The market is starting to see development of next generation networks beyond 3G, which will enable a single mobile handset to access a growing array of mixed mobile networks. This is **only practicable by a heavy use of Embedded Systems**.

Handset market growth limited

Manufacturers of electronic components for use in cellular phone handsets achieved **growth of up to 50% p.a.** In the electronic components segment, production has been steady until recently, promising another year of manufacturing growth for 2001. In some applications, however, such as handsets, the growth rates of the past years will no longer be repeated. Besides, as a result of the market's strong growth, manufacturers of certain types of electronic components have already reached the limits of their capacity [DB02].

3.2.4.3 Impact of ES on Competitiveness

Factors for strengthening competitiveness

Because the telecommunications market tends to be technology driven the competitiveness of the respective enterprises and organisations **strongly depends on essential innovations**, fast translation of R&D results into daily practice and the ability of fast concentration of great industrial capacities on a new field of acting.

User demands in mobile communication

Issues to be resolved include the demand for ubiquitous, secure, instant, wireless connectivity to manifold services. At the same time these must allow unhindered convergence of functions as well as global and narrow-range networks. Light, handy, high-functionality terminals are demanded, in which sophisticated energy management techniques "beat the heat" and ensure that the battery never goes flat. The better and the earlier a supplier meets these demands, the more competitive he will be. **In each of the given areas ES plays a decisive role.** Furthermore it will improve the ultra-low-power connections and increase processing, storage and display capabilities.

Potential of software defined radio (SDR)

In traditional telecommunications solutions, the frequencies and the protocols in use have been integrated into the hardware. This means that the transceiver units cannot be adjusted to use multiple protocols and frequencies. The software defined radio (SDR) technology emerging puts more intelligence in the transceiver unit, enabling it to switch frequencies as required to reduce cost or avoid congestions. SDR technologies and their use in Embedded Systems could have **an important role in a 4G world**, where multiple technologies are believed to communicate and interact.

Contribution of ES in telecommunication

A new generation of chips based on mobile (radio) technology contribute effectively; playing a **positive role in the EU's infrastructure**, and for the first time, give measurable benefits in the service sector [FMS04]. Embedded Systems in telecommunication contribute to competitiveness, employment and economic growth, reducing transactional costs and barriers to entry. They act as real creators of new opportunities, not just cutting the workforce to streamline production, communication and distribution processes [FMS04].

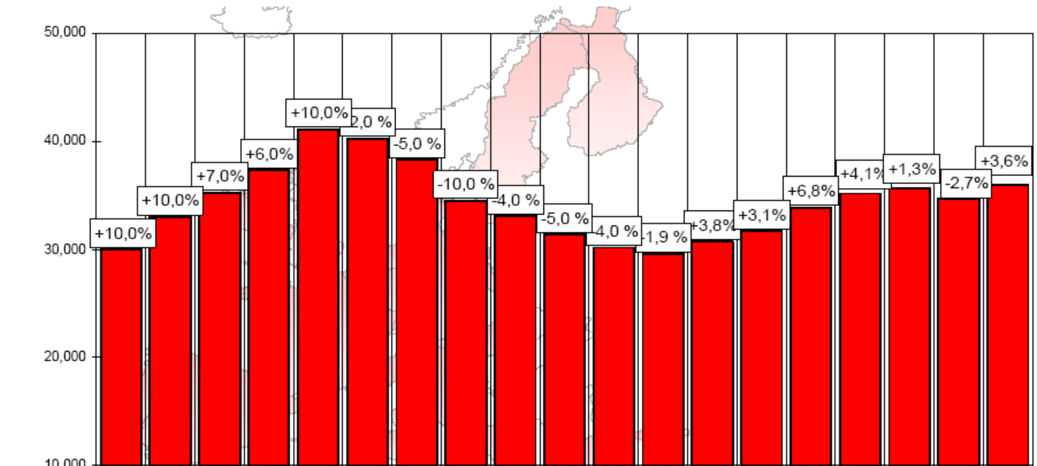
3.2.5 Consumer Electronics and Intelligent Homes

3.2.5.1 Market Situation

Consumer electronics market large and fast growing

The development of the consumer electronics (CE) market is strongly related to the general GDP growth as represented by the up-and downs in Figure 3-10. It can be expected that it will show further growth as the worldwide GDP rises. Either way the CE market is a large sector of embedded industry. The demand for innovative devices wired and wireless, mobile and stationary is boundless. Fast growing technology areas include streaming media, media capture and playback and communications. **These areas will continue to be among the highest growing ones** due to new standards and formats and smaller, more capable devices. **Software content will increase** as more features are packed into smaller devices and new standards emerge, which bring faster media and higher fidelity.

Figure 3-10 Development of consumer electronics market worldwide (million EURO) [ConE04]



	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Mill. EURO	29,954	32,949	35,256	37,371	41,108	40,286	38,272	34,445	33,067	31,414	30,157	29,576	30,697	31,643	33,795	35,191	35,651	34,675	35,913

Small European contribution to ES components sector

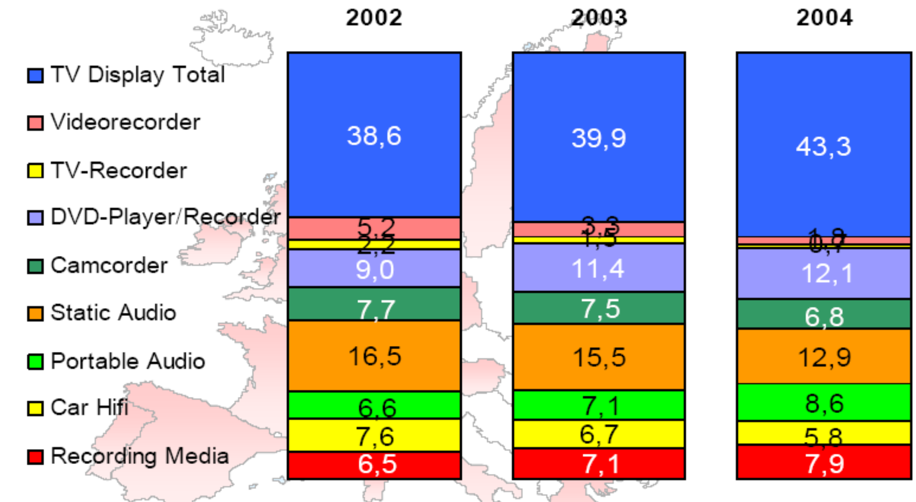
The components sector divides into passive components, comprising connectors, capacitors, resistors etc, and active components such as integrated circuits, tubes, LCDs and other discrete devices. The picture in both is similar, with Japan the world leader, followed by the US. Since 1996, **Europe** has gained in share of world production marginally, **now accounting for** 27% of world share in passive and **13% in active components.**

Greater European market share in private network equipment

Europe has a much greater share of world production in private network equipment, such as telephone sets, mobile phones, switchboards, fax machines etc. **European production levels are about the same as the US and growing at 16% per annum.** However, a productivity gap is emerging with levels of value added per employee in the US three times those in Europe – even among US firms manufacturing in Europe [Com04].

European productivity below Japanese and US's

In consumer electronics, the competitive picture since 1996 has remained broadly stable. Japan retains its world leadership, despite falling production revenues, while **European production has been flat**. Once again, European productivity remains staunchly below that of Japan and the US. Figure 3-10 shows the overall development of consumer electronics worldwide and Figure 3-11 the size of the different segments.



Mio. EURO	35.650,6	34.674,7	35.913,3
+/- previous year %		-2,7	3,6

Figure 3-11: Product segments (Value %) [ConE04]

Home networking as another market driver

Strongly related to consumer electronics is the topic of the intelligent home. Today, only two percent of Germany's houses have a home network. In the US their penetration rate is 17 and in Japan 16 percent [DigH2005]. In total, 34.7 million houses used a home network in 2004 with 107.6 million devices connected. It is expected that in 2005 57.6, in 2006 75.8 and **in 2010 162.3 million networked households** will exist. The **number of devices connected will increase to 973.8 million**. But the growth of this market will be different in various regions: The study expects that the density of home networks in 2010 will be 90% in South Korea, 76% in Japan, **62% in Great Britain**, 42% in US and **38% in Germany**.

Home control system

Approximately 7% of US Internet households already have a home control system (HCS) controlling lights, room temperature and security system in place and another 29% are, to some degree, interested in purchasing such a system [Cons2005]. As experienced in the past, a few years later a similar course of things may be expected also in Europe, at least in West and Middle Europe.

3.2.5.2 Impact of ES on Market

Fast growing impact

The **fastest-growing category** of applying embedded software technology is expected to be **consumer electronics** with a forecast **CAGR of over 15%** [VDC04].

Networking and multimedia will be key drivers

The growing complexity of consumer electronics devices in terms of features, networking and multimedia will be the key driver. These more complex devices will likely require either the addition of a full commercial operating system or the upgrading to a commercial operating system from an in-house OS or executive.

ICT appliances and performance of communication networks

It is easy to guess that the number of household appliances linked to information technology and the performance level of the communication networks supplying the home are two **main factors underpinning the development of the Connected Home markets** [Teaha04].

Connected Home markets now worldwide

In this context, five to ten years ago, it was traditional to consider that the Connected Home markets were developing essentially in North America, Europe and Japan. The fast-growing economic development in Korea, China, Singapore and other Asian countries today leads analysts to consider that the **connected home markets have become worldwide**, affecting North America, Europe and Asia and are both quantitatively and qualitatively comparable in these three regions.

Connected Home market may be developing fast

The connected home market is, in all evidence, in an emergence phase. Currently only some 2% of American, European and Asian homes spend about € 100 per year on connected home equipment and services. The market appears to promise a fast development of 10% per year.

3.2.5.3 Impact of ES on Competitiveness

Global economic conditions led to downturn in investment

The embedded industry continued to be challenged by global economic conditions and the downturn in information technology spending. Uncertain of future business, manufacturers continue to look for ways to reduce costs by closely managing new project starts and investments in products and services, resulting in reduced product purchases, delayed sales cycles, and deferment and cancellation of projects [VDC04].

Enhancement of customers' productivity opens new market possibilities

In contrast to businesses that invest in office automation equipment to increase employee productivity, trying to maximize their return on investment, consumer customers use different criteria at deciding whether to adopt new technologies. For example, housework or other everyday procurements are considered to be time-consuming and tiresome. Household appliances assist busy people enable them to multitask and even take some tasks off their hands. This offers new possibilities to enhance the customers' productivity.

Traditional platforms become more software-based

Serious threats to European manufacturers arise when the traditional platform becomes more software-based and hence open to influences of de facto software standards, such as PC-based operating systems such as Windows CE migrating to digital television. The same threats pose themselves when a given platform is split into separate functions, as in the case of set top boxes for digital television or when one platform is replaced by another platform like game players. In the first cases, European manufacturers are confronted with competitors who have excellent skills in communication, data processing or software systems, though relatively little in terms of traditional television skills. However, the option of competing in this field exists for European suppliers.

"Silicon Valley" products need translations to European context

Where emerging new products with integrated functions are concerned, European manufacturers are likely to tap into the Silicon Valley environment, certainly where Internet-related skills are required. It is important to note that many of these products will have to operate in a specific European service and user context, which may require substantial translations. This may **compensate for some of the weaknesses in the somewhat less advanced position of the European CE industry in this field**.

Increasing importance of content and services

With the increasing importance of content and services, players in this area will determine, more and more, the developments in the CE market. Businesses tend to integrate along the value chain, but the traditional CE industry is usually not involved. This entails the risk of becoming a low value-added supplier of boxes that are specified by others. However, **in Europe a significant content industry for television has developed, and the possibility for cooperation is an important option for the European CE producers**.

Quick shifting of CE manufacturing to attractive regions

On the other hand a **CE manufacturing industry will emerge partly knowledge driven** – thus concentrated in a few knowledge intensive regions of the world – and partly, with regard to the commodity aspects, cost driven. This kind of manufacturing shifts quickly to the most attractive regions, with the lowest sum of production and transportation costs. In addition, the manufacturing sector includes the producers of key components, of parts and additional components (from moulds and plastic parts to fully mounted printed circuit boards), software makers (in particular “embedded software”) and service companies [First00].

3.2.6 Health and Medical Equipment

3.2.6.1 Market Situation

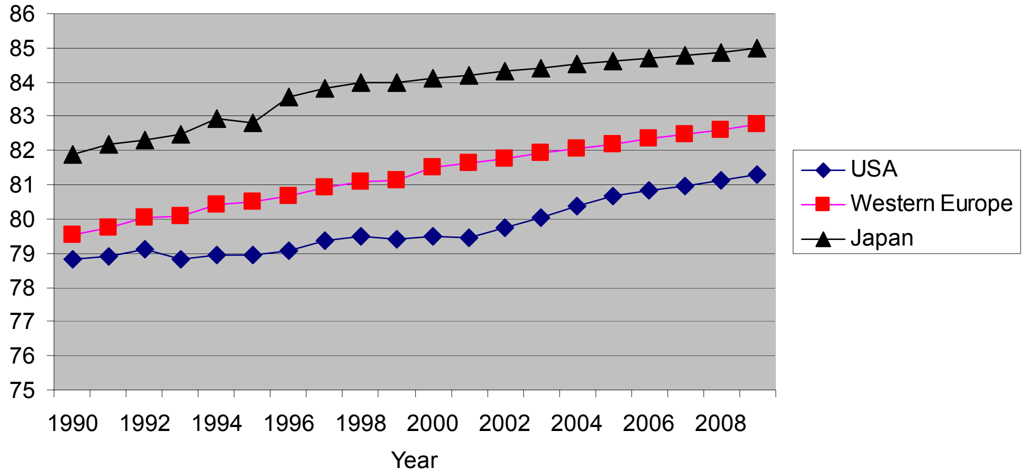
Largest medical technology markets: US, Japan, Germany

The medical technology market is characterised by strong governmental regulations, both on the supply side (e.g., required approval according to certification criteria) and on the demand side (health politics, reimbursement of therapy costs by health insurances). The largest markets for medical technology are the US (total value of production in 2002 $72.9 billion, (approx. € 57.4 billion), Japan ($15.3 billion, approx. € 12.0 billion), and Germany ($12.6 billion, approx. € 9.9 billion) [DGBMT2005]. Typical for the medical technology market is a co-existence of a **large number of small and medium enterprises** (SMEs), which are serving the regional market with **specialised products**, **and** few **globally operating companies** (traditionally from US, Japan, Germany, France, Switzerland, Netherlands; increasingly also Ireland, Sweden, and Denmark) mainly producing **highly R&D-intensive goods**. The data on direct support for health R&D suggest that the United States accounts for over 75% of the OECD total (compared with only 16% for the European Union) [OECDST2003]. Europe needs to keep pace in innovation since in 2003, 350,000 employees worked in Europe in this sector [COMM2005].

Increasing life expectancy in industrial countries

In industrial countries, the average life expectancy is increasing at a fast rate. Figure 3-12 shows that the phenomenon of an aging society is strongest in Japan, followed by the EU and the US. The rising life expectancy is partly caused by the availability of more and more improved medical equipment and thus leads to an **increasing demand in the sector**. However, one should keep in mind that a longer lifespan does not necessarily mean that the time of life in disease increases at the same rate.

Figure 3-12: Average life expectancy (in years) in US, Europe, and Japan



Growth of medical technology sector

Expenditures for medical technology are rising in industrial nations because of the increased demand due to the aging population, age-specific diseases and rising cost of innovative therapies. In the US, the production in the medical technology sector increased by 15% between 1998 and 2001 (compared to a production increase in the industrial sector of only 2%). A similar trend can be observed in Japan and Germany (see Table 3-7) [DGBMT2005].

Table 3-8: Development of production value in medical technology compared to industrial sector

	Production increase 1998-2002 (medical technology)	Expected production increase 2002-2010 (medical technology)	Production increase 1998-2002 (industrial sector)
US	15%	4,1%	2%
Japan	11%	2,9%	-6%
Germany	25%	7,2%	12%

Telehealth market

The market for telehealth (also called mobile healthcare, i.e. providing healthcare services at a distance; see section 4.2.6 alone is estimated to amount to around $380 million (approx. € 299 million) in 2004, with a growth rate of 15-20% [IDI2004].

3.2.6.2 Impact of ES on Market

Market volume of ES in medical devices

Electromedical devices and instruments make up approximately **25% of the total production value** of medical technology (cf. [DGBMT2005]). The industrial respondents to the online questionnaire working in the field of embedded medical devices attribute about **50% of the costs in their products to Embedded Systems**, with a **slightly rising tendency**. So, the estimated market segment volume is approximately € 24 billion, based on a total market volume for medical technology of € 193 billion for the major industrial countries [DGBMT2005].

3.2.6.3 Impact of ES on Competitiveness

Computerisation, miniaturisation, and molecularisation, driven by ES

According to [DGBMT2005], innovation in medical technology is mainly driven by computerisation, miniaturisation, and molecularisation. [Lau2002] describes exemplary development steps in computerisation in medical technology: high performance computers, navigation software, and robotics. Information and communication technology is seen as an **"enabler" of medical technology**, in particular in the form of Embedded Systems. Here, a main innovation area is ambient intelligence provided by networked medical devices [DGBMT2005], as detailed in section 4.2.6. A roadmap by Friedewald and da Costa [FdC2003] projects that until 2008, widespread use of administrative information systems will be established in the medical domain (e.g. electronic patient record), whereas **automated diagnosis is only expected to become mature in 2015**.

Competitiveness due to standards

One of the most important trends ensuring competitiveness in the medical devices sectors is the standardisation to ensure their interoperability. **Standards improve business** profitability and competitive advantage by lowering purchasing costs, increasing quality, promoting innovation, increasing time to market, and enabling compliance with international demands [IDI2004].

Telemedicine Alliance's vision of a network of data repositories grounded on ES

In this context, in Europe the Telemedicine Alliance (TM Alliance) [TM2005] has been set up to pave the way for a unified system of telemedicine. This alliance links the Information Society Technology (IST) program of the European Commission, the World Health Organisation, the International Telecommunication Union (ITU), and the European Space Agency (ESA). The TM Alliance's vision of "a network of data repositories associated with the citizen and used by the principle behaviour 'actors' of provider, educationalist, policy maker, and payer" **strongly builds on Embedded Systems** and their standardization and interoperability.

Studies documenting positive effects of telehealth

Some studies have demonstrated promising results. For example, application of telehealth to managing high-risk pregnancies led to significant **reductions in premature births** [CEM2001]. Other studies showed that hospital **readmission rates for congestive heart failure patients were dramatically lower** after a sustained program of telehomecare monitoring and patient education.[CRT2001] In 2000, break-even of investment into teleradiology was calculated to 7-8 years using a model based on 25 separate factors. Duration may currently be shorter as costs for radiographic image capture devices have dropped dramatically in the meantime [IDI2004].

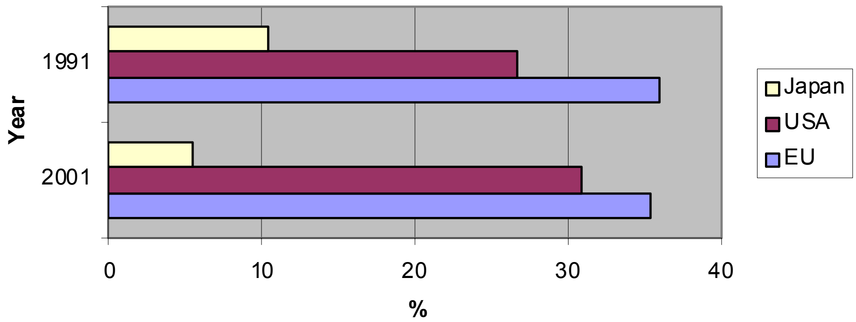
Role of Europe and US

Europe is in a leading position when it comes to embedded medical equipment technology. This is supported by the questionnaire where 65% of the respondents agree or strongly agree to the statement, including the majority of the non-European respondents. Besides, in view of the situation of the US in telehealth, [IDI2004] states that "despite being regarded as one of the world's leading innovators and suppliers of telehealth technologies, US firms' participation in international markets is limited", and that international markets have largely been overlooked by the US. However, [IDI2004] also states that the "US has one of the most active and innovative telehealth sectors in the world", thus **care must be taken that the advantage of Europe in international markets is not lost**.

World trade shares in medical technology

Figure 3-13 shows the share of world trade in medical technology for the EU, the US, and Japan in 1991 and 2001. One can clearly see that **Europe is dominating the market**, but the US have already been gaining market share.

Figure 3-13: Share of world trade in medical technology [DGBMT2005]



3.3 Compliance with Policies

Specific areas of interference with policy, regulations, environment

Embedded Systems have found their way into many different applications and devices. This high penetration leads – in some areas like medical devices or in the automotive industry – to the necessity of regulation and policy. This section shows how strong the interrelations between technologies, their use in specific devices and the market are. We focus on three issues to answer the following questions by giving an introduction in the respective area and by providing some examples:

- How and where can Embedded Systems help to enforce policies for efficiency and support important research?
- What are the negative effects of Embedded Systems and where are regulations needed?
- In which areas would stronger regulations and requirements be helpful for the market and the European industry?

3.3.1 Positive effects of Embedded Systems

There are many relevant areas of Embedded Systems with a tight interference with the consumers' interest in environmentally friendly products as well as with the respective regulation. These areas include the biological impact of electromagnetic emissions, electromagnetic interference (EMI), energy conservation and emissions, and public health, especially prevention of hazards caused by Embedded Systems. The positive effects on the users' well being with respect to progresses in medical applications or through the use of smarter devices etc. are not covered in this section; these topics are described in detail in section 4.2.6.

Increased intelligence improves compliance with policy goals

The increased amount of intelligence supplied with Embedded Systems and the basic enablers for more intelligent control such as electronic replacements for mechanical linkages are often beneficial for compliance with policy and environmental issues. Some examples are:

- increased efficiency of power-consuming machines and devices by improved processor technology, RFID technologies and smarter energy management [IEE2005] in plants as well as in office and private buildings,
- less radiation from mobile devices by smart, power-aware wireless protocols that adjust radiation levels to the demands of the wireless link [IEE2005],
- improved emissions and fuel consumption in automotive and avionics through advanced electronic engine controls that are connected to more sensors to incorporate information that helps to minimize the fuel needed [ACEA2002], (e.g.,

today's cars have 95% less emissions of Kohlenmonoxid and Stickoxiden than those sold in 1990 [PFH2005]),

- reduced emissions and fuel consumption through improvement of traffic flow. Advanced telematics applications in automotive [ITEA2004] and more intelligent, i.e. networked, traffic management systems could help to reduce traffic jams. [PFH2005] estimate that the European market volume for complex telematic and traffic control systems is € 3.7 billion in 2005 and that it will reach € 5.8 billion in 2010. The world market, today worth € 25 billion, is expected to grow by six to seven percent per year.
-

Increase in efficiency of power generation

Also the efficiency of power stations can be increased through better control systems. This is valid for all types of combustion power stations. Also renewable energy sources can be used more efficiently, which increases their cost effectiveness. For example, solar trackers that "follow" the sun across the daytime sky always ensure that solar panels are exposed to the maximum available sun energy. This technology increases the energy output by up to 40% [PPN2005].

Support of environmental research

Besides these positive effects on the use of resources, Embedded Systems ease environmental research or enable many new investigations. The measurement and tracking of diverse data like weather and climate data paves the way for new research insights. In addition, sensors are used more often to identify early indicators for earthquakes, volcanic eruptions or flood waves. Other sensors and wireless sensor networks are used to observe animals and to track changes of ecosystems to better understand these changes and examine the effects of nature conservation activities.

3.3.2 Need for regulation and enforcement of policies

In contrast to the examples presented in the last section, the increased production, use and disposal of devices lead to new problems and challenges.

Regulative sanctions to lower negative impact of electrical disposal

For the last couple of years, the increase of electrical scrap has been discussed in public. As devices get cheaper and even more of them are used for new purposes, this problem aggravates. Despite progress that has been made with respect to more eco-friendly materials and production techniques, politics was forced to react. As US consumers jettison each year about 130 million cell phones, each computer maker in Maryland must kick in up to € 4,000 annually to help recycle their products under a new state law designed to cope with the roughly 60,000 tons of "electronic waste" that pile up in Maryland each year [CRF2005].

Higher resource needs

The underlying problem is the rising demand for resources needed to produce even more embedded gadgetry. Therefore, there is a strong **need for new basic materials**. An example is NEC that partnered with Japanese enterprise Unitika to develop a corn-based plastic for mobile phones that should find its way into NEC-manufactured mobile phones by June 2006. The two enterprises successfully reinforced a polyactide resin, a bio-plastic made mainly from corn, by adding in fibres of kenaf, which is a type of hemp. Polyactide resin is eco-friendly as it bio-degrades after being in the soil for a long time but the use of the material had been limited because it's subject to heat and shock [BTN2005]. Such eco-friendly, bio-degrading materials are especially important as a basis of wireless, autonomous devices that cannot be recycled since they are disposed in huge numbers to deliver data or serve other purposes, e.g. in environmental or climate research or for military usage.

Electromagnetic pollution

Another topic that has been discussed since mobile phones are widely used is the set of negative effects of wireless communication, often called "electro smog". For example, some studies claim that using mobile phones increases risk of cancer. The ongoing discussion shows the need for research to find and use innocuous frequencies and more effective isolation of specific buildings, e.g. of kindergartens.

3.3.3 Stronger regulative incentives to support the industry

There are also chances to support environmental issues and to increase Europe's market position by creating a suitable legal framework for ES deployment. Just a few examples concerning industries mentioned in this chapter are given in the following paragraphs.

ADAS: Europe leads in technology, but tight regulations and slow adoption by home customers are potential obstacles

In case of Automotive, for advanced driver assistance Systems (ADAS), the market is largely driven by innovation in Embedded Systems and electronics. A comparative study [SBD2004] concludes that the **European market for such applications is trailing the Japanese market by 2 or 3 years**. As a potential reason, it is concluded that both slow adoption by consumers in the carmaker's home markets, and tight or **uncertain safety regulations** that discourage introduction of systems, can be a major obstacle to market growth in these segments. For example, thanks to better customer adoption of ADAS technology in the Japanese market, Toyota was able to launch the world's first ADAS system in 1997, while the first European carmaker followed in 1999. From a legislation perspective, the **24GHz band**, which offers the best commercialisation perspective in, has been available in the US since 2002. The same frequency band has only recently been made available in Europe, but **only for a limited time span, and with tight additional requirements**. Consequently, for the European market, the attractiveness of 24GHz from a commercial standpoint will be limited.

Teleservices delivery platforms and content providers

In Telecommunications, convergence of services (cf. section 4.2.4.2) calls for a new level playing field among audiovisual content service providers. **Modern EU rules** should be market-oriented, flexible, and neutral as between delivery platforms, and enable content service providers to compete on an equal footing, ensure regulatory consistency and strengthen legal certainty based on the country-of-origin-principle [Memo05].

Regulatory framework for electronic communications

A migration towards advanced high-capacity networks can primarily be achieved through more competition. As in other network industries **competition is still weak**. The Member States with the highest broadband penetration rates are those where competition between alternative technologies is most keen and the customer has most choice, with both cable and ADSL offers for instance. But **cable coverage is limited** in the EU and competition between alternative platforms is not widespread. Therefore stimulating competition through the full and correct transposition into national law and implementation of the regulatory framework for electronic communications are crucial. This can force the development of new innovations in the field of Embedded Systems.

Lack of efficacy and cost effectiveness data in telehealth

In case of healthcare and medical devices, the effect of innovative technologies using embedded devices, such as telehealth, on the overall health cost is difficult to estimate. [IDI2004] constitutes "the telehealth community's inability to prove efficacy and produce cost effectiveness data through high-quality, peer-reviewed clinical studies", which is "**often behaviour as a barrier to resolving** such diverse issues as provider acceptance, third party payer reimbursement, and liability". Research in Europe in this direction should be encouraged and funded, to remove barriers to innovation, demand, and investment.

Example for policy driving development: eCall system to enhance safety of EU drivers

Finally, there are **legal regulations,** which **only can be complied by** the use of **ES**. In this way the policy builds a favourable framework for economical development in this sector. An example concerning the M2M technology (machine to machine wireless communication) is the so called **eCall system, which** will automatically launch an emergency call after an accident and transmit the exact position of the accident scene to an emergency centre. As of 2009, all new vehicles shall already be equipped with this technology to enhance the safety of EU drivers.

3.4 Conclusions

ES everywhere

Embedded Systems are of extraordinary importance for the future development of the European economy, since they have been and yet increasingly will be integrated both in the products and in the production plants of practically all industries mentioned here.

ES sells

The more value new products will gain by adding intelligent control and other applications of Embedded Systems, the better they will sell.

Europe's potential

Good chances for Europe may be predicted in this area. First, Europe has a strong or leading market position in most of the considered industries. Second, the general development on this technical sector tends to "Softwareization", where Europe can rely on a highly educated engineering' workforce and employ its rich scientific and cultural potential.

Europe's inconsistency

In this context new challenges arise since European countries are traditionally strong in the field of research but, weak in quickly and adequately translating new knowledge into production and market success.

Market chances

It is a positive factor in this game that Europe itself already represents a large market for the products of the examined industries. In addition, European products have good chances to be sold worldwide on other markets, as they have been by now.

- Undoubtedly the strongest impact of Embedded Systems on market opportunities has to be expected in the **automotive** industry. On the one hand, this is the largest market considered here in absolute figures: in 2004 alone, there have been 14.95 million new registrations of cars in the 23 EU states [ACEA2005]. On the other hand, the share of ES in this value volume permanently grows and most likely will exceed the 50% mark after 2010. And finally, innovations, which are possible only by use of ES will decisively contribute for sales of cars equipped with them and therefore to competitiveness in this market segment. Examples of such innovations are safety facilities and ADAS (advanced driver assistance systems).
- Great market chances for ES also exist in the field **avionics/aerospace**. Although in this area quantities like in automotive cannot be reached by far and so, a given expensive innovation cannot be applied (and sold) as frequently as there, this partly is compensated by higher unit prices. In any case there's a broad field of application for Embedded Systems since most control functions used in aeroplanes (e.g., „fly by wire") are simply impossible without ES.
- The same applies to **telecommunications**. There isn't any mobile telecom without ES. Future technological development will make services possible that will meet existing and emerging user demands. This will be a strong motive for market development and trigger new impulses to a market partially stagnating today.
- Special attention has to be paid on **industrial automation**. Europe is leading in automation equipment and delivers almost a third of world's production, about 65 billion € in 2004, building automation included. Loss in this segment is threatening and already behaviour. To stop the loss and to gain ground, new efforts are required. Broader use of Embedded Systems promises to be a good starting point to this.
- In **consumer electronics**, where Europe has a rather little market influence at present, chances arise by future developments. These are particularly the raise of software share in the products' value and increasing quality requirements, for example in the field of networking.
- In the area of the **health and medical equipment** Europe has to make big efforts to keep its present leading market position. ES helps to develop new products that sell greatly, particularly in the areas of diagnosis, telemedicine and administration information systems. So, it is an „enabler" for future medical technology. To make this

positive influence come true, prerequisites must be done in the area of standardization and other legal framework.

The next chapter will show the market and technology trends in ES and the challenges that must be tackled for realizing the further growing market impact.

4 Trends in Embedded Systems

Our study is based on a multidimensional analysis as shown in Figure 4-1. In this chapter, we present the most important trends and challenges concerning Embedded Systems in different dimensions:

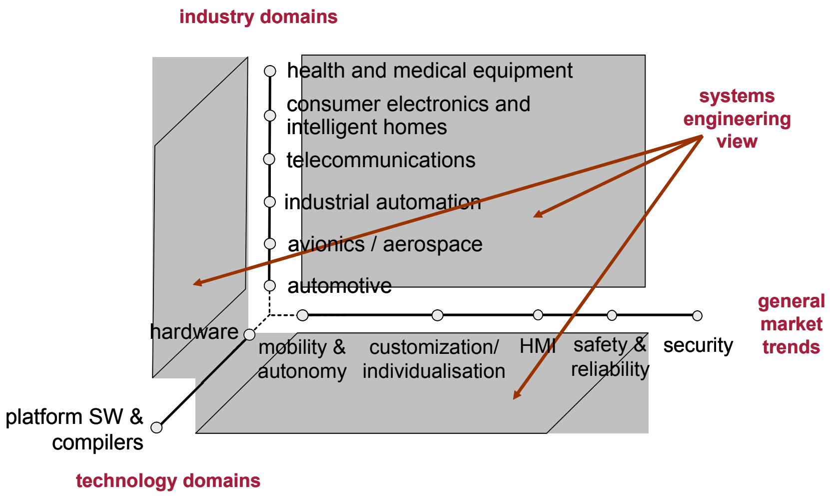


Figure 4-1: Dimensions of ES

Industry domains: Applied technologies in the specific sectors

Industry domains represent the different industry sectors with their specific solutions. The industry trends (see section 4.2) help to address market trends or technical trends in each of these domains. This approach guarantees that **application-domain specific solutions as experienced by the user** (e.g., Advanced Driver Assistant Systems or the mobile monitoring of ill persons) are captured. After characterizing the sector and its technologies, the major trends are presented. For every sector, a short conclusion summarizes the most important findings selected with respect to future competitiveness and / or their respective technological challenges. The authors are aware of the overlaps that exist in some cases between different sectors; e.g., the logic and functioning of drive-by-wire systems are close to the fly-by-wire concepts.

Technology domains: Basic technologies

The technology domains are hardware and platform software. Application functionality generally is distributed across all technology domains of a system. For instance an engine control system has functionality on the software level, network level, sensor level. Hence all levels may be changed during a customisation process. Using a cheaper sensor, for example, may have to be compensated by a more robust computation software on a faster Electronic Control Unit. Thus, an important issue in developing more complex Embedded Systems is to promote a holistic approach, which is needed to address all technology levels of a system under development. In section 4.3 we therefore present **specific technological innovations that are provided by the technical platform and that are relevant for several domains** (e.g., intelligent sensors, standard SW architecture, Bluetooth protocol or Time-Triggered Architecture). Thus, it is ensured that circuit emulators, Digital Signal Processors, Real-Time Operating Systems or middleware concepts are covered in this study, even if they are – to avoid redundancies – not described as part of a specific solution. This approach also ensures that mutual dependencies between application specific trends and technologies are derived and described.

General market trends

The trends identified in the industry and technology domains are – in most cases –driven by one or several **market pull factors**, which we call "general market trends". These trends, as described in section 4.1, show superordinate market needs that are valid for a broad range of solutions and technologies.

Systems engineering perspective

Through these three perspectives it is possible to classify and judge current technological developments and challenges as well as trends in the different sectors. Nevertheless, there are superordinate questions still not answered about the best way to develop Embedded Systems. Since we see a strong overall increase in features and functionality of electronic Embedded Systems, and thus in their complexity, it is necessary to investigate **methods, tools and processes** to optimally support and structure their design and development in order to increase the competitiveness of European firms. The approaches and **advancements in systems engineering** most notably lead to an increasing productivity, decreasing time to market and thus to a higher efficiency of the whole industry. Cost and time of development processes will be decisive for the success of the resulting product. Therefore, trends in these engineering topics need to be worked out explicitly which is done in section 4.4. Some aspects in this systems engineering section show **overlaps to other chapters**, e.g. to some trends in the technology domain. But the explicit coverage of **systems engineering** is needed because most of the problems and solution are valid for more than one sector and combine hardware and software aspects.

Systems engineering: Differences to HW and SW engineering

Numerous examples and challenges will show that it is not enough to see hardware and software engineering as two distinct disciplines that have some intersections at some stages. Instead, today's products and solutions require an interdigitated and mated development process. Therefore, we are convinced that it is necessary to **integrate software and hardware engineering aspects in one discipline.** This also represents the current changes and the hitherto evolution of the engineering discipline in industry and research.

Mutual dependencies between ES trends and policies

Trends in Embedded Systems widely influence society and everyday life. So, development and deployment of ES must follow legal regulations and be aware of policies and **environmental issues**. On the other hand, political stakeholders should be interested in regulations that foster an advantageous development in this area. And finally, strong regulations may also contribute to a faster and wider spreading of new technologies like ES, because without them they could be met hardly or not at all. One of the most important aspects in this context is responsible consideration of environmental concerns.

Overlaps of needs, trends and technologies between sectors

It is obvious that the approach of splitting up the trends in four categories results in **numerous overlaps between different topics** and thus chapters. For instance, developing smallest sensors is a topic of hardware research and an example for the widespread trend towards miniaturisation. The use of such sensors for advanced diagnosis tools is covered in the section on health and medical devices and the processes, tools and methods that are used to develop such new and more complex devices are presented in the section on systems engineering. It would imperil readability to explicitly show all overlaps. Therefore, we show instances of such synergies where appropriate.

4.1 General Market Trends

Used as overall characterization

This section is concerned with general market trends (or "high-level trends") that exist across all industry domains. For the purpose of this document, the general market trends will serve as an overall characterization of the advancement in the Embedded Systems field. Where suitable, the classification will serve as a basis for identification and judgement of concrete current trends. From the multitude of possible superordinate classifications, the authors have identified five high-level trends, aligned with the classifications from related roadmaps (like [AMSD2003], [ROADNL2002], [EAST2002]), which characterize user (or market) demands from a bird's-eye view. These trends are **mobility and autonomy, customisation and individualisation, human-machine interface, dependability, and security**. Other important trends and demands that are often cited, like cost reduction or performance, are also of outstanding importance for the market. But they can be either derived from the trends presented here or are covered in other sections (e.g., cost reduction – besides being of a different flavour – can be reached through lower costs for components and more efficient development processes). In 4.2, the relevant market trends and their interrelations are explained in some cases to underline the basic drivers of a specific development or application.

4.1.1 Mobility and Autonomy

Ongoing trend meeting natural user demands

The continuing rapid growth of markets for mobile embedded solutions has been observable in the last two decades, for instance with the mass deployment of cellular phones, personal digital assistants (PDAs), and similar devices. According to scenario-based studies [ROADNL2002], [AMSD2003], the trend towards increasingly mobile and autonomous devices is expected to continue. From a user perspective, the demand for small, portable, powerful embedded solutions seems a natural one, as it **brings the comfort of information and communication to everyday life**.

Enabling technology for high productivity in factory automation, new applications in avionics

At the same time, decentralized and autonomous systems with wireless connectivity are playing an increasingly important role in application areas that are not primarily concerned with end-users, such as factory automation, or military purposes. In factories, autonomous technology for **spontaneously networking components**, which increasingly relies on wireless communication, will ease installation and re-configuration of automated plants. The expected cost and productivity benefits are accounting for a high growth of autonomous/wireless technology in this area. In military and civil surveillance applications, new technologies such as **unmanned aerial vehicles (UAVs)** will rely on spontaneous connectivity and wireless communication as well.

Advancement governed by technology

However, the transition to mobility and autonomy poses stiff challenges on the technology side. Advancement in the field is therefore strongly **governed by technological advancements**. The key drivers for innovation in the past have been advanced displays, new wireless network standards, faster, highly integrated and more energy-efficient chips, and improved battery technology. In the end-user centric segments, such as telecommunications or home automation, the market for operating systems, development environments, and local-area/wide-area network standards for mobile applications has very much stabilized, and **a few market leading products and standards lead the way** [PCT2004]. In industrial automation and avionics, the technological situation is not quite as mature, partly due to the lack of standards, partly caused by much higher requirements in terms of performance, security, and reliability of the involved technologies, to name a few criteria [DTA2004].

4.1.2 Customisation and Individualisation

Increasing demand for customized features across all domains

Vendors in the embedded market face an **increasing demand for custom-specific, individual features** across all domains. The impact of this trend toward competitiveness and profitability is trivially visible in the market for custom mobile content, such as downloadable dial tones, logos, and games, which experienced multi-digit growth within the last few years. According to [MobC2005], consumer demand for mobile downloads is **set to triple between July 2005 and July 2006**, creating a €7.6 billion global market for mobile content by that date.

Supporting individualisation concerns in a cost-effective and logistically feasible way is key competitiveness issue

The vendor's **ability to support such individualisation** concerns in a cost-effective and logistically feasible way is a **key competitiveness issue** in any of these sectors [Kor2003]. The incorporation of such issues in design and specification is especially challenging in industries where product life cycles are long compared to the frequency of new individualisation requests: for instance, the automotive, avionics, and telecommunications infrastructure sectors with their comparatively long product cycles are each very much affected by customisability issues. In these industries, products should ideally be designed to incorporate future changes and customized features from the very beginning, turning the product yet again into a platform.

4.1.3 Human-Machine Interface

Provide usability, comfort and safety to the "average" user

Exemplified by the luxury segment of the automotive domain, where the user is confronted with more and more complex systems, the design of human-machine interaction systems is becoming a key competitiveness issue [Han2004]. The underlying intuition is that advanced, feature-rich systems will only be accepted in the marketplace **if the "average" user is able to understand and use most of the available features** after a short learning interval, and that features, which require continuous interaction (such as driver-assistance systems) can be operated in a safe and comfortable way. Users are known to benefit much from a **"common usability experience"**, exemplified by the factual standardization of graphical user interfaces in the desktop OS and handheld OS markets. Consequently, there is certainly an ongoing lucrative potential for cross-fertilization of different domains, including consumer electronics, desktop PCs, business information systems, handhelds, and transportation sector, where most suitable user interface concepts for a given purpose can be identified and **transferred across domains**.

Alignment of user interfaces with cultural differences or individual needs and preferences

A new challenge is the alignment of user interfaces with cultural differences or individual needs and preferences. For example, [CLKJ2005] states that 80 percent of Finnish mobile users think that mobile search facilities are important, while only 30 percent of Koreans do. Also, Koreans demand content rankings for data services, whereas Japanese – as an example – are more interested in finding the music that they, as individuals, want to hear. Thus, it is crucial to not only develop easy and usable interfaces, but also to make them easily **changeable and adaptable**. Context adaptive interfaces, which "learn" through the user's behaviour, are a related area of research.

4.1.4 Safety and Reliability

Strong selling argument

In many applications, dependability (composed of **safety**, **reliability**, and **security** concerns) is a strong selling argument [Kop2002]. Consequences of unsafe and unreliable operation range from mere user annoyance, where commercial consequences may already be significant for vendors in heavily publicized markets, to catastrophic failures, exemplified by critical avionics applications.

The general acceptance of computer-controlled systems in society seems heavily influenced by relatively few instances of catastrophic controller failures. This makes dependability issues appear as an **especially important strategic issue for governmental institutions**, who are interested in high public acceptance of research and innovation in the field. As an example, the well-known Ariane 5 incident in 1996 [LeL2002] has attracted heavy media coverage, and incurred follow-up costs in the range of several € 100 million.

Impact of catastrophic failures

The development of networked systems leads to **decreasing reliability**. Therefore, strong efforts are needed to take counter-measures by reliable OS and protocols to avoid a trade-off between theses two goals. Also, the shift from mechanical controllers to more sophisticated hardware and finally to more software-based solutions causes the **desire for more dependability**.

Reliable OS and protocols needed

4.1.5 Security

Information security is concerned with protection against malicious attacks that are carried out, for instance for gaining access to protected networks, or for stealing intellectual property. Embedded Systems can be attacked remotely (if connectivity allows) and physically (if accessible to the attacker) [Mur2004].

Protection against malicious attacks

The possibility of physical attack seems **particularly relevant in the Embedded Systems domain**. An embedded system is frequently deployed close to users in an accessible, transportable package, so “reverse engineering” (opening the package and extracting information about the HW/SW) by attackers is possible. Prominent examples for such easily accessible Embedded Systems are set-top boxes and associated smart cards.

Physical attacks

Remote attacks seem more difficult for embedded devices since there is a plethora of operating systems and communication stacks around. However, with the slowly increasing number of standard-OS Embedded Systems, standard OS capabilities and security holes of these standard components **become exploitable for hackers as well**. As an additional threat, users of special purpose systems (such as an electronically controlled, IP-connected microscope) do not expect to be responsible for administration tasks (for the embedded Linux OS that the microscope controller is running).

Remote attacks

Wireless standards such as **Bluetooth** open up yet another frontier, allowing, for instance, snooping an owner’s phonebook without their notice. Future threat scenarios include **viruses** that spread in a hop-to-hop fashion from one cell phone to another, thus enabling mass attacks similar as the ones observed in the Internet domain in the past years.

Wireless connectivity opens up additional threat scenario.

4.2 Industry Trends

Main industry sectors where Embedded Systems are being deployed and being experienced by users are described within the industry domains. It is here where new user needs are identified in the concrete form of requested new features, or new products (**market-pull**). The demand in the industry domain will trigger innovation in the technological field, and pose new challenges to systems engineering for developing and integrating the new product. At the same time, advances in technologies frequently trigger new products in the marketplace (**technology-push**). Examples include a new technology such as MEMS (micro-electronic-mechanical sensor), resulting in new products in a particular marketplace (such as affordable navigation compasses for small planes in the avionics domain).

User-centric view; interaction with technologies, engineering

Understanding of diversity of different markets

The following classification for industry domains is used: automotive, avionics/aerospace, industrial automation, telecommunications (with a focus on embedded devices), household appliances and consumer electronics, and health and medical equipment. This classification is aligned with related roadmaps [ART2005], [AMSD2003], [ROADNL2002]. For a truly holistic assessment of the current state of the art and future trends in the Embedded Systems field, it will be important to **understand the particular developments and characteristics of each of these diverse marketplaces**. Thus, the selection of the sectors is based on maximizing the coverage of technological solutions and application trends without loosing clarity of presentation. Nonetheless, the list of sectors is not exhaustive; others like **construction, transport, intelligent infrastructure or energy** also broadly use Embedded Systems and offer a big market potential. But since the **applications and technologies in these areas are often similar to those described here**, we decided to focus on the six domains chosen.

Structure of the section

The following presentation of the six sectors always starts with a characterisation of the industry domain and the respective products. Then, the most important trends and challenges for this sector are presented. In the end, the most relevant aspects and trends are summed up in a conclusion, whereas the "relevance of a trend" to be selected for the conclusion is determined by the

- strength of the challenge, i.e. of the underlying technical problems, for this sector,
- existence of interrelations with other sectors, and/or
- impact of the respective trend on future market development and market growth.

4.2.1 Automotive

4.2.1.1 Definition and Characteristics

Passenger vehicle market has most electronics innovations

Embedded electronic automotive devices provide information and communication services to the passengers, and **control many aspects of vehicle functionality**, such as interior body sensors and actuators, or power train and chassis management. This section is somewhat focused on the passenger vehicle market, as this is typically the leading market in terms of electronics innovations [Sie2004].

Examples for automotive ES

Typical electronics systems in a present-day automobile range from the "classic" areas like **engine/emission control**, **automatic gearboxes**, and in-**car entertainment** to new, to more sophisticated areas such as **advanced driver assistance** and **telematics**.

All general market trends apply

Like no other market in the Embedded Systems field, the automotive domain comprises all general market trends:

- quick increase in overall **connectivity**,
- integration of **mobile networks** and
- **autonomous** behaviour,
- **customisation** requests from markets,
- tight safety, security and dependability concerns,

as well as an environment with constantly evolving regulations.

4.2.1.2 Specific Trends

Advanced control systems

Future vehicles will have further optimised control tasks such as coordination of electric/gasoline (hybrid) drivetrains, smart gearboxes, improved vehicle stability, safer and more responsive brakes, and optimised comfort vs. driving stability. The increasing number of sensors and actuators, along with the increased connectivity and computing power enable this growth.

Integration of telematics applications in cars

Telematics applications are an important upcoming class of systems in automotive electronics. The telematics domain is understood here in a rather narrow sense as a class of services related to **traffic management**, **routing**, **wide-area road safety** applications, and **interaction** between groups (platoons) of vehicles.

Example: Floating Car Data

An example for a future telematics service is Floating Car Data (**FCD**) [EAST2002]. FCD systems combine traffic data (e.g. speed, distance to leading vehicle), individually measured by a potentially high number of vehicles, to a comprehensive, on-line estimation of the traffic situation in the covered area. Individual vehicles in the fleet for routing decisions can use this information. In contrast, present-day navigation systems typically incorporate information on the traffic situation, which has been obtained from centralized sources (e.g. highway authorities, radio stations). Due to the limited data acquisition facilities and long response time of such sources, navigation data may be inaccurate, outdated, or incomplete.

Advanced driver assistance systems (ADAS) and passive safety facilities

Because 90 to 95 percent of accidents are caused by human error, advanced driver assistance systems (**ADAS**) are viewed as an important contribution to European road safety [Eur2001][Res2004].

An example for a current driver assistance system in combination with advanced Human-Machine-Interface (e.g. tactile pulse actuator in seats) and sensor concepts (e.g. short range radar, video camera) is the class of **lane departure warning** systems, which is currently available in some passenger vehicles (Citroën C4 series) and trucks (Mercedes).

Substituting mechanical linkages by electronic links (X-by-wire)

An important enabler for much driver assistance-related functionality is the **substitution or suppression of mechanical linkages by electronic links** (X-by-wire). However, this development is currently much challenged by technological, cost, safety, and regulatory concerns. For instance, [Mar2005] states that high-voltage battery technology, which is a prerequisite for widespread use of X-by-wire, is “dead for this decade” for non-hybrid vehicles up to 2010.

Improved human-machine interface (HMI) enable handling of complex functionality in critical situations

Rich human-machine interface devices are an important trend in automotive electronics. The importance of HMI is closely linked to the rapid increase of complex electronic devices operated from the vehicle’s interior. In the late 90’s it quickly became apparent that the “button overload” on the dashboard would be a major obstacle to deployment of further functionality. The current challenge is to **improve the human-machine interface** to a degree so that the driver can use his available senses in the most efficient way, and complex functionality does not overload the driver, especially in critical situations. The human-machine interface of the future will consist of **advanced input/output devices** like mouse/menu-like systems, head-up displays, speech dialog systems, and advanced tactile feedback (e.g. touch screen, seat, steering wheel, pedals).

HMI example: Speech dialog systems

A current example for an upcoming technology in automotive HMI is the class of speech dialog systems, which are already available with a limited range of capabilities in present-day premium cars. Future speech dialog systems will enable the user to initiate and sustain complex transactions with the aid of the communication and information infrastructure built into the car, without having to rely heavily on the driver’s sense of vision, which can be easily overloaded by complex applications. The example of speech dialog systems seems particularly relevant as [ITE2004] identifies **auditory and tactile feedback** as the most relevant research direction in automotive HMI.

Communications and infotainment functions

Apart from sustaining and supporting the basic operations expected from a vehicle, electronic systems enable an ever-growing array of communications, information and **entertainment functions** in vehicles. Practically all communications and **media services** that are currently available at stationary locations will eventually be found in next-generation vehicles.

Increasing relevance of ecological aspects

Ecological aspects gain increasing relevance in Embedded Systems development in the automotive domain. Embedded Systems enable **improved emissions** and **fuel consumption** through advanced engine controls [ACEA2002]. Reduced emissions and fuel consumption can also be achieved through the improvement of traffic flow. In Europe, some 7500km, i.e. 10% of the road network, is affected daily by traffic jams [Eur2001]. This can be solved by advanced telematics applications in automotive [ITEA2004] and by more intelligent, i.e. **networked, traffic management systems**. Another example is the use of sensors in tires that set up a warning system to indicate under-inflated tires, which also reduces rolling noise while maintaining a high level of safety. This is expected to produce a 10% saving on fuel and around 1,000 fewer deaths per year [Eur2001].

4.2.1.3 Conclusion

The most important industry-related trends in the automotive industry are

- safety issues (in this context: telematics, ADAS, X-by-wire, underinflation sensors),
- environmental awareness (nearly zero emission, underinflation sensors),
- car-to-car communication (telematics, safety- and environment-related),
- new HMI (to increase usability, relieve the driver, prevent accidents).

Important R&D in these fields is already being done, but increasing challenges have to be mastered. These trends will be decisive for the future market position of each OEM since they represent visible product characteristics. At the same time, they show the rising complexity of automotive systems since more and more – formerly independent – modules and Embedded Systems need to be synchronized.

4.2.2 Avionics and Aerospace

4.2.2.1 Definition and Characteristics

Avionics is a leading sector in electronics, ES cause large share of aircraft cost

Avionics, which encompasses the electronic devices used in both aircraft and spacecraft, has traditionally been a leading sector in the embedded electronics field. Early applications of electronics in aircraft date back as far as the 1950s, and aviation/space-related government funding has propelled many of the electronics innovations in use today. Nowadays, hardware components and controls are being largely replaced by software-programmed technology, so that even though **already 85% of the cost for design is software-related**, the software share is still increasing [Pri2003]. According to the online survey, Embedded Systems in avionics currently constitute about **51% of the total cost of an aircraft**, with a slight ongoing growth of this share in the future. This underlines the importance of avionics in the aerospace domain.

General market trends: Dependability & security, connectivity, mobility/autonomy

Among the most prominent general market trends visible in the avionics domain are

- dependability and
- security concerns.

While the former is a well-known requirement and not really a “trend” in avionics, the latter currently gains more importance with the advent of networked mission-critical applications. The increased **connectivity** of formerly independent functions, and the adoption of **mobility** and **autonomy** techniques also constitute important trends in this sector.

4.2.2.2 Specific Trends

Unmanned Aerial Vehicles (UAVs) promise to be cheaper and more energy-efficient

The **most important new kind of aircraft in the next decade** will be Unmanned Aerial Vehicles (UAVs). UAVs are already used for surveillance applications in the military field. There is a rising interest in using UAVs for civilian surveillance, or for fire fighting [IST2004]. UAVs promise to be cheaper and more energy-efficient to operate (reduced size, weight) than conventional aircraft. They are harder to detect and can be operated in more hazardous environments, as no human pilots is put into danger. **Different kinds of UAVs under development** include strategic UAVs with long term operation time and extensive sensor suites, tactical UAVs with some sensor suites and strike capability, organic air vehicles (OAVs), which are backpack sized for deployment in support of individuals, and micro air vehicles (MAVs), which are centimetre- or millimetre-sized, and may provide a sort of flying sensor network in the future.

Advanced on-/off-aircraft networking

The aircraft of the future will use advanced networks for on-board communication, mission control, and distributed coordination between aircraft. For civilian applications, one of the ongoing developments in on-/off-aircraft networking is the introduction of **wireless in-flight communication** infrastructure for passengers.

Networking: Wireless and ad-hoc networks

In a recent prototype, which uses satellite links to connect the in-board wireless network to the terrestrial infrastructure, participants were already able to connect to remote targets with cell phones or wireless devices [IST2005]. Ericsson is just involved in setting up the infrastructure on the ground and in the air for wireless on-board communication, and it is **mainly up to regulation authorities** and airlines **when the service will be offered** [Sho2005]. For wireless off-board communication in future military (and civilian) scenarios, manned and unmanned aircraft must be able to connect to each other in a spontaneous and ad-hoc way, similar to **peer-to-peer (P2P) networks**. Related technologies must be adapted to the **special needs of avionics application**, such as **dependability** and **timeliness**. As a general trend in wide-area wireless avionics networks frequently have to meet high demands with respect to non-functional properties such as **robustness/fault tolerance**, **network security**, and quality of service (**QoS**), where the QoS characteristics of the network must be highly adaptive towards disruptions or disturbances on the physical link. Fulfilment of non-functional properties by the wireless network is of special importance if any mission-critical applications are to be adapted on the network.

Networking: Integration to C4ISR systems

Integration of heterogeneous networks to mission- and enterprise-level applications is a strong trend in the military field. The integration of heterogeneous applications is called **C4ISR** (command, control, communications, computer, intelligence, surveillance and reconnaissance). The standard used by the US military is **JTA** (Joint Technical Architecture), and has been published in its first version in 1996. The transition to C4ISR-enabled systems is largely still in progress, and will be an ongoing activity in the next decades [JACG2000].

Partitioning and modular networking

Current avionics systems use physical partitions such as “federated architectures” for fault isolation and containment. At the same time, hardware architectures are in the process of being standardized in the form of **Integrated Modular Avionics** (IMA). Future systems will use advanced operating systems, which provide space and time partitioning within one physical computing node [ARINC653]. Space partitioning ensures that code executing in one partition cannot inadvertently overwrite data or code in another partition; time partitioning ensures fair allocation of computing resources even under fault conditions.

Standardization for software architectures

For high-level description of complex and safety-critical software systems in avionics, **AADL** is an emerging standard for software architecture description, which plays a significant role, for instance, in future development scenarios pursued by Airbus

[Fei2003]. **AADL/MetaH** is largely compatible to established European standards such as **HOOD** [Dis2003].

4.2.2.3 Conclusion

The main industry-related trends in avionics/aerospace are

- unmanned aerial vehicles (UAV),
- standardization of HW/SW architecture, infrastructure
- advanced on-/off-aircraft networking (on-board, to the ground, to other aircraft),
- dependability, robustness, and QoS.

As dependability and security are the top priorities for the avionics industry, increased functionality (e.g., advanced networking) and new product concepts (like UAV) always require adequate development conditions and premises. The trends mentioned here show the different dimensions of challenges the industry is facing in that sector. Also, issues like advanced networking and QoS concerns have strong spillover effects to other sectors. The avionics industry can therefore serve as catalyst for positive effects in other sectors.

4.2.3 Industrial Automation

4.2.3.1 Definition and Characteristics

Automation technology improves manufacturing processes

Automation technology is the discipline that deals with automating machines and plants in order to improve the manufacturing process [Schaudel2005]. The use of automation technology **increases reliability and safety of manufacturing processes** [VDMAK03]. The reliability will be enhanced because individual tasks are standardised, and because the permanent control of the plant conditions through the automation technology detects failures in time. The **level** of automation in plants **increases steadily**, which means that the production process will be performed more and more by automated machines. Amongst others, these machines **replace people in the execution of monotonous and dangerous tasks**. Therefore the safety of plants increases.

Most relevant general market trends for automation: Autonomy and connectivity, customisation, reliability

The goal of automation technology is to provide partially or totally controlled automated technical processes and plants that are **highly flexible**. Different general market trends that achieve this goal can be observed:

- autonomy and connectivity: Autonomous components ease installation and re-configuration of plants.
- customisation: plants have to be customisable for different manufacturing requirements in shorter time.
- reliability: further automation of processes increases the required reliability.

There are many areas of application for industrial automation technology. Some **examples** are printing machines, machine tools, production and assembly lines, manufacturing automation and robots [BSAT2005].

3-level structure of automating solutions

Industrial automation has different levels, illustrated in Figure 4-2. At the lowest level, automated machines with Embedded Systems **control and manipulate processes**. These systems have human-machine interfaces to parameterise the machine and to program the task, which has to be performed in the case of stand-alone machines. For complex applications, different machines are connected to **higher ranking systems**. The connection is established via a **field bus** interface. The higher ranking system controls the low level machines and combines their basic functions to a complex automation process. The higher-ranking controller forms the second automation level. The third level of the automated system is a **human process-communication** system for remote control, monitoring, and linking the manufacturing process with an enterprise resource planning system (**ERP**) [LAG05].

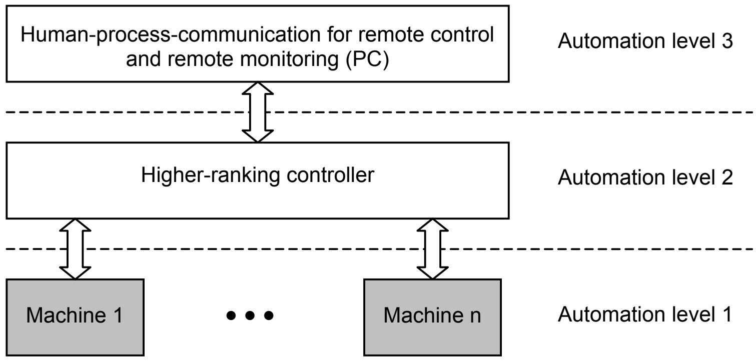


Figure 4-2: Plant automation

4.2.3.2 Specific Trends

Need for customised and individualised plants in shorter time

The main trend in industrial automation is the increasing need for customised and individualised plants. The production lines have to be built up and adapted to new production processes quickly. Concrete targets are to **reduce commissioning time from 3 – 6 month to less than 1 month**, and model changeover time from 8 – 12 weeks to less then 2 weeks [ASRA2005]. To meet this challenge, the architecture of assembly lines has to shift from centralised to **distributed networking systems** with an open architecture. These trends are described in the following.

Open system architecture leads to easier customisation of plants

Assembly systems have to exhibit open system architectures, because flexible and versatile assembly systems are requested by quickly changing markets. Ever faster model updates, more variations, and smaller lot sizes pose increased demands on assembly lines, which have to adapt to new products in less time. Automated factories and processes are too expensive to be rebuilt for every modification and design change [FIA2005]. Therefore the assembly systems **have to be built up by modular designs** that allow for quick reconfiguration by replacing standard modules with new ones. In these approaches, all mechanical, electrical and information technology systems (e.g. sensors, motors, pumps, valves and hardware platforms) are standardised. Also the integration of new functions by additional modules needs standardised modules [VDMAK03].

Distributed (networked) systems increase flexibility

Assembly lines traditionally are controlled by higher ranking control units (programmable logic controllers, PLC's). Nowadays the trend to distributed systems can be observed [ACDMS00][RPA1999]. Distributed in this context means not only physically or topologically, but rather describes the allocation of "intelligence" from the PLC to the subsystems [ART2005][Schaudel2005]. This "intelligence" can **only be achieved by embedding software systems** into the sub devices. These sub devices are easier to replace or broaden to satisfy the growing needs for more flexible manufacturing processes [AWMP2005]. Additionally, the small integration effort will be supported by pre-tested subsystems [DCCS1998]. Therefore the assembly lines **can be faster adapted to the new needs** by which the productivity increases [ACS2005][FIA2005]. The relevance of distributed networked systems is also apparent in the usage of standards such as DIN 19222 or Ethernet/IP. The virtual automation network (VAN) project is an actual work that supports the development of distributed networked systems based on the use of Ethernet [ISTVAN2005].

Simulation of production lines enhances customisation

Off- and online simulation systems will allow the parallelisation of the entire planning process up to commissioning, and even when operation is under way they will constitute an integral part of the control systems. This will significantly **improve the quality** and **productivity** of the planning process and slash commissioning costs, which in turn will enhance the reliability of the plant itself [ACS2005]. The reason is that the possibility to simulate, verify and program a new production line offline reduces its down time massively [TTM04]. So the manufacturing process can be customised faster.

Remote control enhances the reliability of production lines

Industry asks for high availability of production facilities [IPLS2005]. This can only be achieved with a permanent control of the facility for quickly discovering failures of machines. This helps reduce holding times and avoid associated financial losses. To achieve permanent control, the trend goes to **remote control systems**, which allow a much better service and life cycle management than the on-site control of the systems [WBS2002]. For **remote monitoring**, there are two necessities: firstly, every process value has to be measured by sensors, and secondly, every device of the system has to be connected by buses to the monitoring system [WAT1999]. Today, standard Internet will be used more and more for this function [WBS2002].

Safety-critical process control mechanisms

The trend to special applications of large-scale critical networked infrastructures is unbroken, e.g. in energy supply control networks. The impact of failures of such systems is critical in the sense that a failure must not affect the whole system. **Failures have to be located and isolated** where they occur to prevent their broadening. This can be achieved by developing of safety-critical process control mechanism. An example is the decomposition of a system into a conjunction of safety-critical subtasks where every subtask manages failures autonomy [BAS1999].

Standardization of bus systems has to be pushed

The data exchange between diverse parts of an automation solution is often based on proprietary bus topologies. In order to guarantee reliable communication between the systems, a considerable amount of development effort is required. At the moment, efforts are made **to standardise bus systems**. Unfortunately, these efforts are hampered by many barriers. One of the major barriers against the trend for standardization is the fear of more competition [Oet2005].

Most used fieldbuses

Figure 4-3 shows an overview of fieldbuses currently used in the automation process and a prognosis for the future. According to the study [FBUS2004], **the dominant fieldbus is Profibus**. In the future, Profibus' market share will decrease whereas the use of **Ethernet** will **grow** rapidly. Although Ethernet will get more and more popular, there are obstacles to its wide spread adoption, for example, support for real time applications and industry-specific high level protocols on top of Ethernet.

Increase of wireless technology to provide a base for spontaneous networks

The sensor wiring is generally a tedious, time-consuming task. In many applications and particularly where systems include a large number of spatially distributed components, the electric wiring becomes a complex problem, which can cause difficulties in the systems handling and affects its reliability in the long-run [EAS2005]. With wireless technology, **automation equipment is becoming easier to install and operate**. Particularly this equipment is able to build up spontaneous networks. The trend for an enhanced use of wireless technology is shown by the increasing development efforts made for special software application for wireless sensors and distributed peer-to-peer networks based on wireless technology [FIA2005]. Already today, robot sensors are wirelessly connected and handheld, **wireless devices** to program robots or other components are **entering the market** [ATH05].

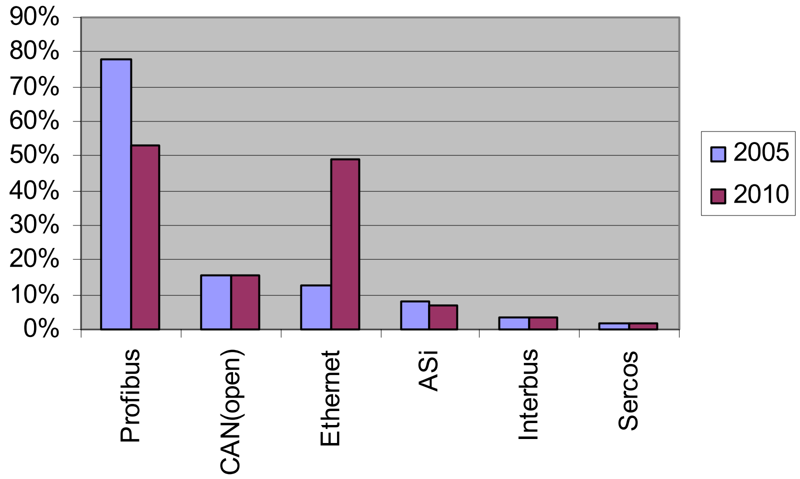


Figure 4-3: Which is the preferred field bus system today and in future [FBUS2004]

Energy autonomous sensors

Wireless technology does not only involve data exchange. Also the wiring for power supply needs to be eliminated for some areas of usage. For that, the use of energy-autonomous sensors and microsystems, having low-power consumption and using wireless data transmission, yields further advantages for many applications such as automation in plants, machinery, and environmental applications. The low-power feature is important for battery-powered devices **to ensure the autonomy for a long time**. Also there are applications where no power supply exists, for example the state monitoring of a bridge. In this case, it is possible to use the oscillation energy of the bridge and to transform it into electrical energy [Gra2005]. Emerging new technologies, especially in the fields of communication, power supply and power generation provide new possibilities, leading to a wide spread use of low-cost energy autonomous sensors and microsystems [EAS2005]. In the context of energy autonomous devices **intelligent software solution can help to reduce the energy consumption**. This is a field, where research has to be enhanced.

RFID-chips for optimising logistics

An **example** of wireless technology is radio frequency identification technology (**RFID**). In the automation RFID-chips can be widely used to gather information for logistics to control the process. Also the connection of part typical information with the part itself is possible. That increases the integration and the transparency and thus the reliability and the customisation of production processes.

Trend: Integration of nanotechnology

Industrial automation will also be an important market for some of the future “watershed” technologies, such as **nanotechnology**, nanoscale assembly systems, micro-electronic-mechanical sensors (**MEMS**), and nanotech sensors. Nanotech sensors promise to be very small, to use low power, and to measure almost every kind of physical value [FIA2005]. As already mentioned, they are a central part of almost each embedded system.

4.2.3.3 Conclusion

The goal of industrial automation is to control manufacturing processes partially or completely. The build up, commissioning, and modification time of assembly lines has to decrease significantly. To achieve these goals, the main industry-related trends to be considered are:

- flexible manufacturing (open system architectures and distributed (networked) systems to improve flexibility, simulation of production lines to enhance customisation),
- networking (distributed systems, open system architectures, standardization of specific bus systems, wireless technology to provide a base for sensor networks),
- remote control (monitoring, intervention, safety-critical process control mechanism),
- RFID-chips for optimising logistics.

These challenges are crucial for the further success of enterprises in the market since they have high impacts on the efficiency of business processes. Embedded Systems in enhanced wireless sensor technology (energy autonomous sensors, micro-electronic-mechanical sensors, nanotech sensors) are the key enabler of this trend.

4.2.4 Telecommunications

4.2.4.1 Definition and Characteristics

ES in telecommunications as enabler

Modern telecommunication systems including Embedded Systems are characterised by dynamic expansion and heterogeneous nature due to the interconnection of components having diverse technical characteristics. With this level of continuous technical evolution it is essential that simple, efficient and highly reliable telecommunications systems are required before network operators offer new services to the users.

Technical features let phones become computers

In the beginning many features of end devices (i.e. cell phones) were realized by using hardware components. By and by the use cases of the devices change from simple communication usage to smart and small entertainment (e.g. MP3 players, game console) and office applications (e.g. organiser, email-client). From these developments followed that cell phones were utilized with (limited) operating systems and **more and more become small computers** similar to standard PCs. Nevertheless the resources of the devices are still limited and much functionality of the end devices are realized by Embedded Systems to save processing power. A few examples are:

- MP3 processing units,
- camera chips and digital optical extensions,
- video/Sound processing,
- Java support.

Different radio networks and software defined radio (SDR)

Another development is the support of many different radio networks. There exist many different types of networks with different applications. Cell phones vendors try to offer devices with as many network interfaces as possible. To reduce cost and to be more flexible in the future software defined radio (SDR) could help **to adapt devices more easily to new access networks**. The aim of SDR is the substitution of hardware components of the signal processing unit by software so that one receiver can be used for different frequency bands.

Fixed to mobile substitution

According to a recent article from The Economist, about 5% of Europeans even decided to quit their fixed line phone for “going entirely mobile” [Eco2004]. This **beginning fixed to mobile substitution** gives operators the opportunity to think of new ways to create value for the customer. This is an additional overall trend besides the convergence of the wired and wireless world. In this context it is also important to stress that consumers are very interested in standardization of devices for mobile communication.

The **general market trends** mainly available in telecommunications are **mobility** and **autonomy**, **customisation** and **individualisation**, **HMI** and **security**.

4.2.4.2 Specific Trends

New services in the future

While digital technology found its way into the mobile market, not only the networks themselves improved but also the devices, i.e. the mobile phones, and the mobile services. These **mobile data services will play a decisive role in the future**: Email communication, downloading music or other kinds of multimedia applications will be offered via sophisticated mobile devices, e.g. smart phones.

Fixed mobile convergence (FMC)

Fixed mobile convergence (**FMC**) opens a new world of possibilities for flexible and intuitive home & office communication. There is a change going on from separate worlds to **seamless connectivity** realized through convergent devices, applications and technologies.

FMC: Features and implications

FMC can be defined as the possibility to transfer similar telecommunication services on different network platforms [Laf2000]. From the Embedded Systems point of view, (functional) convergence involves the provision of the following features and results in the following implications:

- Seamless data transmission and connection switching: Devices have to support **many different access technologies** and **communication protocols**. To handle the increasing costs software should substitute hardware components where possible (i.e. Software defined Radio (**SDR**))
- **Single voice mailbox** and **single number**, with all incoming messages going to a central store regardless of the number dialled. Extensions of the back-end infrastructure are needed.
- Single **personal information management** (e.g. calendar, address book etc.), accessible from or transferable between multiple devices. New communication protocols and interfaces have to be developed.

Generally speaking, functional convergence refers to any form of convergence that provides **cross-service functionality** without requiring a single converged device [Hat2004].

Efficient integration of different radio frequencies

Another way of an efficient integration of different networks (on a lower level) by using Embedded Systems is **direct conversion** (DC) [UMTS15]. DC is a method of converting radio frequency signals into baseband signals. This architecture has **significant potential for reducing the total parts count** and has been one of the main obstacles in the way of **single chip RF architectures**. DC would be an ideal method for multiband mobile phone design.

Direct conversion helps to limit cost of handsets

In GSM dual-mode phone architecture for example, DC could **reduce the number of RF components from the usual 150 to around 90**, reducing Radio Frequency (RF) circuit cost by about 30% and size by 30% to 50%. Especially new communication protocols like **UMTS** (universal mobile telecommunications systems) and its successor **HSDPA** (High-Speed Downlink Packet Access) will increase the cost and chip size of standard handsets. Therefore furtherance of DC can help to limit this development.

Customisation of devices and services

Current and future mobile phones allow customisation. Each consumer has a personal number and the possibility of storing personal information in his or her mobile phone. Finally, the advanced services and values that are offered for mobile devices are already huge – and growing. Former additional services like **SMS** are standard functions today, innovative new services like music applications (e.g. **MP3 player** or radio) or **MMS** are beginning to spread. But huge groups of consumers do not mainly focus on those additional services. Especially senior consumers tend to value those additional services less than young professionals and young people in general [Cap2004].

HMI for simple handling The outstanding importance of convenience to the users of telecommunication services is emphasized in the majority of studies [Sho2004][You1998][Dav2004]. As the modern world gets more and more complex and consumers have to deal with a permanent information overload they are extremely grateful for every kind of **simplification** in their everyday life. Consumers are not interested in telecommunication per se. They usually want to understand new technology only, if it really improves their lifestyle [You1998].

Quality of service: Quality of service includes all the performance features of telecommunication today. The most important feature for voice transmission (fixed-line as well as wireless) is access availability (**coverage)**. For data services and Internet applications, speed is a decisive factor. While the most praised feature of mobile phones is the **user's availability anytime and anyplace**, the outdoor coverage of mobile phones is not very satisfying even for users in Europe, where the coverage is relatively high compared to other regions. Especially in **rural areas** or in isolated mountainous regions, but also already in some low mountain ranges communication is interfered or even impossible.

Coverage in means of transport Travelling on a **train** or by **air** also limits the consumer in the usage of his or her mobile. Recent research suggests that 74 % of users would increase their usage of mobile if the coverage would be better within buildings and in **underground trains and stations** [Cap2004].

Power consumption Many of today's telecommunication devices use programmable microcontroller and digital-signal processor cores combined with embedded memories and numerous peripheral modules all on a single chip. Especially supporting more and more access networks and extending device by **additional technical features** (e.g. MP3-Player, Camera, etc.) increases the **power consumption** of end devices. The overall power consumption of a device is very important and should be **kept to a minimum**. The development cycle for batteries is quite slow and has not yet reached maturity for full-scale deployment.

4.2.4.3 Conclusion:

The main and most relevant industry-related trends in telecommunications are

- specific platforms and operating systems,
- Software defined Radio (SDR),
- new services such as e-mail communication, downloading of multimedia content and application for sophisticated mobile devices,
- fixed mobile convergence defined as the possibility to transfer similar telecommunication services on different networks,
- efficient integration of different radio frequencies,
- customisation of devices and services,
- HMI for simple handling,
- quality of service including coverage and power consumption.

In general, the technologies and concepts from the telecommunications industry are often prerequisites and foundations for other sectors. Thus, some of the trends mentioned here are – to a different extent – enablers and catalysts for other domains. This and the internationally still rising market volume justify great R&D work and standardization efforts that are essential to meet the requirements.

4.2.5 Consumer Electronics and Intelligent Homes

4.2.5.1 Definition and Characteristics

Home devices are heterogeneous systems

Embedded Systems in consumer electronics products and generally in the home environment (e.g. portable DVD player, HDD camcorder) use an architecture that is a heterogeneous collection of very specific building blocks, connected by a complex network of many dedicated busses and interconnect options.

Interworking and Standardization

The major trend of the future in development of products in these areas seems to be **enabling interconnection of different device types**. Intelligent home concepts have failed in the past because of the high costs and too complex approaches. New concepts based on wireless technologies and the Internet protocol could probably overcome the barriers of the past and make the intelligent house idea become real. The realisation of the new approaches makes new standards necessary.

The most important **general market trends** influencing the consumer electronics and intelligent homes industry include **HMI, security, customisation, mobility** and **autonomy**.

4.2.5.2 Specific Trends

Growing importance of new HMI

Getting devices to connect in the home or office is going to change the types of software that have to be developed and the type of capabilities that they should offer through Embedded Systems. The consumer tends to interact with a device through its front panel (i.e. human-machine-interface). In more sophisticated cases, they go through something like a TV or PC display. One trend is connecting many devices and providing natural and **friendly access to those devices from different parts of the home** so that it's not necessary to be interacting physically with the device. For example, turning on a CD player from anywhere in your home by using speech input or some other kind of multimodal input is made possible. High speed (wireless) communication links will become important for Embedded Systems devices, particularly in the home over the next five years [Icon00].

Multimodal input models more complicated

Moving toward multimodal input models, the user interaction model for consumers becomes much more complicated. The idea of talking to something to make it work is still strange for consumers, and acceptance will take time.

Interoperability

Standard interfaces can ensure the interoperability of consumer devices and makes it easy to combine them with other devices that they might buy in the future. Right now too many different standards exist in each of the different layers needed for interconnection. There are almost one dozen different bus technologies competing in the various fields of home automation [Ahl00]. Partly as a result from the standardization issue, the quantity of units produced are generally still relatively low, which prohibits companies from exploiting economies of scale and thus **keeps prices at a high level**. The main cost driver is the special chip and the software installed to enable communication with other devices. Another reason for the high prices of the devices is that for each of the standards additional, proprietary technology is needed, which is built into the device, to ensure compatibility with the other standards.

Example for interoperability

Regarding home networking, there was for example the development of home audio–video interoperability (**HAVI**) home networking infrastructure based on IEEE 1394. Sony has an entire lab dedicated to interconnecting architectures. Embedded devices are connected to other embedded devices with high-speed links.

OSGi approach

Realizing interoperability, a couple of companies have set up a cooperation called OSGi (Open Service Gateway Initiative) to develop a gateway, which connects different networks. Residential Gateways will most likely play an important role in connecting **different kinds of networks**, e.g. **house bus, LAN, Internet** and **wireless network** in a house. The second important layer is the middleware. Right now there are also a couple of technologies centred in this area (e.g. **Jini**, **UpnP**).

Performance-based interoperability

Also a trend regarding interoperability is the performance-based interoperability. Although these complex, ubiquitous systems are glued together with layers of protocols, they still have **time constraints** and other **performance requirements** that impact how it will be accepted by the public.

Example for performance-based interoperability

For example, if there is a deadline for sending videos across multiple links, is it really going to get to the people that want to watch the video in a manner such that they can view the video properly? Solving this issue requires meeting time constraints and going through layers of protocols, software mappings, and switches from one kind of network to another, and through layers of software. If the result is a poor quality video, people will not accept the product. New embedded system solutions can help to realize **real-time interoperability** in the future.

Energy efficiency

When buying or using consumer electronic devices or home appliances, customers nowadays pay more attention to **environmental friendliness** and **energy-saving**. If the washing machine suddenly consumes more water than usually, a signal and the exact data will be sent online to a technical engineer. He could then identify the cause and repair it.

Example for energy efficiency

Through the connection of different devices the air-conditioning does not have to run the entire day if you are not at home. You could switch it on from the distance so that it cools down your room to the right temperature until you get back. Shown by these simple examples the consumer can **save energy and money** [Ele00].

Reliability enhances users' trust

There do exist negative scenarios about Intelligent Homes that do not enhance consumers' trust into the concept. Therefore it is essential that Intelligent Home networks will always work near **100 percent reliability**, which is necessary in such a precarious environment as a family's home, especially since only a small part of the population has the technological expertise to fix the system once a complex problem has arisen.

Smart environments must be safe environments

Another trend for smart environments is safety. For example, in a smart home, you will not want to see doors opening and closing at the wrong times, or windows slamming on somebody's hand. Smart environments will be safe environments. In fact, smart environments must be as reliable as, say, the power grid. We come in every day, we turn on the lights, and the electricity is there. **We may rightly expect the same kind of performance from these smart spaces.**

Importance of quality features

Certain quality features are important **depending on the nature of the application**. If it's a smart card, security is important. If it is a life-support system, availability and reliability are clearly important [Icon00]. A vast number of very innovative, imaginative, smart products will be enabled by the existence of low cost and high-performance computing.

Further trends

Some further trends in development both of the consumer electronics and of the intelligent homes sector are **security, real-time, scalability,** and **high availability**.

4.2.5.3 Conclusion

The main industry-related trends in consumer electronics are

- growing importance of new HMI providing natural and friendly access to devices from different parts of the home,
- environmental friendliness, resource saving and energy efficiency,
- interoperability by using standards (e.g. audio/video interoperability),

- middleware standards such as Jini and UPnP.

To meet all these trends, much further work is needed in research and development. The trends selected for the summary above are decisive for cost, functionality and overall acceptance of future products.

4.2.6 Health and Medical Equipment

4.2.6.1 Definition and Characteristics

Medical equipment: Machinery designed to aid medical therapies

Medical equipment are devices designed to aid medical therapies. Basic types of medical equipment are life support equipment (e.g., medical ventilators, heart-lung machines), therapeutic equipment (e.g., infusion pumps, lasers), medical monitors (e.g., EEG, EKG), medical imaging equipment (e.g., ultrasound, X-ray, CT, MRT), medical laboratory equipment (e.g. for urine or blood analyses), and implants (e.g., cardiac pacemakers). Medical equipment is also referred to as medical devices.

Electronic healthcare systems

Electronic healthcare systems for the storage and administration of medical data are only considered in this section **with respect to their interfaces to Embedded Systems**. Electronic healthcare systems are security critical (e.g., confidentiality of patient data must be ensured) and safety critical (especially if stored data is used directly for treatment).

General Market Trends: Safety & reliability, security, mobility and autonomy

The most important general market trend that applies to the domain of health and medical equipment are **safety and reliability** concerns. Medical devices are to be developed in compliance with rigorous safety standards: as patients' lives may depend on the correct operation of e.g. X-ray devices, failures are not acceptable. Thus, certification is a major issue for the industry. **Security** also becomes increasingly important because of the increased interconnection between different embedded medical systems and to the storage and data administration systems via open networks. Therefore, the methods to prevent malicious attacks and to protect patients' data have to be emphasised. Recently, a demand for medical devices providing **mobility** and **autonomy** has emerged – the most important trend fuelled by this demand is the trend towards mobile healthcare, which is described in more detail in the following section.

4.2.6.2 Specific Trends

Standard products, components and Internet technology

A general trend in base technologies in the medical sector is the move towards standard products and components. This is valid for hardware (e.g. Intel X86 rather than microcontrollers) as well as for **standard embedded platforms**. In addition, there is a trend towards the use of Internet technology as a means of communication [ThoOpp].

Standard components example: ENEA Embedded Medical Platform

For example, ENEA Embedded Technology announced the ENEA Embedded Medical Platform (**EE-Med**), a safety-critical software platform for embedded medical devices. EE-Med provides all of the software components needed to design safety-critical medical devices, including a hard real-time operating system, secure wireless and wireline networking, an embedded GUI, a fault tolerant database, and a comprehensive development environment. This software platform, together with **ENEA** medical reference boards and hardware/software engineering services, encompasses all phases of design, development and deployment, from initial planning to **FDA certification** [Enea2004].

Mobile healthcare

The most challenging trend relevant for Embedded Systems in the medical sector is mobile (or pervasive) healthcare. Here, the aim is to make healthcare available **everywhere and anytime** it is needed. In this way, monitoring of patients is also possible, when they are not in the hospital, which saves health care costs. Mobile healthcare includes remote monitoring of patients, e.g. with the help of sensors attached to their bodies, and assistive technologies such as home automation, remote controls or alarm devices [MH2004][PH2004]. It also comprises the support of healthcare professionals, e.g. by allowing them to **access patient data** via PDAs or Tablet PCs. Mobile healthcare builds on underlying technologies from telecommunications (see section 4.2.4) and consumer electronics and intelligent homes (see section 4.2.5).

Mobile healthcare example: BodyKom

An example scenario for mobile healthcare is the GPRS-based service “BodyKom” launched by Swedish hospitals to monitor ill people who don’t need in-patient treatment. The service has been developed by TeliaSonera, HP and Kiwok and consists of a communication unit, which is connected wirelessly with sensors located at different spots. The sensors measure different body functions continuously and send them to a medical centre. In case of irregularities, an alarm goes off. Since patients can leave the hospital earlier and feel safer, this service **increases quality of living and saves costs** as well. TeliaSonera sells the units and takes over the service providing.

AAL project

In this context, the project **AAL** (Ambient Assisted Living) has been started in September 2004 within the **6th European Framework Programme** to prepare an initiative in the field of “small and smart technologies for ambient assisted living” [AAL2005]. AAL aims at “prolongating the time people can live in a decent way by increasing their autonomy and self-confidence, to monitor and care for the elderly or ill persons, to enhance the security and to save resources”.

Sophisticated extracorporal and intracorporal networked medical devices

As a part of mobile healthcare systems, there is a trend towards the development of sophisticated networked extracorporal and intracorporal medical devices that can store and process data autonomously and communicate with each other. Such devices can be both used for **monitoring patient data** (e.g., heart rate or EEG monitoring) and increasingly also for therapy (e.g., implanted drug dispensers). Low power consumption is an important requirement for medical devices. Increasingly, RFID technology will be used within medical devices (both extracorporal and intracorporal) such that they can identify themselves or the patient carrying them [RF2005][RF2005a].

Integration of medical devices into everyday gadgets

Extracorporal devices will more and more be integrated into everyday gadgets such as glasses or watches. For instance, scientists at Carnegie Mellon University recently developed a **special pillow called “the hug”**, which “uses vibrations and heat, light and sound signals to mimic human interaction, such as a child’s hug” and includes integrated mobile telephone technology. It is aimed to “ultimately help America’s elderly communicate more meaningfully with distant family members” [TH2005].

Enhanced surgical systems

Embedded technology also enables considerable improvements of patient treatment via enhanced surgical systems. Relevant technologies include intelligent surgical tools that provide e.g. tremor compensation or can report their location; surgical robotics where digital information about the patient’s anatomy is used to **plan and carry out operations**; enhanced medical imaging systems such as computer tomography or X-ray systems; and the use of augmented reality (e.g., special glasses displaying additional information to the surgeon) [OR2004] gives a comprehensive overview about trends of future medical technology used in the operating room and describes challenges, problems, and research priorities.

4.2.6.3 Conclusion

Medical/health summary

The main industry-related trends in the area of medical equipment and healthcare systems are

- mobility (mobile healthcare) to support future development of life support equipment and convenient remote monitoring systems,
- safety, security (medical devices, remote use of health databases) and certification,

- networking of different devices, e.g. between implants and monitoring systems or between different diagnosis systems,
- integration of remote monitoring functionalities in everyday devices, requiring further miniaturisation.

Progress in the medical field is directly visible since it increases the effectiveness and efficiency of human health care as a whole. Due to the aging of the societies in Europe, the United States [USCB2005] or Japan [USCB2005a], major progress in this sector is a great chance to take the leadership in a fast growing market.

4.3 Technology Trends

Technology-centric view, systems engineering

The term "technology domain" refers to the underlying, multi-purpose technologies that are used across different application domains in Embedded Systems. With respect to systems engineering issues, new technologies may have a positive or negative effect, depending on whether a technology introduces new complexities, or has the potential for complexity reduction.

Classification: Hardware, platform software

The following classification for characterizing technology domains will be used:

- Hardware denotes physical electronic devices like processors, memories, sensors, and actuators.
- Platform Software and Compilers comprise hardware-specific and/or general-purpose software components, such as drivers, operating systems or middleware, and tools for using specialized hardware in development, such as compilers.

This separation is used to increase readability and achieve a structured presentation of the trends in the Embedded Systems platforms. It does not imply that developments and advances can be reached in hardware without considering platform and application software. Instead, due to the rising functionalities of Embedded Systems and due to the existence of interrelating trends, e.g. performance and power consumption or miniaturisation and individualisation, a joint perspective is crucial for the efficiency of developing Embedded Systems. These are the most relevant reasons why the study covers – explicitly – in section 4.4 the challenges in systems engineering.

4.3.1 Hardware

4.3.1.1 Definition and Characteristics

ES hardware

The hardware of an embedded system consists of one or more software programmable processors that run the software part of the application, a memory subsystem and application specific function blocks including all input or output interfaces as well as sensors and actuators that establish connectivity to the embedding system or to the environment.

Persisting chip complexity growth

The complexity increase enabled by the progress of microelectronics production technology is expected to continue for another two decades, as predicted by the ITRS (International Technology Roadmap of Semiconductors) [ITRS2004], integration of several billions of transistors per chip facilitates the implementation of complete systems formerly realized on board or multi-board level on a common substrate.

Hardware only enabler

Becoming more and more commodity hardware serves as the "enabler" for ES-based solutions. Platform architectures built around specific embedded processors like PowerPC or ARM and associated on-chip bus systems (CoreConnect, Amba) constitute HW development environments that enable the efficient design of complex and yet tailormade solutions for specific application domains. The same holds for board level solutions where discrete components are used. This corresponds to a design style heavily relying on pre-designed IP (Intellectual Property) modules that are connected and extended by specifically design blocks, if needed. The design of these specific platform instances has to be done hand in hand with the development of SW running on these platforms. However, the main functionality is determined by the software implementation that also enables product differentiation from competitors who use the same HW platforms. Nonetheless, the fact that numerous major research projects on hardware have been set up, mirrors the importance of R&D in this area. At the same time, we refer to initiatives, such as the European Technology Platform for Nanoelectronics (ENIAC) [ENIAC2004] and present in this study only a selection of the most relevant current trends and facts.

4.3.1.2 Specific Trends

Increasing chip complexities favour integrated ES solutions

The continuing progress in microelectronics technology is enabling the trend towards single-chip solutions. According to Moore's law, chip complexities double every 18 to 24 months. This means that complete systems previously realized as a board level solution can be implemented on a common substrate, so called **Systems-on-Chip (SoC).**

Integration brings many advantages for ES

Embedded Systems implemented as SoC solutions have the following advantages:

- higher reliability,
- reduced size,
- increased performance,
- lower power consumption,
- lower cost.

Applications with strict requirements concerning environmental conditions (mechanical forces, chemical influences, and temperatures), mobility, and high volume like pervasive/commodity appliances profit from **this trend towards SoCs**.

Applications and new programming models lead to increased performance requirements

Another trend stands out in the use of processors with a higher processing width. Indeed, increased processor performance is required not only by applications with higher complexity, but also as a consequence of advanced programming models (Java, Jini) relevant also in low end markets.

Figure 4-4 shows that single processor solutions still dominate today, however, it is predicted that this situation will flip next year and multiprocessor architectures will prevail.

Productivity gains by IP based design and platforms

In order to cope with increased chip complexities and to meet time to market requirements extensive re-use of components is a decisive factor in SoC design. Platforms are built on the basis of pre-developed IP (Intellectual Property) modules, which are connected by a communication infrastructure. Product differentiation is reached through a suitable combination of IP modules and the addition of application specific HW blocks, according to product needs. Platform specific SW and part of the application SW are often supplied by the IP provider. However, in order to customize a platform to the individual application's needs and for further product customisation this software is **adapted and extended** by the embedded system manufacturer. **Part of the know-how is contained in the software of the embedded system**, enabling patches and updates of the functionality after delivery to the customer.

Radio functionalities realised by software

As a consequence of increased processing power, radio functionalities, traditionally implemented in analogue function blocks, are being moved to software programmable processors (software defined radio – SDR). An update of the radio software enables the adaptation to new radio standards or the provision of additional service features. Theses aspects are of special importance as described in the sections about telecommunications and avionics.

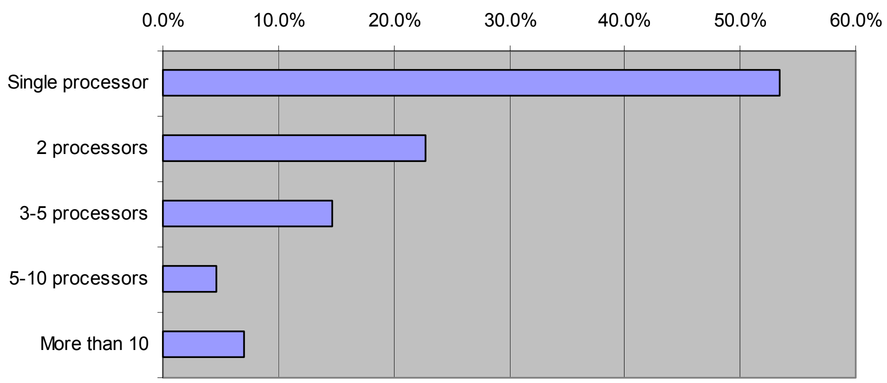


Figure 4-4: Number of processors [STI2005]

On-Chip communication evolves to networks on chip

Communication is a major issue in Embedded Systems. In today's single chip solutions on-chip buses according to industry standards (like AMBA or CoreConnect) are mainly used. However, these approaches do not scale to complex SoCs with many processor tiles. For this purpose the concept of Networks on Chip (NoC), based on principles of data communication networks, is currently a hot topic of research.

Off-chip communication

Concerning off-chip communication different standards like PCI Express, Infiniband, Hypertransport, RapidIO are currently competing. Considering high volume commodity appliances **integration of hard macros that implement an Internet Protocol stack** for ubiquitous Internet connectivity will be of importance.

Smart sensors

Sensors are in broad use in almost each industrial domain as Figure 4-5 shows. To satisfy the increasing requirements of Embedded Systems the capability of sensors has to improve steadily. In sensor technology, three trends are identifiable:

- miniaturisation,
- increase of functionality, and
- network capability.

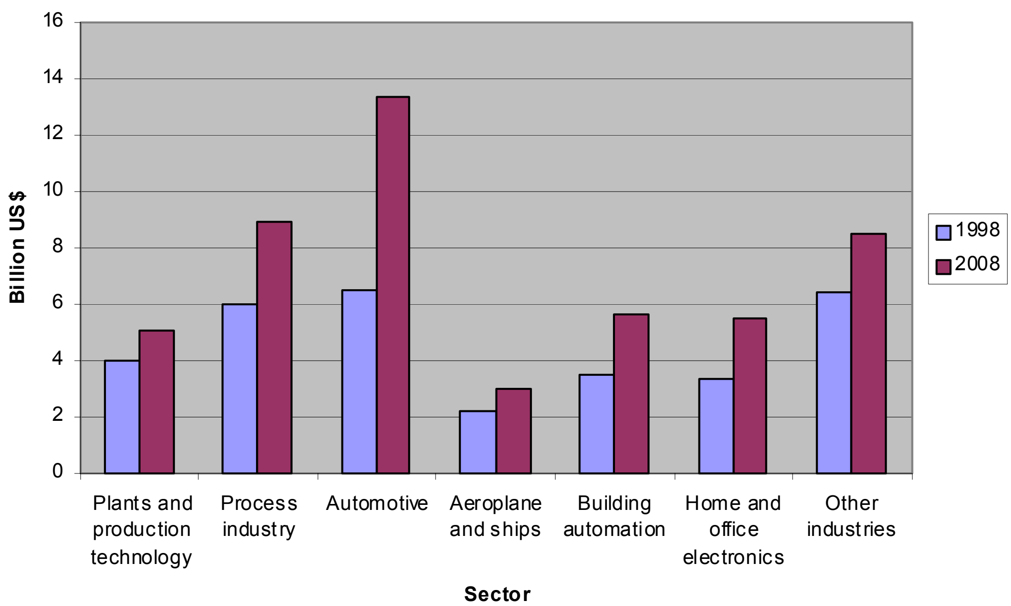


Figure 4-5: World wide sensor market, INTECHNO Consulting, 1999

Intelligent sensors through MEMS technology

Miniaturisation becomes apparent through the deployment of micro-electro-mechanical systems (MEMS)**,** which combine mechanical elements, sensors, actuators, and electronic on a common silicon substrate through microfabrication technology (SoC). This integration of electronics results in programmable sensors**,** which can be customised for special kinds of application. **Sensors become intelligent, their functionality and network capability increase** so that they are usable for a wide range of applications. Thus it is not any longer necessary to develop new sensor hardware for every application. Only the software or the parameterisation of the device has to be adjusted to fulfil new tasks [ASDS1996]. Thus future challenges in sensor development shift from hardware to software (see section 4.3.2.1).

4.3.2 Platform Software and Compilers

4.3.2.1 Definition and Characteristics

Platform SW provides HW abstraction layer

The term "platform software" (also called system software) subsumes application independent software components, which manage the hardware components and provide services to applications with a well-defined interface. Thus, platform software provides a level of abstraction for the application software layer lying on top. For providing the basic software layer on a system, platform software is therefore sometimes referred to as low-level software. Typical examples of platform software are first and foremost operating systems (OS) and I/O drivers, but also middleware implementations as well as other software frameworks such as application platforms or runtime libraries are considered to be platform software.

Distinction between platform software and compilers

A main characteristic of platform software is the fact that it provides its service at the runtime of a system. In contrast, a compiler transforms a given (program-) representation over a well-defined (source-) language into a semantically equal representation over a different (target-) language at the compile time, i.e. prior to the runtime of the system. According to this difference between runtime and compile time, compilers are treated separately from platform/low-level software.

Platform software: Proprietary vs. open source, in-house vs. off-the-shelf and commercially available vs. non-commercially available

In general, platform software can be separated into **proprietary** or **open source** software. While the source code of open source software is freely available and the use or acquisition of such software is free as well (granted by a respective open source license), proprietary platform software is developed and controlled by a certain company and usually not freely available (restricted license). For the scope of this document, open source software can be further split up into **commercially available (commercial)** and **non-commercially-available (non-commercial)** open source software. Commercially available means that the software is distributed commercially by a certain vendor who usually markets general open source software in combination with some added features that offer a kind of additional value, i.e. the guarantee of support or adjustments addressing for example regional specialties. Another distinction of platform software can be made between **in-house** and **off-the-shelf** platforms: In-house platforms are developed by a company for a special purpose and mostly for internal use, while off-the-shelf platforms are not very specialised with the intension to be applied in a wide range of various application areas.

Operating systems: "small" and "large" embedded devices

For explaining trends and technologies in the operating systems market, we will distinguish between 4-, 8- and 16-bit systems (**small embedded devices, SE**), and systems with 32-bit architectures and beyond (**large embedded devices, LE**).

Low-level vs. high-level programming languages

For a better understanding of trends in the market of embedded programming languages we separate primarily between low-level and high-level programming languages. Programming languages (such as Assembler) that are very close to machine languages are referred to as **low-level** programming languages. In contrast, **high-level** languages (such as Ada, C++, Java, Lisp) clearly abstract from machine languages and provide more programmer-friendly constructs, which are closer to human language. High-level languages again can be split up into different levels or groups. For example, there are some high-level languages, which exhibit a very high level of abstraction and which therefore are usually limited to a very specific application domain or a very specific purpose (e.g.: Logo, Erlang). These languages are – depending on the field of application - commonly referred to as very high-level languages and/or Domain Specific Languages (DSL). In the area of Embedded Systems, naturally many DSLs can be found, simply due to the fact, that an embedded system represents a very specific application domain, i.e. is limited to a very specific purpose. Since DSLs are usually declarative languages, the transition from DSLs to specification languages in particular in the embedded sector is blurred. Architecture Description Languages (ADL) and System Description Languages represent another group of high-level languages, which not only allow modelling a system or some system-properties, but also to generate code out of these models. The UML and Matlab /Simulink shall be mentioned representatively for this family of general modelling and/or description languages.

4.3.2.2 Specific Trends

Increasing importance of platform software on the success of an embedded device

In general, the impact of the software compared to the hardware on the success of an embedded device is increasing dramatically. This becomes obvious when regarding the platform software market for traditional hardware vendors: Here, the share of low-level software R&D expenses associated with the overall launch of a new hardware product is already estimated at more than 50% of the total R&D expenses, with a growing tendency [Büt2005]. This refers in particular to the increasing provision of drivers and runtime libraries/platforms. The importance of producing platform software as an upcoming source of revenue for traditional HW vendors becomes even more obvious in the case of Infineon Technologies AG with the recent setup of a corporate software R&D centre in Bangalore, India, which mainly focuses on providing software competence in the areas of wired/wireless communication and automotive electronics [INREP05].

Increasing production of hardware related software by traditional HW vendors

Also in the compiler market, traditional HW vendors are currently seeking new business opportunities by developing more and more software on their own [Büt2005]. Besides the possibility to generate new revenues from previously uncovered markets, accompanying compilers and drivers are important enablers for generating revenues of related hardware products. For instance, a new microcontroller series may have very limited success with potential customers if the corresponding software products, such as compilers for the code generation and optimisation or hardware drivers for runtime execution, are not available at the right time, with the right quality.

Standardized OSs for large embedded devices

For large embedded devices (LEs), there is a trend towards the use of standardized OSs (operating systems). Here, standardization means that an OS is mainly made out of standardized, common and well-known parts, which offer some standard functionality. In other words, the core functionality of the embedded OS is the same, independent of the specific hardware it is running on. The existence of standardized OSs for LEs is enabled because - compared to small embedded devices - LEs usually have less hardware restrictions and/or requirements. The fact that a standardized OS can run on a specific device opens this device to a wider range of application programmers. In other words, standardised embedded OSs form a kind of abstraction layer between the specific potential of the hardware and the general needs of application programmers with which new developments can be engineered with reduced effort.

Small embedded devices still require more individual OS-solutions

For small Embedded Systems (SEs) the situation is different: Even though some standardized execution platforms, such as for example JavaCard or TinyOS, could have been established lately, very often unique OS solutions still have to be tailored individually for the respective devices due to the various requirements and restrictions of the specific hardware. Additionally, because of the large diversity of SEs, standardization in the sector of SEs is more domain specific than for LEs. As a consequence, the formation of domain-spanning standardized OSs has been traditionally slow, e.g. successful standardized OSs like for example the OS specified by the OSEK standard are limited to the automotive domain. In general, if an OS is used at all, then specialised or proprietary solutions dominate the field. Other reasons for this slow adoption of standardized OSs for SEs in general seem to be performance and correctness issues [Tim2005].

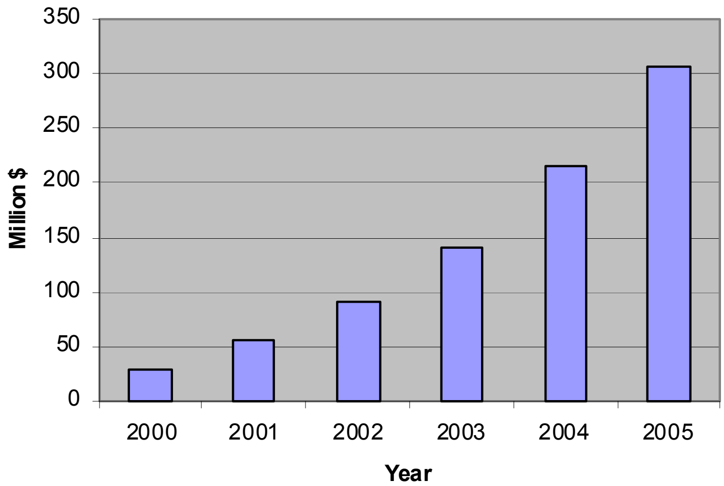
Increasing use of non-commercial, open source software in the area of embedded OSs

Together with the increasing use of standardised software in the embedded OS sector, embedded programmers tend more and more to use Open Source OSs as the software platform for (especially large) embedded devices. Some reasons might be that for a short time, developers tend to seek access to source code [Quest2005] and reduced licensing costs. Among Open Source OSs, the trend goes clearly towards non-commercial versions/ distributions of Open Source OSs.

Open source operating systems: Forecast for worldwide shipments of operating systems and related software products

Concerning open source operating systems, a study by Venture Development Corporation (VDC) forecasts that shipments of embedded GNU/Linux operating systems, software development tools, and related services will increase significantly. While in 2000, worldwide shipments of embedded Linux OSs, software development tools, and related services reached an estimated $28.2 million (approx. € 22.2 million) (see Figure 4-6). By 2005, VDC estimates that shipments will reach $306.6 million (approx. € 241.4 million), a compound annual growth rate (CAGR) of 61.2% [Bal2001]. Concerning shipment destinations, the American region is accounted for the greatest share of shipments in 2002, however, both the Asia-Pacific and EMEA regions are expected to grow the fastest over the forecast period. This increase shows clearly the growing impact of Open Source technologies in the sector of Embedded Systems.

Figure 4-6: Worldwide shipments of embedded Linux operating systems, software development tools, and related services, 2000-2005



Operating systems: In 2005 the actual use of Linux catches up with projected use

However, 2005 marks the first year that the actual Linux use really seems to be catching up with the optimism behind embedded Linux [ELMS05]. In particular, at the moment embedded **Linux** systems clearly **prevail the market of gateways, servers, and access points**, while the market of GUI-centric **handheld** and **mobile** devices (PDAs, tablets, and mobile phones) is rather dominated by **Windows** [GGSD2005].

Market development for operating systems: Non-commercial open source systems advancing

Among Open Source Systems, non-commercial options were identified as the current or future preference by more than half of the participants of [ELMS05] which use Linux in embedded applications. A survey conducted by EDC [EVANS2005] shows that together with the increasing use of open source software in the embedded sector, also the preference for non-commercial versions of Embedded Systems increases. According to EDC, two years ago, developers chose commercial versions of Linux twice as much as non-commercial versions. Mid of 2004, they were still favoured equally, while now in 2005, for the first time, non-commercial versions of Linux are more popular than commercial distributions (see Figure 4-7). A factor, which supported this development, is certainly the increasing availability of qualitative tools aiming for non-commercial systems, which traditionally only came along with commercial systems in the past [EMBNT03].

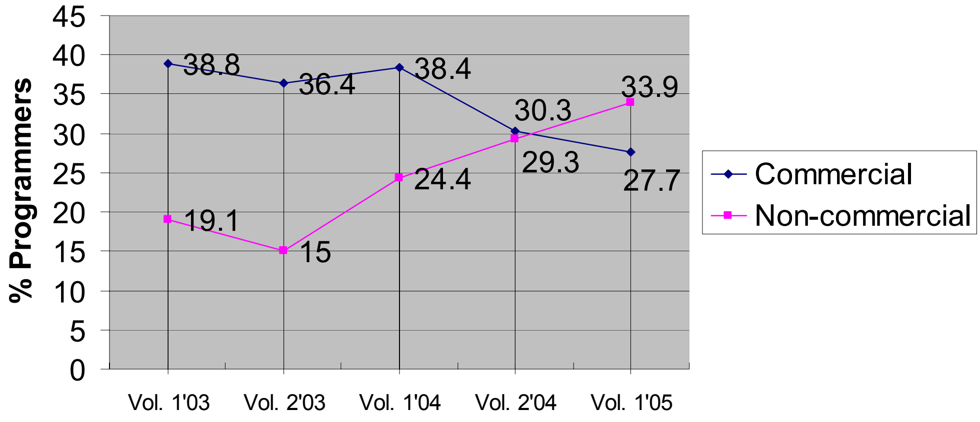


Figure 4-7: Preference for commercial vs. non-commercial versions of Linux

Influence of standardized middleware platforms

In the field of application platforms, the current trend is that various application platforms advance to become the de facto standard for developing software in certain domains. Open, general platforms like J2ME (Java Microcontroller Edition) or OSGi (Open Service Gateway Initiative), which have originally been designed for a wide, domain-independent use, are established as a de facto standard in certain domains. Also proprietary platforms like AUTOSAR (automotive sector), AADL (Architecture Analysis & Design Language; formerly: Avionics Architecture Description Language), or IMA (Integrated Modular Avionics) are on the journey to become such de facto standards: Taking for example the automotive sector, the OS defined in the OSEK standard is established as a de facto standard in the domain. Building on the OSEK standard, the even more powerful AUTOSAR middleware platform seems to become a new standard in the domain. Quite naturally, the AUTOSAR standard is designed to be compatible with the established OS standard OSEK. To highlight the effect of middleware platforms becoming de facto standards: For some manufacturers of embedded devices [SYMDEB05] the main consideration is (or will be) no longer which OS to employ for their product but instead, which application and middleware platform to use and to deliver together with the product.

Middleware platform J2ME is widely used in the market of mobile devices

Regarding general, non-proprietary application platforms, since 2002, J2ME is rapidly becoming the de facto platform for mobile and wireless devices from smart phones to PDAs [SFWJ2002], and is now widely supported by various mobile device vendors. The Java 2 Platform Micro Edition™ (J2ME) is the implementation of the Java programming language for so-called “embedded consumer products”. J2ME is based upon configurations, which comprise a virtual machine and a minimal set of class libraries, and profiles, which customise a configuration for a specific device category by providing a set of higher-level APIs. In that way, applications based on J2ME specifications can be written once for a wide range of devices, yet exploit each device's native capabilities by refining basic configurations with (device-) individual profiles (product lines character). While in May 2002, approximately a total of 70 models of J2ME-enabled mobile devices were around in the market [JRWP05], there were already over 300 Java models and a total of 250 million devices from 32 different manufacturers available in May 2004 [BD2005]. Some companies such as Motorola planned to rely exclusively on J2ME (or wireless Java) as the mainstream development platform for their devices [SYMDEB05]. Other players in the mobile device market have also realized the attractions of the Java language for mobile devices: The Symbian platform, which is used for example by Nokia, is capable of interpreting Java, too.

Successful example of middleware adoption: OSGi based middleware provides business opportunities

The OSGi platform is a successful example of the adoption of standards: The rigid definition of the **OSGi Service Platform enables components that can run on a variety of devices**, from very small to very big. Adoption of the OSGi specifications could therefore reduce software development costs as well as provide new business opportunities [OSGI05]. Many manufacturers have already realised these advantages and make use of the OSGi framework: According to [OAPR04], BMW has based the high-end infotainment platform in its latest generation 5-Series car on OSGi specifications, while German company RaumComputer AG is already realising the vision of a Computer Integrated Building based on the OSGi platform. In addition, manufacturers such as Philips and Bosch-Siemens household appliances have already launched the first domestic products based on OSGi technology [OAPR04].

Increasing networking capability of embedded (operating) systems

The networking capability of an embedded system is becoming more and more important because the general structure of man-machine interaction has dramatically changed during the last decades: After the (first) era of central mainframes and the second era of personal computers, we have by now entered the **third era of ubiquitous computing**, where the environment is saturated seamlessly with computers and intelligent Embedded Systems and where the user can move within this environment at will. This growth in complexity, in particular the need for interconnection of large numbers of different, Embedded Systems (at a global scale) requires the management of concurrency. Hence, **an increasing demand in the field of Embedded Systems is the connectivity** between different systems, i.e. the networking capability of an embedded (operating) system. Additionally, the networking capability of an embedded system is the basis for other trends for the near future, such as self-updating or remote-controlling of Embedded Systems.

Introduction of a component-oriented approach for ES

With component technologies, a large, complicated software design can be composed of pieces that expose interfaces that abstract their own complexity. In general, the application of component technologies has achieved significant progress towards providing composability and interoperability in large-scale application domains [MIDAS03]. Furthermore, component-oriented software has many advantages (e.g. increased re-use, update and exchange capabilities) from which the software designer can benefit during all phases of the software lifecycle. A strictly component-oriented approach would also push the adoption of COTS technology. But the introduction of component technologies into the field of Embedded Systems poses new challenges: Additionally to the capabilities of a regular interface, an interface definition for an embedded system has to consider the specification of time (e.g. a temporal order on the in-/output parameters, methods, etc.) or the provably correct composition of multiple component interfaces to a resulting interface-specification. Here, general frameworks such as for example JINI are only partially suited. A more promising representative of a framework, which organises its application software using the component-model, is AUTOSAR, which allows mapping components onto roles (functionality), and thus gives the possibility to actually use a component-oriented modelling technique already in an early phase of the design process.

Smart sensors as autonomous systems

The evolution of sensors is a prime example for the increasing importance of software for an embedded device: Up to today, sensor development activities have shifted from hardware to software and to the integration of sensors into a network. Nowadays, sensors have become “intelligent” and can already be deployed as a stand-alone system, which is running an “own” primitive operating system and which is capable of communicating over a network with other Embedded Systems that request the collected data. As a result of being such autonomous systems, modern smart sensors not only collect an enormous amount of data, but they already are able to pre-process the data in order to reduce the data traffic on the network.

4.4 Contributions of Systems Engineering

Definition of systems engineering

Systems engineering is “the branch of engineering concerned with the development of large and complex systems and focuses on: the real-world goals for, services provided by, and constraints on such systems” [UCL2005]. “It is also concerned with the processes, methods and tools for the development of systems in an economic and timely manner.”

Competitive edge shifts from superior base technology to superior embedded intelligence

In the past years, the main competitive factors in Embedded Systems have shifted in many sectors from provision of superior base (hardware) technology to the smart integration of commodity technology with superior embedded intelligence. In these software-intensive sectors, **critical issues in hardware technology** have already been addressed, and **solved to a sufficient degree**. Thus, in the software-intensive field, functionality/innovation leadership is determined by the amount of embedded intelligence built into the system. The **success** of the system in the marketplace highly **depends on innovation in the embedded intelligence**.

Examples: Smart protocols in wireless networks, smart solar panels for satellites

Two examples from recent years illustrate this trend: In telecommunications, radio transceivers as a base technology alone could not push the physical limits of the existing radio spectrum granted for **cellular networks**. The current **high-bandwidth networks** of embedded cellular phones are only possible through development of senders and receivers **capable of smart data and transport protocols**, which are a prerequisite for achieving the high effective bandwidth within the given spectrum. In space technology, solar panels as an existing base technology for autonomous energy supply are only seeing slow improvement in (hardware-) efficiency. However, by developing **smart solar panels**, which exploit irregular and unpredictable solar winds by applying a complex heuristic and adjusting the panels’ position accordingly, the yield of solar energy can still be increased, despite the slow progress in the related hardware.

Need to increase development productivity

The growth and increasing **complexity** and **heterogeneity** of embedded intelligence, the **decreasing product lifetime** requiring even shorter time-to-market, and the strong market demands for **customisation** and **dependability** all **call for an enormous increase** in the overall **development productivity** in order to keep up with the technological advances. Thus, for the future of Embedded Systems, and as a consequence of the fact that hardware is becoming a commodity, a **productivity increase** particularly in the **design of embedded software** is essential.

Strengthen European leadership in systems engineering

Given this requirement, the potential of excellent systems engineering practice in the Embedded Systems field becomes obvious: If Europe manages to establish its position in **systems engineering** as it did in other traditional engineering areas (e.g. mechanical engineering) in the past, the market of Embedded Systems will certainly be **mainly influenced by Europe** in the near future.

Specification, design, implementation

In systems engineering, **specification** is concerned with the question "which services should the system provide to its environment?", while **design** is concerned with the question "how is the system going to realise its specification?", but still at a limited level of detail. The actual running system, described at an arbitrary level of detail, will be coined as the **implementation**. **Verification, validation and testing** are applied throughout the development to assure the quality of the developed system, and **maintenance** is concerned with modifications of a system after delivery.

Systems engineering needed as distinct and dedicated perspective

The definition at the beginning of this section and the specific fields of systems engineering mentioned, like specification or maintenance, show that systems engineering is by far more than a simple combination of hardware and software engineering methods. Software Engineering has, due to the immateriality of the product and the complex functionalities and interfaces of software, other methods and tools than hardware engineering. Therefore, naively combining the respective approaches for developing Embedded Systems is neither effective nor efficient. On the contrary, new processes and methods are needed to support the complex development tasks for today's Embedded Systems industry. These needs are confirmed by the results from the questionnaires where experts ask for a dedicated "systems engineering discipline" to better educate students and practitioners in developing Embedded Systems.

4.4.1 Requirements Engineering

Central and critical activity in systems engineering, but slowly adopted

Requirements engineering (RE) is a central and critical activity in the software development process: It has been estimated that the cost of fixing a requirements error can be **up to 100 times the cost** of fixing a simple programming error [SS1997]. Faulty or incomplete requirements engineering is a **major source of complications** in the design process. If detected after shipment it may cause to expensive and even catastrophic failures [LeL2002]. Despite its importance, software developing **organisations** have been rather **slow at increasing their efforts on RE activities**: Out of the total effort spent to develop a software solution, estimates for the effort spent on requirements engineering range from 15% [SS1997] to 40% [AB1995]. It is estimated that only 5% to 15% of IT organisations that could benefit from requirements-management tools actually use them [Inf2001]. A potential reason for the slow adoption of RE techniques may be that requirements engineering is inherently a complex and heterogeneous field, as there are many kinds of sources for requirements, and many types of requirements to consider. It is also the point in the process where **informal and unstructured information about the future system** are organised **in a structured way**. There are four critical aspects to requirements engineering whose mastery will be crucial in order to meet the competitiveness challenge, and which deserve further research [Fin1994][AMSD2003][ROADNL2002]: these aspects are requirements elicitation, requirements modelling/evaluation/ combination, requirements tracing, and standardisation/tool exchange. The latter aspect is especially important for acceptance of RE techniques and tools in industry.

Requirements engineering for ES

Considering the variety and diversity in the field of Embedded Systems and its application environments, the **challenges** posed to RE **for Embedded Systems** are even **higher than those for regular systems**, since here, the influences, constraints and effects of the system are even more manifold, while the requirements analysis still has to **address all relevant properties** of these systems in a very concise way. In particular, a tight interoperation with surrounding systems, physical (changing) environment, and human operators, means to capture a comparatively complex field, as Embedded Systems **interact with a complex real-life environment**. Additionally, tight **non-functional constraints** such as timing, resource consumption, cost, size and reusability expand the set of ascertainable properties. To this end, ES-specific requirements engineering tends to incorporate even more heterogeneous system attributes, making a good RE process for Embedded Systems a particular challenge and even **more important than for other systems**.

Requirements elicitation

A typical initial problem in requirements elicitation is to obtain sharp decisions about a **system's boundary** already at an early stage in the process. Once the scope of the system is clear, the system's requirements typically emerge from identifying and querying relevant **stakeholders** (customers, designers, domain experts, marketing, finance), analysis of **predecessor** (legacy) systems that the system is designed to extend or replace, and analysis of **surrounding systems** with specific technical constraints. If a predecessor system in some form exists, it is important to understand how to combine existing with new requirements in **incremental development**.

Requirements modelling, evaluation, and combination

Research in requirements modelling is concerned with providing models and tools to support precise **specification of functional and non-functional properties**. Good models for requirements engineering should ensure the capture of requirements in a structured, precise, and formal way, while still allowing systematic exploration of the specification space. Customisation and extension concerns ("**product families**") are a **current topic of high interest** in requirements modelling. Models should allow identification and capture **interdependencies between requirements**. Requirements modelling techniques should provide techniques to classify and/or quantify such interdependencies. Additional support for specification decisions by **estimation techniques and metrics** is also a very desirable strain of research. Such support could e.g. be based on feasibility, risk, cost, and interdependencies analysis.

State of the art: weak structure of requirements models, little analysis support

State-of-the-art requirements management tools such as Telelogic DOORS or IBM Requisite Pro do support capturing and modelling requirements both in textual and graphical form, and have capabilities to manage interdependencies between requirements, along with goal-oriented partial views on the database. However, the **predefined structure** of such models is **weak**, and does not specifically capture know-how about best practices from the problem domain: arbitrary information can be modelled and interrelated in arbitrary ways **[Hei2005]**. **Nontrivial analysis features** have to be **hand-programmed** and are not part of the standard distributions **[BRS2000]**.

Requirements tracing

The results of systematic requirements elicitation and modelling will only come to full effect if each requirement is effectively linked to those **design artefacts** that are in conceptual correspondence (post-tracing). In addition, structured and system-oriented requirements should be linked to the **information sources** where they originated from (pre-tracing). Seamless transfer to the design phase requires an incremental process **from** more or less **unstructured requirements** to a **structured and classified requirements base**, which matches the structure of the design. Current approaches for semi-automated support for incremental structuring and classification are a **promising strain of research**.

Standardisation and tool exchange

In industrial practice, the value of tools for requirements engineering is determined to a large extent by their ability to **interface with other (third-party) tools**, e.g. design tools, or configuration management tools. Even if RE tools are conceptually well-designed, they will **only be accepted** by development organisations (and therefore have an impact on productivity in ES engineering) if **sufficient interfacing capabilities are installed**. **Standardisation** on the level of notations and exchange formats is **currently poor**, as established design-level standards such as UML do not cover large parts of the requirements engineering process. The situation is even worse for specific tools providing their own notations as for example Matlab/Simulink. Here in most cases only vendor specific interfaces exist. However, there are domain-specific efforts to provide standardised exchange formats for requirements engineering such as the **HIS** initiative for the **automotive** domain [HIS2005]. Unfortunately standardised exchange formats alone will not help as the example of the currently available UML tools unveils. Besides the existing standardised exchange format, the exchange of models is not always possible and in many cases information is lost.

Current tool couplings not adequate for flexible and consistent modelling, lack of workflow support

The commercial software engineering tool market currently does provide some "peer to peer" couplings between popular design tools, such as Simulink and Rational Rose, with requirements tools. These couplings support tracing between requirements and design artefacts. However, **navigation** between models is often **unidirectional**, **impeding flexible and consistent handling** of both design and requirements model **[BRS2000]**. Moreover, important **methodological know-how**, such as support for incremental structuring of requirements and design, is **not supported** by state-of-the-art tools **[Hei2005]**.

4.4.2 Design

Design becomes more important

The creation of a consistent, reusable, and well-documented design will become the **most important stage in the development of ES** in the future. Due to the increasing complexity of the developed Embedded Systems it will become more and more important to do the design right and to implement the chosen design in a correct way.

Some design issues are well understood, but lack of adequate standards and tool interoperability hinders progress

The **design** terrain has a somewhat **clearer** technical and academic **background** than the specification and requirements engineering field. However, there is a surprisingly high number of models, notations, and techniques employed both in research and in industry to get from specification to design, while the degree of **industrial adoption** for new techniques is **surprisingly low**. Especially in large and heterogeneous design chains, such as vehicle vendors vs. suppliers in automotive, innovation in the field is often hindered due to a **lack of common standards**, **agreements** and wide **CASE tool support**. Specific to the Embedded Systems field, **notations and techniques must be suitable for the different technical disciplines** involved, such as discrete controller design, continuous controller design, and HW design, and user-centric/data-heavy functionalities. Tools and development environments must match the **specific constraints** of **heterogeneous development organisations**.

Shift from implementation to design

The future importance of design-level methods and tools is illustrated by the current shift from implementation towards design. Many **decisions** formerly made during **implementation** have to be made **already on a higher level** in a consistent way **during design**. This shift is also reflected by the increasing use of modelling and design tools, like **Simulink** or **UML-based tools** [ACA2003][UFR2003].

Behavioral design: programming languages vs. behavioral modeling

It is important to note that **approaches to design and programming based on sequential languages**, such as object-oriented modelling (e.g. UML) and high-level programming languages such as Ada 95 and Java, **enjoy a varying degree of acceptance within the different ES domains.** For instance, the inherent paradigms of UML structural modelling and object-oriented programming are highly accepted in user-centric and data-heavy domains of ES, such as human-machine interface design, and infotainment applications in cars. In these domains the task of structural design profits from the abstraction and focus given by object-oriented modelling, while behavioural design is largely carried out using "classical" high-level programming techniques. Consequently, ES-specific issues in high-level programming languages will be discussed in section 4.4.3 while object-oriented structural modelling is in the focus of this section. In other domains, such as discrete and continuous controller design, both structural and behavioural modelling (e.g. Simulink, Statecharts) is accepted.

Automatic generation instead of manual implementation

With the trend towards behavioural modelling in some ES domains, the **implementation** of such behavioural models will gradually become **more straightforward**. So, the competence of the engineers is needed at the design level while the **role of the**

traditional programmer will become **more restricted** on exploiting the remaining degrees of freedom on the implementation level. Already design-level models tend to be more and more executable, allowing for **virtual prototyping** and **integration** or **transformation** into **different models** for other design purposes. As a consequence of the increasing possibilities in design-modelling, the traditional way of implementation will change as well: Substantial parts of the implementation will be **generated** based on **design models**. So, **code generators** will play a similar role as compilers do nowadays. They will generate highly optimised code, which will be compiled in the traditional way for different platforms. Such an approach is manifested within the standardisation efforts of the OMG in the context of **model driven architecture** (MDA) [MDA2003], where platform independent models (PIMs) can be enriched with platform specific information. The resulting platform specific models (PSMs) are then the basis for code generation. While the idea behind MDA seems to be appropriate for Embedded Systems, currently the suggested general approaches are weighted too much. On the other hand, for example the used approach in AUTOSAR [ASAR2005], which is more specific but contains also the idea of MDA, shows that it will be possible in the near future to generate optimised code from design models, which is at least as good as carefully handwritten code.

Product line engineering

In order to exploit the specific capabilities of a device while still gaining the benefits of a generic software architecture, an important concept is the idea of product line engineering, where a software architecture (the **product line architecture**) is built for a **set of similar products** that share a common technology platform as well as having common functionality. The **individual products are derived** from the product line architecture. Some hypothesized benefits of this concept are: reduction of time-to-market, reduction of effort, and quality improvement [SCHM01].

Productivity gains through product-line engineering

The use of product lines in industrial software development is steadily gaining acceptance, especially since it has been shown that their disciplined use can lead to significant advantages in terms of **reduced development cost and time**. Organisations such as Nokia, Alcatel and Philips have already reported on successfully introducing product lines for some of the software they are developing [Envi2003]. [SAL05] reports for a case study that **reuse levels of up to 97%** can be achieved, and that follow-up products can be developed with up to **30% less effort** by exploiting the reuse potential. Another case study [SPL2002] for a military boat application showed a **decrease** in the software development cost **from 65% of total production costs to 20%**. The productivity benefits seem to be largely independent of the specific domain: other successful case studies in the embedded domain have shown significant productivity benefits by introducing product line engineering techniques, for instance for elevator systems [ECS2000], control software for space vehicles [CCT2001], and control software for Diesel engines [DPLA2000].

Model-based development

Model-based development is a very important trend in the design of embedded system. In model-based designs, a model of the application is used to represent complex designs at **higher levels of abstraction**; showing only dedicated pieces of information for the purpose of understanding and analysing large designs. The model forms the basis for further activities, such as **verification, code generation, or model transformations**, for instance to introduce new functionality or platform specific information. Model-based software development is nowadays considered a very important topic in ES engineering, undermined by the already large number of licences for modelling tools in use today. For the case of visual modelling languages, productivity benefits of 4 to 10 times are claimed by some authors [BH1995]. Standardisation efforts for model-based development in the context of the UML (and QVT as a transformation language) are underway within the OMG MDA approach [MDA2003].

General-purpose models and methods not sufficient for ES

As of today, many general-purpose software modelling techniques are inspired from an implementation and sequential programming: an example is the widespread UML standard for general-purpose software specification and design, where the notion of interface revolves chiefly around sequential-language method calls. Such formalisms tend to be traditionally weak on issues like parallelism and non-functional properties, such as **real-time behaviour**, despite some recent real-time extensions.

Synchronous modelling techniques offer potential for real-time design, currently limited to application in non-distributed control SW, and HW

In addition to UML and related techniques, there is already a variety of commercially established modelling languages and tools that have **stronger inherent synchronization and timing** assumptions, and capture the requirements of application areas like mixed continuous/discrete (hybrid) control more adequately. For instance, the Matlab/Simulink tool for **control modelling and design** enjoys a market share of about **50%** in some domains such as automotive [Han2003]. The discrete-time subset of Simulink allows **efficient code generation**, indicated by a variety of commercial code generators. Though increasingly used as a "SW modeling language", Simulink has strong deficiencies e.g. in describing data types. Synchronous languages like Esterel and Lustre (SCADE) are established in the HW and safety-critical control SW field, respectively, have **stronger typing mechanisms**, are more focused around synthesis and formal verification, and have **clearer semantics**. However, it is currently unclear how the simplicity and adequacy of the synchronous paradigm can be carried towards the design of complex distributed ES, and how relevant concepts from the control field can be reconciled with concepts from general-purpose software modelling. Thus, in order to support especially ES-architects, **further research** that combines the former properties with modelling-techniques has to been seen as **essential**.

Need for component-based engineering and flexibility of software solutions

Design-level software modelling in the embedded domain revolves around software components: During the past decade, **component-based software engineering** has become very important for the further growth of large, interacting networks of Embedded Systems. The models, methods, middleware-architectures, languages and tools in component-based software engineering mirror, in a way, the established approach of integrating and assembling hardware components on the physical level. The main reasons why future ES will require component-based development techniques and the flexibility of software solutions is their capability of abstracting from the heterogeneity of the underlying hardware devices and operating systems services, and their lower production and management cost. In the automotive industry, where suppliers provide components for the OEMs, the need for better component-based techniques is obvious by the efforts in the context of AUTOSAR [ASAR2005]. The foundation of the OSGi Alliance [OAPR04] shows a similar trend within the consumer electronics market.

Component-based engineering with ES-specific interface descriptions

A central notion in component-based modelling and development are **explicit, well-defined interfaces**: Interface requirements and assertions (similar to post- and pre-conditions) allow virtual composition, execution, and analysis on the abstract design level, before the actual system integration on the implementation level is performed. Specifically for the ES domain, **non-functional properties** such as **timing** or **resource consumption** are **critical parameters in interface descriptions** and have to be integrated into ES-specific IDLs (Interface description languages) respectively. Currently such interface descriptions are recognized as a necessary prerequisite for managing the distributed development of ES. So for example AUTOSAR [ASAR2005] as well as AADL [Fei2003] addresses the description of well-defined interfaces. While both standards deal with many of the aspects mentioned above, the development of appropriate interface description languages has to be the subject of further research. So for example the description of communication patterns of a component in a way such that it is usable in practice and the composition is possible is an aim of ongoing research. Such a disciplined methodology with suitable, formal interface descriptions has the potential to prevent costly redesign cycles and allows the use of well-documented, **off-the-shelf**

component libraries, which in turn are characterised by productivity benefits and as being an important **enabling-technique for product-line engineering**.

Cross-discipline modelling and theoretical foundation

Because of their heterogeneous nature, functional designs for ES are frequently characterised by **close interaction with the physical environment** and mechanical parts, and by control and signal processing algorithms. In these domains, there are established modelling theories, notations, and tools. Since software modelling techniques have been entering the ES field in the last years, there is a need to integrate and understand more thoroughly the techniques employed in both fields. This supports our proposal of a dedicated Embedded Systems discipline. The experts in the online survey explicitly expressed both the demand for a better theoretical foundation as well as for interdisciplinary approaches.

Standardisation and tool exchange to be developed

Similar to the specification field, the value of design tools in industrial practice hinges to a large degree on interoperability with third-party tools, and the suitability of the tools environment in heterogeneous supply chains. **Acceptance of design tools and methods** in development organisations will be poor if there's the danger of being "locked in" by a specific tool vendor and no open standards exist. Even more important system development processes used in practice, like for example in the automotive or in the avionics domain, typically different tools are used. This is not only but especially a problem of the design phase where the information in different design models maintained in different tools have to be consistent. In the long run, the possible productivity effects of improved design practice will only be unleashed if adequate, **open standards simple techniques for establishing tool chains** exist. So for improving the situation two steps are required. First, open standards for model storage like for example XML-based formats and model access have to be developed and established. This will provide an opportunity to build customer specific tool chains with less effort and greater impact. Second, simple techniques for transforming models and building tool chains have to be developed. Currently used specific techniques for transforming models like XSL have many shortcomings. For example wrong transformations are hard to debug and the maintainability is bad [TRAF2002]. In tightly integrated tool chains the different tools have to be adapted to achieve a better usability. The tools have to provide extension mechanisms. Here the situation is very different for existing tools but the sometimes provided mechanisms build upon scripting languages seem to be appropriate. A common standard would decrease the effort to build tightly integrated tool chains. Furthermore besides those two steps the long term aim to develop open standards for design models will reduce the necessity to build customer specific tool chains. Existing cross-domain efforts like the **embedded-specific extensions in the 2.0 version of UML** are a step in the right direction, but currently fall short of capturing important domain-specific knowledge. Thereby it is very important to define a precise semantics for the developed design model standard so that the interpretation of models is consistent in different tools.

4.4.3 Implementation

Role of implementation in ES

Though the focus of attention in ES engineering is slowly shifting from the traditional implementation-level view towards a more holistic design-level view in systems engineering, the **implementation level remains important** as a self-contained representation between the executable design and the running system. In an implementation, software components are implemented in a programming language, and the single threads of control are executed by a run-time platform combined of operating system, communication layers, and middleware at the software level, and processors and communication networks at the hardware level.

Use of middleware platforms for portability and modularity

Probably the **most important trend** on the implementation level is the introduction of **advanced platform software** and **service frameworks**, which ease the development of large, modular, portable Embedded Systems. As a prominent example in the automotive sector the **AUTOSAR** standard [ASAR2005] is currently defined, which will help to provide a platform independent standard for developing automotive systems. It introduces many high-level concepts easing the development of embedded software. On the one hand, AUTOSAR unifies formerly different forms of local and distributed communication between software units, while being designed carefully so that this does not lead to unacceptable timing and resource overheads. On the other hand, AUTOSAR separates sensor- and actuator-specific functionality from application-level functionality, and therefore **greatly improves portability and modularity** of both application-level and sensor/actuator-level software components. AUTOSAR is an initiative driven by the industry sector (see other examples in section 6.4.1), initiated by major European and worldwide car manufacturers and suppliers who have committed themselves to use the standard and to further develop it. Similar approaches exist in other sectors like the ENEA Embedded Medical Platform or the Open Service Gateway Initiative (OSGi) in the consumer electronics sector. Also general middleware like Jini or UPnP are of some importance especially in the consumer electronics and the telecommunication sector.

High-level ES programming languages

For those sub domains of ES where “classical” high-level programming is dominant, there is currently a problem of adequate representation of the implementation: the main benefits of a domain-specific high-level language should be that it enables the programmer to abstract away from implementation details, and to **concentrate on solving the problem** at hand. But the expressive power and semantic features of most modern **high-level languages** are targeted at general-purpose software development, and are **not particularly suited to ES**. Especially in markets with high production, cost and efficiency concerns, which are mostly per-unit, are considered very important. ES-specific high-level programming may even help to reduce the gap between an abstract specification produced in a design and the implementation. So the design of programming languages specifically suited for ES is still an active area of research.

Up to 300% productivity increase by adoption of specialised high-level languages

In contrast to the use of general-purpose high-level languages, the application of specialised (very) high-level languages (**domain specific languages**, DSL) and compilers/virtual machines in the ES field has been claimed by industry participants to bring a four-fold increase in productivity [Wig2001]. Compared to general-purpose languages, such domain-specific specially tailored languages try to combine a number of different programming techniques from various programming paradigms to meet the specific needs that appear in embedded-specific programming tasks. As a result, the use of suitable high-level languages may yield a significant improvement in **design efficiency** and **error-reduction** compared to current non-specialised high-level programming languages.

Characteristics of ES languages

Because of cost and efficiency concerns, ES developers constantly have to be concerned with the cost and resource consumption associated with particular language features [RTSPL2001]. Besides **resource efficiency**, there are some other important characteristics of Embedded Systems, which greatly affect the implementation level:

- Programming languages with support for concurrent programming will ease a correct distributed implementation enormously.
- As of today, it is often very difficult to design and implement systems, which guarantee predictable real-time behaviour. So support for real-time monitoring and prediction is needed.
- Other important programming language design criteria are: safety, readability, flexibility, simplicity, portability and efficiency [RTLDD1982].

As an example from the telecommunication sector, **Java** as a **platform independent language** is used to minimize development costs for supporting applications running on different mobile phones. Due to the hardware-dependent parts of Embedded Systems it is difficult to achieve portability. Therefore platform software is very **important to** abstract from hardware and platform details. As already discussed in detail efficiency is a main issue in the embedded system context. Language constructs, which lead to **unpredictable run-time overheads**, like for example the garbage collection in Java, should be avoided.

Example: Java in telecommunications sector

Also coding standards play an important role. With the help of coding standards the proper use of languages should be improved. So the use of uncertain or error-prone features of languages, compilers, or development tools should be avoided. For example in the automotive industry, the Motor Industry Software Reliability Association (MISRA) defines a subset of C and coding standards for its proper usage, which is of great importance in the automotive sector [MISRA2004].

Development and use of coding standards

4.4.4 Validation, Verification and Testing

Validation, verification, and testing (in general, quality assurance activities) are especially important in the domain of Embedded Systems because of the usually **high dependability requirements** (safety, reliability, and security). The purpose of **validation** is to confirm that the developed product meets the user needs and requirements. **Verification** ensures that it is consistent, complete, and correct at the different steps of the life cycle. **Testing** means exercising an implementation to detect faults, and can be used both for verification and for validation. An important aspect and application area of validation, verification and testing is their use for the certification of products, especially in safety-critical domains. New certification standards (like the followers of the DO-178B in the avionics industry) increasingly require the creation of formal models. As an example, it is expected that DO-178C “will support the use of formal verification methods” [Rei2005].

Importance of verification, validation and testing in ES domain

The main challenge with validation, verification and testing of ES is the large state space that is to be explored. ES have a reactive behaviour, i.e. they **do not terminate but continuously respond to inputs** while at the same time changing their internal state. This leads to a theoretically infinite number of different possible executions. On the other hand, if high dependability is required, **only very small error rates are acceptable**. For example, to prevent any single catastrophic failure in any aircraft of a given type during its entire lifetime, one estimates that the maximum admissible failure rate for each failure condition is about 10^{-9} per hour [SSAS1992]

Challenge: Large state space

In addition, the requirements that must be fulfilled are comparatively complex, as ES **interact with a complex real-life environment**. Often, the requirements include real-time, stochastic, or hybrid aspects that have to be expressed via complex mathematical formulas.

Challenge: Complex nature of requirements

Quality assurance costs make up between **30% up to 80% of the total R&D costs** in Embedded Systems [Jon1991][Büt2005][ART2005]. The impact of research into methodologies that reduce this effort is therefore very high.

High costs for quality assurance

Test automation is highly relevant with respect to **reducing quality assurance costs**. Test automation includes tool-supported test organisation (planning of the test process, management and version control of the applied tests), automated test execution, and semi-automated **generation of tests** from models (specification-based testing). Automated test execution includes environment emulators (“hardware-in-the-loop”) to stimulate the system with typical, rare, or extreme usage patterns. The respondents to the online questionnaire considered test automation the most relevant issue in systems

Automated test organisation, execution, generation engineering of ES. The **market for test automation tools** was estimated at **€ 43 million** in 2002 [AMSD2003]. [ART2005] lists relevant tools in the area.

Challenge: Better tool support for all activities of quality assurance

The need for better and more adequate tools is not only visible for test automation, but is a general topic in the area of quality assurance. Future tools face two important requirements that are not properly met today:

- Integration in the tool chain to avoid manual or semi-automatic transfer of models and/or code.
- Proper formal foundation, which also eases tool development.

Increasing use of formal methods

A fundamental limitation of testing is that it is inherently incomplete, since only a very small fraction of the possible behaviours can be tested. For systems with very high dependability requirements, testing alone is therefore **insufficient**. More rigorous, formal validation and verification techniques such as **model checking, static analysis, and theorem proving**, will be used increasingly for this purpose. According to Gartner Dataquest [Mut2005] the formal verification market is growing at a **CAGR of 20.9%** and is expected to reach **€ 110.3 million** by 2008.

User-friendly verification tools

With respect to the industrial use of formal verification methods, it is especially important to develop user-friendly verification tools that separate the verification and validation functionality from the underlying mathematics and help the user in specifying properties [AMSD2003].

ES-specific concerns in formal verification and validation

The scope of the study does not permit a detailed examination of the different formal and informal verification and validation techniques applicable in ES development. A detailed treatment with an overview over existing tools is given in [ART2005]. Embedded-specific concerns are in particular real-time and hybrid model checking, stochastic model checking, determination of worst-case execution times, concurrency, and scalability.

4.4.5 Software Maintenance

Software maintenance highly relevant for large ES

In general, software maintenance is concerned with the modification of an existing software product/system or component after delivery to **correct faults**, **improve performance** or other attributes, or to **adapt to a changed environment**. Concerning ES, some products that feature them are small, relatively inexpensive and have a short lifetime of a few years before the next-generation product replaces them, e.g. mobile phones and other home electronics. In contrast, large, expensive and complex capital equipment, such as telephone switches, automobiles, airplanes, and industrial machines, are often **safety-critical and in operation for several decades**. From this point of view, software maintenance is an important issue, in particular for **long-living, large ES**.

Lack of research

Unfortunately – and in contrast to the importance of software maintenance especially for long-living ESs – there is a lack of research in particular in the field of embedded software maintenance [DACS2003]. Compared to other, more “traditional” phases of the software development process (e.g., design, implementation), the area of software maintenance has long been ignored by research, for the importance of this area to the software engineering process has been recognized only relatively lately with the growing tendency of having to deal with more and more complex legacy systems. Of course, this does not imply, that only little research must be done related to the other phases of the software engineering process. But in contrast to the past, where electronic control units were not that complex and could simply be replaced as a whole, the current trend is to “refurbish" Embedded Systems in place with updated software [DACS2003]. In turn, this requires a profound knowledge in the field of embedded software maintenance. Therefore – and in particular in these days, where reactive software maintenance becomes more and more complex and expensive **–** research in the area of software engineering for Embedded

Systems in general, but also in the area of embedded software maintenance, should be intensified. Some topics of interest include the influence of using models for the design of a system on the maintainability of the system or how the architecture of a system has to be structured in order to support a comfortable way of making late changes (after delivery).

Product-line engineering facilitates software maintenance

Software maintenance as well as the idea of product lines have in common that they both deal with evolving (software) products that exhibit a sort of life time cycle. In particular in the field of embedded software, software maintenance is not only concerned with **correcting errors** but also with **reacting to environmental adaptations**, **functional enhancements** as well as introducing **changes to increase the maintainability** of the embedded software. Thus, the application of product-line engineering in embedded software design can greatly help to improve the way of maintaining embedded software because the maintenance task of the individual systems can partly be shifted to the product line.

Concerns related to embedded software maintenance

In particular for ES, software maintenance has some specialities compared to the maintenance of non-Embedded Systems. Here, [Tam1996] identifies the following concerns:

- A new version of non-unique product software (i.e., a piece of software used in several kinds of applications) may be incompatible with the rest of the software in the system.
- System software may be so specific that a change of operating system or hardware might require extensive modifications or a total rewrite of other code.
- Product software often operates only on a specific hardware platform, so that hardware changes make the original software incompatible.
- Application software may become incompatible with the special system software and hardware when switching to new computing platforms.

Difficulty of changes and corresponding solution trends

While changes are made difficult in particular by high reliability demands, primitive software engineering environments, sharing of software parts in several products or product families, and concurrent (hardware/software) engineering [Mäk2000]. There are the following possible technical **trends towards solutions that address the stated problems**:

- maintainability (development of a system in such a way that maintenance issues are considered during all stages of the development process, in particular in the analysis and design phases),
- software configuration management,
- technical management of external teams,
- impact analysis (identifying the entities that are affected in the software by a software change).

4.5 Recommendations

A look from the bird's-eye view on the presented trends makes clear that the given stage of development is not sufficient to address the market needs and trends and that furthermore the gap between capabilities and expectations is dramatically growing. This mainly concerns the fields of software development and systems engineering for Embedded Systems. Great efforts have to be made to bridge that gap and not to lose ground in the worldwide competition in a field, where Europe has great chances to become (or to stay) a major player. So, the publishers of the study derive the following recommendations from the represented trends and the challenges connected with them.

4.5.1 General Recommendations

In general, great efforts have to be made to strengthen the technological and knowledge base for further progress in development and deployment of ES. This mostly concerns **fundamental and pre-competitive research,** and **education** in university and at school as well as the creation of a **convenient legal framework**, especially in **standardization**.

Overview

In detail the following would be useful to hit the target:

- establishing a true Embedded Systems discipline in education and research which fully reflects the multidisciplinary character of ES in development,
- creating dedicated curricula and institutes for ES,
- encouraging technical and mathematical comprehension at school,
- making engineers sensitive for advantages of standardization,
- supporting inter-domain development of platforms and standards,
- intensifying research on environmental effects of ES.

Further topics are addressed in the sections on several industry and technology domains (4.5.2 and 4.5.3 of this chapter).

ES needs to be established as proper discipline

Due to the **multidisciplinary character** of the embedded domain, and the pressing problems in productivity and competitiveness for the European ES industry, it will be necessary to further **establish ES as a proper discipline of its own**, considering relevant aspects of several or all of the following disciplines:

- mechanical hardware, physical environment,
- electronic hardware, e.g. mechatronics such as sensors and actuators,
- communication networks (e.g. field bus systems) to provide these systems with the required data, often under consideration of real-time constraints,
- software,
- user input/output (human-machine interface, HMI),
- system of systems (e.g. integrate several sensors and actuators),
- integration with other embedded and non-Embedded Systems,
- application domain, in and for which the system is finally used.

Dedicated curricula for ES – a foundation for future market position

But at the moment, curricula in computer science, electrical engineering and mechanical engineering are seldom combined. It is necessary that a **technological transfer** between these different disciplines occur already at university. This can be achieved by **special Embedded Systems courses** or by **institutes**, which focus on the field of Embedded Systems in particular [ART2005].

School education must be improved

Another important aspect is the education at school. As several interviewees mentioned, it is necessary to encourage the technical and mathematical comprehension already at school.

Push standardization of platform software indirectly by facilitating education

Standardization is an essential means to reduce the costs of developing embedded software because of its synergistic effect: With the help of standardization solutions can be exchanged and re-used between different devices. Considering that the added-value of embedded products in the future will mainly be determined by the Embedded Software, **standardization** of embedded software must be a major concern for Embedded Systems engineering. The success of standardised Embedded Software cannot be pushed by any governmental institution or statutory presetting. Usually, the success of a standard is determined by the degree of adoption from the industry. So, a feasible way to push the formation of standards is to make software engineers sensitive for the advantages of standardised embedded software. This can be achieved by pushing the education of future software engineers and making them aware of the importance of standardization in particular for embedded software. This again addresses the **general need for more education in particular in the field of ES**.

Support inter-domain development of platform and standards

It seems to be very important to support the development of **standard platforms** and **standard ways of using them**. Today, work on standards takes place separately in different industry domains and even in different corporations while many problems are independent of a concrete domain. The same holds for the development of coding standards. So for example **programming languages are used in different domains** and if a language feature is error-prone this holds independently of the concrete domain.

Intensify research on environmental effects of ES

Gaining even more relevance in diverse domains and offering manifold interesting application areas, Embedded Systems need to be **better understood concerning their ecological impacts** and the opportunities and risks their use offers. We recommend intensifying the effort to develop an "ecological balance", i.e. developing calculations and gaining a holistic view on the different effects of the use of ES. A better understanding of the different applications can be gained through this, for example when analysing hybrid engines that have higher energy efficiency or intelligent CHP ("cogeneration", combined heat & power plant).

4.5.2 Recommendations Concerning Industry Domains

4.5.2.1 Automotive

Telematics recommendation: Install adequate networks, standards, information

The success of a widespread introduction of automotive telematics services hinges on technical and organisational factors: **creating wireless networks** with adequate capacity, security, and availability (range), **enforcing industry wide standardization** to ensure a commercially viable user base and availability of cost-effective technical components, and providing of adequate information about traffic flow and routing, e.g. by government authorities, or private enterprises.

ADAS: Improve HMI capabilities, extend automated controls, improve sensors/actuators

In automotive **driver assistance systems**, research should focus on **further exploiting the human-machine interface** to enable better and faster intervention of the driver, **unburdening of the driver** from driving-related tasks by **automated controls** (e.g. vehicle dynamics control), and **improved sensors, actuators, and information/communication services** to recognize and prevent critical situations. Examples for sensors include short-range radar sensors (24GHz, already available), long-range radar sensors (77-79GHz, under development), and combined laser/radar (Lidar) sensors.

HMI: Intelligent management of information

HMI-related research efforts are an important enabler for other technologies in the automotive sector. Such HMI-related efforts must be targeted at the **intelligent and flexible management of the information flow** between the driver and the environment. For instance, in a critical driving situation (low traction, skid, danger of collision), the information management could assign yet a higher priority to auditory and visual alarms related to the driving situation. Such **information management-related research** should be concerned with combining the best available techniques (intelligent agents, neural networks, formal methods, etc.) to enable context-aware management of user information flow.

Infotainment: Improve interoperability, strengthen standards, provide adequate platforms

For the infotainment sector, it is recommended that **standards and technologies for interoperability and adaptiveness** are strengthened. Standards and execution environments from the telecommunications and desktop PC sectors have to be ported to the automotive domain, where additional technical concerns such as size, weight, adverse operational conditions, timing requirements, and power consumption are relevant. As an example, important "virtual machine"-based technologies such as Java or

.NET may currently be rejected for an automotive application for performance reasons. Therefore, research in technologies that are more specifically suited to the application domain is needed.

4.5.2.2 Avionics/Aerospace

UAV recommendation: Tackle technical and regulatory hurdles

It will be important in the near future to tackle the numerous **technical challenges for UAV applications**: dynamic replanning/retasking for the mission-level, multi-vehicle coordination, autonomous take-off & landing, and miniaturization and weight reduction of the electronics and sensor/actuator technology. The **regulatory environment** for aerospace development and operation is also an important issue: while Israel and the US have issued clear regulations for development of UAVs, which can then be flown over a large share of the terrain, test flights within the EU are currently restricted to small, enclosed areas due to a lack of adequate safety regulations for development [Gos2005]. It is vital for European UAV technology leadership that **regulatory hurdles be harmonized internationally**.

Adopt and improve standards for SW/HW development, military infrastructure integration

Current **standardization efforts in the avionics field**, such as AADL and IMA for SW and HW engineering, and JTA for integration of command-and-control infrastructures in military applications, **are important enablers for more productive engineering** of more efficient and dependable avionics systems. Research in this area should focus on quick adoption and improvement of these standards within the European industry and academia. For safety-related applications, strong **research and standardization efforts** in **formally defined and tractable models for HW/SW systems** are important.

Networking: robust and dependable protocols needed, favour existing standards

On-/off-aircraft networking, especially towards **adopting and profiling existing networking standards** for avionics needs, is an important topic in avionics research. Key issues to consider include robustness, fault tolerance, quality of service, and network security. Moreover, **existing regulations for on-/off-aircraft wireless applications** should be **reviewed** with consideration of the market potential and competitive position of the European industry.

4.5.2.3 Industrial Automation

Realising open distributed systems

Interface and service concepts for sensor and actuator modules have to be investigated and standardised to fulfil the needs for open system architectures and distributed (networked) systems. Also research in the topic of real-time and secure data exchange has to be intensified. New engineering processes have to be introduced that are necessary to manage the development of complex distributed systems. These development processes **require the teamwork of different technical domains**, e.g. mechanical engineer, electronical engineer, and computer scientist. To improve this team work it is recommended to establish special courses for multidisciplinary education at university.

R&D on simulation

The competitiveness of European producers of **assembly lines** enhances with further **reduction of planning and commissioning time** of their products. Therefore additional research activity is recommended on virtual planning of assembly lines.

R&D on sensors

Continuous improvements on sensor technology are necessary to address the **increasing demands on control and monitoring of plants** and systems to guarantee **reliability** and **safety**. Thus the research on sensor technology has to be intensified to make Europe to an active part in the creation of standards for new sensor technologies.

Research activity in the field of industrial Ethernet

The predicted increase in using Ethernet as field bus shows that it is **essential for European automation to be in the front row of research, technology and development of industrial Ethernet**. This is the most promising way to be able to participate from the new product opportunities enabled by Internet based technologies. Therefore the investigation to overcome the obstacles has to be intensified especially in the topic of real-time and secure data exchange.

4.5.2.4 Telecommunications

Full convergence of telecom services and technologies

Full convergence is the ultimate stage of convergent efforts. It disaggregates the service from the network. The consumers, no matter if they are at home, in office or on the way, can seamlessly move between different networks and devices while retaining services and their personalized profiles. Users use their computers, mobile phones, analogue and digital fixed line phones etc. in order to complete different tasks. The consumers can use different services as among others mailbox, Emails and phone numbers. The concept of Fixed Mobile Convergence (FMC) allows such integration and could bring value to consumers, but also to other players in the field of telecommunication [MBG2004]. The problem is that these services available on different networks are not integrated so far. Therefore, **research in service and technology integration is needed**.

HMI for older consumers

Whereas young consumers and partly the young professionals prefer devices that are packed with new technologies and additional services, older consumers prefer devices that are easy to use and handle [Cap2004]. The most important aspect in this context is the usability of handsets and should be a **major objective of further research**.

QoS in telecom

The development of coverage improvements and research on fault tolerant and reliable radio communication will increase the revenues per customer.

Power consumption to a minimum

It takes battery manufactures between 5 and 12 years to develop batteries with increased power that maintain the size required for a UMTS device. Current battery technologies (Ni-Cd, Ni-MH, Li-Po) are not always able to support the increased power requirements. **New concepts have to be developed** for hardware and software design taking into account reducing the power consumption of end devices. Also the further development of the **hydrogen fuel cell** can secure the necessary power consumption of future device. A lot of research is still needed till fuel cell batteries will be available in the mass market.

4.5.2.5 Consumer Electronics and Intelligent Homes

Interoperability through standard APIs

There is a need for standardizing the interfaces between Embedded Systems that must interoperate. For example the development of standard application programming interfaces (APIs) could help to connect different devices. However, devices do need to communicate over a wire or some kind of median to another computer somewhere, and it's on those interfaces where **standards are crucial**.

Appropriate Human-Machine-Interfaces

User-friendly Human-Machine-Interfaces (HMI) are needed to increase acceptance of the applications. Not only for home networks and intelligent home concepts that are based on connecting different devices and functionalities, but also for **complex systems-of-systems**, as well as for stand-alone devices.

Safety and security

At the same time, as systems get more complex and store more data, safety and security issues arise. Both aspects have not been in the centre of interest in the Consumer Electronics industry for long but **gain importance**, especially regarding Intelligent Homes.

Research for lower energy consumption

A future research topic is how Embedded Systems can help to reduce **energy consumption in the house**, thus decreasing cost of living and contributing to the protection of our environment.

4.5.2.6 Medical / Healthcare

Mobile healthcare: Research towards data integration

A central concern in mobile healthcare is data integration. We recommend funding of research towards the integration of data collected and used by Embedded Systems. Approaches are needed for better data integration both on the syntax level (e.g. standards for domain-specific data exchange formats) and on the semantic level (e.g. approaches to ensure consistency between the data collected and to derive new information). The current integration, achieved e.g. in the BodyKom example (see section 4.2.6.2), is limited to exactly the used embedded devices and the supported scenarios. A more ambitious goal is to **integrate clinical data collected by embedded devices** (e.g. genetical, chemical, or blood data) and to perform risk predictions based on this data and data in an existing medical database. A corresponding integrated project is in the proposition phase at time of writing of this study.

Medical devices: Research into improved and new HMI

Further research into improved human-machine interfaces in medical devices is needed. The human-machine interface in medical devices is particularly critical for extracorporal devices used by patients, as these **must be easy to operate, even in emergency situations**. This is aggravated by the fact that the average user of such systems is usually not familiar with new technology [PH2004]. Going further, there is a need for research into new kinds of human-machine interfaces to improve communication capabilities for disabled people (e.g. reading and interpreting brain waves).

4.5.3 Recommendations Concerning Technology Domains

Overview

Efforts in technology domains should concentrate primarily on the following topics:

- establishing parallel design processes for embedded hardware and software,
- creating reference designs and architectures for ES components,
- overcoming technical and administrative hurdles in wireless technology,
- promoting and using Open Source software,
- pushing the use of standardized middleware platforms,
- designing appropriate high-level programming languages,
- developing appropriate tools and tool chains for ES systems engineering,
- launching knowledge transfer campaigns in testing techniques,
- putting forward industrial application of formal methods in systems engineering,
- integrating validation, verification, and testing into common design tools,
- promoting certification of components and products based on formal evaluation,
- enhancing systems engineering on nanotechnology-based ES.

4.5.3.1 Hardware

Hardware abstraction and APIs reduce time to market

In general, **hardware abstraction** and the definition of **APIs** is a key issue to enable the independent development and test of the hardware platform itself and the associated application software. **Parallel design processes** for hardware and software parts of Embedded Systems enable **shorter time to market**. Moreover, this approach improves reuse of software on different platforms and contributes to **higher design productivity**.

SoCs only economically for high volume markets

Considering development and manufacturing costs, SoCs will only be economically feasible where the **economy of scale** justifies the development of specific solutions, like in the consumer business where smaller, cheaper, and power-saving implementations are of particular importance. Mask costs as a main factor of nonrecurring engineering (NRE) costs, increasing from about $1 million (approx. € 0.8 million) for 90 nm technology to $ 3 million (approx. € 2.4 million) and higher for 65 nm technology [Mall2004] necessitate very high unit-sales in order to achieve adequate returns on invest. Therefore it is necessary to **develop solutions that can be re-used** in a number of industry domains (product line engineering, standard architectures).

Reference designs and architectures underpin cost-effective development

In order to exploit the advantages of integration an IP (intellectual property) based design style heavily relying on **pre-developed modules** is a key item. The usage of SoC platforms consisting of a balanced mix of standardized, configurable, or specifically developed IP modules is the **main trend in HW design for Embedded Systems**. Reference designs and architectures – the creation of a generic platform and a suite of abstract components – could underpin new developments in different applications.

SoCs design still behind

However, an integrated design flow for complex SoCs as a key factor for market success is still missing. Automated or semi-automated design processes that encompass **methodologies and appropriate tools** for specification, concept evaluation, design, implementation, and verification are major issues that need attention.

In this context the following topics have to be covered:

IP reuse has to be improved, standardization needed

- Procedures are needed for an efficient use of IP modules in order to reduce time to market. This includes **qualification** and **selection** of IP as well as its **integration** on different abstraction layers, especially on the system level. An **important pre-condition** in this context is **standardization**, e.g. the VCI on-chip interface from VSIA.

Holistic low power design is necessary

- Low power aware design tools have to exploit **power saving approaches** on all levels of design abstraction and overall in a SoC solution for the different IP modules that are used. This also encompasses the consideration of power consumption in CPUs when executing the application code. Power is an additional optimisation criterion that has to be taken into account when partitioning the HW and SW parts of the application and that needs to be considered explicitly in SW design. Especially for the telecommunications domain power efficient solutions are **of highest importance for market success**.

Reliability aware design is needed

- CAD tools have to consider **increasing requirements** concerning **reliability** and have to support the definition of **fault tolerant hardware architectures**. Recent quality problems with automotive electronics have demonstrated that there is currently a **deficit in the design of reliable ES**. Therefore, modelling and verification concepts from different engineering domains have to be combined to enable reliable solutions.

Overcome hurdles in wireless technology

Before the use of the wireless technologies will become widespread, there are some hurdles to overcome. First of all, **security** and **reliability** has to be **improved** and **standards** have to be **created** [DTA2004] what means that further investigation of secure and reliable wireless technology has to be supported. Also research activities in the topic of software that allows nodes to communicate with each other like one complex adaptive system as a **base for spontaneous** networks have to be supported further.

4.5.3.2 Platform Software and Compilers

Open source can help to break the monopolistic position of non-European competitors

Some fields in the sector of Embedded Systems are clearly **prevailed by non-European key players**. This is not only because the products of these non-European competitors are superior concerning innovation or technical lead, but very often because these competitors hold a highly monopolistic position in the respective domain. The idea of Open Source could be one way to weaken such monopolies. A key strength of Europe is to produce innovative products. If Europe would spread its innovative ideas and **techniques using Open Source**, many global companies could more easily access these innovative concepts and ideas and compare them with the monopolistic technologies without the risk of having to pay for the new concepts in a first step. Here, Open Source can be one way to promote the innovativeness of Europe in the embedded software sector.

A very desirable and promising position for Europe in the embedded sector is the role of a global innovation and technology provider. By being such a provider of technology, Europe would implicitly control the global supply chain for embedded products.

Increase use of standardised middleware platforms to facilitate formation of global "supply chain"

But in order for such a global supply chain to work properly it is essential that an embedded product can **seamlessly run through the supply chain** during its production process. One way to achieve this is the establishment of standards, since a market that has a high adoption of standards makes it much easier to split up the production process between multiple participants. Especially concerning the **production of embedded software**, the **establishment of standards** is essential for such a scenario. From that point of view, a major interest of Europe must become to push the use of standardised (European) middleware platforms.

Programming languages supporting efficiency, reliability, and portability

Research activities in the Embedded Systems' context should concentrate on **designing appropriate high-level programming languages**. Those programming languages should especially support reliability, efficiency, and portability aspects. **Efficiency** is the most crucial aspect where real-time aspects and costs per unit are important. Therefore especially predictable run-times require further research to improve the reliability of hard real-time systems. **Reliability** is one of the most important aspects in Embedded Systems. So a programming language should have a precise, well-defined semantics, so that appropriate verification, validation, and test techniques of programs could be used. Especially the static analysis of programs and the way to handle run-time exceptions is an important aspect. The use of Ada and the more recently refined dialect SPARK Ada [SPARK1995] shows the relevance of using an appropriate language for developing embedded software [CBC2002]. Examples in the avionic industries have revealed that Ada programmes were found to have only 10% of the residual errors found in C [CBC2004]. The use of **Java** shows already the importance of portability aspects in embedded software development. However, a programming language should be capable of isolating the machine dependent part from the machine independent part. Currently the overall figure of an ideal programming language is uncertain. But it is obvious that some aspects could be improved further. So for example efficiency aspects could be improved by integrating implementation and abstract data types. It is easier for the programmer to use abstract data types like for example floats in the early stages, but these types have to be mapped onto more efficient representations during realization in an embedded target platform. For example visual modelling tools like ASCET show how this aim could be achieved to some extent.

4.5.4 Recommendations concerning Systems Engineering

4.5.4.1 Requirements Engineering

Strengthen RE research: exploit automation, improve tracing.

Despite the rising interest in requirements engineering (RE), the **current share of research activities** related to RE and the adoption of RE techniques in industry **do not yet adequately reflect the great importance** of this activity for productivity and quality. As the state of the art, available **commercial tools do not fully exploit automation and process support capabilities**. **Requirements tracing techniques** need to be strengthened, both by commercial activity and academic research, in order to enable transparent, flexible, and consistent handling of integrated requirements and design models.

Among the RE issues that will deserve special attention in the future are **ES-specific aspects** of requirements engineering. Examples for ES-specific concerns are non-functional aspects such as timing, performance, weight, and power consumption. Both within the RE and design space, **product line engineering techniques** have the potential to leverage existing potential for reuse and increased productivity. On the commercial side, spreading of **open standards for tool exchange** will be crucial for better adoption of RE techniques in the industry

Investigate ES-specific aspects and product-line engineering techniques; improve standardization

4.5.4.2 Design

For successful application of model-based design for the ES domain, the current **challenges in modelling languages** need to be addressed: **integration of existing, heterogeneous modelling paradigms** from ICT (e.g. UML) and industrial engineering (e.g. continuous-time block diagrams) to modelling languages that are **suited for the domain by considering parallelism and non-functional properties** as first class-citizens, and have well-defined syntax and semantics.

Intensify research in integrated, well-suited, and well-defined modelling languages

Standardisation in the design field has to be pushed further in order to encourage adoption of industrial CASE tools in industry. Only by standardisation and tighter interoperability, the global value chain will become a reality with the aid of **tool chains** supporting **different development environments** and **different modelling tools**. Also the tight connection between the tools and methods used in the **design** phase and the tools used in the **implementation** phase will become very important for a seamless development process.

Push standardisation in design languages; enhance interoperability

Product-line engineering techniques are promising for improving the productivity and degree of reuse on the design level. Again, **tools, modelling languages, and standardisation** are critical aspects for the adoption of product-line engineering techniques in industry.

Strengthen adoption of product-line engineering

4.5.4.3 Implementation

A challenging long-term vision for model-based engineering is the **automation of the implementation process** for Embedded Systems based on design-level models **(correct-by-construction)**. There are several open questions with respect to **correctness and certifiability of code generators**, and **generation of distributed systems** on the basis of commercially viable platforms. These open issues must be met by a strong European research effort in this field. At the same time, by raising the level of abstraction at the platform level, the increasing adoption of platform solutions such as middleware will be an aide for introduction of correct-by-construction techniques.

Support research in correct-by-construction design and implementation

The introduction of high-level programming techniques for implementation must be flanked by the introduction of appropriate **tools** for using these techniques. With the shift from implementation towards design, the use of different programming languages, the use of possibly different software platforms, and most importantly the use of different development and modelling environments, it becomes important to intensify the research not only for **single development environments** but also for **tool chains**. Only by the use of tightly connected tool chains will it be possible to develop Embedded Systems in an efficient way [ACA2003][EAST2004][UFR2003].

Support research of appropriate implementation tools and tool chains

4.5.4.4 Validation, Verification, and Testing

A primary concern in testing Embedded Systems is **the lack of information/education** in advanced **testing techniques** and **scalability** with respect to the number of components of the system to be tested [ART2005]. It is therefore recommended to initiate well-focused **knowledge transfer campaigns**.

Knowledge transfer in advanced testing techniques

Strengthen research on effectiveness assessment of test automation techniques

Though specification-based testing is generally considered as being effective within Embedded Systems development in comparison to traditional testing techniques, there is a lack of studies that prove its effectiveness quantitatively. In [EMBT2005], a network controller for an in-car infotainment infrastructure (MOST, Media Oriented Systems Transport) was modelled and tests were derived from the model and applied to the implementation. It was observed that the use of models significantly increased the number of detected errors. It is recommended to further encourage and fund work to assess the effectiveness of different automated testing techniques.

Put forward industrial application of formal methods in Europe

Formal methods are mathematical approaches to software and system development, which support the rigorous specification, design and verification of systems. Today, the US and Europe seem to be at a similar stage in using formal methods in the development of safety-critical ES [Rei2005]. Formal verification, being today's main areas of application for formal methods, means **mathematically proving the correctness of a design** with respect to a mathematical formal specification. The design can then again be further concretised and serves as a specification for the following step ("stepwise refinement"). Formal verification is already commonly used in the development of embedded hardware for parts of the design [Har2005][FVCS1997], e.g. by Intel – triggered in particular by the Intel Pentium bug, which cost approximately US$ 500 million (approx. € 394 million). For software, the **industrial use of formal methods is still in an early phase**. Some of the few companies applying formal methods in software development are Bell Labs (for telecommunication protocol verification, see e.g. [IEFV1995]). Microsoft also conducts research in the area (for compiler and driver verification, see e.g. [SLAM2005]). While Europe has been traditionally strong in developing formal verification methods, the US are in a leading position with respect to their industrial use. It is therefore important to further put forward and fund knowledge transfer between Universities and industry in Europe such that the **results of research lead to a competitive advantage**. And there is indeed a competitive advantage of using formal methods since "the usual experience is that costs are greater and time-scales longer during the earlier stages of the life-cycle, but are **more than compensated by lower costs and shorter time-scales in the later stages** of the development" [FME2005].

Integration of validation, verification, and testing support into common design tools

Besides ease of use, an important factor determining the impact of the use of formal verification and validation on productivity is its **integration into common design tools** and processes for ES design. This requires a rigorous formalisation of their semantics. Formal verification and validation should be integrated with testing activities [AMSD2003], and processes should be developed that allow a **certification** of thus developed systems at low additional cost.

5 R&D Programmes and Initiatives for Embedded Systems

Trends and new markets are the results of research and development (R&D). R&D is defined by the Frascati manual [Fras1994] as "creative work undertaken on a systematic basis in order to increase the stock of knowledge". Comparing the R&D programmes and initiatives within Europe with the rest of the world allows to **look one step further into the future** than only comparing the trends.

Use of scoreboard indicators for comparing countries and regions

The indicators currently measured and published by the Organisation for Economic Co-operation and Development (OECD) or by the European Innovation Scoreboard (EIS) [EIS2003] do not differentiate between R&D investments in ES, but measure and compare the **economic power**, the **potential** and the **overall R&D intensities** of countries. The indicators are generally accepted by countries as a means to compare themselves with the rest of the world and to **measure the effectiveness of their policies**. In the following the indicators are used to relate them to investments in ES and to reach conclusions and recommendations for Europe.

Private investments in ES

The investments of the top 700 companies in terms of R&D investment was analysed to estimate the **worldwide investment of private industry into ES**.

Public funding for ES

In addition to the **overall public funding situation** on country level a more detailed view on the national funding programmes was made. Based on their descriptions a classification according to their relevance for ES was performed and the **budgets allocated** by the nations **within their funding programmes** for **ES was estimated** for 2003.

Recommendations for Europe

Based on the previous analysis the authors of the study propose a **set of recommendations** for public measures to support the leadership of Europe in Embedded Systems in a comprehensive form.

5.1 Key Indicators

Key indicators are GDP, GERD, patents and VC

A **good measure to compare the economic power** of a country is the gross domestic product (GDP), which is often used to give a relative comparison for the R&D expenses. Its **determination to invest in innovation** can be described by the number of scientists and the total expenses in R&D (GERD) of a country. The number of patents measures the **effectiveness of past R&D investments** while the volume of venture capital and the amount of foreign investments into a country reflect the **trust into future revenues** and **success of the innovation** in the market.

5.1.1 Gross Domestic Product (GDP)

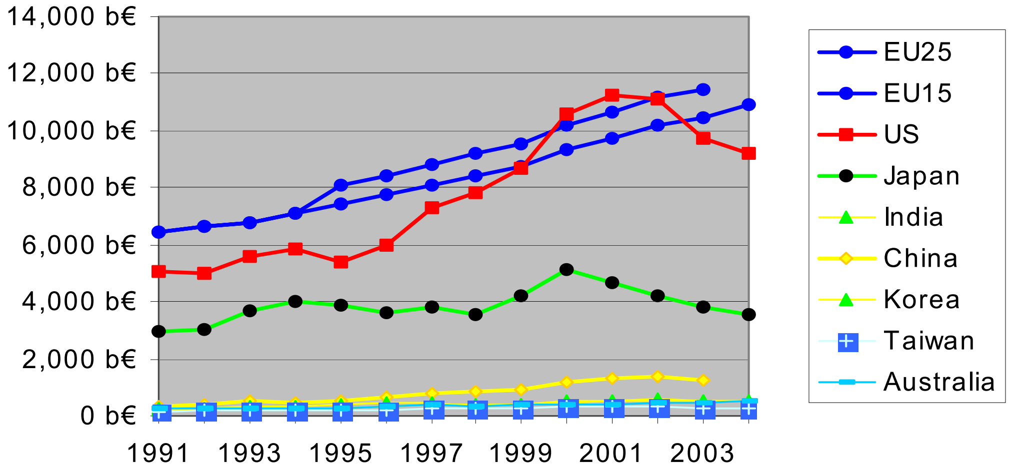
GDP = goods and services produced

The gross domestic product (GDP) of a nation is the total value of all goods and services produced within that nation within one year. It is usually taken as a measure of the **economic power** of a nation.

Europe and US are by far the most powerful economies in the world

As expected EU and US are clearly the **dominating powers** with a constantly **rising GDP**. Japan shows some fluctuations but has barely increased its GDP over the past 10 years (Figure 5-1). The data was compiled from data by OECD [ODB2005] and by converting the $ into €, using the median exchange rate of that year. The phenomenon of the sudden increase of the GDP of US between 2000 and 2002 in Figure 5-1 is an artificial effect introduced by the currency conversion.

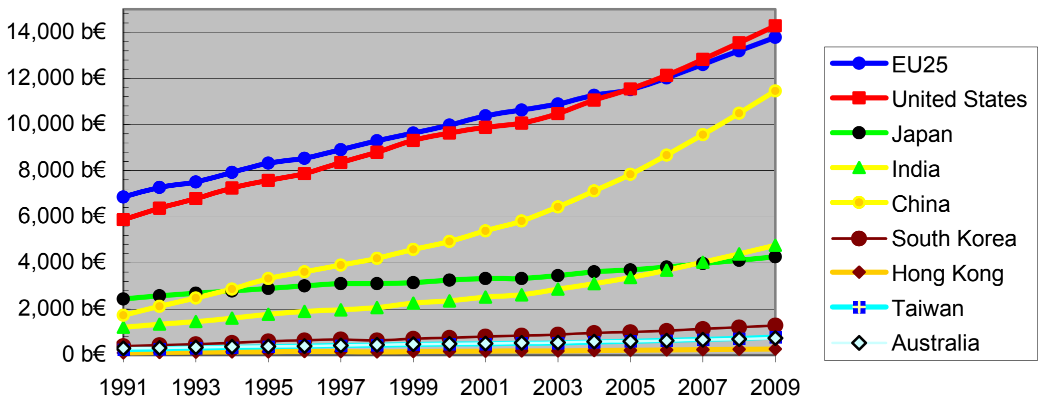
Figure 5-1: GDP of selected countries (local currency converted to €) [ODB2005]



Comparing data by purchasing power parities (PPP)

The comparison of international data is not only complicated by the exchange rate and the inflation, which varies per year and country. Even converting the currencies into so called constant values is not painting a fair picture. In essence one would compare the income of people rather than the value of their work, e.g. **with € 100,000 in Europe the salary of two person years** could be covered, **whereas in China** with the same amount **9 person years could be paid**[4]. For the international comparison of funding data all values in national currencies need to be converted into their Purchasing Power Parities (PPP). The conversion rates differ for each country and for every year. **All funding expenses in this chapter are therefore stated in PPP**.

Figure 5-2: GDP of selected countries (in billion PPP €) [EIU2005]



[4] The situation is different for market values which are traded across country and for which the set price has to be paid irrespectively of the purchasing power of the buyer.

EU and US are equal in value and growth

Figure 5-2 shows the same GDP as in Figure 5-1, but all values are expressed in their relative Purchasing Parity Power. The data shows that currency fluctuations are eliminated and that **EU and US are** not only very **similar in terms of their absolute values** but also in terms of their **growth rates**.

Recognition of economic power of China and Japan

The most dramatic effect in using PPP values is the recognition of the "real" economical power of developing countries like India or China. Thus, **China is the 3rd powerful region** after EU and US, followed by Japan and India.

Future importance of China and Japan

In Figure 5-2 the European Intelligence Unit (EIU) [EIU2005] has also extrapolated the GDP and predicts that **within 5 years** China will be **playing in the same league as EU and US** and India will be comparable to Japan due to their large growth.

Importance of GDP and how it relates to R&D for ES

Hence the GDP does not have a direct relationship with Embedded Systems, however, **countries with a large GDP tend also to high R&D investments**. It is therefore justified to limit the comparison to the countries with highest GDP. One might **also include countries with high growth rates**, because young and fast growing economies often participate of the growth of high tech products. Latter are interesting for this study since they represent the natural market for ES requiring intensive research and thus high R&D funds for ES.

Role of high-tech products in European trade

Checking the above assumption, we compare the trade of high-tech[5] products from Europe's point of view (Table 5-1). The columns on export show that **export markets** are **growing by 10-20%** and that **Europe's main market are the US**. Regarding the import of high-tech products it is surprising to notice the **high percentage of Asian countries as producers of high-tech products** and the **enormous growth rate** of 36% for China and 28% for South Korea.

High-tech Exports					High-tech Imports			
		Share of EU-15 (2000)	Average annual growth ('95-'00)				Share of EU-15 (2000)	Average annual growth ('95-'00)
1	US	27,7 %	19,6 %		1	US	35,6 %	18,1 %
2	Switzerland	7,3 %	15,2 %		2	Japan	11,8 %	11,4 %
3	Japan	4,6 %	10,8 %		3	China	6,2 %	36,4 %
4	China	3,4 %	15,9 %		4	Taiwan	6,1 %	23,0 %
5	Turkey	2,8 %	27,0 %		5	Switzerland	5,0 %	15,0 %
6	Singapore	2,8 %	16,4 %		6	Singapore	4,6 %	13,9 %
7	Hong Kong	2,6 %	8,1 %		7	South Korea	4,5 %	27,6 %
8	Canada	2,5 %	24,5 %		8	Malaysia	3,7 %	16,5 %
9	Taiwan	2,3 %	22,2 %		9	Canada	2,4 %	20,5 %
10	South Korea	2,1 %	17,9 %		10	Philippines	2,0 %	42,7 %

Table 5-1: The EU's top ten partners in high-tech trade in 2000 [S&T2003]

Production of ICT goods moves to Asia

Table 5-1 supports the overall picture of a **global shifting of the location of production** of ICT goods from Europe, Japan and the US **to Asian countries**. In 2002, the European Union, Japan and the United States accounted for **less than two-thirds** of global ICT goods production, compared with **over four-fifths in 1990** [OECDIT2004].

[5] High-Tech products are defined by OECD and listed in [S&T2003]. They include ICT hardware, avionics, instruments, electronics and selected items from chemistry, pharmacy and machinery.

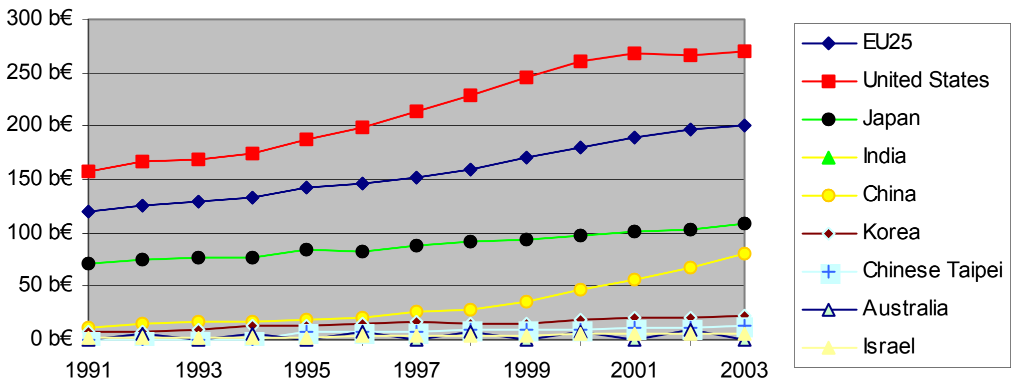
According to the evaluation of OECD there is evidence that the above change in global distribution for high-tech products is also happening for ICT-enabled services [OECDIT2004].

5.1.2 General R&D Expenses (GERD)

GERD = total R&D expenses

The Gross domestic expenditure on R&D (GERD) is the **total intramural expenditure** on R&D performed on the national territory during a given period, that includes R&D performed within the country and funded from abroad but excludes payments made abroad for R&D. As with the GDP the GERD is usually stated in terms of PPP.

Figure 5-3:Absolute R&D expenditures (GERD) in PPP€ [ODB2005]



A weakness of European investment in R&D

Figure 5-3 clearly shows that the EU-25 have been investing **much less** in R&D **than the US** for **more than two decades**. This gap is even **increasing over time**. Since US and EU have comparable GDP values the expenses in R&D can directly be compared.

Importance of R&D, especially for high-tech industry

In general, a 1% increase in the stock of R&D leads to a rise in output of 0.05-0.15% [NewE2000]. The importance of R&D is higher for products with high innovation, as is the case with ES. In 2001 the ICT sector in the private industry contributed close to 10% of OECD GDP, but spent around one-quarter of total R&D of the industry [OECDIT2004].

R&D intensity

Although the total R&D expenses of a country (GERD) are compared by using their Purchasing Power Parities exchange rate (PPP), the absolute value of the GERD still depends on the size and power of the country. Therefore for a **direct comparison of all countries** independent of size the **R&D intensity** as **a relative measure** of GERD per GDP is used.

EU is loosing ground

Comparing the R&D intensity of countries (Figure 5-4) [OECD2005] the **EU-25 devoted 1.85% of its wealth (GDP) to science and technology investment** – compared with 2.60% in the US and 3.15% in Japan and a staggering 4.92% in Israel. Perhaps the most startling comparison is with China. Although its R&D intensity at 1.3% is smaller than Europe's, China has been increasing that investment by about 10% per year. If these trends in Europe and China continue, **China will be spending the same amount of GDP on research as the EU in 2010** - about 2.2% [Slow2005]. The data for Taiwan was only available after 1995, but shows a high commitment to R&D, which was constantly increased. The strong emphasis of Taiwan and Korea to R&D is explained by their emphasis on high-tech products. Following our earlier discussion this indicates, that the Asian "tigers" are investing relative to their size large amounts into R&D for ES.

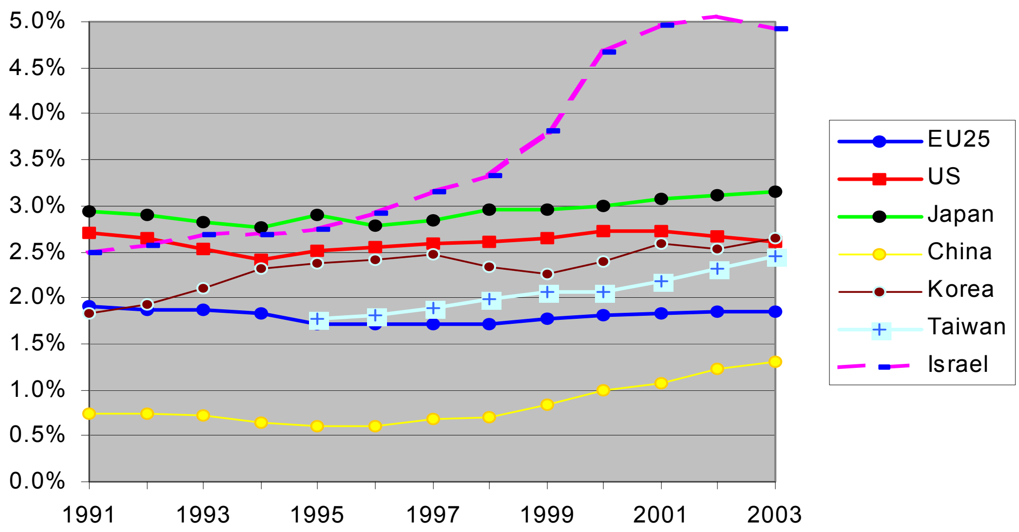


Figure 5-4: R&D intensity (GERD/GDP) [ODB2005]

The R&D intensity varies only little

With the exception of a few countries like China, Taiwan and Israel the R&D intensities of the countries is rather stable over the years. The **EU-level of R&D intensity** has been substantially **lower than in the US and in Japan for the past 20 years**. It appears that a major effort is needed to increase the R&D intensity as is planned with the **3% target** set by the EC.

R&D intensity used to define targets

Many nations across the globe have used the R&D intensity to define targets for their R&D expenditures to give a strong signal and to document the ambition of the nation.

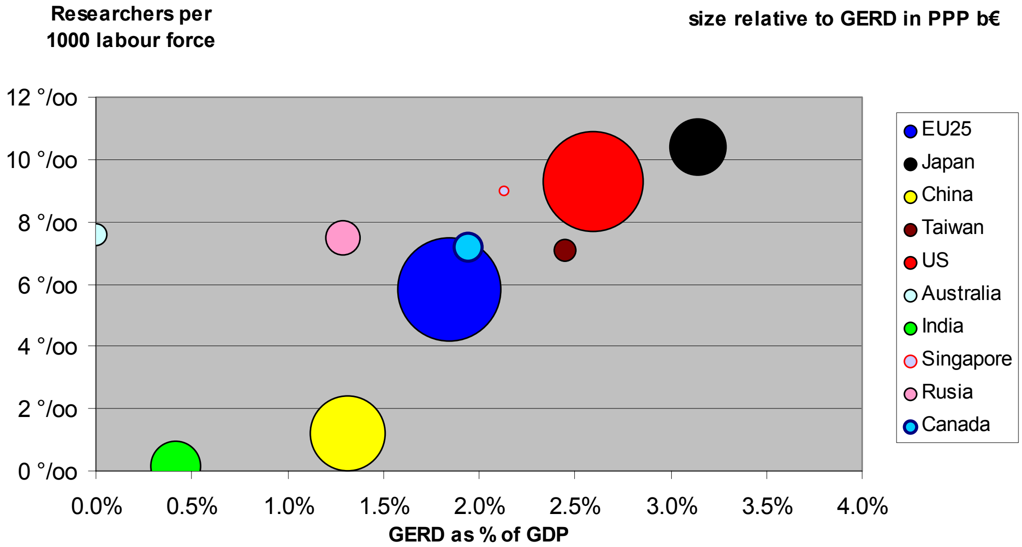
Table 5-2: R&D expenditure targets [NSC2004] with additions by [WTT2004]

Country	Target	for Year
South Korea	Increase government R&D investment to 5% of total government budget	2002
Spain	Boost R&D spending to 1.29% of gross national product (GNP)	2003
Austria	Increase share of R&D expenditure in GNP to 2.5%	2005
Norway	Improve level of R&D funding to reach at least OECD average (a rather stable 2.3%)	2005
China	Raise R&D expenditures as a percentage of GDP to 1.5%	2005
Taiwan	Raise R&D expenditures as a percentage of GDP to 3%	2006
India	Sets a target of 2% of GDP to R&D and innovation from 0.5% in 2000.	2009
Africa	Devote 1% of GDP to R&D and innovation from the current 0.3% in 2003	2009
EU	Devote 3% of GDP to R&D and innovation	2010
Canada	Advance ranking to 5th place in OECD community	2010

R&D intensity is correlated with ratio of researchers

In Figure 5-5 the **R&D intensity** is correlated with the **number of researchers per 1,000 employees** and the absolute value of **GERD** is shown by the size of the data point. In general the nations with a higher research budget (GERD) in absolute terms, also invest more in relative terms. Exceptions are countries like Taiwan, Singapore and Japan who have a high R&D intensity despite their small size in GERD and conversely China and India with a low R&D intensity relative to their sizes.

Figure 5-5: The R&D Expanses in absolute and relative terms [ODB2005]



Composition of GERD For a more detailed analysis the composition of the GERD is important. GERD can be broken down in three ways – by who conducts it, by who funds it and by its ultimate purpose.

GERD in terms of performers The detailing with respect to performers is based on the most accurate data. Within **the list of performers** the largest part by far is conducted by business enterprises (**BERD**), followed by higher education (**HERD**) and government owned R&D centres (**GOVERD**) and finally a relatively small amount of R&D conducted by other non-profit organisations.

Table 5-3: Splitting the GERD into performers and funding sources in 2003 in PPP€ [ODB2005]

R&D in 2003 expenditures		in % of GERD EU	US	JP	China	in absolute PPP€ EU	US	JP	China
Performing	GERD (total)	100%	100%	100%	100%	201 b€	271 b€	109 b€	81 b€
	BERD	63%	69%	75%	62%	128 b€	187 b€	81 b€	50 b€
	HERD	22%	17%	14%	11%	44 b€	45 b€	15 b€	8 b€
	GovERD	13%	9%	9%	27%	27 b€	25 b€	10 b€	22 b€
	other	1%	5%	2%	0%	2 b€	14 b€	2 b€	0 b€
Sourcing	GERD (total)	100%	100%	100%	100%	201 b€	271 b€	109 b€	81 b€
	private	55%	63%	75%	60%	110 b€	171 b€	81 b€	48 b€
	public	35%	31%	18%	30%	70 b€	85 b€	19 b€	24 b€
	other	11%	6%	8%	10%	22 b€	15 b€	8 b€	8 b€

GERD in terms of funding source The sources of R&D are the same entities as the performers, however, with different ratios. Direct data only exists in terms of budgets planned, which often do not match the budgets actually used. The method used by OECD is to ask each performer about the source of funding for his expenses and summing up all sources.

- Industry usually covers most of their expenses themselves. They can apply for reimbursements from tax reductions and direct funds by selected projects within public funding programmes. The part of BERD funded by government is usually larger for less developed countries.

- The costs of HERD are covered to a small extent by industry, usually due to some partnering in research projects. The main part of funding is provided by the government, however, in US the private funds raised by universities amount to 23% and in Japan they even reach 48% of HERD.
- The expenses for government owned R&D centres again are largely funded by the government in most countries.

If no data on the funding sources is available, the expenditures by industry (BERD) are a good approximation of the privately financed part of GERD.

Private R&D expenses are much lower in EU compared with US

Table 5-3 shows that **in Europe industry** is the **largest performer of R&D** with **63%,** but still low compared with US and **Japan (75%)**. A relative large part of **R&D is performed by higher education (22%)** and government owned **research institutes (13%).** As both HERD and GovERD are mainly financed by public funding, it is not surprising that the **share of private funds from industry in Europe is rather low with 55%**, compared to 63% in US and 75% in Japan. The low commitment of industry to R&D and innovation is key cause for the relative low GERD of Europe.

GERD in terms of funding target

A third **detailing of GERD** can be realised by looking at the types of funding, e.g. basic, applied or in terms of defence or civilian, **along the research sectors** or along the budget authorities of ministries. Unfortunately **there is no agreed classification scheme** of sectors or ministries. Data on R&D expenses used for a certain sector, e.g. ICT or ES, can only be estimated, by using the national classification schemes or enterprises, by translating functional roles of ministries into responsibilities for R&D research sectors and by interpreting the descriptions of funding programmes.

2003	GERD (all in PPP)	Business total R&D expenditure BERD	Business R&D expenditure in ICT BERD (ICT)	Business R&D expenditure in ES BERD (ES)	BERD (ICT) / BERD	BERD (ES) / BERD	BERD (ES) / BERD (ICT)
EU25	201.2 b€	127.5 b€	21.7 b€	12.1 b€	17%	9%	56%
US	270.8 b€	186.6 b€	68.0 b€	28.3 b€	36%	15%	42%
JP	108.5 b€	81.4 b€	24.8 b€	15.4 b€	30%	19%	62%
IN	12.0 b€						
CN	80.5 b€	50.2 b€	2.5 b€		5%		
TW	13.0 b€	8.1 b€	4.0 b€	2.9 b€	49%	36%	73%
KR	23.2 b€	17.7 b€	7.7 b€	4.7 b€	44%	27%	61%
Sum	709.2 b€	471.5 b€	128.6 b€	63.4 b€	27%	13%	49%

Table 5-4: Estimates of R&D performed by the Industry in 2003 in PPP

Industry in Europe is not investing enough in innovation, especially for ICT

The industry in **Europe is investing substantially less in R&D than industry in US** as noted in other studies [S&T2003]. The absolute difference in overall R&D expenses of almost PPP€ 70 billion as shown by GERD, are **mainly due to the low investment in innovation by industry**, a minus of almost PPP€ 60 billion in BERD. The situation is far more pronounced in the area of ICT, where the industry in Europe only invests 17% of all efforts, compared with US, where 36% is invested. It is alarming that Japan is investing more funds into ICT and ES than Europe, with only half of the total R&D budget (GERD) available.

As of 2003 ES already account for half of R&D in ICT

Embedded Systems is a part of ICT that already in 2003 made up an **average of 49% of ICT** in terms of research. The high ratio of ES may come as a surprise, however, it is explained by analysing the expenses per sector. In Table 5-6 it is shown that in Europe almost 50% of all research in ICT is performed by industries in the secondary sectors, where a high percentage of the software is embedded.

5.1.3 Human Resources in R&D

Estimated need for ES Experts

Within the ARTEMIS strategic research agenda [ASRA2005] a source of VDC was cited which estimates the worldwide population of Embedded Systems developers to be 460,000 in 2005, growing to **530,000 in 2007** at the start of FP7. Keeping the same growth rate (10 %/year), the Embedded Systems **R&D population** is therefore expected to **double over the next 10 years**.

460.000 experts worldwide in ES

The estimate of VDC is confirmed by this study. In Table 5-4 in section 5.2.2 the total expenditure by industry in R&D for Embedded Systems was estimated to PPP€ 63 billion. Assuming the costs for a researcher to be PPP€ 130 thousand, the 488,000 researchers are inferred.

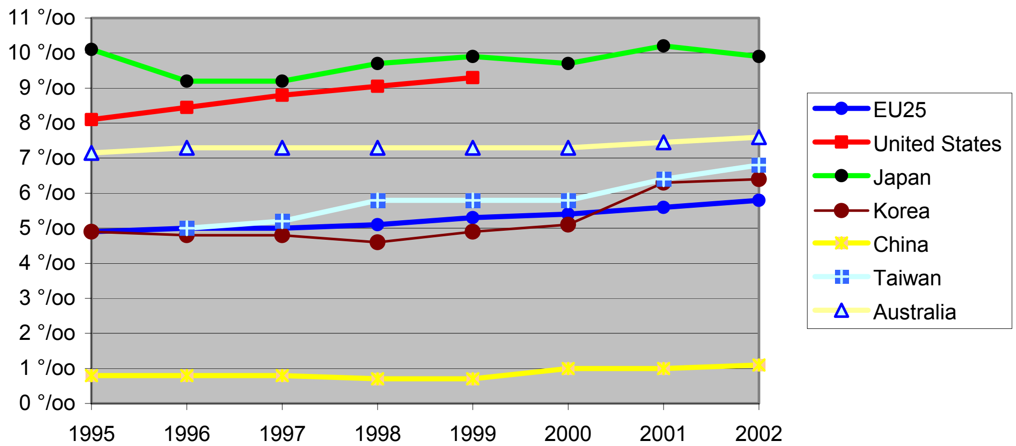
Education and training of scientist

Regarding the education and training of experts the universities in EU and US are at a par with a total of 2.1 million graduates per year each, whereas in Japan only 1.1 million students graduate per year [S&T2003].

EU is lacking highly skilled experts in the labour force

Comparing the number of researchers per 1.000 in the labour force (Figure 5-6), however, the **European Union is with 5.8 °/oo far behind** Japan (10.4 °/oo in 2003), the United States (9.2°/oo in 1999) and even below the average of all OECD countries (5.5°/oo) [EIU2005]. The percentage of Chinese researchers in the labour force is with 1.2°/oo in 2003 the lowest, but it is expected that the absolute number of **Chinese science and engineering doctorates** awarded will **surpass** those earned in the **United States** by **2010** [Chin2005].

Figure 5-6: Researchers per 1000 labour force [EIU2005]



US is attracting foreign scientists

The low ratio of researchers in the labour force in Europe is surprising. The absolute number of researchers is about 10% less in EU than in US. One possible explanation may be the **large number of foreign students in US**. It is estimated that **foreign scholars** represent **30% to 40%** of the total university researchers in **US** with a growing tendency. 17.7% of them are from China [OECDIT2004]. In 2001-2002 universities in US received 86,015 foreign scholars compared to 59,981 in 1993-1994. With **five percent of**

the world's population, the United States employs almost **a third of science and engineering researchers**.

High potential of Europe in science and engineering graduates

Keeping in mind that the fields of science and engineering are the reservoir that generates future ES experts, Europe has a high potential in fighting for leadership in ES as the numbers of science and engineering graduates from European universities are soaring. Thus, universities in the **European Union awarded 40 percent more science and engineering doctorates** in 2001 than the United States while in the US the percentage of incoming students in computer science has dropped by 60% between 2000 and 2004 and now is 70% lower than its peak in the early 1980s [Coll2005]. But Asia is also well positioned with 52% of university bachelor degrees in science and engineering in 2000, compared to a world average of 27% and 17% in the US [USLo2005].

Keeping scholars within Europe

Relying on the high potential of Europe for a large body of qualified scientists and engineers, however, is not enough. **Europe has to take measures to stop the brain drain**. Especially, Europe has to offer attractive positions to academia to stay in Europe; otherwise scholars receive the benefit of an education and leave the region. If the government does not have sufficient resources to provide new research positions, new models should be discussed where private industry can participate more in funding research work at universities.

Europe needs to stimulate the employment of scientists

The international comparison clearly shows a **weakness of qualified personnel** in **industrial research**. On the other hand the industry is well aware of the huge demand of research to cope with the new challenges of ES. Europe should welcome the opportunity of leadership and **create a positive climate to attract researchers** (see also section 6.4.2)

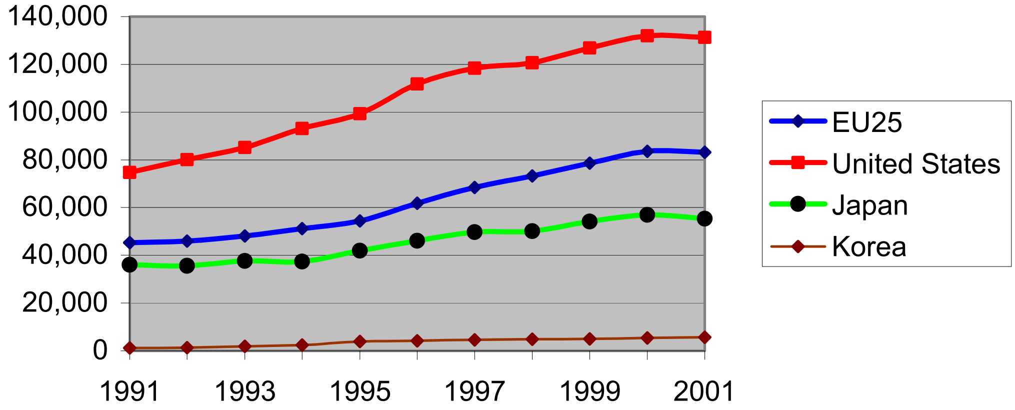
5.1.4 Patents

A good measure of success for **industrial research** is the **number of patents.**

Comparison of patents

Patents can be filed and protected locally at **national patent offices** like the United States Patent and Trademark Office (USPTO), a **regional patent office** like the European Patent Office (EPO), or **in more than one patent office**. The latter are called patent families, as the same patent is filed in different offices. Naturally inventors first tend to protect their invention in the home market and only if the invention is very important a world patent is applied for. The OECD reports statistics [OECD2005] on patents filed at EPO and patents granted by the USPTO and about patent families in EPO, USPTO and Japan. Comparing the patents filed in **EPO** is clearly putting **a bias to European companies** and using the number of patents in the triad family favours large global players. In order to compare Europe with US the sum of patents at EPO and USPTO was used in Figure 5-7 to put both countries on equal footing.

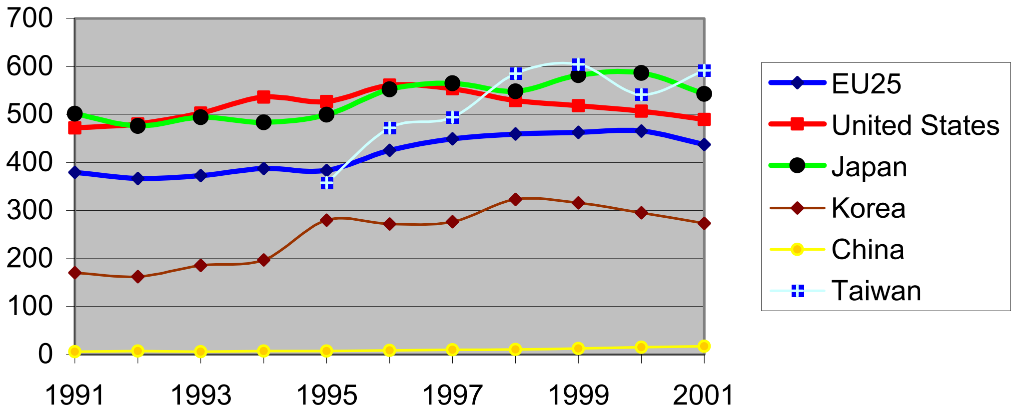
Figure 5-7:Patents applied in EPO or granted by USPTO



Effectiveness of R&D

Comparing the number of patents in EPO and USPTO per PPPb€ invested in GERD Figure 5-8 shows that in US patents are filed more easily, but **Europe is catching up**. Surprising is the high increase of effectiveness of research in Taiwan.

Figure 5-8:Number of patents in EPO and USTPO per PPPb€ of GERD



The number of patents per billion € funding was calculated using the data published by OECD [OECD2005], but should not be taken face-on. **The funding in R&D will lead to patents with a delay of some 2 to 4 years** building on accumulated knowledge of the past.

Estimating the number of ES-related patents

The number of patents in ES gives a good indication about where in the world researchers are active and secure their results with patents. However, to select patents that are relevant to ES from other patents is not an easy task, as **patents are classified according to their target sector** and **not according to the technology** used.

We used a **list of keywords** as described in the annex. Our list of relevant patents may be too narrow, but if so the error would be uniform for all countries and years of the patent. In order to apply our algorithm a different database had to be used. In the database we used, the local patents of 71 countries are included.

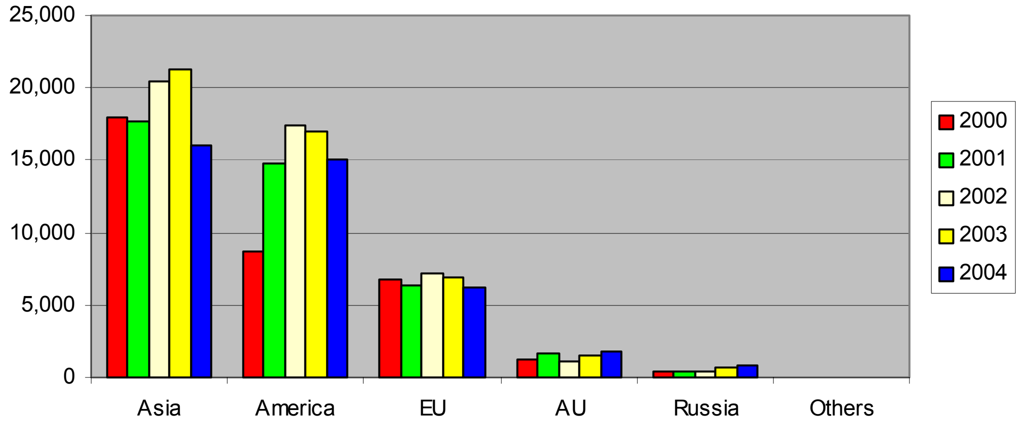


Figure 5-9: Number of patents per year and region related to ES

Comparison of patents worldwide

As can be seen in Figure 5-9 the most active regions in ES are Asia and America with **Europe possessing only half the number of patents compared to America and even less compared to Asia**. The clear dominance of Asia lies partly in the removed bias for US and EU, by using a database where national patents from Asia are included, and partly in the relative importance of high-tech and Embedded Systems in Asia.

Evolution in patents' numbers

The process for registering a patent is quite long and not all patents registered in 2004 and 2005 are already granted, the respective numbers are too low. Nevertheless it is apparent that the number of patents granted in Asia is growing in 2003, whereas **in America and Europe** the number is slightly **reduced**.

Europe shows a far less ratio of patents in ES than other regions

A direct comparison of the patents that were found in the European Online Patent Portal of esp@cenet® with the sum of patents applied by EPO and granted by USPTO is only possible for EU and US. The representation of Asian countries is far higher in the Online Portal, which collected abstracts of patents from 71 countries including from Japan. For EU and US **the ratio of patents related to ES was 6%** in 2000. The ratio was unchanged for EU in 2001, but increased for the **US to 11% in 2001**. The ratio for **Taiwan was 14% and for Korea and Japan 25%** partly due to the different databases. However, the numbers generally fit well with a reported ratio of patents related to ICT. The ratio was in 1999 for EU 25%, for US 36%, for Taiwan 42%, for Korea 54% and for Singapore 64%. The ratio was calculated by taking the sums of patents reported by OECD for patents EPO and USPTO [OECD2005].

5.1.5 Venture Capital

Venture capital for seed and start-up companies

Venture capital plays a **special role for the dynamics of the economy** as it finances risky, promising new business plans. The seed capital **for early stage** grew in Europe very dynamically from € 0,3 billion in 1995 to € 4 billion in 2001, but it was still considerably lower in absolute value than in the US (€ 2,4 billion in 1995 and € 11,2 billion in 2001). The venture capital **for the expansion phase** increased more than 10fold in the US from € 2,3 billion in 1995 to € 25,7 billion in 2001, compared with a doubling in Europe from € 2 billion to € 4 billion in the same period [S&T2003].

Share of VC for electronics in US highest

The last three columns in Figure 5-10 show the composition of the venture capital for EU, the US and Japan. In the **US** electronic companies received **65%** of the venture capital, in **EU 28%** and in **Japan 36%.** Electronic companies are the ones that make most extensive use of ES. However, Figure 5-10 also shows a huge variation of capital investments within Europe. Although some countries like Ireland support a very positive climate for companies in electronics to grow, the overall trust of investors of VC into the innovation of electronics and hence into the innovation through Embedded Systems is rather low.

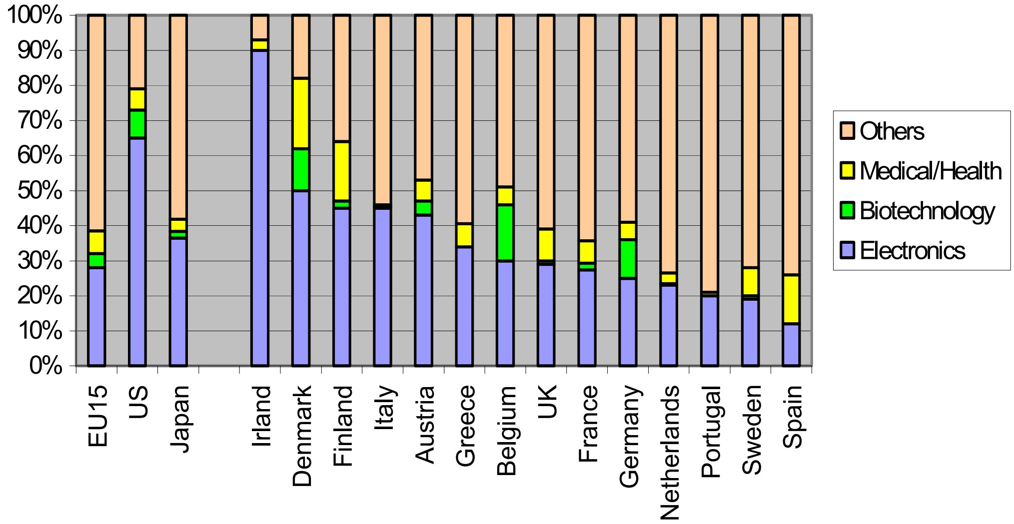


***Figure 5-10: Share (%) of high-tech sectors in equity capital investment in 2001** [S&T2003]*

New technologies need new money

The need of **venture capital** is more **important for new industries** as can be seen in other innovative sectors. In 2001 the ICT sector attracted around half of all venture capital investment through 2003, and took out close to one-fifth of all patents [OECDIT2004].

Europe's high tech industry needs an easier access to VC

The **weakness of the European venture capital market to invest into high-tech values** was recognised by the European Commission and resulted in the **Innovation 2000** initiative by the **European Investment Bank (EIB)** together with a memorandum of the EIB with the European Commission to ease the access especially of high-tech SMEs to the venture capital.

VC is not only coming from within a nation, but also through foreign investors. Figure 5-11 shows that the "tiger" countries Singapore and Hong Kong attract more than 10% of foreign investments (FDI) related to GDP, whereas all other countries attract less than 5%. Many of these investments not only use the manufacturing power of Asia, but also the cheap brain power and transfer R&D laboratories into the countries, thus **raising the level of BERD**.

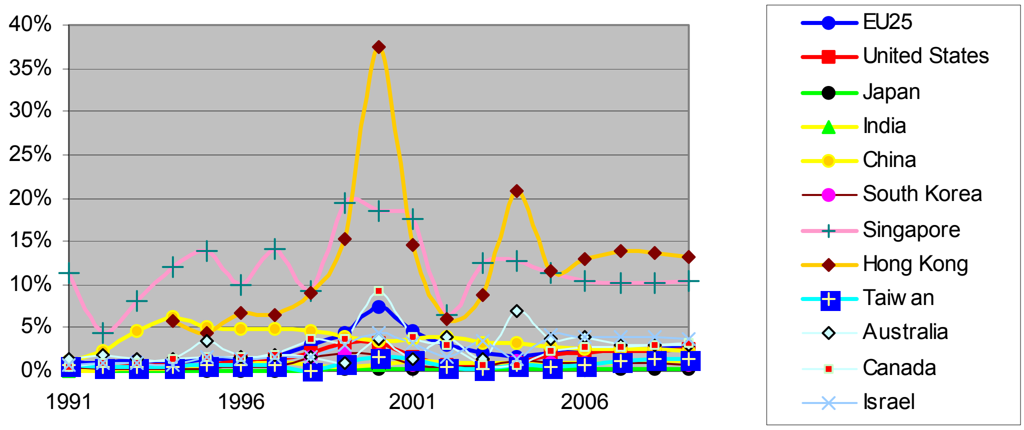


***Figure 5-11: Foreign direct investment (FDI) per GDP in %** [EIU2005]*

5.2 Business R&D Expenses

Business Enterprise Expenditures on R&D (BERD)

When trying to estimate the R&D expenditures for Embedded Systems, it is useful to look at the **private industry** as the **largest performer of research** (see section 5.1.2). For the industry R&D is an investment and hence decisions about research topics are solely made by industry, irrespectively of any reimbursement of expenses through public funds. The amount of research performed by the business enterprises (BERD) is therefore a measure of the importance of innovation for the industry and hence for the climate of innovation within a country.

Weakness of private investments is the cause for the low R&D intensity in EU

The comparison of the BERD in Figure 5-12 clearly unveils the weakness of private industry as the cause for the low R&D intensity of Europe. Whereas in US the private sector invested PPP€ 187 billion in 2003, **European industry only invested PPP€ 127 billion**, almost PPP€ 60 billion less. In other words the **private sector is responsible for 85% of the difference in the total GERD**. In terms of R&D intensity the private **industry in US invested 1.8%**, in **Japan 2.4%** and in **Israel 3.6% in R&D** compared with the industry in **Europe of only 1.2% of its GDP** [ODB2005]

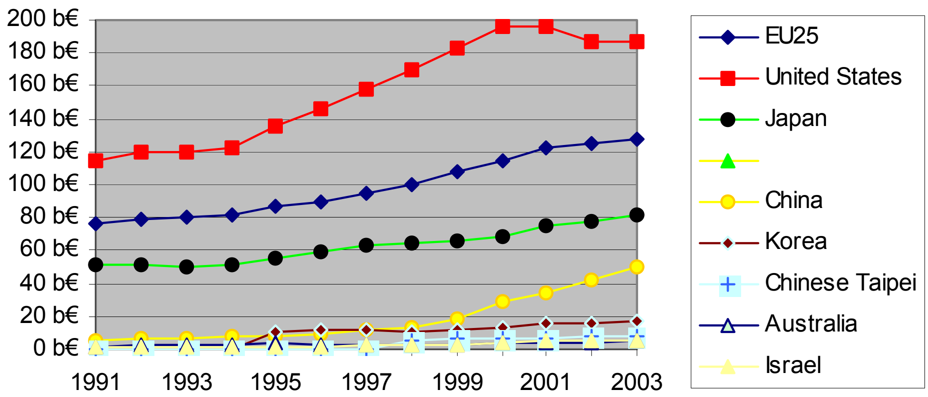


Figure 5-12: Business Expenses in R&D (BERD) in PPP in 2003 [ODB2005]

Higher rate of BERD is needed

The low rate of BERD over the past 10 years is alarming and not consistent with Europe's claim of leadership in innovation and knowledge. Another **worrying finding is that Europe was becoming a less attractive place to do research.** The data shows that between 1997 and 2002, R&D expenditure by EU companies in the US increased much faster than R&D expenditure by US companies in the EU (by 54% compared to 38%). Even the high R&D-intensity of Israel in Figure 5-4 is solely due to the high investment of the private sector. The industry in **Europe is investing even less than the OECD average. Europe urgently must increase the investment in research to keep up with the pace of innovation.**

Europe needs strong actions to change the climate in favour of R&D

Stepping-up the investments of the private industry all over Europe does **not come easy**. Europe needs clear visions, a strong motor and a combined effect that **changes the climate** in favour of research and innovation for this to happen. Europe needs once again to become proud of its virtues and to **establish centres of excellence** that are internationally recognised and inspire companies to participate and to invest in the future of innovation.

5.2.1 R&D factors for ICT and ES per sector and country

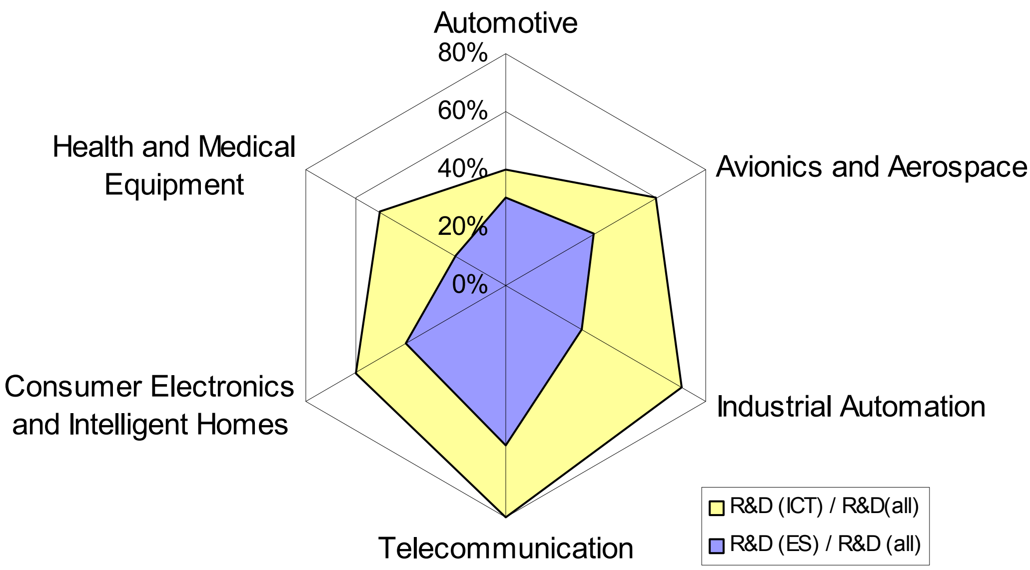
ICT is performed in the primary and secondary sectors

In chapters 3 and 4 the most relevant sectors for Embedded Systems were listed and discussed in terms of markets and R&D trends. In all of these sectors system engineering and ES were recognised as the technologies to drive and enable innovation. Traditionally the technology of systems engineering (IT) belongs to the sector of IT, e.g. is performed by the IT industry. The IT sector is therefore often referred to as the "primary" sector. However, it is obvious from chapter 4 that **R&D expenses within the "secondary" sectors** in the area of ICT and ES **are also relevant** to get a complete picture.

Estimate R&D expenses for ICT and ES

To calculate the R&D expenses by industry in the technologies or areas of ICT and ES requires first to split BERD into the "primary" sector of IT and the relevant "secondary" sectors introduced in chapters 3 and 4. Whereas all R&D expenses within IT are related to ICT, only a fraction of the R&D expenses by the secondary industries are related to ICT or ES. The share of R&D expenses in ICT and ES for 2003 is based on assumptions by the authors of this study and is depicted in Figure 5-13. The R&D factors represent the importance of research for ICT and ES in the various sectors.

Figure 5-13: R&D factors for ICT and ES estimated for secondary sectors for 2003



The meaning of R&D factor for ICT

A R&D factor for ICT for avionics, e.g. indicates that 85% of all R&D performed by all industry within the sector of avionics is related to information and communication technology (ICT). The R&D expenses for ICT must not be confused with general expenses in ICT, e.g. it does not include expenses for packaged software or hardware that was procured.

"Software" and "hardware" aspects of Embedded Systems

Embedded Systems by their nature combine "software" and "hardware" aspects into one product. For a long time the R&D efforts were dominated by the "hardware" aspects of miniaturisation of sensors and actuators. Embedded Systems had sometimes been classified as "electronics" rather than "ICT". This **study focuses on the "software" aspects of Embedded Systems**. In the sector of IT Industry companies like Microsoft, Texas Instruments and IBM are listed. Some of these companies produce IT hardware. It is assumed that all R&D performed by these companies is related to information and communication technology (ICT), but only a fraction is related to research for software embedded in their hardware.

In the sector of telecommunication, for example, the R&D factors for ICT and ES are estimated to be 80% and 55% respectively as shown in Figure 5-13. In this sector there are companies that also produce embedded hardware, nevertheless it is assumed that 80% of all R&D expenditures can be attributed to ICT and the remaining 20% are attributed to other areas, like physics or health. In a similar fashion the R&D factor for ES estimates that 55% of all R&D expenses are related to ES.

The meaning of the R&D factor for ES

Since both R&D factors refer to the total of R&D expenses their ratio of 68% in this case indicates what percentage of R&D expenditures for ICT are embedded. In other words 32% of the R&D in ICT will be spend on "non-embedded" research, like sector specific adaptations of packaged software for data storage, simulation, communication, security and control or management.

High share of ES within ICT in the secondary industry

The factors in Figure 5-13 have been estimated on basis of data provided by the questionnaire, judged by the opinion of experts and applied using a well-founded methodology. The definition of industry domains as described in chapters 3 and 4 was based on a classification by VDC [ESSM2004]. The classification by VDC had a narrow focus on Embedded Systems, which was widened for telecommunication and health to include relevant industry for ICT. When comparing R&D factors for sectors it is important to include the definition of the sector in the comparison. The Annex contains an example showing how the R&D factors stated in Figure 5-13 have to be modified in order to apply them to a different classification of sectors (see A.2.2).

R&D factors depend on definition of sectors

In interviews many experts stressed the importance of differentiation of R&D factors per country. For instance it is commonly assumed that there is more innovation and research in the automotive sector in Europe than there is in Asia.

Need for country specific R&D factors

In order to differentiate the R&D factors per country we adopted the methodological approach employed by IDATE when comparing the ICT expenditures of selected countries [IDATE2002]. IDATE related the R&D factor of ICT with its contribution to the gross domestic product (GDP).

The approach used by IDATE [IDATE2002]

Applying the approach of IDATE we used the data on the top 700 companies [Dti2004] and were able to derive the R&D intensities of each company using their expenditures in R&D per sales. The R&D intensity was then used to relate the R&D factors to the R&D intensity of each sector in every country (for more details refer to Annex A.2.2).

Dependence of R&D factors on research intensity

5.2.2 Private Business R&D for ICT and ES

To estimate the worldwide private business expenditures for R&D (BERD) related to ICT and ES the R&D expenses of the top 700 companies [Dti2004] have been extrapolated using a factor (X-factor) as calculated in Table 5-5. All R&D expenses have been carefully converted into PPP values to eliminate differences of salaries and exchange rates.

R&D expenses by the top 700 companies

Table 5-5: R&D expenses (in PPP€) of the 700 companies [Dti2004] in 2003 per country

2003 Country	Number of companies	BERD (700) in 2003 in PPP	Total BERD in 2003 in PPP [ODB2005]	X-Factor %
EU	217	57,7 b€	127,5 b€	45%
US	306	56,9 b€	186,6 b€	30%
JP	154	29,4 b€	81,4 b€	36%
CN	2	0,8 b€	50,2 b€	2%
TW	8	0,9 b€	8,1 b€	11%
KR	9	3,5 b€	17,7 b€	20%
AU	2	0,3 b€	4,3 b€	7%
Sum	698	149,5 b€	471,5 b€	32%

The X-factor is calculated by comparing the total R&D expenses of all companies, out of the 700 of one country with the R&D expenditures of all industry in that country, in other words with the BERD of that country as listed by OECD [ODB2005].

The estimates for China and Australia are disregarded as only 3 companies from these countries had been among the 700. The resulting extrapolated R&D expenses in ICT and ES are shown in Table 5-6 and as a graphic in Figure 5-14

Figure 5-14: BERD for R&D in PPP € in 2003 for ICT and ES. Data from 700 companies [Dti2004] multiplied by R&D factors and extrapolated to World

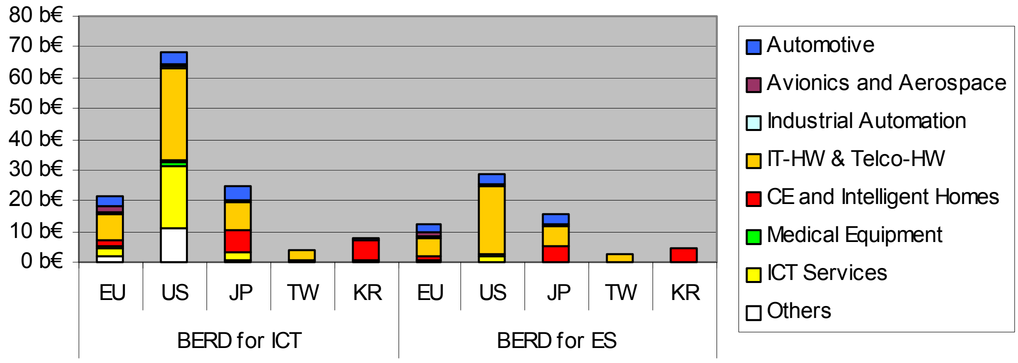


Table 5-6: BERD for R&D in PPP € in 2003 for ICT. Data from 700 companies [Dti2004] multiplied by R&D factors and extrapolated to world

2003	Business Enterprise Expenditures for R&D in ICT = BERD(ICT)									
Data in PPP€	Automotive	Avionics and Aerospace	Industrial Automation	IT-Hardware & Tele-communications	Consumer Electronics and Intelligent Homes	Health and Medical Equipment	ICT Services	Others	Total	BERD(ICT)/ BERD
EU	3.2 b€	2.1 b€	0.8 b€	8.5 b€	2.1 b€	0.3 b€	2.9 b€	1.7 b€	21.7 b€	17%
US	3.9 b€	0.7 b€	0.3 b€	29.8 b€	0.9 b€	1.2 b€	20.0 b€	11.2 b€	68.0 b€	36%
JP	4.4 b€		1.0 b€	8.8 b€	7.4 b€	0.0 b€	2.6 b€	0.5 b€	24.8 b€	30%
TW			0.0 b€	3.6 b€	0.3 b€				4.0 b€	49%
KR	0.4 b€		0.2 b€		6.3 b€		0.7 b€	0.0 b€	7.7 b€	44%
Sum	11.9 b€	2.8 b€	2.3 b€	50.7 b€	17.0 b€	1.6 b€	26.2 b€	16.1 b€	128.6 b€	27%

Europe invests 17% of BERD in R&D for ICT compared with 36% in US and 30% in Japan

Table 5-6 shows that in **Europe** the **industry only invests 17% of all R&D into areas related to ICT**, compared with an investment of **36% of all R&D in US** and a staggering **49% in Taiwan**. The latter may be too high, as only 8 companies of Taiwan had been listed among the 700. However, this in itself is an alarming signal. It shows that innovation and commitment for R&D are far higher in other regions than in Europe.

Table 5-7: BERD for R&D in PPP € in 2003 for ES. Data from 700 companies [Dti2004] multiplied by R&D factors and extrapolated to world

2003	Business Enterprise Expenditures for R&D in ES = BERD(ES)										
Data in PPP€	Automotive	Avionics and Aerospace	Industrial Automation	IT-HW & Tele-communications	Consumer Electronics and Intelligent Homes	Health and Medical Equipment	ICT Services	Others	Total	BERD (ES)/ BERD	BERD(ES / ICT)
EU	2.4 b€	1.3 b€	0.3 b€	6.3 b€	1.4 b€	0.1 b€	0.3 b€		12.1 b€	9%	56%
US	2.9 b€	0.4 b€	0.1 b€	22.0 b€	0.6 b€	0.3 b€	2.0 b€		28.3 b€	15%	42%
JP	3.3 b€		0.4 b€	6.5 b€	4.9 b€	0.0 b€	0.3 b€		15.4 b€	19%	62%
TW			0.0 b€	2.7 b€	0.2 b€				2.9 b€	36%	73%
KR	0.3 b€		0.1 b€		4.2 b€		0.1 b€		4.7 b€	27%	61%
Sum	9.0 b€	1.7 b€	1.0 b€	37.5 b€	11.3 b€	0.3 b€	2.6 b€		63.4 b€	13%	49%

Weakness of Europe for R&D in ES due to weak IT-sector

The **European weakness of R&D in ES is** mainly a **result of the weak** performance of Europe in the primary **sector of IT**. Whereas Europe had expenditures in **R&D for ES** of **PPP€ 6.3 billion in the sector of IT hardware and telecommunications**, the corresponding expenditures in **US were PPP€ 22.0 billion** (Table 5-7).

Importance of ES within ICT

Almost 50% of all **research in ICT** is already **related to Embedded Systems**. This ratio is even higher in Europe than in US, but is easily topped by the Asian countries. In absolute terms the **US is investing PPP€ 28 billion that represents more than twice** the investment of Europe. Even **Japan** is investing more **in ES** than Europe.

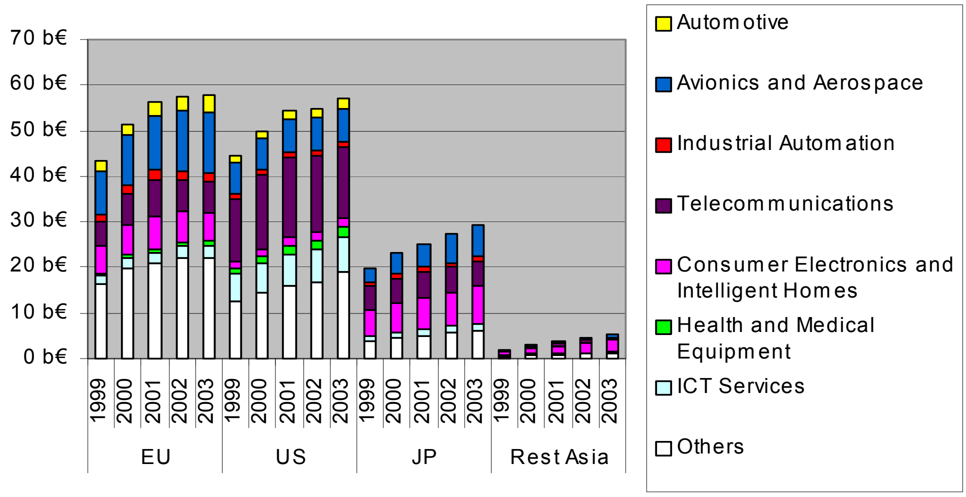


Figure 5-15: BERD of the top 700 companies in different regions (Data from the R&D scoreboard [Dti2004]) Values are market data converted to PPP €

Concentration on ES relevant industries

Europe on the other hand excels in the secondary industry in the sectors of **automotive and industrial automation. Europe is a match with US but weak compared with Asia in the sectors of aerospace and consumer electronics.** Since in the sector definition of the 700 companies the hardware for telecommunication and IT is mixed together, Europe is weak in this sector.

ES will grow faster than the market

A forecast of the synoptic view on BERD (Table 5-6) for the year 2009 was calculated by assuming a market growth of 4% per annum for GERD and BERD (Table 5-8). For Embedded Systems the growth rate for each sector was used (Table 3-3). Notably ES in the sectors of avionics, telecommunications, consumer electronics and health will grow according to the experts three times faster than the market. Since ES is contained within ICT, the ICT sector will also profit from the stronger growth in ES. If expenditures in R&D grow in a similar fashion, the gap between Europe and the rest of the world will be augmented.

Table 5-8: Forecast of the R&D performed by the Industry in 2009 in PPP

2009	GERD (all in PPP)	Business total R&D expenditure BERD	Bus. R&D expenditure in ICT BERD (ICT)	Bus. R&D expenditure in ES BERD (ES)	BERD (ICT) / BERD	BERD (ES) / BERD	BERD (ES) / BERD (ICT)
EU25	252.9 b€	163.4 b€	34.6 b€	22.9 b€	21%	14%	66%
US	350.0 b€	247.6 b€	103.2 b€	54.9 b€	42%	22%	53%
JP	142.6 b€	109.6 b€	40.7 b€	29.3 b€	37%	27%	72%
IN	14.6 b€						
CN	98.0 b€	61.1 b€	3.1 b€		5%		
TW	18.1 b€	12.2 b€	7.2 b€	5.9 b€	59%	48%	82%
KR	31.8 b€	25.0 b€	12.9 b€	9.3 b€	52%	37%	72%
Sum	908.0 b€	618.8 b€	201.6 b€	122.3 b€	33%	20%	61%

5.3 Public R&D Expenses

Rational for public spending in R&D

The rational for public spending on R&D is to act as an **incentive for the private enterprises to invest in high risk and longer term R&D** or as an incentive to invest in areas of public interest, e.g. health, ecology, or as a means to influence the market structure.

Protection vs. Publication

Contrary to the European tradition of public funding oriented towards **a rapid and wide dissemination of new achievements**, the US relied more on the incentive of intellectual property rights (IPR). The dichotomy can be applied to distinct “science” and “technology” [CHSM2002]. In modern economics both concepts are employed and the fear that public funding is only substituting private investments, as is often stated by people fighting for a free market can be put at peace **if the public funding is oriented more towards basic rather than applied research**.

Direct funding through FP

Funding programmes are a special form of direct funding, where the government publishes the budget it intends to allocate to certain research objectives. For this reason the funding programmes (FP) deserve a special attention, although the funds used may not always match the budget appropriations (GBAORD) of the government.

Direct funding by contracts

Another form of direct funding is the outsourcing of mission oriented research, which is often done by defence ministries. The R&D activities are not supported by a grant, but paid through a contract. Since the contracts are not always published, data is more difficult to obtain.

Who Pays \ Who Decides	Government	Industry
Government	Direct Funding • Funding Programmes • Procurement Indirect Funding • Institutional funding • Public VC	Indirect Funding • Tax Incentives • Public VC
Industry	Taxes	Industry R&D • mostly financed by industry • partly by VC and • partly using Funding Programmes

Figure 5-16: Taxonomy of R&D funding

It makes sense to differentiate public funding into direct and indirect funding.

While indirect funding is provided to all industry and sectors, direct funding is only available for selected projects in line with the objectives of a funding programme.

A taxonomy for the public funding is shown in Figure 5-16.

5.3.1 Overall public funding

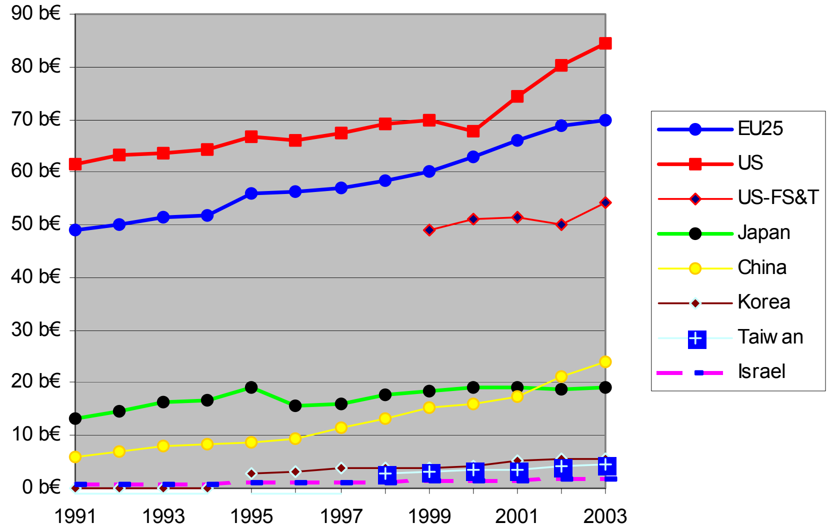
Estimating the total amount of public funding

The amount of R&D funding (GERD), which is paid by the government can be calculated by asking each performer in hindsight (BERD, HERD, GovERD see section 5.1.2) for the source of their expenditures. These figures were not available for all countries, but the sum of HERD and GovERD is a good approximation.

European public R&D funding is comparable with US

Comparing the total public funding of US and Europe in Figure 5-17 it is evident that the **US government** has traditionally **invested slightly more in R&D than Europe**, however that difference decreased up to 2000. The rise in public funding after 2000 in the US is mainly due to increased expenses for security measures against terrorism and to a smaller extent due to a rise of public funding for ICT.

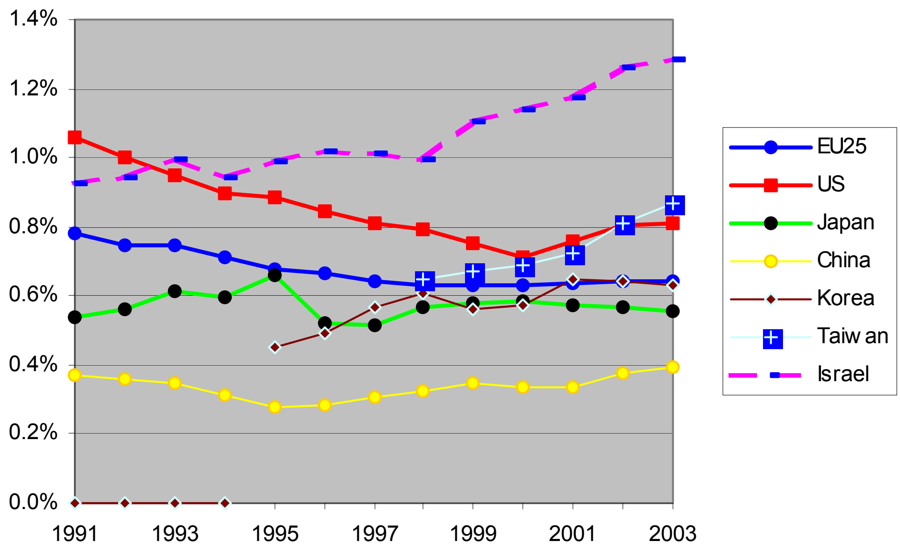
Figure 5-17: Part of GERD financed by government, calculated in PPP [ODB2005] For US corrected FS&T numbers added



Some uncertainty about the R&D data of US

The data on public R&D expenses published by the National Science Foundation (US) is somewhat misleading, as the data includes the development and testing of complex weapons [NAS1995]. In 2002 the Office of Management and Budget (OMB) introduced a new "Federal Science and Technology" (FS&T) budget to make the reports more comparable [AAAS2002]. The **correction of the federal R&D expenses of US** have not yet been included in the official OECD statistics, but have been included in Figure 5-17, as they **reverse the above statement** and would indicate that the governments of Europe invest more in R&D than US.

Figure 5-18: Public Expenses in R&D in % of GDP [ODB2005]



Comparing the R&D intensity of public funding

The public R&D intensity (public GERD in percent of GDP) allows the comparison of countries irrespective of their economic power in Figure 5-18. It shows that **Israel** is leading the lot with a **ratio of 1.3% of GDP**, followed by Taiwan and **US** with **0.8%**, and **Europe with 0.6%.** The public R&D intensity of China is still low with 0.4%, but already China has surpassed Japan in absolute terms of purchasing power parity (PPP).

The government invests less in ICT than business

In order to estimate the total public funding for ICT and ES an average R&D factor across all sectors of a country is needed. The study of Strategic Advisory Board on IT for the French Ministry [CSTI2003] estimated the R&D factors for ICT, as shown in Table 5-9. Surprisingly the **governments tend to invest much less into ICT than industry**. With the exception of Europe where only 8% of public funds were reserved for ICT, other countries had R&D factors for ICT of about 10%.

Table 5-9: Comparison of R&D factors for ICT for 2002 [CSTI2003]

2002	GERD(ICT)/ GERD	BERD(ICT) /BERD	pubGERD(ICT)/ pubGERD
EU	14.3%	17.6%	7.8%
US	22.9%	28.0%	10.4%
JP	23.7%	27.4%	10.6%
KR	41.2%	53.0%	9.9%

Estimation of the R&D factors for public funding in ES

Consequently an estimate of the public R&D expenditures for ICT and Embedded Systems can be made using the R&D factors for ICT from Table 5-9 while maintaining the same ratio of the R&D factors for ICT/ES as in the business sectors to construct the R&D factor for ES. The results are shown in Table 5-10.

Table 5-10: Estimates for the public expenditures in 2003 in PPP

2003 in PPP	Public R&D expenditure (public GERD)	Public R&D expenditure in ICT	Public R&D expenditure in ES	Pubic GERD (ES) / (ICT)	Public funding programmes in ICT	Public funding programmes in ES	Public funding (ES) / (ICT)
EU25	70.0 b€	5.5 b€	2.9 b€	53%	3.4 b€	0.4 b€	11%
US	84.5 b€	8.8 b€	3.4 b€	39%	2.5 b€	1.2 b€	48%
JP	19.2 b€	2.0 b€	1.1 b€	56%	0.6 b€	0.0 b€	5%
IN					0.9 b€	0.1 b€	7%
CN	24.1 b€				2.2 b€	0.2 b€	8%
TW	4.6 b€	0.5 b€	0.2 b€	51%	1.1 b€	0.2 b€	17%
KR	5.5 b€	0.6 b€	0.3 b€	61%			
AU	4.3 b€	0.4 b€	0.1 b€	13%	0.1 b€	0.1 b€	72%
Sum	212.2 b€	18.5 b€	8.7 b€	47%	10.7 b€	2.0 b€	19%

Budgets of funding programmes for ICT and ES

With the direct measures the governments can define their own country specific research priorities independently from market requirements. A summary of data found by categorising and counting individual funding programmes is included in Table 5-10.

Politics in Europe underestimates the importance of ES

Comparing the ratio of public funding programmes for ES within those for ICT shows that Embedded Systems are not yet recognised by politics for what they are worth to business. It is noteworthy that after a revision of their funding strategy Australia has taken on that idea and uses it to simulate innovation.

US has low budget in funding programmes for ES

The low volume of funding through public funding programmes **in US** is mainly due to the high amount of **public funding realised by the Department of Defense (DoD) using direct contracts**. As can be seen by the total amount of public funding for R&D **in ICT the US is clearly leading the world**. As **for ES** the US has surpassed Europe in their total public funding, but **the lead is still comparatively small.**

5.3.2 R&D Funding Programmes

The means of direct funding

The R&D funding programmes (FP) are a direct means for the governments to selectively support research projects on the basis of an open competition of excellence in certain research topics. For each research topic a certain budget is earmarked for R&D by the government.

Funding topics not standardised, but follow similar patterns like ICT, engineering, life science, ecology, defence etc.

A major goal pursued by governments is the fostering of technology transfer. R&D programmes are therefore often constructed to explicitly require research consortia rather than single companies. Since research follows along research topics, it is not unlikely for companies from different industry sectors to form a consortium. Hence, the notion of primary and secondary industry is irrelevant. Although there is no standard classification of research topics for all countries, research for ICT is often bundled as a special programme, which in most cases is funded by the ministry responsible for ICT. A noteworthy exception is US, where such an agency does not exist. R&D expenses are merely coordinated by a national advisory group (NITRD).

ES often hidden within ICT programmes

A classification of Embedded Systems usually does not exist, but funding is mostly hidden within ICT funding programmes. Only recently some countries like US, AU, Taiwan and in Europe have started to explicitly define funding programmes for ES.

The software aspect of ES

Unlike in the case of private R&D expenditures the funding programmes can be classified and rated individually with respect to their relevance for research in ICT or ES, without reference to the R&D factors per sector.

Categories to classify the funding programs

For the classification of the FPs the characteristics of ES were used, as described in section 2.1 and in more detail in the annex A.2.2. They cover one or more of the following research topics: fault tolerance and autonomous working, real time concerns, system engineering including the real world aspect, minimising the use of resources in terms of memory, battery and processing time, spontaneous networks of possibly large dimensions. The list of research topics related to the soft aspect is neither complete nor exclusive, hence a simplified means for estimating the percentage of embedded software. All areas were classified into one of the five categories ranges from A (no ES) to E (fully dedicated to ES).

Putting the numbers in context

In order to put the budgets of the FPs in context, for each country the total GERD and the public share of it were stated using the data from the OECD database [ODB2005] . The budget appropriations of the funding programmes for ICT and ES can be used as **new indicators for ICT and ES.**

2003 Data in PPP Country	GERD	Public GERD	HERD [6])	Funding programmes (FP) in ICT	Funding programmes (FP) in ES
EU	201.2 b€	70.0 b€	44.0 b€	3.4 b€	0.4 b€
US	270.8 b€	84.5 b€	45.4 b€	2.5 b€	1.2 b€
JP	108.5 b€	19.2 b€	14.8 b€	0.6 b€	0.0 b€
IN	12.0 b€	12.0 b€		0.9 b€	0.1 b€
CN	80.5 b€	24.1 b€	8.5 b€	2.2 b€	0.2 b€
TW	13.0 b€	4.6 b€	1.6 b€	1.1 b€	0.2 b€
AU	8.8 b€	4.3 b€	2.8 b€	0.1 b€	0.1 b€
Sum	694.8 b€	218.7 b€	117.1 b€	10.8 b€	2.1 b€

Table 5-11: Summary of GDP and R&D expenditures in 2003 in PPP for different regions. GERD and HERD from [ODB2005] the other data see annex A.2

Public ES investing in US at least three times as high as in EU

Table 5-11 gives a summary of the indicators of all selected countries in order to allow an easy comparison. It is remarkable to see the **high budget for ES in FP in US**, especially when noting that a large amount of funding is issued by direct contracts through the Department of Defense. The **published budget for ES** is already almost **three times the value for Europe.** It can be expected that the total direct funding for ES is much higher.

ES has high priority in Taiwan and China

Surprising is the large public engagement of **Taiwan** into R&D for ES. With only **5% of the GDP** compared with EU [ODB2005], the Taiwan government invests **50% of the amount of all Europe** in **ES research**. Striking is also the high importance of ES for the government of **China**, knowing the early development state of their economy.

ES has lower priority in India, Japan and Australia

For India very little data was available and the split of R&D into public and private was not possible. India, Japan and Australia are investing comparatively few resources into ES. In the case of India, however, **foreign companies have moved their R&D facilities** in **chip design** to **India** and created a very active industry. The **support** of the Indian **government** for this development consisted in the provision of **tax incentives** and in **allowing foreign companies to move into the country**.

US has low budget in funding programmes for ES

The low volume of funding through public funding programmes **in US**, as explained before is mainly due to the high amount of **public funding realised by the Department of Defense (DoD) using direct contracts**.

2003	R&D intensity GERD/GDP	BERD/ GERD	FP(ES)/ public GERD	FP(ICT)/ public GERD	FP(ES)/ FP(ICT)
Europe (EU25)	1.85%	63%	0.55%	4.9%	11%
America (US)	2.60%	69%	1.41%	2.9%	48%
Japan (JP)	3.15%	75%	0.16%	3.1%	5%
India (IN)	0.42%		0.53%	7.6%	7%
China (CN)	1.31%	62%	0.68%	9.0%	8%
Taiwan (TW)	2.45%	62%	4.08%	24.3%	17%
Australia (AU)	1.71%	44%	1.32%	1.8%	72%
Sum	2.00%	66%	0.95%	4.9%	19%

Table 5-12: Comparing budgets in 2003 in funding programmes with public GERD from [ODB2005]

[6]) HERD = Higher education Expenditures on R&D (see glossary)

Public R&D in ES/GDP ratio

In proportion of budgets in funding programmes for ES in terms of total public funding Europe (0.55%) is dominated by the US (1.41%) and Australia (1.32%). India (0.53%) and China (0.68%) follow, however, Taiwan (4.08%!) is far ahead.

Relative importance of ES in ICT research

Comparing the importance of ES relative to ICT (Figure 5-19), it seems to be obvious that **in Europe** the importance of ES has not yet been fully recognised. So, **only 11% of** the **ICT budget in funding programmes** that is only 0.55% of the public GERD is **dedicated to ES**. In **Australia**, on the contrary, the funding for ICT is relative small in comparison to the overall funding, but the importance of ES has been fully appreciated. Especially, the **ES/IT ratio** is the **highest worldwide** with about **72%**, followed by Taiwan with 17%, US with 48%. With **8% China** plays almost in the **same league as Europe** (11%).

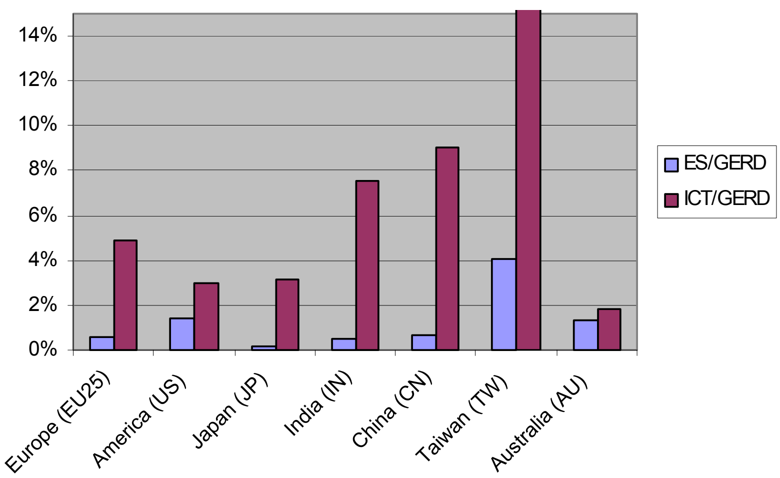
Importance of ICT by regions

Considering all of the public R&D expenditures in funding programmes in ICT **Europe** lies with **4.9%** of public GERD before the US with 2.9%, Japan with 3.1% and Australia with 1.8%. However, Taiwan (over 10% of GERD) and India (about 7.6%) and even China with 9% place a far higher importance on ICT.

Detailed analysis of nations

In the following sections the **selected regions and nations have been analysed** and their **public funding programmes** are **qualitatively described**. To ease the comparison of relative amounts of funding all nations have been summarised in the same table format. The figures on **GDP, GERD** and public funding for higher education (**HERD**) have been compiled using the data available from **OECD** [ODB2005]. The **new indicators** on **public funding for ICT** and **public funding for ES** have been compiled by **educated estimate for rating the funding programmes**, as described in the chapter and listed in the annex A.2 of the corresponding country as a synoptic view. Details on the data in the tables for each country can be found in Annex B.

Figure 5-19: Budgets in FP as percentage of public GERD for ICT and ES from 2003



5.3.2.1 Europe (EU-23)

Statistical indicators yet uncertain

Europe is a union of federated and strong member states. **Only recently** serious **efforts for a combined research area** have been started. Hence, all statistical indicators vary considerably across the nations and the interpretations of the indicators have to be done carefully.

The survey of CISTRANA

In order to estimate the public funding for ES a survey performed by the project CISTRANA [CIS2005] was used. In that survey **all nations** were asked to report the list of their **national funding programmes** in **ICT** along with a short description of the **objectives of the programmes**. Preliminary results of 23 European countries and a total of 122 funding programmes were categorised in terms of relevance for topics of Embedded Systems (see annex B.1).

Expenditures in 2003 (PPP)	Europe	%GDP	% GERD	% public GERD
GDP	10,884.5 b€	100.0%		
GERD total	201.2 b€	1.8%	100.0%	
BERD	127.5 b€	1.2%	63.4%	
GovERD	27.1 b€	0.2%	13.5%	
HERD	44.0 b€	0.4%	21.9%	
pubGERD	70.0 b€	0.6%	34.8%	100.0%
FP(ICT)	3.4 b€	0.0%	1.7%	4.9%
FP(ES)	0.4 b€	0.0%	0.2%	0.5%

Table 5-13: Summary of expenditures for Europe in 2003. Values in PPP

5.3.2.2 United States of America

The US is the **most powerful economy** and is the **technology leader for ICT**. The Network and IT R&D Programme ([NITRD2005]) is a consolidated multi-agency research programme with a budget of PPP€ 2.2 billion for networks and IT. The NITRD is explicitly researching **large networks of distributed components**, the **software design of dependable multidisciplinary systems** and the **high confidence software systems**.

The soft aspects of Embedded Systems are interesting for the defence agency, the national security, and the health department for the use of telemedicine and for the department of energy for the network management.

Expenditures in 2003 (PPP)	US	%GDP	% of GERD	% of public GERD
GDP	10,422.4 b€	100.0%		
GERD total	270.8 b€	2.6%	100.0%	
BERD	186.6 b€	1.8%	68.9%	
GovERD	24.5 b€	0.2%	9.0%	
HERD	45.4 b€	0.4%	16.8%	
pubGERD	84.5 b€	0.8%	31.2%	100.0%
FP(ICT)	2.5 b€	0.0%	0.9%	2.9%
FP(ES)	1.2 b€	0.0%	0.4%	1.4%

Table 5-14: Summary of expenditures for US in 2003. Values in PPP

The US government support for research (public GERD) was more or less **constant of around PPP€ 50 billion** from **1985** to **2000**, whereas the industry investment in R&D (BERD) was tripled in the same period from **PPP€ 48 billion** to **PPP€ 154 billion** [ODB2005].

It is notable that almost **a quarter of the total GERD** is reserved for **higher education**, **strengthening the basic research of the universities**. Compared with the HERD the funding for ICT is rather low, however, a large percentage of nearly 30% of it is reserved for ES (see annex B.2).

5.3.2.3 Japan

The vision of Japan

Japan is driven by the vision to become a nation that creates wisdom by fostering science, maintains vitality for sustainable economic growth and uses the wisdom for securing the safety and quality of life [MEXT2005].

Table 5-15: Summary of expenditures for Japan in 2003. Values in PPP

Expenditures in 2003 (PPP)	Japan	%GDP	% of GERD	% of public GERD
GDP	3,449.6 b€	100.0%		
GERD total	108.5 b€	3.1%	100.0%	
BERD	81.4 b€	2.4%	75.0%	
GovERD	10.1 b€	0.3%	9.3%	
HERD	14.8 b€	0.4%	13.7%	
pubGERD	19.2 b€	0.6%	17.7%	100.0%
FP(ICT)	0.6 b€	0.0%	0.6%	3.1%
FP(ES)	0.0 b€	0.0%	0.0%	0.2%

The research priorities

For the direct funding programme Japan has defined **8 areas of importance** for basic research: life science, ICT, environment research, nanotechnology, nuclear energy science, manufacturing technology, infrastructure and frontiers in space & ocean; the first four being of high priority.

Research topics related to ES

Within the ICT the research topic about **advanced networks** is relevant for the expected large number of connected ES. Through this funding the technologies that provide the foundations to support a safe ubiquitous network society, such as next-generation electronic tags, shall be created. A second research area related to ES can be seen as part of the **improvement of the manufacturing technology** and to some minor degree within the **space programme** (see annex B.3).

Indirect measures

Japan has formulated a number of indirect measures in public funding to **counteract the brain drain**. The basic plan for the next period (2006-2010) includes "**training** and ensuring sufficient numbers of science and technology-related human resources," "construction of a creative and **high-quality research and development system** including reform of universities," "promotion of **basic research**," "strategic **prioritisation of** science and **technology** corresponding to national and social issues, such as priority fields and interdisciplinary fields, critical technologies, etc.," "**creation of innovation** through a virtuous cycle of wisdom creation and utilization, for example the promotion of **cooperation between industry, academia, and government**," and "development of the foundations to promote science and technology, for example the development of facilities at universities" [S&TJP2003].

Public funding for ES

The total budget for competitive funding (FP) was about PPP€ 2.4 billion in 2003 the rest was invested into the infrastructure [MEXT2005]. In 2002 the number of electrical & telecommunications engineers accounted for 24% of the total researchers [MEXT2005]. Since these researchers had to compete with their fellow researchers for the competitive funding, one can estimate the amount **in the order of PPP€ 600 million** available for funding of ICT. Given the low visibility of ES in the research agenda of Japan, the programme is rated as category B and funds for ES will only be a small proportion of 5 %, or PPP€ 30 million.

5.3.2.4 India

ICT in India

Today, researchers in India, including topics that are „hot“ elsewhere such as multi-media, workflow automation, virtual reality, and hardware-software co-design, cover **almost all areas of computer science research**. However, most of the reminder of research is found wanting in quality [Rama1995].

Table 5-16: Summary of expenditures for India in 2003. Values in PPP

Expenditures in 2003 (PPP)	India	%GDP	% of GERD	% of public GERD
GDP	2,872.5 b€	100.0%		
GERD total	12.0 b€	0.4%	100.0%	
BERD				
GovERD				
HERD				
pubGERD	12.0 b€	0.4%	100.0%	100.0%
FP(ICT)	0.9 b€	0.0%	7.6%	7.6%
FP(ES)	0.1 b€	0.0%	0.5%	0.5%

Offshore business in India

India's **software exports** grew from practically nothing in the late 1980s to **$9 billion (approx. € 7 billion)** last year (**2004**) — up 26 percent over 2002 [Brier2005]. The figures reported have to be questioned, as the official report by the Indian Ministries on their export does not match with summed import figures by OECD. Nevertheless it is without doubt that India is now home to some of the **world's best software consultants**, providing offshore support to organisations abroad, in areas such as **operating systems**, database management systems, and **graphical user interfaces**.

Role of ES in the offshore business in India

NASSCOM is the Indian National Association of Software and Service Companies published in 2002 that the ES market, a key driver of the Indian R&D off-shoring engine, accounted for around **$25 billion** (approx. € 20 billion) in revenues at a global level and that Indian exports of ES and software touched $1.6 billion (approx. € 1.3 billion) in 2003-04, a significant jump of 44 percent over 2002-03 [NAS2002].

ES companies in India

Well-reputed global companies such as **Samsung, Texas Instruments, Delphi**, among others are already sourcing a part of their embedded system requirements from India. Offshore Embedded Systems development is taking place at the captive R&D facilities of international majors such as **Motorola, Intel, Cadence, Analog Devices, National Semiconductor** among others [NAS2002].

From offshore to genuine R&D

Lately India is progressing from offshore to genuine R&D and is increasingly perceived as the **chip design powerhouse of the world**. "India is creating an environment of chip design activity that **over the next decade will rival the best in the world**," says Vinod Dham, formerly of Intel who is considered to be the father of the Pentium chip. Dham now funds Indian chip design companies [NAS2005].

Public funding situation in India

Compared with the fast track progress in business promoted actively by NASSCOM the indigenous funding situation in India is **progressing only very slowly towards ICT and ES**. Other priorities are more pressing to ensure the raise in the standard of living [S&TIN2003].

Overall R&D in India

India's world share of GERD actually dropped slightly between 1997 and 2000, from 2.0 percent to 1.6 percent. National investment in R&D (up from just under PPP€ 11 billion to PPP€ 12 billion) has failed to keep pace with healthy growth in GDP (from PPP€ 1539 billion to PPP€ 2200 billion). However, this trend may be reversed in the next few years.

The government of India has since bolstered research spending and **plans further increases** [WTT2004].

Funding programme by Ministry of IT

The annual report of the Ministry of IT [ITIN2005] is listing the funding programmes, the funding for infrastructure and the measures to provide human resources for ICT. The funding that is specifically allocated for Embedded Systems comprises **12% of the ICT budget** of PPP€ 900 million (see annex B.4).:

- *Convergence communications & broadband technologies (CCiBT)*
  funds research in **broadband wireless access technologies** and **hybrid secure networks**
- *IT Act / Certification & Network Security*
  to provide frameworks for **managing enterprise network security** for embedded devices and systems
- *Special Manpower for VLSI Design*
  a **training centre** started in 1998 for VLSI design
- *Semiconductor Complex Limited (SCL)*
  known chip design, development and manufacturing company

5.3.2.5 China

China's industrial development has been based on the abundant low cost labour force. Many consumer electronics products are manufactured in China, but rarely they contain advanced technology originating in China.

Table 5-17: Summary of expenditures for China in 2003. Values in PPP

Expenditures in 2003 (PPP)	China	%GDP	% of GERD	% of public GERD
GDP	6,132.9 b€	100.0%		
GERD total	80.5 b€	1.3%	100.0%	
BERD	50.2 b€	0.8%	62.4%	
GovERD	21.8 b€	0.4%	27.1%	
HERD	8.5 b€	0.1%	10.5%	
pubGERD	24.1 b€	0.4%	29.9%	100.0%
FP(ICT)	2.2 b€	0.0%	2.7%	9.0%
FP(ES)	0.2 b€	0.0%	0.2%	0.7%

Lack of raw data, only very rough estimation possible

China managed to double the GDP from 1996 to 2003 by investing in the infrastructure, by upgrading the education system and by adopting the technology. Since the research programmes are valid for 15 years with an update every 5 years, the programmes are not very detailed in the budget allocation and **neither the public funding for ICT nor for Embedded Systems can be deduced directly**. However, assuming that currently 98% of the research is done by the national laboratories one could further assume an **even split** of the funding. Out of 154 laboratories listed by the Ministry of Science and Technology 16 (10%) were in the area of ICT and 6 laboratories (4%) had a special focus of functionality relevant to Embedded Systems. Since these laboratories were not exclusively focused on ES a rating of category C with 20% the effort for ES would lead to **around PPP€ 163 million**, knowing that this estimation is rather uncertain and knowing that this number will be rising in the future as China is **putting more emphasis** on the new technologies (see annex B.5).

China will move to brainpower industries

Due to its family planning programme, China will rapidly become an aging society and **median age of the population will climb** from 32 in 2003 to around 45 in 2040

[Sig2004]. Hence China needs to further develop from labour-intensive industry to a brainpower industry. China is therefore **shaping regional competence blocks** like the Pearl River Delta with Guangzhou and Shenzhen near Hong Kong or the Yangtze River Delta near Shanghai to expand and exploit business ideas.

Ongoing development in direction of own technology

China has to establish its own technology in order to reduce licence fees to foreign high-tech companies. The announcement of the Chinese **WAPI** standard in December 2003 caused serious discussions with the US government and the run for a **Linux** version for Chinese language will reduce the market dominance of Microsoft.

Competitively financed research system

With the funding of the **National Natural Science Foundation** of China (**NSFC**) in 1985 a new competitively financed research system was superimposed onto the old Soviet-type scientific and university system. In the new system allocation of funding and promotions are heavily dependent on the output of the scientists, e.g. the number of publications and has attracted many Chinese scientists to return to China.

Fast growing R&D expenditures

For a long time private and public GERD were both around 0.3% of the GDP, but **BERD had a growth rate of 50% in the last three years** and reached 0.82% in 2003. Although the combined private and public spending (GERD) is still rather low at 1.29% of GDP in 2002 it still positions **China as the world's third-largest investor in R&D** after US and Japan [ODB2005].

China has become a competitor to developed regions

As a consequence **industrialised countries** no longer **see China** as a challenger from the developing world but increasingly **as a competitor**. It appears that the high-wage **tiger countries** around China, Hong Kong, Singapore, South Korea and Taiwan, have found a way to collaborate. They do outsource manufacturing to China, but at the same time upgrade their own manufacturing to higher value-added and participate on the **growing domestic market**.

A region of high potentials

Though only 5 percent of China's total R&D spending was devoted to basic research in 2001, the Chinese government wants to increase that percentage at least threefold by 2020 [Chin2005]. China is already the world's leading television manufacturer, as well as the world's largest mobile phone market and second-largest PC market.

5.3.2.6 Taiwan

Taiwan is **comparable to Australia** in population, GDP in PPP and number of Internet users. **Compared with Europe or the US it has only 5% of their GDP**.

The vision of Taiwan

The government seeks to realise the vision of Taiwan as a “Green Silicon Island” with a humane outlook, a core value of sustainable development, and balanced concern for the environment [YBTW2004]. The vision of Taiwan is to **establish a world-class academic environment for a high-tech industry** with a target of 60% of the GDP in the next decade. The vision will **transform** Taiwan into a **knowledge society** with major improvements in health, housing, transportation and environment.

Strong technology focus

The focus on Embedded Systems and micro-electromechanical technology is apparent in the **ratio of public funding for ES** compared with the total public funding for R&D of **6%,** which purchasing parity power equals **80% of the expenses of the European Commission for ES**.

Public funding grouping

The public funding can be split into three groupings: the **academic research** in national labs and universities, the **general funding** and a **special program for Science and Technology** (see annex B.6).

Table 5-18: Summary of expenditures for Taiwan in 2003. Values in PPP

Expenditures in 2003 (PPP)	Taiwan	%GDP	% of GERD	% of public GERD
GDP	531.7 b€	100.0%		
GERD total	13.0 b€	2.4%	100.0%	
BERD	8.1 b€	1.5%	62.5%	
GovERD	3.2 b€	0.6%	24.9%	
HERD	1.6 b€	0.3%	12.0%	
pubGERD	4.6 b€	0.9%	35.5%	100.0%
FP(ICT)	1.1 b€	0.2%	8.6%	24.3%
FP(ES)	0.2 b€	0.0%	1.4%	4.1%

High tech strategies of Taiwan

The strategies of the government of Taiwan are

- to train and recruit **skilled researchers**,
- to stimulate **private investment in R&D to grow** at a ratio of 7:3 with respect to public spending,
- to encourage interdisciplinary research in a number of **key technology** areas of ES:
  - **micro-electro-mechanical technology** especially for precision machinery and avionics, telecommunications,
  - **advanced materials** for biomedical and life science, and
  - environmental technology using **remote sensing technology**.

Support by raising VC

The government of Taiwan provided **PPP€ 2.7 billion in R&D loans** and raised **PPP€ 5.4 billion in venture capital** (VC). The venture capital available on high-tech ventures amounts to **1% of the GDP** and is compared with the **OECD average of 0.2%** very high.

5.3.2.7 Australia

Australian investment program

The Australian Government announced in 2001 an action plan "Backing Australia's Ability" to **increase investment in science and innovation** with a 10-year commitment of PPP€ 5.9 billion.

The action plan aimed at **raising the private investment in R&D** (BERD), which had be traditionally rather low by 0.72% of the GDP in 2002 compared with an OECD average of 1.53% of GDP. Within 2 years a **raise of the BERD by 3.6%** and an increase in HERD by 23% was noted in the official innovation report [AUInno2005].

Research priorities in Australia

The national research priorities are focused on sustainable environment, health, and safeguards against diseases and attacks and to a rather small extent the exploration of frontier technologies. In the later the concrete measures supported research, commercialisation of solutions, linkage with partners outside Australia and education.

Small investment, strongly focussed

Categorising the funding programmes with respect to their relevance to ES (see annex B.7) shows that **only PPP€ 56 million** were invested into research for ES. The bulk of the investment was handled by the **National ICT Australia Limited** (NICTA) a union of national laboratories with a strong focus on software engineering for dependable, intelligent systems and human-machine interaction. Even though the absolute amount of public GERD for ES is not very impressing it represents almost **72% of the public GERD for ICT** and 1,2% of total public GERD. Only Taiwan spends a higher ratio of its total public R&D funding into ES (3,9%) (see annex B.7)

Expenditures in 2003 (PPP)	Australia	%GDP	% of GERD	% of public GERD
GDP	573.0 b€	100.0%		
GERD total	9.8 b€	1.7%	100.0%	
BERD	4.9 b€	0.8%	49.6%	
GovERD	1.8 b€	0.3%	18.4%	
HERD	2.8 b€	0.5%	29.0%	
pubGERD	4.3 b€	0.7%	43.5%	100.0%
FP(ICT)	0.1 b€	0.0%	0.8%	1.8%
FP(ES)	0.1 b€	0.0%	0.6%	1.3%

Table 5-19: Summary of expenditures for Australia in 2003. Values in PPP

5.4 Recommendations

Challenges by ES technology – enterprises don't keep pace

Embedded Systems is the key to innovation and innovation is the key to growth as it provides the competitive edge to products. Hence it is in the natural interest of all enterprises to invest in R&D for innovation. However, with ES the enterprises no longer are able to keep pace with the **high speed of change**. New hardware for ES, although smaller in size, offers dazzling new functionality with each generation and the complexity enters a new dimension. Soon all ES-devices will be able to spontaneously form networks. New products will be programmed and updated remotely rather than produced and delivered.

Summary

To meet the new requirements it is recommended the political stakeholders should launch a bundle of activities flanking the efforts of private industry, in particular:

- applying higher public investment in R&D on ES technology,
- stimulating private investment in this sector,
- supporting the emergence of a new supply industry based on SMEs,
- broadening education and knowledge transfer in ES topics,
- attracting scientists from abroad to work in ES development in Europe,
- stimulating patents and publications,
- providing a favourable climate for investors,
- supporting technology transfer, e.g. in centres of excellence (see section 6.3),
- strictly monitoring the development in the ES area and the impact of the measures mentioned above.

5.4.1 Step-up Investment in R&D

Private industry need to double R&D investments (BERD)

Huge efforts in R&D are needed by the private industry. Currently private industry in Europe is investing with 1.2% of GDP far less than other countries like Israel with 3.7%, Japan with 2.3% and US with 1.8% [OECD2005].

Active engagement by the government to trigger private funds

As a consequence **Europe would need to stimulate further private investment in R&D**. Australia had faced an even grimmer outlook in 1996 and decided to upgrade the public investment in order to trigger private funds. The initiative "Backing Australia's Ability" has already shown good results. In Europe such common efforts of private industry and government will become crucial for keeping technological leadership in ES and redressing the present imbalance in productivity growth compared with US and Asia.

Potential of ES

As ES is penetrating almost all areas, the use of ES opens the field for innovation on a much larger scale than it was possible in the past. ES can become **the key engine of future growth and innovation in Europe**, if the entry barrier for SMEs is low by providing common tools, architectures and standards that can be applied and used across sectors.

Increased funding of basic research

As ES is still in its infancy a major and coordinated effort is needed in basic research for **common techniques, tools, architectures and designs** that can be used by all sectors and are needed to satisfy the stringent requirements. The basic research following a common research agenda is maximising the synergy by **focussing research and development**. It counteracts current fragmentation.

Evaluation of funding programmes

An online consultation [ECCom2004] of over 1700 organisations performed in 2004 gave a strong support of over **97% in favour of direct funding** of research on the European level. The European Commission is constantly evaluating their funding programmes and develops new instruments to **overcome** the recognised **disadvantages**, like under-representation of SMEs, the high number of rejected proposals and the high administrative effort.

A new supply industry will be created favouring the existence of SME

Once the basic technologies are available, innovation is created by embedded software and by applying the technology to other fields. In the automotive industry a similar trend resulted in a rich supply industry, where SMEs thrived and competed within a managed market. A **similar development, but on a much larger scale**, can be foreseen for Embedded Systems. SMEs may provide software for ES **across all domains**.

Using the diversity of Europe

The scale of the new supply industry will be much larger, as it is already apparent that sectors are growing together. The diversity of Europe in industry can become **a major asset**. Innovative technology of ES can be used throughout the sectors and **make Europe a leader in innovation**. The diversity of Europe across nations puts Europe in a similar position as Asia, where "tiger countries" were used to gear-up the economy of the whole region.

Industry needs to be more active in innovation

As seen in the analysis of the total R&D expenses (GERD) Europe needs to change its climate in favour of innovation. **Without the industry** to step-up their engagement in research for ES **negative effects**, like lack of innovation and competitiveness, **will slow down the economy** in Europe in the future.

5.4.2 Increasing the Ratio of Researchers

Europe needs to increase its share of researchers

The data on the **share of researchers in the labour force** showed the US in the lead along with Japan. In order to have the same proportion of researchers in the labour force as the high performing US, the EU needs an **additional 835,000 researchers** given the current growth rate in US. This is equivalent to an annual growth rate of 6%. Such a growth rate is way above the average annual growth rate of 2.6% achieved by the EU during the 1990s. Thus these figures suggest that the EU has a long way to go if it is to match US efforts and even further to catch up with Japan [S&T2003]. EC Commissioner for Research Philippe Busquin calls this **an alarming conclusion** [ELS2001].

Only action on three fronts can promise success

To keep pace with this dynamic growth Europe has to be active in three areas simultaneously:

(1) The **education system has to be upgraded** to cope with the specific needs for ES.

(2) A **technology transfer scheme has to be introduced** to train experts in the multidisciplinary way needed for ES.

(3) The **brain drain has to be reversed** and foreign experts have to be attracted to Europe.

Consequences for education policy

Regarding the multidisciplinary character of the ES domain, it is necessary that a **technological transfer** between these different disciplines occurs already **at university level.** This can be achieved by **special Embedded Systems courses** or by **institutes**, which focus on the field of ES in particular. Another important aspect is the education **at school**, where the technical and mathematical comprehension has to be encouraged. Fragmented knowledge needs to be put together and taught in new courses at university.

Programme for re-training and knowledge transfer urgently needed

Given the **tight time frame** Europe cannot wait for the measures in education to show effects. From the idea of a graduate course in university to the provision of a large number of graduate experts a time span in the order of **7 to 10 years** is needed. To provide the necessary experts sooner, an organised knowledge transfer to **re-school and train experts** to become certified developers for ES is needed.

Europe has to stop the brain drain

The low share of researchers in the labour force shows that Europe has to reverse the brain drain and **become a place of attraction** instead. Today many scholars have to search for academic employment in universities elsewhere in the world. Europe has to make an effort to **re-emphasise the value of research** in universities. **New financial models** need to be discussed allowing a co-financing of the research activities by private industry. At the same time the **private industry** has to **increase their research** in Europe and to actively support Europe's leadership.

European S&T report

The loss of human resources puts a strain on national education systems and at the same time strengthens knowledge intensive industry elsewhere. A list of "**supportive factors in the mobility of highly skilled workers**" to attract foreign experts is given in the Third European Report on S&T Indicators [S&T2003].

5.4.3 Stimulate Patents

ES requires basic research

In the past the **European Commission was over-emphasising the importance of applied research** in order to directly increase the competitiveness of European companies. As a consequence the quality of basic research at university was lowered by sheer lack of volume. In order to tackle the challenges posed by the field of **Embedded Systems**, however, **requires a strong and sound basic research**, as many aspects of system engineering have to be radically improved.

Importance of dedicated research centres

The role of universities as centres of free exchange of knowledge financed by public money is traditionally at odds with centres of research financed by private money and obliged to file patents to assure their long-term sustainability. Rather than mixing research and teaching, one might think about establishing dedicated centres for research apart from universities. Comparing Europe with other countries it is remarkable, that R&D performed by private non-profit organisations amounts to **less than 1% of GERD** compared with 5% in US and over 2% in Japan (see Table 5-3).

Emphasis on importance of IPR for ES

As production costs are basically reduced to development costs the protection of **intellectual property rights** becomes important. Since ES by nature are partly software and partly an integral part of a physical device patenting is possible, but the process of patenting is new to classical software engineers.

High cost in filing a patent in EU

The **underperformance of EU in terms of patents** filed may also be a result of the high costs in filing patents, which are for European patents € 50,000 per patent, e.g. five times higher than in US [S&T2003]. The public administration should conceive means to **ease the process of filing** a patent and take measures to raise the **awareness for the importance** of patents.

5.4.4 Provide a Climate for Investors

Indirect measures

The climate for investors is a measure of the general and indirect conditions supporting innovation. They are not directed towards the R&D of a concrete product, but are rather incentives to **stimulate the industry to make investments in R&D** and to boost the nation's rate of commercialisation of new products, processes, or services.

Financial measures or instruments

The indirect measures can be financial instruments, like **fiscal incentives**, financing of the infrastructure of **public research centres or laboratories**, as e.g. the European Molecular Biology Laboratory (EMBL) or the European Organisation for Nuclear Research (CERN), or **public venture capital or securities** to enable the formation of a new innovative industry in Embedded Systems. In Israel an interesting funding concept is used, where the state provides the funding budget and the market decides how the budget is allocated or directed towards funding projects.

Venture capital funds

Innovation often leads to spin-offs or to investment in new technology by SMEs. Both **need** the financial resources **at an early stage**. As private investors usually lack the trust to invest in the early phases, public support on an institutional level is needed to trigger the **forming of new jobs** and to support a **vibrant spin-off culture**. One form of direct support, which has been introduced in recent years, is a system of guarantees and warranties to support VC for SMEs. These schemes aim to **share the risk** in the early years of projects **between the state and the VC provider**. The seed capital market with € 4 billion in 2001 in Europe is considerably lower than in US (€ 11.2 billion in 2001). Europe's high tech industry needs easier access to venture capital.

Innovation 2000

The **weakness of the European venture capital market** to invest into high-tech values was already recognised by the European Commission and resulted in the Innovation 2000 initiative by the European Investment Bank (EIB) together with a memorandum of the EIB with the European Commission to **ease the access** especially of **high-tech SMEs** to the venture capital.

Use of structural funds

The European Commission has permitted the use of its **structural funds** in the field of R&D in those countries that have been attempting to catch up with average general development levels in the EU.

Non-financial measures

Other measures are more political in nature and try to inspire the people by setting clear goals, like the declarations of Lisbon [COM2003]. Concrete partnerships, like the **technology platforms** and **centres of excellence** that are visible far beyond Europe, document the ambition and seriousness of a country to follow its goals. Politics that ease the **attraction and employment of foreign researchers** and politics that supports the importance of research and stimulates excellence by **public prizes** for successful research help Europe to become a brain magnet. Another form of political support for a positive climate for business and research is the hosting of **trade fairs**, **conferences** and the **marketing of Europe's leadership**.

Europe needs to openly claim its leadership

For many years Europe has silently led the ES revolution. It is time to speak up and to step out of the closet. The label of "European Leadership in ES" will attract foreign investors, stimulate capital flow and lead to growth.

Exploiting Europe's values for meeting the challenges

Europe's leadership is threatened by US and challenged by Asia. The favourable conditions of cheap labour and a large domestic market in China, together with the proximity to high-tech production centres in Taiwan and Singapore and the capital in Hong Kong allow for a rapid and continuing growth in the region. Europe therefore has to hone its values of highly skilled labour, close markets and good infrastructure.

5.4.5 Stimulate and Support Technology Transfer

International collaboration for critical mass

The scale, facilities and the range of expertise needed for many modern R&D tasks require international collaboration. EU policy has since 1985 funded **research on a European level** and is strengthening the foundation of the European Research Area (**ERA**) with specific measures in the VI Framework Programme (FP6).

Technology Platforms

Huge efforts have to be coordinated and results need to be shared within an active community. The task of the Technology Platforms is to **coordinate the national funding programmes** and to derive a coherent **research agenda** and **common strategy**.

European networking

Networking has emerged as the dominant structure of operation in the field of R&D. The Information Society Technology (IST) Partner Search Network (www.ideal-ist.net), the networks of excellence (NoE) and networks within integrated projects (IP) or EUREKA clusters have strongly influenced the European Research Area (ERA).

Transfer across sectors

Especially with ES where sectors are merging and technology needs to be transferred it is important to encourage knowledge transfer across sectors. Transfer can be achieved in **joined projects**, but also in **organised competitions** to honour best ideas in transferring knowledge and by **broadening the academic education**.

Europe needs to become more attractive for scientists

Networking and knowledge transfer, however, have to take place on an international level. Europe needs to **invite top experts in ES** to share their knowledge. A useful means would be international conferences, professionally organised in the setting of an old and young Europe. In order to get the proper attention and to truly become a knowledge society Europe needs clear **signals to proof its leadership**.

Create the world leading ES centre

Internationally recognised **centres of excellence** will demonstrate **the competence of Europe** and globally attract researchers from all major players. Already the **announcement** of such a centre will **upgrade the value of Europe** in the world and make other buyers to look here before going somewhere else.

Creating a European Identity

The centre of excellence and the community of researchers working in Europe should develop a European identity, where they like to work and stay in Europe and are proud of being part of it.

5.4.6 Monitor the Development

For ES a set of new indicators are needed

The existing set of indicators proved to be a very useful means for governments to compare themselves and to measure the effectiveness of their politics. However, **none of the current indicators** can be used to measure the readiness of states and effectiveness of measures with respect to **Embedded Systems**. Also the citation of patents filed at EPO or granted at USPTO is the narrow view of European and US. The rapid growth of Asia, especially in the area of ES, indicates an Asian angle is badly needed.

GERD for ES is difficult to compile

Obvious indicators would be to measure the amount of funding (GERD) earmarked for research in ES. However, it would be rather difficult to unambiguously define criteria for funding programmes in such a sense. The use of simple categories as used in this study can provide an **indication**, but is rather **imprecise**.

Experts in ES a measure for ES-readiness

An alternative would be to measure the number of experts that have graduated in ES or have an equivalent international certification. Another measure would be the number of experts in ES per 1000 employees in the labour force to indicate the readiness of a country to participate in R&D in ES.

Measuring success by patents and citations

The success of R&D is usually measured by stating the number of patents or publications. The **impact of publications** can be measured by giving the **number of citations**. There are also soft measures that are derived by the number of conferences held or the number of the top 10 lists of research centres. The number of patents only is an **indication**, as it does not show how much revenues they generated or how valuable they have been to protect a business. For this data on the trade and industry sectors would be needed.

New Technique to retrieve ES specific patents and citations

To make the measures of success specific for ES, the study defines a new technique. A **list of key words** is used to filter relevant patents within a database of patents. As the same list of keywords is used for all patents, no bias towards a specific country or year is made and the resulting data is significant to show trends. The technique can be easily applied to the existing data. The **technique can be extended in future studies** to extract the number of publications in the field of ES by using the same list of key words, or even be adopted to other fields by changing the list of key words.

6 Initiatives Similar to Technology Platforms

R&D in ES requires a holistic approach

Research and Development in Embedded Systems requires a holistic approach due to the complex nature of Embedded Systems (described in section 2.3). This approach must be

(1) driven by the requirements of the application domain,

(2) supported by the industrial context,

(3) based on the cooperation of multidisciplinary specialists in the development of methods, tools and basic technologies, and

(4) encouraged and assisted by specific initiatives.

Public private partnership (PPP)

Technology Platforms were conceived at the Lisbon **European Council in 2000** [TPStatus05] to "…bring together public and private stakeholders to set up and implement common research agendas in fields of industrial relevance …". The objectives of such public-private partnership in Europe can be summarised as:

- achieving future growth and competitiveness of the whole region,
- focusing on issues of high societal relevance in a given domain,
- improving major research and technological advances in the medium to long term.

3% objective of European Technology Platforms

In terms of R&D funding the motivation of the European Technology Platforms is to achieve the "3% objective" [TPDefIm04]. The aim therefore is to mobilise a critical mass of – national and European – public and private resources in order to raise **Europe's economic growth potential and industrial competitiveness** in areas of strategic importance for the future of the European industry. Indeed, the action plan is defined by a set of stakeholders of a wide spectrum of organisations, which have committed themselves to organise themselves within this type of initiative and to participate in the elaboration of the action plan to achieve the "3% objective".

TP as accelerators to innovation process

MIT economist Robert Solow (Nobel Prize 1987) said that **80% of all economic growth comes from the technology**, but the main problem is that the trajectory from basic research to a lucrative product takes **about 30 years**. Technology Platforms as **ARTEMIS** are created to act as accelerators to this innovation process.

6.1 Examples for Public-Private Partnerships

Elements characterising PPPs

Many public-private partnerships (PPP) have been formed with different motivations, and different models for finance and operation. The following elements characterise PPPs:

- long duration of the cooperation between public and private partners,
- work on a planned project,
- funding of the project comes in part from the private sector, but is complemented by public funds (in some cases the public part is rather substantial),

- clear definition of the roles of the public and private sectors, where the public sector concentrates on defining the objectives to be achieved in terms of public interest, pricing policy, and quality of services,
- risk distribution between public and private partners.

In order to learn from best practice of successful partnerships in high-tech areas we focused in our analysis mainly on **successful public-private partnerships** related to the Information and Communication Technology **(ICT) area**.

Risk in best practice transfer

Although the goal to learn from the best is noble, a **word of caution** is in order. It is always necessary to take into account that transfer will not be successful, if frameworks and conditions, cultures and research traditions are not respected and do not harmonise with the objectives of Technology Platforms.

Our approach consists not in a broad review of all similar cooperative initiatives. Instead, the selection allows for the illustration of the **most relevant characteristics** and **best practices** of technology partnerships, which are summarised in section 6.6.

Table 6-1 presents a brief overview of the initiatives that were chosen for the analysis.

Table 6-1: Selected initiatives

Initiative	Short	Country/ Region	Started in	Goal	Impact
Association of Radio Industries and Businesses	ARIB	Japan	1995	Promote realisation and popularisation of new radio systems that contribute to public welfare	Development of standards
Center for Hybrid and Embedded Software Systems	Chess	US	2002	Research on design issues for supporting next-generation ES	Creation and transfer of knowledge from academic to industry members
Cooperative Research Centres	CRC	Australia	1994	Bring together researchers and research users	Attraction of researchers from abroad
Embedded Systems Institute	ESI	The Netherlands	2002	Basic research in ES engineering	Less conventional forms of knowledge transfer involving LEs and SMEs
Interuniversity Micro Electronics Centre	IMEC	Belgium	1984	New technologies and materials for design, production and packaging of the chips of the future	Creation of jobs
Multimedia Super Corridor	MSC	Malaysia	1996	To attract leading ICT companies to the MSC location, undertake research, develop new products and technologies, and export from this base.	Creation of more than 1000 companies

Initiative	Short	Country/ Region	Started in	Goal	Impact
National Aeronautics and Space Administration Ames Research Center	NASA Ames	US	1939	To support NASA mission and nation's vision of space	Transfer of NASA technology for industrial and commercial objectives.
Semiconductor Manufacturing Technology	SEMA-TECH	US	1987	Leverage resources, development of collaborative solutions, reduce R&D costs	Competitive advantage for members in semiconductors production
Sophia Antipolis Science Park		France	1984	To facilitate partnerships and exchanges in fields of science, industry and culture, and support technology transfer.	"laboratory of the future"

Success criteria

Public-private partnerships were selected according to success criteria. Successful partnerships are those, which **achieved their objectives**, lasted for sufficient time, and have become an **important reference within their community**. We focus on the strength of these initiatives, although we also give some hints in order to learn from failures and less successful experiences in other partnerships.

The following initiatives are used to show further examples of best practice: Advanced Technology Program (US), Asia Nano Forum (Asia), Cambridge High-tech Business Cluster (Great Britain), DSP Valley (Belgium), EMTech (EU), ITEA/MEDEA within the EUREKA programme (EU), Scottish Enterprise (Great Britain), Silicon Valley (US), and Tekes (Finland).

Initiatives in other domains

There are also public-private partnerships in non-ICT domains with a long success story. Such is the case of many initiatives in the transport domain bringing automakers, suppliers and governments together. Worth to mention are the Partnership for a New Generation of Vehicles (PNGV), EUCAR and BAIKA (see Table 6-2).

Boomerang effect in automotive domain

The **PNGV organisation** is a federation of many committees of three US car companies and seven government agencies. PNGV was founded in 1993 and set in motion a dynamic that accelerated commercialisation of advanced energy-efficiency technology. It produced a so-called "boomerang effect" as PGNV was seen as a threat by European and Japanese automakers, which increased their investments in advanced propulsion technologies in their companies. US automakers react to the aggressive commercialisation efforts of Toyota, Honda and DaimlerChrysler [PNGV2001]. The impressive number of technological advances achieved in the first 5 years of the PNGV programme has stimulated similar efforts all over the world and has created pressure to accelerate technological progress internationally.

Knowledge transfer between international automotive enterprises and automotive suppliers

The European counterpart to the PGNV initiative was the European Council for Automotive R&D (**EUCAR**) created in 1994 [EUCAR00]. The members of EUCAR are the most important European vehicle manufactures: BMW Group, DaimlerChrysler, Fiat, Ford Europe, Opel, Porsche, PSA Peugeut Citroen, Renault, Volkswagen Group and Volvo [WGEU05]. An even more localised organisation is **BAIKA** – an active cooperation among 12 main automotive manufactures and more than 850 supplier companies of Bavaria [BANET05]. BAIKA is involved in R&D projects, transfer activities such as the organisation of conferences, working circles, and national and international cooperation.

The analysis of similar initiatives resulted in a set of success factors and best practices for appropriate governance structures, evaluation practices of the initiatives and their successful operation models.

Table 6-2: PPPs in automotive domain

Initiative	Short	Country/ Region	Started in	Goal	Impact
Partnership for a new Generation of Vehicles	PNGV	US	1993	Commercialisation of advanced energy-efficiency technology	Stimulated the automotive industry in US as well as in EU ("boomerang effect")
European Council for Automotive R&D	EUCAR	EU	1994	To strengthen the competitiveness of the European automotive industry	Stimulation of automotive industry under consideration of environmental and safety aspects
Bavarian Innovation and Cooperation Initiative for the Automotive Suppliers Industry	BAIKA	Germany	1997	Increase of the competitiveness of the automotive component suppliers	Transfer activities between car manufactures and automotive suppliers (mainly SMEs)

Conditions for successful PPP

To be effective, initiatives in which public and private sectors work together require an appropriate environment and must fulfil a set of conditions. From our analysis we learned that successful public-private partnerships fulfil conditions of clearly defined objectives, the **strong engagement** of the **industrial sector** in the initiative, the **commitment of the public sector** to support the initiative, **education and transfer programmes** and the improvement of the programme trough **assessment of the results**.

The analysis showed that well-structured and well-operated public-private partnerships work. **The impact of such PPP on economic growth is important**.

6.2 Stakeholders and Leadership in Public-Private Partnerships

Stakeholders in public-private initiatives are organisations in the area of public research, industry, financial institutions, users, regulatory authorities of multiple nations and policy-makers. It is important to understand the various roles of the stakeholders. Table 6-3 shows a synoptic view of the relevant stakeholders in PPP, the main roles they play and benefits they obtain from their participation in an ICT related PPP.

The public or the private sector may drive the initiative. A public leadership is needed for highly innovative areas or non-traditional sectors for a region, in which the industry has still a weak position. In such cases the public sector has to lead the initiative and contribute often with a funding of more than 50%. Examples for public leadership in the area of ES are Chess in the US and ESI in The Netherlands. Private leadership of a PPP is instead, the result of a strong industry that achieves some innovative improvements in the sector or the region such as inclusion of new technologies. Enterprises define their objectives and require public funding support to achieve the goals. ARIB, SEMATECH, and PNGV are examples of private leadership of PPP.

Table 6-3: Stakeholders roles and benefits [NRC2003]

Stakeholder	Roles	Benefits
Government	initiator of PPP creation and support function	economic growth job creation
LEs	market oriented researcher	market leadership industrial competitiveness
SMEs	innovative developer	business opportunities risk reduction
Research institutes	applied researcher	technological expertise project chances
Universities	basic researcher	scientific leadership

6.2.1 The Role of Stakeholders

Role of government

The **government** pursues the above objectives (enumerated at the beginning of the chapter) and intends to initiate the process, to gather all relevant players, and to obtain further financial resources. Effective public support is an asset in stimulating the involvement of the private sector.

Joint Technology Initiatives

Within the scope of the 7th Framework Programme (FP 7) Joint Technology Initiatives (JTIs) were created as a new way of realising public-private partnerships at European level. Joint Technology Initiatives involve a legal structure to implement the European Technology Platforms with the aim to combine funding from the FP 7 with other public funding sources, which in turn may have a significant effect on private investments in JTIs.

Example

The government of Malaysia, for example, started the **Multimedia Super Corridor (MSC)** with the purpose to elevate the country to the status of a developed nation by 2020. The corridor was initiated in 1996 and is a success story shown by numbers such as a growth of over 36% from 2003 to 2004 and the creation of more than 1040 companies of which 60 are world-class enterprises [MSC2004]. Although the government is the chief architect of the MSC vision, the **implementation is largely driven by the private sector** [IPIPWG9.4] [MGCC2003].

Role of industry

The **industry** is represented in PPP by LE and a set of SMEs. **Large enterprises** are the focal point and very often lead the partnership. They provide the market access, have a direct benefit of competitiveness and hence invest additional funds to finance the R&D work of the other partners.

Active participation of senior industries

Industry involvement provides technical expertise, experienced management and consortium credibility. The experience of the **SEMATECH** consortium underscores the need for the commitment of senior participating companies in such an initiative [NRC2003]. The active participation and the assignment of top-quality staff are essential to achieve the government support [SEMA2005].

Innovation driven by SME´s

Innovation instead, often comes from SMEs. "..to create a stronger industry give smaller players a chance to grow from small projects and ultimately graduate to bigger and more complex undertakings" [MSC2004].Therefore the interplay of SMEs and LE is fundamental to get many SMEs involved. The Multimedia Super Corridor (MSC) is quite conscious of the relevance of SMEs for the Malaysian economy (92% of all companies) and put therefore special emphasis in fostering SMEs. As a result of the MSC initiative the number of ICT SMEs increased from less than 300 in 1996 to more than 2000 in 2004 [MSC2004].

European SMEs in ES doubled by 2016

ARTEMIS in its Strategic Research Agenda [ASRA2005] clearly defined as a high level target that by 2016 the umber of SMEs engaged in Embedded Systems supply chain within Europe has doubled.

EMTech initiative

In the area of Embedded Systems a new initiative was started to organise SMEs within the scope of the IST project **EMTech**, which supports their interests and coordinates certain activities for the group.

R&D actions led by the industry

Regarding the role of SMEs the **Embedded Systems Institute (ESI)** in The Netherlands has a different opinion. The ESI prefers to limit the participation of SMEs to the last phase of the projects mainly to assure the technology transfer [Lier2005]. In the ESI initiative the industrial partners, in particular LE, act as initiators of projects. They proposed to the board topics and ideas for future projects, at which the industry cooperates with universities and research institutes [ESI2005]. The experience of the ESI has shown that the **participation of SMEs** in large and long-term projects **involves certain risks**, as SMEs could be either absorbed by large enterprises or cease to exist during the project lifetime.

Role of research sector

The **research sector** in PPP is represented by **universities** focusing on basic research topics and **research institutes** participating in a more applied line of investigation. Research at universities has more depth and less width. In contrast, the industry focuses on strategic and market oriented research while institutes are interested in applied research.

Funding of high-risk research

The Advanced Technology Program (ATP) for example funds high-risk research in the US to accelerate development of new technologies by sharing the costs and the risk with companies when research risks are too high for the private sector to bear alone [ATP2003] [ATP2005].

6.2.2 Success Factors of Partnerships

Work together effectively

To achieve the goals of a public-private initiative, all stakeholders of the partnership – large, medium and small enterprises, government agencies and non-profit organisations – have to be able to work together effectively. The innovation environment that is created conditions the productivity and performance.

Influence of policies and regulations

Not to be underestimated is the importance of the regional and local policies and regulations that can affect the innovation process decisively. They include **government policies** such as taxation, especially capital gains; fiscal and monetary matters; education and training; **regulatory policies**, such as anti-trust and environment, intellectual property protection, government procurement and **export control** [Zch1986] [NRC1999].

Within a context of initiatives the characteristics of the partnership and the organisational features clearly matter. The main characteristics that successful partnerships share are:

Strategy / Objective	Improving Motivation	Improving Knowledge
Improving Coordination	effective leadership	agreement & roadmaps, metrics & goals
Improving Cooperation	costs & risks distribution, share of outcomes	regular evaluation & member feedback
Improving Transfer	exploitation mechanisms, patents & open source	education & training

Table 6-4: Characteristics of successful partnerships [NRC2003],

Leadership based on selection of sectors and applications

A condition for an effective leadership in the area of Embedded Systems can be achieved faster **using the principle to go deeper instead of wider**. The careful selection of the most relevant topics, the most promising sectors and the most challenged applications is therefore the appropriate mechanism. Such a selection is not static at all; it will evolve based on evaluation and adaptation to a continuously changing environment [MSC2005]. The Multimedia Super Corridor (MSC) for example, selected six primary areas for multimedia applications that were identified to start the development of the MSC and accelerate Malaysia's progress towards the knowledge-base economy they achieve for 2020 [MSC2004].

The importance of roadmaps

The importance of strategic research agendas and technology roadmaps was recognised by all successful public-private initiatives. **ITEA** and **MEDEA** within the **EUREKA** programme and **PROGRESS** (Dutch Programme for Research on Embedded Systems and Software) have realised the relevance of roadmaps to avoid the coordination problems that could arise by multiple participants, complex technologies and many different procedures [ROADNL2002]. See further details in 6.5.1.

Close cooperation between research sector & industry

Thus, the cooperation of both, the research sector and the industry contribute to an integral success of R&D initiatives. The aim in the embedded field is the co-research of pre-competitive application context and Embedded Systems research on methods, tools, and technology and skill creation. [DeMan04a]. The research institutes can participate in horizontal and vertical cooperations, e.g. in so called centres of excellence and centres of competence.

Horizontal and vertical cooperation

The **EUREKA** initiative has demonstrated through the success of their projects that cooperative R&D work (MEDEA Bluebook [MED2003]) is the best scheme to facilitate exchanges between all the stakeholders involving companies of different sizes, academia and research institutes to implement industry-driven and time-to-market projects. In the ICT area of the EUREKA programme a total of 650 organisations are involved (113 large companies, 354 SMEs, 99 research institutes, 59 universities and 25 governmental national administration units) in 174 running projects with a budget of € 523,95 million [EURE2005] (EUREKA projects, issue date: Nov. 2004).

Appropriate risk distribution among stakeholders

On the one side, an obvious advantage of cooperation is for the private sector to load some of the research costs and risks onto the shoulders of the public research institutes. At universities new research topics can be easier integrated and exploited in education or training programmes than in the industry production process. On the other side having an adequate share of outcomes enhances motivation of the participants involved to make the partnership succeed.

Vital role of assessment

The assessment process of the Advanced Technology Program (ATP) of the **National Institute of Standard and Technology** (NIST) can be taken (at least partially) as a reference model for evaluation. ATP is based on competitive selection process, independent evaluation and analysis of broad-based economic benefits [ATP2003].

Ongoing assessment programmes, such as those performed by the **Scottish Enterprise** [SCOTT2005] are strongly based on the OECD statistics, for example the objective of the Scottish Enterprise is to move Scotland from the mid-to-lower ranges to the top quartile in the ranking of the OECD.

Creation of jobs Another measure of success is the number of jobs created. An impressive example is the Multimedia Super Corridor (MSC), which resulted in the generation of **7,000 jobs** [MGCC2003] and is expected to create at least **60,000 by the end of 2008**.

Knowledge transfer styles In the US innovation transfer happens mainly through market leaders that sell their innovation as a product or patent. In Europe research results are often publicly available and used by multiple small and large enterprises independently (Further details in 6.5.4).

6.3 Eco-Systems of High Tech Clusters

High tech clusters similar to eco-systems High Tech Clusters are a concentration of various stakeholders for the benefit of all participants. Like in the biological eco-systems there is no need for a formal partnership between all components of the system, but the mutual benefits ensure a stable and sustainable environment.

Horizontal and vertical cooperation EUREKA is a good example for both horizontal – so called Centres of Excellence – and vertical cooperation – so called Centres of Competence. A **Centre of Excellence** (CoE) is a localised cooperation of different disciplines in a given application [DeMan04a]. A **Centre of Competence** is a tight interaction among experts of related disciplines for solving hard problems (formal and lasting solutions).

Centralised vs. decentralised High Tech Clusters are usually **geographically centralised** on one location, whereas Centres of Competence or Centres of Excellence **could also be virtual** and thus be geographically distributed.

Need of European eco-systems in the ES area In the area of Embedded Systems **such eco-systems are missing at a European level**. The support of such eco-systems facilitates a more effective transfer from research to product development. It promotes the creation of new industries for the production of design tools, embedded components and software.

Advantages of Centre of Excellence in ES area At country level the **Interuniversity MicroElectronics Centre** (IMEC) in Leuven, **Belgium** is a Centre of Excellence in the area of microelectronics, nanotechnology, ICT technologies and Embedded Systems design. IMEC was founded by the Flemish government in 1984 [IMEC2005]. The total amount of R&D budget has grown from € 318 million in 1995 to € 778 million in 2004; only the 25% is subsidised by the public sector [Benc2004]. IMEC's strength is the **combination of fundamental and applied R&D**. Due to the IMEC initiative, international companies, such as Infineon, Intel, Samsung, STMicroelectronics and Texas Instruments create high value added jobs in Belgium.

6.3.1 Geographically centralised Clusters

High-tech Centres as magnet for research and industry In many cases **science and technology (S&T) parks** have been initiated by public agencies with the help of public funds until reaching self-sustaining levels of activity. High-Tech Centres serve as a natural magnet for attracting researchers and industries and to further promote the technical excellence of the region and the cluster.

Advantages of geographical proximity Geographical proximity of industry to research institutes and universities allows for an **optimal triad of innovation** (**education, investigation and transfer**). Mainly the transfer is a critical aspect in the Embedded Systems community as horizontal transfer of know-how (between sectors) and vertical transfer (from research to application)

improves the chances of excellence in the domain. The main advantages of close geographical proximity are:

- concentration of experts to be hired,
- concentration of companies as future employers,
- large enterprises acting as a magnet for research and industry, especially SMEs, as the transport costs are minimised,
- access to national & private funding,
- sharing of expensive equipment, especially in the area of chip design and development,
- benefit of cross-fertilisation between sectors or by knowledge transfer,
- increased market potential for suppliers of common services or goods, for example programming, tools and design methodologies.

Eco-system proposed for ES

The Embedded Systems domain is considered an area where innovation is mainly provided by SMEs, which work in tight relationship with large enterprises (LE), research institutes and universities building eco-systems, such as proposed in Figure 6-1. LEs act as sponsors and leaders attracting SMEs, research institutes and universities. A widespread involvement of small and medium sized companies is favoured [SchEm05].

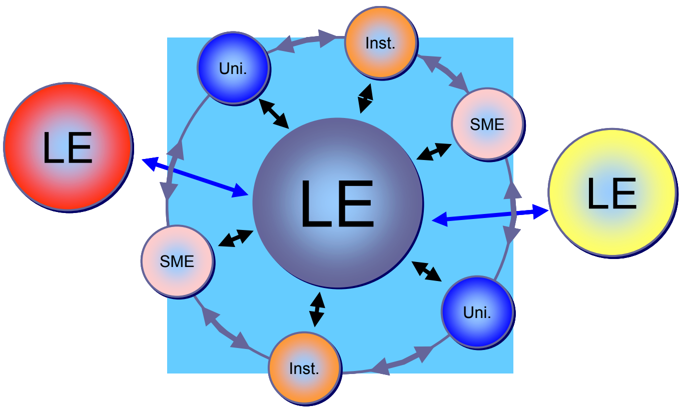


Figure 6-1: The Large-Enterprise R&D eco-system [SchEm05]

Increased investments

Concentration of activities in some geographical areas and scientific domains encourages increased investments. In particular, the involvement of **regional governments** in innovation and S&T parks is considered helpful providing among others **physical infrastructure.** See Table 6-5 for examples of worldwide IT clusters by 2003 [PAC2003].

Table 6-5: Examples of worldwide IT clusters [PAC2003]

Cluster	High-tech Companies	High-tech Employment	Main Industry Sectors
Greater Cambridge	3,500	42,000	ITC, biotech, instrumentation
Hsinchu (Taiwan)	287	102,000	IT, electronics
Israel	4,000	100,000	IT, telecoms
Kista (Stockholm)	700	29,000	IT, telecoms
Silicon Valley	7,000	780,000	IT, electronics, defence/aerospace
Singapore	6,000	93,000	IT, telecoms, electronics
Sophia Antipolis	1,200	22,000	IT

Eco-systems can be built

- around **universities**,
  such as the Cambridge Cluster with a high percentage (58%) of very small companies employing less than 10 people and only 1% of the companies are employing more than 1000 people [CAM2004], or
- around **large companies**,
  like in the area of Sophia Antipolis, which got started by the large enterprises of Texas Instruments and IBM and now comprises about 1.200 companies, 15 Universities and Engineering Schools and 6 large research institutes [SA2005],
- around a **kernel of university and industry**,
  such as Silicon Valley, which was built on the intensive cooperation between Stanford and Berkeley Universities and important industries located in the valley such as Hewlett Packard [JVSV2005] (see section 3.2.5.3).
- around a **government administration**,
  as the Malaysian Multimedia Super Corridor (MSC) located in the north of Kuala Lumpur covering an area of 15 x 50 km.
- around military research or other **national research institute**,
  like the Tel Aviv cluster.

Example of a small cluster for the development of embedded software

An example of a small business eco-system in the specific area of Embedded Systems is the **DSP Valley** located in **Leuven, Belgium** [DSP2005]. It is a technology network organisation, focusing on the design of hardware and software technology for digital signal processing systems. DSP Valley members are active in the research and/or production of methods and tools for one of the following applications: digital audio, digital imaging or telecommunication & navigation technologies. Based on the expertise and the knowledge available in the DSP Valley network the IWT (Institute for the Promotion of Innovation by Science and Technology in Flanders) is **promoting and stimulating embedded software development in Flanders**. DSP Valley is an ecosystem that counts more than 30 members including LE such as Philipps and Siemens VOD Automotive, research institutes as IMEC, universities of Leuven, Gent, Eindhoven and Brussels and many SMEs.

6.3.2 Geographically distributed Clusters

Access to national & private funding

Examples for decentralised networks are **EUREKA** and the **Asia Nano Forum (ANF)** founded in May 2004. EUREKA offers project partners access to knowledge, skills and expertise across Europe and facilitates access to national public and private funding schemes.

Avoid duplication of effort

Similarly the ANF is supported by 13 economies in the Asia Pacific region [ANF2004]. The ANF network is a young regional initiative, by influential leading scientists, R&D managers as well as policy makers with the goal to obtain views on the status of nanotech R&D in each Asia Pacific economies and coordinate their activities in order to avoid fragmentation and duplication of efforts.

Benefit of cross-fertilisation in Eco-systems

The creation of an ICT eco-system for the stakeholders of the Embedded Systems area would facilitate a relationship between research and product development addressing **fragmentation** that is **one of the main current problems** of the Embedded Systems market. The cross-fertilisation, in for example, topics such as tools and design methodologies between different sectors such as consumer electronics, health and telecommunications will benefit existing enterprises and new Embedded Systems industries.

A quite different university-industry-government partnership is pursued by the **Center for Hybrid and Embedded Systems (Chess)**, which is leaded by the University of California at Berkeley [CHESS05]. Industries can become members of Chess by either supporting research through donations of products, equipments or technology, or an annual membership fee. Associated members benefit from having access to all research results, review and member day conferences.

Cooperation through donations or membership

6.4 Successful Governance Structure

"A single market for research in Europe" to be achieved by 2010 will not be viable without appropriated public-private initiatives. The governance structure of such public-private partnerships within the scope of the ERA objectives has to **support intensive co-operation, stimulate competition and allow for better allocation of resources**. In addition, the mission is the improvement of the coordination of national research activities and policies and the creation of an area for the free movement of knowledge, researchers and technology.

The vision of ERA as a governance principle for TP

For public-private initiatives the **public administration** uses its authority to set specific objectives and needs to apply the five principles of good governance – **openness, participation, accountability, effectiveness** and **coherence** – when public money is involved and needs to be accounted for [EUGov2001]. On the other hand the **private industry** has to find the common ground by a democratic (forges consensus through participation) and affiliative (creating harmony and building emotional bonds) leadership, based on the common goals by setting the pace.

Principles of good governance: Openness, participation, accountability, effectiveness, coherence

The High-Level Group of **ARTEMIS** [BuildAR2004] has established as its mission to facilitate **productive engagement** and **interdisciplinary working** between **public and private** organisations in the area of Embedded Systems. Therefore ARTEMIS will support not only collaborative research programmes between academia and industry, but also mechanisms for coupling the effort of all stakeholders – from the public and the private area – in the research and development of new technologies and systems as well as their involvement in education and training. Centres of Excellence with a centralised location will be adequate to achieve the **strategic objectives for Europe** in the area of Embedded Systems that have been set by ARTEMIS:

ARTEMIS goal: Europe for leadership in embedded technologies

- to achieve world leadership in those embedded technologies that underpin European competitiveness in intelligent systems, products, services and processes,
- to advance European solutions for the deployment of globally networked interoperable Embedded Systems that can connect to the Internet and are open to third parties,
- to favour the creation of new markets and enable societal-scale applications that enhance the safety, security and well-being of citizens.

The analysis of other public-private initiatives in the high-tech area revealed the importance of the private component, which acts as the driver of innovation. The public component instead plays more the role of the facilitator contributing through funding directly to research and development or indirectly through universities and research institutes.

Roles of the private and public components

Lessons learned from other initiatives, even from other regions or centred on other topics could be helpful to analyse. Such lessons learned are:

Lessons from other initiatives

- leverage resources,
- reduction of time from innovation to manufacturing,
- long-term economic development,

- attraction for scientists from abroad,
- creation of spin-offs,
- improvement of the initiative profile by offices abroad,
- raising the role of a specific domain,
- involvement of representatives from the participant states.

6.4.1 Private-Driven Initiatives

The Commission noted the potential of technology platforms to make a major contribution to competitiveness through mobilising the private sector including the participation of SMEs [TPDefIm04].

Leverage resources

The R&D model of SEMATECH – a private-driven initiative in the area of semiconductors of the state of Texas – counts on the membership of the companies that represents about **50% of the world's semiconductor production** [NRC2003]. SEMATECH has already existed for over **15 years**. Consortia Members of the Texas Initiative are AMD, Freescale, Hewlett-Packard, Infineon Technologies, IBM, Intel, Panasonic, Philips, Samsung, TSMC and Texas Instruments [SEMA2005]. The R&D model is a global network of alliances with equipment and material suppliers, universities, research institutes, consortia, start-up companies, and government partners. The strategy consists in of co-operating to leverage resources and keep the industry vital and growing ever stronger.

Reduction of time from innovation to manufacturing

SEMATECH has as main objectives **R&D costs and risks reduction** required for:

- first-to-market solutions – members get full and detailed, actionable data,
- cost avoidance – members avoid spending the full R&D costs of ultimately unworkable solutions and lower their learning curve for new processes,
- inside track – members receive early evaluation of new materials and technologies without contamination and equipment risk.

Long-term economic development

The strategy of SEMATECH is to enable members using what they learn at SEMATECH, to spend more resources on developing their own competitive advantage rather than funding solutions individually.

Knowledge integration

Another example of a successful public-private initiative is **ARIB** (Association of Radio Industries and Businesses) of **Japan**. ARIB was **established in 1995** in response to several trends such as the growing internationalisation of telecommunications, the convergence of telecommunications and broadcasting, and the need for promotion of radio-related industries [ARIB05]. ARIB's goal is to advance rapidly the use of radio technology for the benefit of society. This is done by integrating knowledge and experience in various fields of radio use such as broadcasting and telecommunications, research and development in radio technology, and serving as a **standards development organisation** for radio technology.

Supplementing governmental standardisation activities

ARIB's members are enterprises such as Fujitsu Limited, Hitachi Ltd, Sony, Toschiba Corporation, Mitsubischi, NEC Corporation, Panasonic Mobile Communication, SANYO Electric Co. Among others ARIB's activities focus on standardisation with the objective to guarantee compatibility of radio facilities and transmission quality as well as offering greater convenience to radio equipment manufactures and users, in contract to the government standards focus on encouraging the effective use of frequency and preventing interference. Radio equipment manufacturers and users can participate openly in the ARIB Standards Assembly, which is the final step in establishing such standards.

6.4.2 Public-Driven Initiatives

Direct contribution 0.25% of the turnover of LE in Hungaria

A different schema with a strong participation of the private sector but with the leadership in hands of the public sector is provided by the **Hungarian** policy, which establishes that apart from the micro- and small enterprises, every enterprise is obliged to pay at least 0.25% of its turnover into a **Technology Innovation Fund**. The National Office of Research and Technology (NKTH) manages the fund that creates a predictable environment for the exploitation of R&D results. The Hungarian government contributes to the fund with an equivalent amount. The goal of NKTH is to provide sufficient funding for innovation programmes in which representatives of the academic and industrial spheres participate.

Australian CRCs to attract scientists from abroad

Although the **Australian** Innovation System (NIS) is described as highly fragmented, partially due to the geographical conditions, the high ratio of investment in public sector research and education can be seen as strength while the weakness is shown by a low rate of patenting, low investment in venture capital and a large number of scientists moving abroad. One of the programmes of NIS promotes the creation of **Cooperative Research Centres (CRCs)**. The mission of CRCs is to **attract scientists from abroad** through world-class applications-oriented centres that link outstanding research groups from the public and private sectors [Sla1993]. The capture of human resources is a particular problem in Australia. Europe has to focus instead on the high cost of the local human resources.

Raising the role of a specific domain

The **Asia Nano Forum** network (**ANF**) has been recently started in order to constitute a collaborative framework to enhance the global competitiveness of Science and Technology in the Asian region and to contribute to the prosperity of the region economy through public-private partnerships at Asian, national and regional levels. In 2003, Asia contributes 50% of the global nanotech funding and it is continuously raising its role in the global nanotech area [ANF2004]. Significant funding has been strategically allocated to this topic defining it as one of the priority areas in Science and Technology policy making. Unlike the European countries, the integrated regional coordination and cooperation in R&D is a very young initiative when compared to the **NanoForum** launched by the European Commission.

An Asia ES Forum: Coming soon?

The emergence of this forum points out that a similar network could be created for Embedded Systems. Currently these initiatives are more a network of researchers than an industry-driven initiative, but could evolve rapidly into organisations with increased participation of the private sector. In Europe instead, there is a strong industrial participation in initiatives related to nanoelectronics and Embedded Systems demonstrated for example in a set of EUREKA programmes.

Costs distribution between private and public sector

A national public-driven initiative in the area of Embedded Systems is **PROGRESS**. With a focus on The Netherlands the target group consists of **ten universities, five large companies and one hundred SMEs**. PROGRESS shows good practice because of the success in setting up a cooperation of between academia and industry. 35% of the budget is subsided by the government, 35% by the universities and 30% by the industry [ROADNL2002].

6.4.3 Participation of Local Representatives

Involvement of representatives from the participant states in regional R&D initiatives

Another feature of the governance structure – relevant for regional R&D initiatives – worth analysing is the cooperation of the national governments of the participants. ANF in Asia is such a regional initiative that is **coordinated by a government organisation** including representatives of leading R&D organisations or a national nanotech coordination office of each participating economy, similar to the mirror group of the Technology Platform of

Embedded Systems [ANF2004]. Among others the **Japan** National Institute of Advanced Science and Technology (AIST), the **Korean** Nanotechnology Researchers Society (KNoTRS) and the **Vietnam** Academy of Science and Technology (VAST) are involved together with similar organisations from Australia, China, Hong Kong, Indonesia, Malaysia, Singapore and Taiwan.

6.5 Best Practice in Modus Operandi

The analysis of successful ICT initiatives focusing on world leadership provides mainly valuable information about their modus operandi. The lessons learned in those initiatives could be transferred to the Embedded Systems sector, providing cultural differences and domain specific aspects are considered.

6.5.1 Long-term Plans, Roadmaps and Strategic Agendas

Long term plan to succeed

For a public-private partnership to succeed a long-term plan is needed. The vision of the Multimedia Super Corridor **from 1996 to 2020 is a good example**:

(1) a creation phase of 8 years, followed by

(2) a link phase of the corridor to other cities in Malaysia and worldwide (2004-2010),

(3) and the final phase to transform Malaysia into a knowledge society.

Strategic agendas, roadmaps and operational plans

Operation and coordination of initiatives where stakeholders of many countries are involved is normally the **responsibility of boards** like steering boards and executive boards supported by a set of working groups. Mission and objectives of such public-private partnerships are defined in so-called **strategic agendas**, **roadmaps** and **operational plans**, which also regulate the operational activities and those actions performed for coordination. Examples of very concrete roadmaps are those for the PROGRESS, ITEA and MEDEA and for SEMATECH ([ROADNL2002], [ITEA2004] [MEDEA2003] [SEMA2005]).

Only a few programmes in Europe dedicated to ES

At national level in Europe there are many programmes related to ICT. Only very few are dedicated specifically to promote Embedded Systems technology and R&D in this field, such as the Embedded Systems Institute (ESI) or the PROGRESS programme of The Netherlands [ROADNL2002] and the Austrian Initiative FIT-IT [FITIT05].

6.5.2 Coordination

Long-term economic development

Coordination activities allow for a long-term economic development strategy to **organise advanced technology activities** throughout the region, and **accelerate commercialisation** from R&D to the marketplace to drive new business development. The strategy of SEMATECH is to enable members using what they learn at SEMATECH, to spend more resources on developing their own competitive advantage rather than funding solutions individually.

Australian CRC: Flexibility in the involvement of participants, mainly SMEs

One of the characteristics reported about the **Australian Program for Cooperative Research Centres** (**CRC**) is the flexibility in the range of participants and mechanisms to increment the involvement of SMEs that make an integral part of the Australian industrial structure. CRCs, similarly to the ESI of The Netherlands develop links to SMEs with regard to technology transfer [CRC2005] It is notable that the definition of SMEs is different from that in EU. LEs have more than 100 employees; SMEs have 100 or less employees. In the research and development instead larger companies are involved than SMEs, according to an evaluation report of 2002 (597 LEs and 371 SMEs in 48 CRCs).

Network of research and commercial applications

The concrete objectives of the CRC described in [Sla1993] [MAP2004] include the **establishment of internationally competitive industry sectors, high quality scientific and technological research**, to strengthen the network of research and commercial applications. The organisational structure of the CRC programme consists of a CRC Committee and a CRC Secretariat, both directly related to the Minister of Education, Science and Training. CRCs announce calls publicly every two years. The selection is described as "single-staged", but has to go through three filters:

- evaluation by an expert panel and the CRC committee,
- assessment by referees proposed by the applicants,
- interviews for the discussion of the application performed by the chairs of the expert advisory panels and independent experts in the domain.

Contributions of public and private sectors

Coordination activities include the management of the contributions of the EU, of the local states participating in the initiative as well as of the contribution of the industry. Usually funding schemas are based on pre-determined contributions of the stakeholder, for example 50% is provided by the public sector while the other 50% is carried by the private sector.

Open vs. pre-established topics funding schema

The decision about themes to be funded requires coordination for the selection of such themes or definition of a funding programme. In an open funding schema instead, coordination will focus on evaluation of proposals to determine its appropriateness. The EU follows the first funding schema while Israel provides an example of open funding schema without topic limitation. Israel provides funding for sectors or bilateral co-operations with countries such U.S, Korea or the European Union, but not pre-assigned to specific themes. The MAGNET programme of the Office of the Chief Scientist is such an initiative aiming to provide a competitive position in stat-of-art technologies [ISR2005]. The relevance of the proposal is analysed by experts and a committee. The selection criteria are given by the technological novelty and the economic justification.

Disadvantages of the EUREKA two-step call procedure

EUREKA's two-step call procedure involves the public authorities of the participating countries in the second step to approve the project proposals labelled during the first step by the EUREKA programmes such as ITEA or MEDEA [EURE2005]. This means that they have to meet a number of criteria, e.g. that they comply with the ICT strategies set by their respective national authorities. This two-step selection procedure has an important **disadvantage** as the **double evaluation effort** introduces not only **delay in the project approvals** and **rejections**, but also it produces incompatible evaluation results due to different evaluation criteria used by ITEA or MEDEA and by the national programmes.

6.5.3 Funding Strategies

Balance of funding is a crucial aspect. It influences the role the stakeholders play in the partnership. Those stakeholders who invest more will usually lead the PPP. The strategy strongly depends on the targets and needs of government and industry. For EU-wide PPPs funding will necessarily go beyond EU funding, involving additional funding from Member States own national programmes.

The Partnership for a New Generation of Vehicles (PNGV) is one typical model for government-industry R&D partnership showing how both public and private sectors can benefit from a cooperation started by a government initiative in 1993 [PNGV2001]. The primary goal of PGNV is to develop a vehicle that achieves up to three times the fuel economy of mid-size US cars build in 1993 with no sacrifice in performance, size, cost, emissions, or safety. A billion dollar (approx. € 0.78 billion) project to be spent over 10 years and funded roughly 50% by the government and 50% by the industry. These split 50/50 between government and industry direct funding is followed by many other initiatives, such as Tekes [Tek2005] and ESI [Lier2005].

Another model used in PPPs is implemented by IMEC, whose projects in contrast, are funded only 25% by the Flemish government while the remaining 75% is provided by the private sector. A higher public funding rate can be observed mainly in innovative and not yet well-established domains and regions where trough intensity of public funding important changes in the sector are achieved. Such a strategy is followed by PROGRESS, which aims at increasing knowledge and competence in the area of ES in The Netherlands with only a 20% to 30% subsided by industry; the remaining 70% to 80% is financed by the government and the universities [ROADNL2002]. Chess (US) [CHESS05] instead, follows a fixed annual membership fee strategy for the industrial partners. Industrial partners have the opportunity of direct involvement in the research activities. Within the EUREKA programme governmental funding depends on the local programmes of the member countries moving in the range from 25% to 100%, including also an exception in which project costs are not covered.

Infrastructure, security & employment

Specific incentives for investors and companies can be offered in addition by the public sector to make the joining of the PPP attractive. The **MSC** project offers a set of securities, for example provision of physical infrastructure, unrestricted employment, unrestricted property, tax benefits, etc [MGCC2003].

Creation of spin-offs

Australian CRCs are run as unincorporated joint ventures or as incorporated companies, governed by a director and a board. The rules governing a CRC include the visibility at national and international level and commercialisation of the results. CRCs were involved in 787 international collaborative agreements in the period 1990 to 2002 [MAP2004]. This frequently leads to the formation of spin-offs in a higher percentage than in other comparable institutions [Yen2002].

Snowball effects

Well functioning public-private partnerships will attract more companies and investors. Such is the case of the **Cambridge Cluster** with investments of more than € 500 million in the first 8 months of 2004 [Estar2004].

6.5.4 Transfer & Exploitation

Transfer and time-to-market of research results

Attention should be paid also to transfer and exploitation actions. **Transfer is a key success factor** in the long-term. As shown in Figure 6-2 a delay of about **7 years** is to be taken into account **before results will be used** over a wide area by industry **with the exception of partners involved in the eco-system** [DeMan04a].

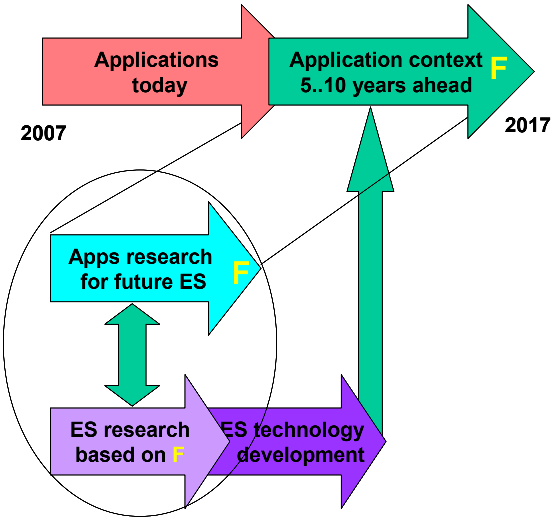


Figure 6-2: R&D projection 5 to 10 years ahead [DeMan04b]

Success criteria for knowledge transfer

Successful knowledge transfer means in most cases to reproduce knowledge in new contexts. Incoming knowledge has to be evaluated, interpreted and used for special purposes in the specific sector or other sectors. Hence, new knowledge needs first to be de-contextualized and subsequently integrated into the new context. The general process for knowledge transfer from publication to teaching/training to innovation is depicted in Figure 6-3. Although the following best practices are important for the embedded domain in the same way they are relevant for most high-tech innovative areas.

The issue of technology transfer in the field of Embedded Systems has three dimensions.

Transfer & cooperation among different disciplines

The first dimension is the **multidisciplinarity**, which means that knowledge from a large number of disciplines is required in order to design and develop an embedded system, including computer science, electrical engineering, mechanical engineering and other engineering disciplines. The multidisciplinary character of Embedded Systems **requires the adaptation of traditional development processes**.

Knowledge transfer between different organisations

A further dimension describes the knowledge transfer **between different organisations** as LE and SMEs, universities and research institutions. Single enterprises are very often **not able to acquire each base technology** used in an embedded system as a result of the complex structure of such systems. Hence, the companies depend on expertises, which are available from other specialised companies, universities or research institutes where new basic technologies and basic applications are developed.

Knowledge transfer between industries

The last dimension deals with the knowledge transfer **between different sectors**, as innovations of certain systems components for example could be transferred to other domains for developing new products.

Multidisciplinary research activities

The combination of the different disciplines has to take place in research institutions, too. The **multidisciplinary exchange** between groups working on different aspects of Embedded Systems has to be raised as already is done by many initiatives.

Best practice in knowledge transfer

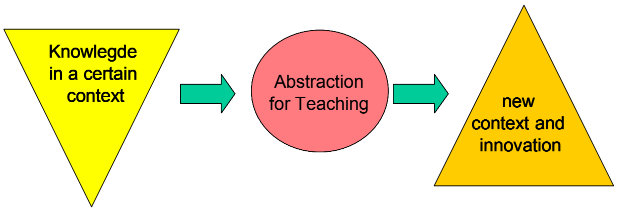
A good transfer of knowledge has always been a goal of all R&D initiatives. Transfer policies **vary from country to country** and are also influenced by **cultural aspects**. Some examples of good practices or innovative ideas related to transfer and exploitation use the following transfer media:

Knowledge transfer media

- publications and patents,
- education,
- postgraduate education and training,

- knowledge circles,
- Internet portal.

Figure 6-3: Process of knowledge transfer



Examples of successful technology transfer are those initiated by the University of Cambridge within the Cambridge Business Cluster [PDM2003], and by the Ames Research Center [NASA2005]. The latter focus on commercialisation and transfer of NASA technology to US industry.

6.5.5 Education and Training

Accelerated training of human resources

The combination of different engineering fields in the domain of Embedded Systems requires **new curricula and new courses at universities** and **new trainings at company level** to allow appropriate education for those who work in the field of Embedded Systems in particular participating in design, development and integration of Embedded Systems [ART2005] [ESC2002].

Need of specific training

An innovative technology – as Embedded Systems – based on multidisciplinary knowledge and on cross-fertilisation of industrial experience requires new or at least an improved education and training concept. An interesting approach is pursued by the Multimedia Super Corridor (MSC) in Malaysia that first concentrated in identification of critical gaps in the education of multimedia and analysed their impact [MSC2004]. The MSC proceeded then to develop new forms of merged **content for the training program** including **improvements in curricula**, **grants** for more than 400 student-talents and a **mentorship program** getting direct guidance from experienced and high-qualified industry staff [MSC2005].

Postgraduate education and training

The Federal Government of Australia supports a **wide spectrum of interactions between universities and industry** under a number of programmes overseen by research councils, R&D corporations and other organisations. Long-term collaborations and know-how transfer are facilitated for example through the Cooperative Research Centres (CRC), an ongoing programme that started 1990. [MAP2004]. They seek to contribute to postgraduate education and training to raise transfer knowledge.

Knowledge circles speed up dissemination of ES knowledge

The Institute for Embedded Systems (ESI) of The Netherlands deploys a new concept of technology transfer – so-called **knowledge circles** with the objectives of synthesizing, creating and disseminating knowledge [Lier2005]. They describe it as “knowledge on a slice of the Embedded Systems design pie” [ESIKC05]. **The knowledge carriers are actual, real-life, cases**, brought in by the participants and often related to one or more related ESI projects. The results are that fruitful interactive discussions take place in which not only knowledge is shared but also augmented and enriched with new knowledge, thus providing a channel for dissemination. The participants of the circles are **recognized experts** in the field who are **communicative, willing to share and discuss in a positive and constructive way**. These experts are selected by the ESI on the criteria mentioned before. Knowledge circles are closed by necessity in order to create an atmosphere of trust and willingness to share.

The online survey performed within the scope of this study covered some technology transfer aspects [Quest2005]. In the opinion of programme managers of funding programmes the most effective means to enable the knowledge transfer are obtained when stakeholders cooperate in **multi disciplinary projects,** and participate in **conference** and **workshops**, followed by **seminars** and **Internet portals**.

The most effective ways to transfer innovation

6.5.6 Programme Evaluation

Although they have the same goal finding out how the objectives of an initiative are reached R&D programmes and initiatives of different countries or regions **manage evaluation differently**. The aim of an evaluation is

Regional different ways of evaluation

- to provide feedback on how the programme objectives have been realized,
- to find out the relevance of the programme,
- to report about strategic decisions of the programme and to the authorities. The results of the evaluation are documented in the evaluation and final reports.

Evaluation aims

Best practice in programme evaluation can be summarised as follows:

- use of evaluation results to adjust programmes,
- impact assessment to track the need of change,
- use of OECD indicators to adjust strategy periodically,
- use of quantitative evaluation,
- involvement of foreign evaluators, and
- use synergy by simultaneous evaluation.

Best practice in programme evaluation

Evaluation is a **powerful tool for policy and decision making**, but means having a clear set of objectives, a logical framework and using correct and valid methods. Evaluation involves the selection and implementation of systematic and appropriate methodologies including market-data-based analysis, patent-based studies, comparison to foreign counterpart studies, failure and success analysis. It also requires management and dissemination of a portfolio of studies and, which is even more important, the **use of the results** of the evaluation by decision makers **to adjust the programmes**.

Use of evaluation results to adjust programmes

In Scotland, for example, a well-measured industrial initiative with focus on opportunities for companies and for human resources has been implemented. This initiative – called **Scottish Enterprise Network** [SCOTT2005] – was started in the nineties with the key role in delivering the Scottish Executive's top priority of economic growth. The objective towards a "Smart Successful Scotland" is reached through the preparation of an operational plan, which has the character of a strategy agenda, the actions implementing the defined strategy and the evaluation of the results based on the differences made in the economy rather than the effort invested. The organisation has a wide organisational experience and consequent use of the results of impact assessment to provide answers to open questions and track the need of change.

Impact assessment to track the need of change

The main mission of the Scottish Enterprise is to change the position of the Scottish economy shown by the major economic indicators of the OECD [ODB2005], where Scotland stays at just a quarter of the level achieved by the top performing economies. The Scottish Enterprise recognises the need to bridge the gap that is moving from the mid-to-lower ranges in direction to the top quartile of the OECD, publishing annually the priorities set out in the plan, which are based on the relative performance of Scotland against the OECD comparator countries. **The Technology Platform could use similar indicators** that are relevant in the area of Embedded Systems and follow a similar strategy for evaluation and strategy research agenda evolution.

Use of OECD indicators to adjust strategy annually

Use of a quantitative evaluation

The Australian CRC programme has been evaluated several times, although in a different degree of depth, the most significant evaluations have been performed in 1995 and 1998. Evaluation **results are used** to **repositioning the CRC programme** or **redesigning elements** of the programme before the next selection round takes place. The results of the assessments were the **remarkable success of the programme** that can be illustrated quantitatively by figures such as [MAP2004]:

- 920 companies involved in research and commercialisation activities,
- more than 1000 students enrolled for their PhDs,
- more than 200 courses for more than 6000 undergraduate students,
- 68 patents, 100 IP licenses and 21 technology agreements in one year (2001),
- 787 international collaborative agreements.

Involvement of foreign evaluators

The technology programmes within the scope of the **Finnish Technology Platforms** is another initiative that has a strong focus on evaluation [Tek2005]. Evaluation of Tekes technology platforms is performed at least at the end of the programme, but often also at midway. **Foreign evaluators** have assessed many of the completed programmes.

Use synergy by simultaneous evaluation

The evaluation practice within Tekes may be either for an individual platform or one evaluation can cover several programmes if they belong to the same field of technology, or cluster, or if they have similar goals, or some other common denominator (for example, digital media programmes have already been assessed in one go, as a whole).

6.6 Recommendations

To guarantee success, we strongly recommend that a **public-private initiative** in the area of Embedded Systems (ES) in Europe meets the following set of requirements:

- definition of a strong and long-term vision,
- provision of financial resources,
- active participation of industry, academia and government,
- creation of a business eco-system,
- professional management.

How to become a successful PPP

The requirements can be implemented in different ways, as shown by successful examples of PPPs, but it is important that they are all solved in a favourable way for a PPP to become a **lasting and successful partnership**.

6.6.1 A PPP needs a Strong and Long-Term Vision

Other than the funding of a project a public-private partnership should have a longer time horizon and therefore needs a strong vision. The vision defines the **purpose of the partnership** to build and maintain the asset.

Vision of public administration or industry

The vision can be defined by the public administration, like in the case of the European TP or in the case of Multimedia Super Corridor in Malaysia. The vision can arise from the need of an industry, like in the case of SEMATECH or EUCAR.

The vision needs to be ambitious and inspiring, because it is the foundation of the PPP. The motivations of each partner have to be completely aligned with the vision and require the commitment of all partners. The aligned motivation is the legitimation for each partner to ask for active support.

Technology Platforms have been created in order to provide a business development service previously run solely by the public sector. This service aims **to strengthen the innovative power of an entire industry.** This entails not only R&D, but also the education of trained experts. Hence all partners have to be aware of the public service the TP have to provide in addition to the individual goals each of them is pursuing.

Public responsibility of TP

The TP needs to gain visibility for promoting its vision. Therefore it has to create a **presence** of their own, represented by a spokesman in public interviews or conferences. A logo and a label that is visible and marketed also expresses the identity of the TP in all projects and activities started by the TP.

Visibility of TP

For ARTEMIS it is important

- to proclaim and achieve leadership in ES,
- to overcome the productivity gap of ES,
- to achieve a European coordination and cooperation on common topics in ES,
- to agree on a common strategy research agenda by selecting and prioritising a set of applications and sectors,
- to elaborate a roadmap based on the strategy research agenda,
- to support the entire European industry by providing expertise, know-how and solutions in ES,
- to develop the infrastructure that will underpin emergence of new ES markets,
- to emphasize knowledge-transfer to SMEs.

6.6.2 A PPP needs Financial Resources

Knowing the target the "special purpose vehicle" of the partnership needs fuel to come alive. For a long lasting partnership the financing has to be organised with the sustainability of a biological eco-system in mind. All partners need to align their motivations and financial commitments with the vision and mission of the partnership. Only **if the partners get their value back** by the accomplishments of the partnership they will continue to supply the financial resources needed.

Financial commitments of the partners

As with any public organisation a PPP needs to apply a very **transparent accounting and reporting** on the use of its funds. It must be open and easy for each partner to check the investments and gains of each partner. The partnership has to agree on the way to use the funds based on the common strategy agenda based on their common vision.

Benefits for each partner

For ARTEMIS it is important

- to set clear goals for a financial target,
- to provide a platform to achieve coordination of funding from FP7, EUREKA and national funds,
- to get the financial commitment of large enterprises (LEs),
- to get the financial support by regional and local governmental organisations,
- to decide on a budget plan to strategically use the resources, e.g. for research, to knowledge transfer, for the acquisition of additional funds or resources from SMEs,
- to create attractive conditions for investors.

6.6.3 A PPP needs Active Participation

To become an active PPP that transfers visions into accomplishments a PPP needs not only financial resources provided by the partners, but also the active participation of **the**

From visions to actions

partners on all levels. Active participation implies support at management level, and engagement and contributions with innovative ideas, own knowledge and specific programmes at staff level.

Industrial management support

From the industry the PPP needs the active support of the management, which requires the management to be engaged in person to forward the mission. Industry representatives working at the PPP have to be part of the high-qualified staff of the enterprises in order to increase the chances of success.

Governmental support

The public administration has to support the PPP by helping to overcome administrative hurdles, like for the settlement of a new enterprise, to attract foreign ES experts, or preparation of special training programmes. The government can be very efficient in supporting the goals of a PPP internationally by **advertising the PPP** as their instrument and by showing how their politics align with the vision of the PPP.

Academic support

The universities can support the PPP by participating in the R&D in projects or by proposing students for working at research departments of enterprises for practical experience, by inviting practitioners to teach at university, and by transforming knowledge into new curriculae.

For ARTEMIS it is important

- to get the support of the management of the most important European LEs in the most relevant sectors of ES, such as automotive, avionics, industrial automation, consumer electronics and health. The management must design competitive and enough staff to make the active participation feasible,
- to enable the involvement of a large number of small and medium enterprises (SMEs) getting the commitment of a relevant group of them,
- to acquire the commitment of regional and local governmental organisations,
- to accelerate human resources training by special programmes for the selection and grooming of student-talents to fill the critical gaps,
- to influence the improvement of education plans,
- to focus on knowledge transfer (between research institutes and industry as well as between different industry sectors).

6.6.4 A PPP needs Industrial Eco-Systems

Benefits of eco-systems

The benefits of business or industrial eco-systems are well known: they **drive economic growth and competitiveness**, they act as **magnet for large companies**, they provide a stimulating environment for the **creation of new enterprises** and promote the **innovation and learning co-operations**. All of these benefits lead to the advantage Europe needs: **job creation**.

ES eco-systems

For new industrial partnerships to form, proximity is most useful to support the formation of a nucleus. However, the nucleus needs to be open and transparent to get wide public support. Due to their heterogeneity the ES stakeholders in Europe build a series of eco-systems, mainly related to key sectors, such as automotive in central Europe, telecommunications in the north of Europe and aerospace in the south west. A PPP based on a set of industry eco-systems is conceived as **local nodes in global networks**.

CoE for ES area

A set of Centres of Excellence (CoE's) should be established to **reinforce the medium and long-term research activities** needed by the eco-systems. The CoE's will allow for R&D driven by the industry, will be systems-oriented and domain-specific, and join the efforts of multiple disciplines. The CoE's will overcome the current fragmentation of research efforts and address the need of appropriate education, skills development and standardisation. Public support should share the high risks and achieve the goal of world-leading CoE's.

For ARTEMIS it is important

- to support the operation of distributed industrial eco-systems,
- to establish a new infrastructure of multidisciplinary Centres of Excellence,
- to assure the involvement of universities and research institutes,
- to attract large enterprises,
- to stimulate the creation of start-ups and spin-offs in the supply industry,
- to pursue the implementation of industrial research,
- to launch a series of action plans to consolidate the eco-systems.

6.6.5 A PPP needs Professional Management

Required administration

The principles of openness and transparency require a professional management. The agreements of the partners have to recorded and published. The multitude of actions have to properly managed and reported.

Governance bodies

In many successful PPP dual governance structure has been used. One is the executive branch of the partners and another is an independent body that is responsible for the evaluation of the executive management and advising the management in matters of orientation.

Roadmap based on strategy agenda, and trends and impacts

A **roadmap is the main instrument** used for selection of applications and industry sectors that will be focus of funding R&D activities. The roadmap has to be defined on basis of the strategy research agenda and the results of this study regarding worldwide trends and impacts (chapter 3 and 4). The focus of the roadmap has to be to strengthen the European leadership in ES.

PPP results

Apart from the engagement of each partner the life of the PPP is expressed by the number of successful projects, workshops, conferences performed, and results published in yearly reports and on their Web site.

Life cycle of a roadmap

A **periodical evaluation of the results** is needed in order to adjust the roadmap and the operational process. Evaluations should be based on a thoroughly selected set of measures (using for example the Advanced Technology Program as reference model for assessments).

For ARTEMIS it is important

- to establish a professional administration,
- to elaborate and use an operational process to ease coordination and cooperation,
- to prepare a roadmap as basis for the operational programme,
- to establish transparent and efficient processes to manage a large number of projects and activities, learning from experiences from ITEA and FP6,
- to define measurement criteria for the evaluation of the PPP results,
- to perform habitual, rigorous and systematic evaluations.

Annexes

A Research and Methodology

A systematic procedure and consistent methodology were the prerequisites to obtain an overview of the Embedded Systems domain, to focus on **worldwide trends** from the technological and sectorial point of view, and of **worldwide** on-going **R&D initiatives and programmes** at **public** and **private** level. The strategy and methodology used for the identification and collection of **information sources**, for the elicitation of the state of the art and the assessment technological changes and their impacts are described in the following.

A.1 Identification and Evaluation of Trends

Through the mutual dependencies and the complexity of the Embedded Systems area (see section 2.3), we needed to develop a taxonomy to describe standards and trends in Embedded Systems. On the basis of a literature review and discussions with experts in different areas, **four dimensions** were chosen that allow different views on Embedded Systems and their trends and challenges:

- **Industry trends** as experienced by users through new application specific solutions in each of the domains. These domains have been chosen such that the industries most important for the future developments of Embedded Systems are covered. In addition, these sectors share similar trends with many of those which cannot be explicitly presented here.
- **Technological innovations** that are relevant for several domains are not described as part of a specific solution, but in a separate chapter in order to find mutual dependencies between application specific trends and technologies. The technological advancements are splitted up in hardware and platform software related topics. This separation was chosen to structure the technological trends – not to state that isolated approaches which focus either on hardware or software without considering the other can be successful.
- **General market trends** show the user needs that are valid for a broad range of solutions and technologies.
- **Systems engineering challenges** to derive recommendations how the trends and challenges in the first two dimensions can be tackled best. These “solutions” are often based on new processes, methods and tools that are to be introduced to serve more than one sector since the basic challenge is to handle the more complex systems and the ways they are developed. . The authors are well aware of the overlaps in this study, for example between the industry trends and the systems engineering trends. The difference is that, in section 4.4, we describe method, process and tool related topics that are valid for most of the industry sectors. More

application related issues are described in the chapters on the respective domain, i.e. section 4.2.

These four dimensions are shown in Figure 4-1 in section 3.1. There are many developments that can be accounted to and presented in more than one of these dimensions. But we decided – for example – to present sector or industry specific trends in section 4.2 and separate from overlapping trends in hardware and platform software which are covered in section 4.3. Thus, we introduced a higher level of abstraction when subsuming several specific developments in the chapters on technology, engineering or market trends. We believe this increases the added value of this study, since most findings in these three sections can be adopted for applications outside the "original" sector or solution.

As opposed to scenario-based roadmaps such as [ROADNL2002], our approach did not rely on top-down application scenarios. Relevant trends were compiled in a bottom-up fashion instead. Our approach, which we applied successfully in several other studies before, such as [KIT2000], [IGS2001], [KIT2003], is based on several steps; each of them will be described later in more detail.

After dividing up the field, the most important topics in each of these dimensions have been investigated through an intensive **Web and literature review** (see A.4.1). After that, we refined the topics through **interviews** with experts from academia and industry (see A.4.2) to identify higher-ranking needs (or **"market-trends",** see 0) as well as specific theses and detailed topics that allow a very detailed analysis for each part of the study. Thus, individual trends are identified and classified to one or several high-level concerns.

Finally, a broad **online survey** (see A.4.3) was conducted to validate these findings from the literature. We conducted the interviews, to integrate the individual trends and subjective expectations and to collect additional suggestions. Many experts in different countries and with different professional backgrounds participated.

Thus, the trends and standards described in this document are based on four pillars: literature investigation, **Web** research, interviews, and online questionnaire.

This approach guarantees that existing knowledge and experiences have been used comprehensively. Research results as well as individual perceptions detailed knowledge as well as fundamental estimations have been incorporated with this process.

To manage the information overload and to enable a synergy effect, special care was taken to manage the information sources and to make all findings available for all chapters (see A.4).

After identifying trends in the different domains, we formulated **recommendations on the technologies and the engineering issues** and their future potential**.**

As a first step, every trend was seen as a potential area that needs to be supported. To select the promising topics, several criteria were used:

- analysis of existing **quantitative and qualitative results**, e.g. on market size, to motivate and substantiate the potential recommendation,
- analysis of **impact on European competitiveness**, either by numbers or qualitatively,
- analysis of **Europe's market position and its potential** to improve it by public support (as an example, supporting highly price-sensitive technology areas where Europe has a strong technological backlog are not seen as promising areas of research),
- analysis of **mutual dependencies between technical and applied solutions** and the spill-over effects on other industry sectors or technology areas; e.g. investments

in the improvement of engineering methods and processes are not limited on the sector or horizontal domain initially supported through a program.

These criteria ensure that only those technologies and trends are recommended for support that have the potential to generate substantial returns on the initial investment.

As the most important field, we see the improvement of engineering methods and tools, since their use – in most cases – covers several sectors and has a very long-term effect. In contrast, explicit support of single technologies bears the risk of short-term results and is dependent on market trends that can be subject of short-term changes. Nonetheless, we tried to identify and take into account mutual dependencies between technical and applied solutions and trends, based on the selected application-domains and to assess the influence of technical solutions to productivity and competitiveness.

A.2 Identification and Evaluation of R&D Expenditures

In order to find the amount of **worldwide** investments in R&D for Embedded Systems it would be necessary to analyse "all" countries.

However, it is justified to reduce the task to the relative small number of countries that are active in Embedded Systems. In order to find those countries, a first boot-strap approach was used.

A.2.1 Selecting relevant Countries and Finding Data

In a first step the five countries with the highest economical power were analysed. The top 5 countries, comparing their GDP based on their Purchasing Power Parity were EU, US, China, Japan and India. The assumption that the economically rich countries also invest most in R&D is justified, as the top 5 together invest 90% of the total R&D expenses worldwide.

In a second step was noted that although the top 5 countries lead the GDP by a large margin, there were other countries like Taiwan and Australia that had relative low GDP but came close or even exceeded India in their investment of GERD. In addition for Taiwan it was known, that the country has placed their focus on high-tech products suggested a high ratio of funding for ES. Hence Taiwan and Australia were also analysed.

The data on GDP and GERD was readily available for OECD countries in online databases from OECD [OECD2005], of the European Intelligence Unit [EIU2005], and of the world bank [WBData2005]. Since all data was differing slightly a decision was made to base all data on the **OECD database**. Only for India no general data could be found and we had to rely on partial evidence from Internet news.

In a next step we were searching the **Web** for international comparisons or annual reports. Searching for **keywords** like "Embedded Systems" did not yield satisfying results. Most successful were keywords like "scoreboard", "GovERD", "R&D GERD" that resulted in a wealth of scoreboards from EU, Canada, Taiwan, and Australia. Even though the data was useful to get circumstantial evidence in terms of patents filed or in terms of Internet connections per inhabitant, it was not apt, however, to deduce efforts specific for ES.

For all countries an extensive search in official **Web** pages of the governments of the countries was performed. Difficulties were encountered by the language barrier, by figures in local currency that had been inflation corrected or by not finding numbers. It was critical to get a complete picture of the government, in order to be able to sum up all figures. In other countries the problem consisted in avoiding counting programmes twice if they were partially funded by two ministries, who both referred to the programme.

When funding programmes lasted for more than one year, the budget was evenly split over the years and only the budget for one year, preferable **2003**, was counted. For Europe the European Funding Programme FP7 and the EUREKA projects MEDEA and ITEA were considered, plus a list of funding programmes that were collected within the project of CISTRANA.

In order to estimate the public funding for Embedded Systems a survey performed by the project CISTRANA [CIS2005] was used. In that survey all nations were asked to report the list of their national funding programmes in Information Technology along with a short description of the objectives of the programmes.

A.2.2 Calculating Private R&D Expenditures

To overcome the lack of data on private investment in R&D, in particular, investments allocated to Embedded Systems, we analysed in detail the data of the top 700 enterprises in terms of R&D investment [Dti2004].

Our analysis is based on an elaborate methodology comprising of the following steps:

No	Step to derive at BERD for ICT and ES of private industry per sector and country
1	Estimation of R&D factors for ICT and ES per sector
2	Published data on 700 private enterprises were mapped into sectors defined in chapter 3 deriving a relevance factor.
3	R&D factors defining the percentage of R&D for ICT and ES, as stated in chapter 3 have been multiplied with the relevance factors of step 2.
4	The R&D expenses of each company were divided by their sales figures to derive a matrix of R&D intensity factor for each sector and country.
5	Adopting the approach of a study by IDATE the R&D factors were modulated by the R&D intensity factors of step 4, resulting in a matrix of country specific R&D factors for each sector.
6	The R&D expenses of each company were multiplied by the country and sector specific R&D factors as calculated in step 5.
7	The R&D expenses were for each country converted into PPP € values using conversion factors from OECD.
8	The converted R&D expenses of all companies of a country results in a country specific share (X-factor) of the 700 companies on the total BERD of the country.
9.	All data in step 7 was extrapolated using the X-factor to give estimations for the total worldwide R&D expenses per country and sector by the private industry in ICT and ES.

Table A 1: Listing of method for calculating BERD in ICT and ES

The method listed in Table A 3 is described in more detail below and is valid in its own right. We shall first describe the steps of the method in detail and show how the results for ICT match with [IDATE2002] and [CSTI2003] at the end of this chapter.

Step1: Estimate R&D factors per sector

The R&D factors for ES in Table A 2 state the percentage of R&D expenses within each sector that are related to ES. The factors have been estimated on basis of data provided by the questionnaire resulting in a range for each factor. The ranges were further narrowed by using the judgements of experts in interviews [Rei2005], [Büt2005], [Tim2005], different studies and reports [ASAR2005][DGBMT2005] against the definition of sectors as used by VDC [VDC2004]. The authors of the study estimated R&D factors for ICT considering the additional research necessary for non-embedded software for sector specific adaptations, simulations, control and management of data. Thus for avionics the R&D factor for ICT is higher than for automotive, as there is a greater need for formal verification and simulation. The industry domain of health and medical equipment focuses on medical equipment as can be seen by the domain definition in Table 3-1 in section 3.2.

2003 Industry domains	R&D-ES factors	R&D-ICT factors
Automotive	30%	40%
Avionics and Aerospace	35%	60%
Industrial Automation	30%	70%
Telecommunications	55%	80%
CE and Intelligent Homes	40%	60%
Health and Medical Equipment	20%	50%

Table A 2: R&D factors for ES and ICT assumed for this study

It should be noted that ICT is used here as a classification of technologies and not as a sector. With this understanding the R&D efforts for Embedded Systems are an integral part of the R&D efforts in ICT.

Step2: Deriving the relevance factors

Each enterprise of the 700 is registered in a specific economic groupings following the categorisation used it the FTSE[7] Global Classification Systems, which is widely used at the Stock Exchange. A mapping of FTSE classes into the sectors used in this study is only possible to a limited extent, as indicated by the relevance factor in Table A 3.

In the sector “CE” as described in section 5.2.1., for instance, we estimated that only 90% of the companies were relevant with respect to our definition of the sector “CE and Intelligent Homes”, as the FTSE “Media & entertaining class” also contains companies like Time Warner.

In the FTSE class “IT hardware” no distinction is made between IT hardware and hardware for telecommunication. Comparing the R&D expenses of the companies revealed that a split of 50:50 is valid.

Likewise companies within the FTSE class of “Health” were producing medical devices, but they were also active in clinical research. For lack of more data the assumption was

[7] The company originated as a joint venture between the Financial Times and the London Stock Exchange.

made that 50% of the R&D expenses were related to the medical equipments and 50% related to the clinical research.

A new class or ICT services was introduced by combining the FTSE classes of software and telecommunication services. Finally a large number of FTSE classes were grouped together under the heading of others, as they are not relevant for R&D in Embedded Systems.

Industry domains	FTSE- Classes	Top 10 Companies	Rele-vance
Automotive	Automobiles & parts	Toyota Motor, Nissan Motor, Honda Motor, DaimlerChrysler, BMW, Ford Motor, General Motors, Renault, Denso, Harley-Davidson	100%
Avionics and Aerospace	Aerospace & defence	Boeing, Honeywell, Lockheed Martin, EADS, General Dynamics, Northrop Grumman, Raytheon, BAE Systems, Smiths, Rolls-Royce	100%
Industrial Automation	Engineering & machinery	Illinois Tool Works, Caterpillar, Volvo, Deere, Danaher, Ingersoll-Rand, Paccar, Thyssen Krupp, Sandvik, Mitsubishi Heavy	100%
	Electricity	Electricite de France, Tepco, Areva, Kansai	100%
ICT hardware (new)	IT hardware (incl. telecom)	Intel, Cisco Systems, Dell, Hewlett-Packard, Qualcomm, Nokia, Ericsson, Motorola, Texas Instruments, Taiwan Semiconductor	50% 50%
Consumer Electronics and Intelligent Homes	Electronic & electrical	Siemens, Samsung Electronic, Canon, Matsushita Electric, Sony, Philips Electronics, Emerson Electric, Sharp, Schneider, Ricoh	90%
	Household goods & textiles	Swatch, Mattel, Adidas-Salomon, Newell Rubbermaid, Black & Decker, Electrolux, Whirlpool, Yue Yuen Industrial, Brunswick, Hasbro	
	Media & entertainment	Time Warner, Vivendi Universal, Fuji Photo Film, Dai Nippon Printing, Reuters, Eastman Kodak, Toppan Printing, Konica (now Konica Minolta), Scientific-Atlanta, Pentax	
Health & Medical Equipment	Health	Abbott Laboratories, Medtronic, Boston Scientific, Stryker, Zimmer, Baxter International, Guidant, St Jude Medical, Becton Dickinson, Synthes-Stratec	50% 50%
ICT Services (new)	Software & computer services	Microsoft, IBM, Oracle, SAP, Yahoo!, Nintendo, Electronic Arts, Computer Associates, Symantec, Adobe Systems	100%
	Tele-communication services	Vodafone, NTT, Deutsche Telekom, Telefonica, France Telecom, Telecom Italia, BT, Telstra, KDDI, TeliaSonera	
Others (new)	Banks, Beverages, Chemicals, Construction & building, Diversified industrials, Food & drug retailers, Food producers, Forestry & paper, General retailers, Leisure & hotels, Oil & gas, Personal care & household, Pharma & biotech, Speciality & other finance, Steel & other metals, Support services, Tobacco, Transport, Utilities - other		-

Table A 3: Mapping of FTSE economic groups to industry domains used in this study

Step3: Relevant R&D factors for the 700 companies

The classification of FTSE has introduced new sectors for which R&D factors need to be estimated.

For the telecommunication hardware we can use the R&D factors from Table A 2. For IT hardware we assumed lower R&D factors of 30% and 35% for ES and ICT respectively, because many components are used and controlled by PC drivers, without the need for extensive research in ICT for management of data or networks.

A new class or ICT services was introduced by FTSE and a R&D factor for ES was derived from the analysis of funding programmes in Europe (see Table 5-11), ignoring the high ratio of Australia and Asia.

In health for the research for medical equipment again the factors from Table A 2 were used, but for other research no relevance to ES was assumed.

Analysing the companies grouped under the heading of others, revealed that about 50% of all R&D expenses were consumed by the pharmacy industry. For those companies it is obvious that some research in R&D for ICT is needed to cope with the huge data volume. Hence it was assumed that an overall R&D factor for ICT of 5% is valid for companies in that category.

Multiplying the relevance factors of the Table A 3 with the R&D factors result in relevant R&D factors that will be used for calculating R&D expenses of companies classified by FTSE.

2003 FTSE classes and domains	R&D-ES Factor	R&D-ICT Factor	Rele-vance Factor	Relevant ES-Factor	Relevant ICT Factor
Automotive	30%	40%	100%	30%	40%
Avionics and Aerospace	35%	60%	100%	35%	60%
Industrial Automation	30%	70%	100%	30%	70%
IT-hardware & telecommunications				43%	58%
Telecommunications	55%	80%	50%	28%	40%
IT-Hardware	30%	35%	50%	15%	18%
CE and Intelligent Homes	40%	60%	90%	36%	54%
Health & Medical Equipment				10%	45%
Medical Equipment	20%	50%	50%	10%	25%
Health without "	0%	40%	50%	0%	20%
ICT Services	10%	100%	100%	10%	100%
Others	0%	5%	100%	0%	5%

Table A 4: Mapping of R&D factors from industry domains onto classes of FTSE for 2003

The derived relevant R&D factors for ICT and ES are shown in a diagram in Figure A 1.

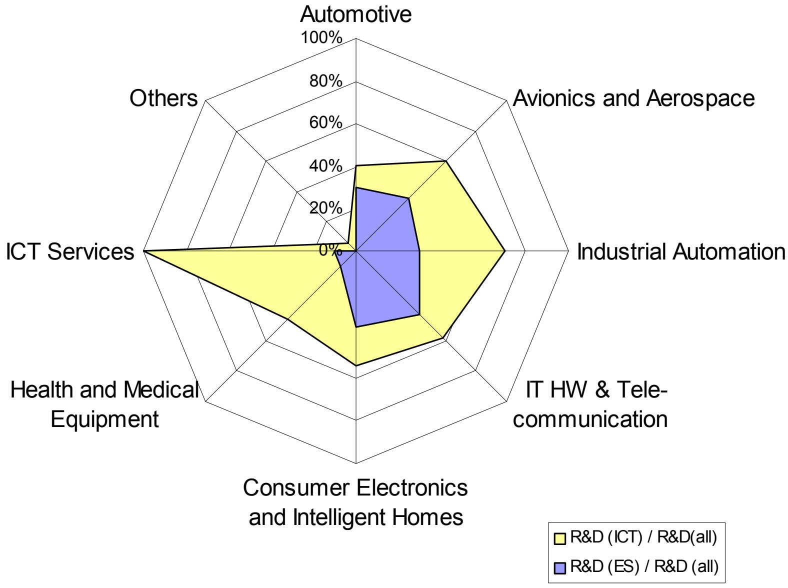


Figure A 1: Relative R&D factors for ICT and ES

Step4: R&D intensity factor for each sector and country

The R&D intensity was calculated from the data of the 700 top companies by dividing their expenditures in R&D by their sales figures in 2003.

2003 / Country	Automotive	Avionics and Aerospace	Industrial Automation	IT-Hardware & Tele-communications	Consumer Electronics and Intelligent Homes	Health and Medical Equipment	ICT Services	Others
EU	4.8%	7.6%	3.3%	17.5%	4.9%	6.2%	8.7%	12.7%
US	9.2%	3.8%	2.8%	22.1%	5.3%	8.6%	17.7%	79.7%
JP	4.7%		3.1%	8.4%	5.1%	5.7%	5.2%	5.7%
CN								0.6%
TW			0.7%	9.5%	4.5%			
KR	2.1%		1.2%		4.7%		2.4%	1.3%
AU							2.9%	1.0%

Table A 5: Average investment of companies relative to their sales figures in 2003 (calculated from DTI [Dti2004])

Table A 5 shows that **major players in US make higher investments relative to their economical power** than those in Europe. Second there are a number of companies, especially in the pharmaceutical sector where public money is used to substantially support research that amounts to 880% of the sales.

However, when averaging the ratio over all companies in one country the ratio provided a weighting for the interesting sectors. In order to compensate for general differences in the R&D intensities of countries, the ratios were normalised to give 100% for the IT-hardware & telecommunication sector in each country.

Step5: Country specific R&D factors for each sector

In a study by the IDATE institute [IDATE2002] the contribution of the ICT sector to the gross domestic product (GDP) was used to derive a R&D factor for ICT.

Following this line of arguments the **R&D intensity**, calculated by step 4, was used to modulate the R&D factors of each sector per country.

The reason behind this argument draws on the fact that the companies that invest more in R&D also invest more into ES and ICT considering that those areas are secondary or "outside" their domain. On the other hand companies that only invest a small budget into R&D will focus on their main topics.

The application of Table A 5 onto the relative R&D factors for ICT and ES from Table A 4 results in a modulation of the relative R&D factors for each country and sector based on the R&D intensity of each sector in each country in Table A 6.

2003	Automotive	Avionics and Aerospace	Industrial Automation	IT-Hardware & Tele-communications	Consumer Electronics and Intelligent Homes	Health and Medical Equipment	Others	ICT Services
ICT factor	**40%**	**60%**	**70%**	**58%**	**54%**	**45%**	**100%**	**5%**
EU	11%	26%	13%	58%	15%	16%	50%	4%
US	17%	10%	9%	58%	13%	17%	80%	18%
JP	22%		26%	58%	33%	31%	63%	3%
TW								5%
KR			5%	58%	25%			
ES factor	**30%**	**35%**	**30%**	**43%**	**36%**	**10%**	**10%**	
EU	8%	15%	6%	43%	10%	4%	5%	
US	12%	6%	4%	43%	9%	4%	8%	
JP	17%		11%	43%	22%	7%	6%	
TW								
KR			2%	43%	17%			

Table A 6: Relative R&D factors for ICT and ES in bold and their relative importance in the countries (2003)

Step6: R&D expenses for ES and ICT from the 700 companies

Using the data from the R&D expenses of the 700 companies their R&D expenses in ICT and ES can be calculated.

2003 from 700 companies [Dti2004]	Automotive	Avionics and Aerospace	Industrial Automation	IT-Hardware & Tele-communications	Consumer Electronics and Intelligent Homes	Health and Medical Equipment	Others	ICT Services
BERD (ICT)	**4.3 b€**	**1.2 b€**	**0.9 b€**	**16.5 b€**	**5.2 b€**	**0.5 b€**	**8.7 b€**	**4.5 b€**
EU	1.5 b€	1.0 b€	0.4 b€	3.9 b€	0.9 b€	0.1 b€	1.3 b€	0.8 b€
US	1.2 b€	0.2 b€	0.1 b€	9.1 b€	0.3 b€	0.4 b€	6.1 b€	3.4 b€
JP	1.6 b€		0.4 b€	3.2 b€	2.7 b€	0.0 b€	0.9 b€	0.2 b€
TW								0.0 b€
KR			0.0 b€	0.4 b€	0.0 b€			
BERD (ES)	**3.2 b€**	**0.7 b€**	**0.4 b€**	**12.2 b€**	**3.4 b€**	**0.1 b€**	**0.9 b€**	
EU	1.1 b€	0.6 b€	0.2 b€	2.9 b€	0.6 b€	0.0 b€	0.1 b€	
US	0.9 b€	0.1 b€	0.0 b€	6.7 b€	0.2 b€	0.1 b€	0.6 b€	
JP	1.2 b€		0.2 b€	2.3 b€	1.8 b€	0.0 b€	0.1 b€	
TW								
KR			0.0 b€	0.3 b€	0.0 b€			

Table A 7: R&D expenses for ICT and ES of the 700 companies in current € for 2003

Step7: R&D expenses for ES and ICT from the 700 companies in PPP

Using the conversion rates for the countries for 2003 the expenses were converted into PPP€.

PPP factor in PPP€ / Cur	2003	2002	2001	2000	1999
EU	1.1	1.1	1.1	1.1	1.1
US	1.0	1.0	1.0	1.0	1.0
JP	0.9	0.9	0.8	0.8	0.8
CN	4.6	4.6	4.5	4.5	4.4
TW	2.0	1.9	1.8	1.8	1.7
Korea	1.6	1.6	1.6	1.7	1.7
Australia	1.4	1.4	1.4	1.4	1.4
UK	1.0	1.0	1.0	1.0	1.0
India	5.4	5.6	5.6	5.7	5.9
HongKong	1.2	1.2	1.1	1.1	1.0

Table A 8: Conversion factors calculated using OECD conversion rates to US$ and PPP$ [ODB2005]

Step8: Calculating the country specific X-factor

In Table A 9 the consolidated and converted R&D expenses of the 700 companies are listed per country and compared with the total BERD of that country using the data from OECD [ODB2005], to derive the country specific share of BERD.

2003 Country	Number of companies	BERD (700) in 2003 in PPP	total BERD in 2003 in PPP [ODB2005]	X-factor %
EU	217	57,7 b€	127,5 b€	45%
US	306	56,9 b€	186,6 b€	30%
JP	154	29,4 b€	81,4 b€	36%
CN	2	0,8 b€	50,2 b€	2%
TW	8	0,9 b€	8,1 b€	11%
KR	9	3,5 b€	17,7 b€	20%
AU	2	0,3 b€	4,3 b€	7%
Total	698	149,5 b€	471,5 b€	32%

Table A 9: R&D expenses (in PPP€) of the 700 companies that invested most into R&D in 2003

The X-factor is calculated by comparing the total R&D expenses of all companies, out of the 700 of one country with the R&D expenditures of all industry in that country, in other words with the BERD of that country as listed by OECD [ODB2005].

Step9: Extrapolating the BERD of ICT and ES

The data calculated in step 7 is extrapolated using the X-factor from step 8 and result in the table stated in text (see Table 5-6 and Table 5-7 respectively).

Validation of our methodology

Applying the above methodology ultimately results in a matrix of R&D factors that are specific for country and sector. One can regard the factors as parameters of a complex model to calculate the desired BERD in ICT and ES. For ES no comparable figures are available, but for ICT one could use the study of IDATE [IDATE2002] and the study by the French Conseil Stratégique des Technologies de l''Information [CSTI2003] to validate the methodology.

Since the original R&D factors per sector from chapter 3 were derived in a similar fashion, it can be legitimately assumed that the model will also produce correct figures for ES if those for ICT are valid.

The good match for EU, US and JP of the data shown in Table A 10 justifies the assumption made in our estimates for the R&D factors. The data for the other Asian countries like South Korea are less reliable due to the few companies present among the top 700. It is known that many of the top 700 are based outside Asia, but still invest into R&D in Asia. Nevertheless the resulting numbers are quite striking, as they **confirm the data on ICT from studies** from **IDATE** [IDATE2002] and by a later study from the **Strategic Advisory Board on IT for the French Ministry** [CSTI2003], although these studies analysed in much more detail the expenditures in ICT in the various countries.

2003	BERD(ICT) in PPP		BERD(ICT)/ BERD in %		
	based on DTI	CSTI 2003	based on DTI	CSTI 2003	IDATE 2002
EU	21.7 b€	21.9 b€	17.0%	17.6%	18.2%
US	68.0 b€	52.3 b€	36.4%	28.0%	35.0%
JP	24.8 b€	22.3 b€	30.4%	27.4%	33.6%
KR	7.7 b€	9.4 b€	43.6%	53.0%	-
TW	4.0 b€		49.2%		-

Table A 10: Comparison of Business R&D expenditure in ICT of DTI extrapolated and [IDATE2002],[CSTI2003]

Table A 10 thus confirms the picture that Europe only invests 17% of BERD into ICT compared with 35% in US. The Table 5-7shows a slightly better picture for **Europe for investments into R&D for ES. The ratio of R&D for ES to BERD is 9% for Europe, 15% for US, Japan 19% and 36% for Taiwan**. The difference arises from the different ratios of sectors in the areas.

A.2.3 Calculating Public R&D Expenditures

In order to estimate the total public funding for ICT and ES an average R&D factor across all sectors of a country is needed, as it is not possible to split the indirect public funding into sectors.

The study of Strategic Advisory Board on IT for the French Ministry [CSTI2003] estimated the R&D factors for ICT, as shown in Table A 11. Surprisingly the **governments tend to invest much less into ICT than industry**. With the exception of Europe where only 8% of public funds were reserved for ICT, other countries had R&D factors for ICT of about 10%.

2002	GERD(ICT)/ GERD	BERD(ICT) /BERD	pubGERD(ICT)/ pubGERD
EU	14.3%	17.6%	7.8%
US	22.9%	28.0%	10.4%
JP	23.7%	27.4%	10.6%
KR	41.2%	53.0%	9.9%

Table A 11: Comparison of R&D factors for ICT for 2002 [CSTI2003]

Consequently an estimation of the public R&D expenditures for ICT and Embedded Systems can be made using the R&D factors for ICT from Table A 11 and maintaining the same ratio of the R&D factors for ICT/ES as in the business sectors to construct the R&D factor for ES. The results are shown in Table 5-10.

A.2.4 Calculating Public R&D Expenses of Funding Programmes

Generally funding programmes are, with a few exceptions, not specific for Embedded Systems, but more generally for IT or research in telecommunications. Nevertheless, many projects are funded that have a high relevance to Embedded Systems.

As it is not possible to analyse all funded projects, a general classification of the programmes in terms of their intent to fund projects related to Embedded Systems was made, based on the descriptions of the research topics of the programmes.

Research topics relevant for Embedded Systems are defined by the **software aspect** of Embedded Systems, as described in section 2.1 and refer to:

- autonomous working,
- spontaneous networks of possibly large dimensions.
- fault tolerance and
- real time concerns,
- system engineering including the real world aspect,
- minimising the use of resources in terms of memory, battery and processing time.

The list of concern is neither complete nor exclusive, hence a simplified means for estimating the percentage of embedded software was used. All programmes were classified into one of five categories:

Category	Description	Percentage of ES
A	no embedded software contained	0%
B	contains Embedded Systems, but the soft aspect is minimal, due to simple functionality	5%
C	contains stand-alone Embedded Systems, with controlling functionality of higher complexity	20%
D	contains multi-functional or connected Embedded Systems with high constraints	50%
E	fully focussed on Embedded Systems	100%

Table A 12: Classification of FP based on software aspects related to ES

The method used is a rough estimation, as it considers earmarked budgets and not budget paid to concrete projects. The **choice of 5 categories** is sufficient for this granularity of analysis. A clear distinction is made for the categories A and E. The other categories may not be correct for each individual programme, but the errors made will be averaged over the large number of programmes analysed.

For Europe the preliminary results of the survey performed by CISTRANA were used and a total of 122 **funding programmes** of 23 European countries were categorised in terms of relevance for topics of Embedded Systems. The budget of each programme was evenly distributed over the live period of the programme to give an average figure of budget spend per year.

The method is quite accurate if a country had a large number of small programmes, which could be categorised. The method is crude if only one funding programme of a country is given, as was the case in UK. Without further information such a general funding programme was assigned to the category B.

To give an impression of how the description of funding programmes were used to assign a ES-category, examples of programmes in each category are given using the funding programmes as reported by CISTRANA from Finland:

	Funding Programme	Funding Period	Total Public Funds	Average Funds in ES
A	Fenix : Hybrid-media and entertainment applications www.tekes.fi/english/programmes/fenix The Programme has four focus areas: • Content management applications that ensure easier and more accurate creation, storage, distribution and finding of information in various network services • Game and entertainment applications often requiring technically demanding solutions. Often involving software technology, computer graphics, multimedia content and telecommunications technology • Community interaction services meaning solutions for the virtual assembly of large groups of people, for voicing opinions and learning • Hybrid-media meaning applications that combine paper and electronic media or properties of printed and infocom products The topics are rather general and not specific to Embedded Systems.	2003-2007	39 M€	0 M€
B	MASI - Modeling and simulation www.tekes.fi/ohjelmat/masi Focus areas • multiphenomena/multiscale modeling • modeling methods and tools • development of services and business processes • utilization of modeling in industry/service sector The extension of modelling to real world multphenomena and multscale projects is often needed in embedded engineering.	2005-2009	46 M€	1,15 M€
C	CONE - Converging Networks www.tekes.fi/ohjelmat/cone The main objective are: • To intensify and enhance the national strengths of the broadband communication • To strengthen the strategic basic research and applied research know-how in the field of broadband communication • To create new strategic know-how in the key broadband technologies • To increase international cooperation especially in the research field between universities and research institutes • To contribute to the international standardization	2005-2010	100 M€	8,00 M€

	Funding Programme	Funding Period	Total Public Funds	Average Funds in ES
	The key features in broad band communication are based on embedded processors and quality of service, related to like real time, reliance and security.			
D	Vamos - Value Added Mobile Solutions www.tekes.fi/ohjelmat/vamos Goals are: • Increase utilizing wireless & mobile technology widely in industries like paper, traffic, constructions and services, • Improve productivity by developing mobile solutions for businesses, • Improve internationally successful mobile business solutions • and create new business opportunities. The embedded technology has to work together to utilize new business opportunities. Some parts are, however, related to business solutions in general.	2005-2010	30 M€	4,80 M€
E	NETS - Networks of the Future technologies of wireless systems and networks www.tekes.fi/ohjelmat/nets The objectives of the NETS Programme are: • to promote the leading position of the Finnish telecommunications industry in technologies of wireless systems and broadband packet switched networks, and also in the technology sectors critical for the current and future business • to generate new business opportunities for the markets of wireless and broadband networks, terminals, and software for achieving an internationally leading position • to promote leading positions of Finnish enterprises as innovators and developers of applications, services, and contents based on the mobile and broadband technologies • to expand and diversify the business and service activities utilising telecommunications technologies The emphasis is not to apply existing knowledge, but to create new technology and functionality for embedded telecom systems.	2001-2005	102 M€	25,50 M€

Table A 13: Use of classification of FP according to software aspect in ES (values in PPP)

In some cases, e.g. Japan and China, it was not possible to find descriptions of funding programmes that were matched with allocated budget.

In the case of Japan the ratio of funding for ICT was estimated by using the ratio of researchers in mechanical engineering, shipbuilding and aeronautical engineering to the total of researchers. The ratio of ES funding was estimated with a flat 5% corresponding to the category B.

For China, instead of funding programmes, a list of laboratories was used for the classification into the categories and used to extract a ratio for ICT and ES.

A.3 Identification and Evaluation of Initiatives similar to Technology Platforms

The task was to report about best practices of successful public-private partnerships mainly in high-tech areas. Although it makes sense to learn of the experience made by similar initiatives, it is always necessary to take into account that transfer implies certain risks if frames and conditions, cultures and research traditions are not respected and harmonise with the objectives of the new initiative.

In a first step we aimed to identify similar initiatives to Technology Platforms. Thus, we focused on **public-private partnerships (PPP)** related to the/an Information and Communication Technology (ICT) area and on **business eco-systems,** mainly those with a centralised location. The most successful eco-systems are well known and relevant information could be found. In addition, we extended our scope to include initiatives in the automotive area where such organisations have been very successful in the past.

The **second step** of our approach consisted in the **selection of a reduced number of similar cooperative initiatives** for the analysis in detail, instead of a broad review of all similar cooperative initiatives. Instead, the selection allows for the illustration of the most relevant characteristics and best practices of technology partnerships. The criteria for the selection of PPP were: the fact that they are a relevant reference within a specific community, the achievement of their goals, the existence for a long period of time, and their relation to the information and communication technology area.

Our list of public-private partnerships and clusters include:

- Asia Nano Forum (ANF), Asia
- Association of Radio Industries and Businesses (ARIB), Japan
- Cambridge High Tech Business Cluster, Great Britain
- Center for Hybrid and Embedded Software Systems (Chess), US
- Cooperative Research Centres (CRC), Australia
- DSP Valley, Leuven, Belgium
- Embedded Systems Institute (ESI), The Netherlands
- Interuniversity Micro Electronics Centre (IMEC), Belgium
- ITEA and MEDEA within Eureka initiative, Europe
- International SEMATECH, US.
- Multimedia Super Corridor (MSC), Malaysia
- NASA Ames Research Center, US
- Silicon Valley, US
- Sophia Antipolis, France
- Scottish Enterprise, Great Britain

The **third step** consisted in the **search of information** about the selected PPP and clusters. We mainly used the Web to find the appropriated documents, such as

roadmaps, studies and reports. The documentation allowed us for an analysis of the governance structure and modus operandi of the PPP in depth.

It was not our goal to provide an exhaustive report of all the characteristics of each public-private partnership we analysed. In fact, most of them have similar structures and base their organisation and operation on similar operational practices. Our objective was to make a more comparative analysis showing examples of best practice of operation, coordination activities and transfer of results. We focus mainly on those, which have been proven to be effective, but also are innovative for fields such as Embedded Systems.

The aim of the **fourth and last step** was to present a set of **recommendations for the establishment and operation** for the Technology Platform in Embedded Systems based on the comparative analysis done.

A.4 Management of Information Sources

The results in this study could only be achieved and derived by working with different types of information, ranging from technology reports to individual opinions. All of the data are important to draw a picture that is as complete as possible. Nevertheless, some sources have a bigger importance for different sections than others. Table A 14 shows the relevance of a source type for every section.

	Information Sources Used for	Objectives of EC	Web	Questionnaire	Interview Key Player	Country Contacts	Interview R&D Org	Other Studies	Financial data	Conferences	Patents
	Foreword										
	Executive Summary										
1.	Introduction	x									
1.1	Background Information	x									
1.2	Objectives of the Study	x									
1.3	Scope of the Study	x									
1.4	Structure of the Study										
2.	Characteristics of ES	x	x	x	x		x	x	x		
2.1	Definitions and Characteristics	x	x					x			
2.2	Penetration of ES	x	x		x						
2.3	Challenges in R & D		x	x	x		x	x			
2.4	Conclusions	x			x			x	x		
3.	Impact on Market Development, Productivity and Competitiveness		x	x	x	x		x	x	x	x
3.1	General Overview		x	x	x	x		x	x	x	

	Information Sources Used for	Objectives of EC	Web	Questionnaire	Interview Key Player	Country Contacts	Interview R&D Org	Other Studies	Financial data	Conferences	Patents
3.2	Impact on Industries		x	x	x	x		x	x	x	x
3.3	Compliance with Policies		x	x				x			
3.4	Conclusions	x	x	x	x			x		x	
4	Trends in ES	x	x	x	x			x	x	x	
4.1	General Market Trends			x	x			x		x	
4.2	Industry Trends		x	x	x			x	x	x	
4.3	Technology Trends		x	x	x			x	x	x	
4.4	Contributions in Systems Engineering			x	x			x		x	
4.5	Recommendations	x		x	x						
5.	R&D Programmes and Initiatives for ES		x	x	x	x	x	x	x		
5.1	Key Indicators					x		x	x		x
5.2	Business R&D Expenses				x		x	x	x		
5.3	Public R&D Expenses					x		x	x		
5.4	Recommendations				x			x			
6.	Initiatives Similar to Technology Platforms	x	x	x	x	x	x	x		x	
6.1	Examples for Public-Private Partnerships		x		x	x	x	x			
6.2	Stakeholders and Leadership in Public-Private Partnerships		x		x	x	x	x			
6.3	Eco-Systems of High Tech Clusters		x					x		x	
6.4	Successful Governance Structure		x	x				x		x	
6.5	Best Practice in Modus Operandi		x		x	x	x	x		x	
6.6	Recommendations	x	x	x	x	x	x	x			

Table A 14: Information Sources and their relevance for the chapters of this study

For all sources it is extremely important to make sure that the selection of information sources does not cause any bias or lead to any regional or thematic focusing that is not meant. The detailed approach in each step is described in the following.

A.4.1 Literature and Web Research

The complexity of the Internet with its millions of related Web pages of unstructured information requires a methodological and structured research approach in order to find relevant data with a sufficient degree of completeness. Therefore the team kept track of the search strategies used and kept a record on data found.

A bibliographic database has been set up in order to maintain references to books, magazines, articles and reports related to this area that are valuable for the readers. In this database, all sorts of documents and links have been collected and catalogued. It is of capital importance for the use of the document. Since this study cannot describe all various trends in depth, this **bibliographic database** can also be used as a comfortable entry-point for further in-depth information on the respective trends.

When collecting data, we focussed on roadmaps by major industry players, technology reports by (market) research groups, project reports (IST, ARTEMIS, ARTIST Roadmap for Research, ITEA EAST EEA Scenario 2005 etc.) and academic literature (e.g., http://citeseer.ist.psu.edu/ or http://scholar.google.com/, which enable to search specifically for scholarly literature including peer-reviewed papers, theses, books, preprints, abstracts and technical reports from all research areas), other books and articles, newsgroups, and press rooms.

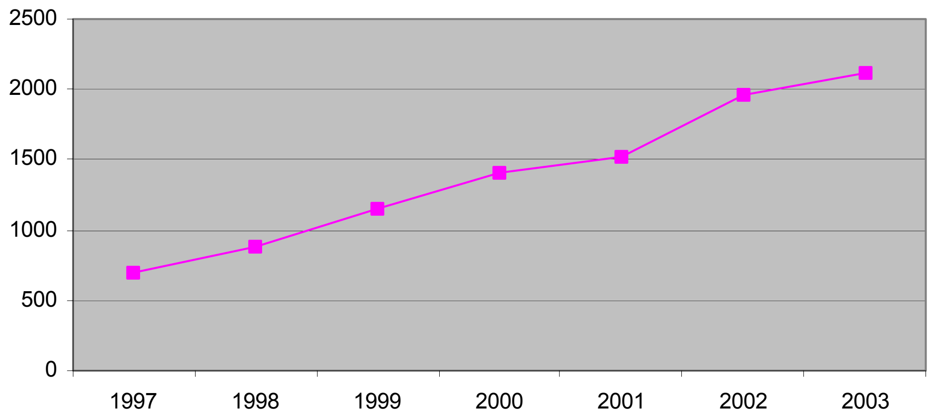


Figure A 1: Number of hits for searching the phrase "Embedded Systems" in scholar.google.com

Additionally, due to the requirements for this study, **governmental information sources** have been identified and various governmental reports on funding programmes and results have been obtained.

Through the broad and careful analysis of all these relevant documents, a detailed, worldwide picture of embedded technologies could be obtained as a first step for the study. All documents we refer to in this study can also be found in Bibliography.

A.4.2 Interviews

After reviewing existing trend studies and research reports, interviews were organised with experts who work for international companies and/or have a strong international background through international co-operations or their exposure to the latest results

from research and industry. The interviewees were selected to cover all domains and fields of interest for the study. These discussions helped to detail the topics and to derive theses and expectations that have been used as input for the questionnaires.
From March to May, the interviews with experts in the relevant fields have been conducted as the second pillar for the further work. It was important to choose experts from **multinational companies** and/or with a **strong international perspective**. The authors are grateful that the following persons invested several hours to provide their knowledge and additional information:

- Andrey Bachvarov, Sciant AG
- Wolfram Büttner, Infineon AG
- Bruce Douglass, I-Logix
- Florian Grätz, Institute for Machine Tools and Industrial Management, Technische Universität München
- Alexander Klapproth, Hochschule für Technik und Architektur Luzern
- Ralf Kompe, 3Soft GmbH
- Marloes van Lierop, Embedded Systems Institute
- Nassir Navab, Computer Aided Medical Procedures and Augmented Reality, Technische Universität München
- Claus Oetter, VDMA
- Rupert Reiger, EADS AG
- Wilhelm Stork, Institute for Information Processing Technology, Universität Karlsruhe
- Martin Timmerman, Dedicated Systems
- Eric Verhulst, Open License Society
- Jing You Wan, School of Software Engineering, Tongji University, Shanghai/China

The interviews were based on a **list of topics and questions**, which has been developed during the first step, i.e. the literature review. Also, interviewees were confronted with some of the statements of other people from around the world. This is a very important means to gather arguments and identify interrelations.

When the first results of the online survey (see next section) had been released, additional interviews with experts from outside Europe were scheduled to discuss some of the results acquired so far and get background information on them. The authors are grateful that

- Shigeharu Teshima, Toyota Central R&D Labs (Japan)
- Drora Goshen, Israeli Aircraft Industries (Israel)

provided helpful information and discussed the preliminary results:

All of these discussions provided **helpful additional information**. But maybe the most important aspect of the interviews was to understand the interrelations between the different dimensions and their trends. The discussions often detected connections between individual answers from the survey or results from the literature review since the complexity of some changes and challenges cannot be read out from even the most comprehensive reports. This aspect confirmed that the engineering dimension of Embedded Systems development is absolutely needed to derive applicable results and recommendations

A.4.3 Questionnaires

After the first round of interviews, a questionnaire was prepared that covers the topics identified as being most relevant for the study. The answers were evaluated to

- identify further problems and challenges not detected so far,
- show statistically significant data on different topics to support and to broaden the results.

The questions could be answered over a Web interface set up as a PHP application with mySQL as database or as a printed version that was sent back by regular mail or fax and added to the database.

To guarantee that true data is submitted and to maximize the number of participants, the survey has been anonymous. On the other hand, participants were asked to select the organisation they work for, select the application domains as well as the technology areas they have expertise in and name their country of residence. Thus, although being anonymous, this valuable data about the experts' background was used to make the questionnaire context-dependent. According to the personalization, only the relevant parts of the survey were displayed in order to collect the respective information.

The questionnaire was designed to deliver timelines and numbers as well as information on different topics. Therefore, the evaluation delivers two distinct types of results:

- **quantitative analyses** for questions that asked for percentages, absolute numbers or check marks. Therefore, a system of question types and respective statistical methods has been developed. For the interpretation and presentation of quantitative data, different statistic methods have been used.
- **qualitative analyses:** text provided by the participants has been collected, analysed and integrated into the results. These comments and suggestions were a helpful source for additional information, brought up further issues or formulated recommendations to tackle problems.

For three weeks, more than 2,000 persons from more than 30 countries have been informed about the survey and over 240 filled it out entirely. The results of the online survey are listed in annex C.

A.4.4 Assessment and Classification of Patents relevant to ES

Besides asking the experts in the field the number of patents granted and the number of publications are the key indicators for market trends and R&D activities.

Different **tools for patent research** have been analyzed:

- *Impadoc* provides full-text search but this services is neither on-line nor for free. Users who want to use Impadoc services must fill a form with search information, which is sent to the European Patent Office in Vienna. Printouts are send back by regular mail. Some commercial hosts offer access to Impadoc databases via their own query systems.
- *Derwent* claims to be the most comprehensive database of value-added patent documents published in the world. However it includes only 13.5 million unique basic patent records (see http://thomsonderwent.com/products/patentresearch/dwpi). Derwent is also not for free.
- *Access* is a PC-based patent research tool offering a full-text search of the project titles. Although Access is not for free the licence is quite accessible. The yearly fee is about 200 Euros and monthly updates are included in this price. Moreover, at many libraries Access is available for free.
- Esp@cenet®: is the European Online Patent Service, a free service offered by the European Patent Organisation's (EPO) [ESP2005], where patents dating back to 1970 can be accessed online. In February 2005, esp@cenet®, held data on 50 million patents from 71 countries. A total of 25.6 million of these patents have only a

title, 26.2 million have a title and a patent classification, and 16.6 million patents have an abstract in English.

The choice had been to use the **European Online Patent Service, Esp@cenet**, as it was online and the abstracts were sufficient for the purpose of this study. The following search facilities are provided:

- quicksearch with keywords, or for persons or organisations,
- advanced search using any of the available fields,
- number search using application, accession, publication or priority number,
- classification search for browsing in a sector by the Classification System of the European Patent Office.

Every record has the following layout:

MICRO CONTROLLER FOR PROCESSING COMPRESSED CODES	
Inventor:	YAMADA HIROMICHI (JP); ABE YUICHI (JP); (+2)
Applicant:	HITACHI LTD (US)
EC: F03G7/10	IPC: G06F9/30
Publication info:	US2005021929 - 2005-01-27

- On top appears the title of the patent.
- In the second line the inventor(s) and the third line are applicant(s) listed.
  The two letter code between brackets is devoted to the country code of the inventor respectively applicant.
  Inventor, Applicant, EC, and IPC might have attached a number between brackets with the plus sign prefixed, indicating that there are more entries, but only two are shown.
- The fourth line is reserved for the European classification and international patent classification (IPC).
- The publication info contains the publication number and the publication date, the application number and the application date or a priority number for a bundle of patents. The first two letters of the number are the country code of the patent office (US in this case).
  Unfortunately, the country code information is not always available. Moreover, sometimes all fields besides Publication Info are empty.

Search results of Esp@cenet

Given the data above for each element in the result list of a search the following fields were extracted and stored with each search:

- Keyword(s) in title (in English), for example “plastic AND bicycle”
- Title, for example “MICRO CONTROLLER FOR PROCESSING COMPRESSED CODES”
- Publication number assigned when published, for example “ US2005021929”
- Publication date, e.g. 2005-01-27
- Applicant, for example “ HITACHI LTD”
- Inventors, for example “ YAMADA HIROMICHI “ and “ABE YUICHI”
- European Classification (ECLA), for example “F03G7/10”
- International Patent Classification (IPC), for example “ G06F9/30”

Finding relevant patents with a list of keywords

The International Patent Classification (IPC) is a hierarchical classification system applied to published patent documents. Unfortunately “Embedded Systems” does not fit in this classification, as the classification states the affected sectors and not the technology used.

Searching for the term “embedded system” in title or abstract resulted in only 342 patents in the database containing the exact words. In order to find patents related to Embedded Systems a **large list of key words** was therefore used (see annex Table A 17). For each key word the patents found in the period of January 2000 up to May 2005 were recorded:

2005 Sector	# Keyword	# Patents
General	46	85.868
Electronics	34	37.249
Telecommunication	12	33.868
Consumer Electronics	28	27.474
Medical	16	23.002
Militar	6	15.846
SE	9	12.359
Automotive/Avionics	11	449
Financial	1	437
OS	5	228
Sum	168	236.780

Table A 15: Classification of key word into sectors and number of patents found in 2005

Using a list of keywords to find relevant patents has two obvious risks:

- The list of key words may not be complete, which implies that not all relevant patents can be found. This is an error that cannot be easily fixed, but that will be uniformly distributed across all countries and for the entire period of time considered. The resulting list of patents may be too conservative, but the relative comparison will be correct.
- The keywords may not be selective enough. For each keyword within the result list random entries were checked manually and in some cases the keywords had to be refined, as in “digital+input”, where only the combination was selective enough.

Using the already mentioned keywords in multiple inquires a total of 612.914 patent records were found and reduced to **215.484** patents by eliminating the double counting.

Without redundancy the resulting patents and keywords were stored in a database for further analysis. An **overview of the patents per year and country** is given in Table A 16

Patents in from Country		Year 2000	2001	2002	2003	2004	2005	Sum
Asia		**17.940**	**17.636**	**20.451**	**21.321**	**15.957**	**2.288**	**95.593**
JP	Japan	14.158	14.075	15.869	15.295	10.401	1.879	71.677
KR	Korea	2.394	1.414	1.830	2.046	627	169	8.480
CN	China	659	1.132	1.580	2.312	3.392	101	9.176
TW	Taiwan	628	907	1.013	1.505	1.340	102	5.495
…..								
North America		**8.645**	**14.817**	**17.308**	**16.925**	**14.984**	**4.580**	**77.259**
US	USA	8.147	14.360	16.822	16.406	14.482	4.415	74.632
CA	Canada	491	453	473	500	475	157	2.549
…..								
Europe		**6.735**	**6.315**	**7.115**	**6.866**	**6.148**	**1.378**	**34.557**
DE	Germany	2.596	2.161	2.314	2.167	1.806	319	11.363
FR	France	1.197	1.127	1.289	1.254	1.220	139	6.226
GB	Great Britain	726	732	845	850	771	278	4.202
NL	Netherlands	362	421	536	624	586	167	2.696
SE	Sweden	423	418	531	366	380	90	2.208
…..								
Australia		**1.188**	**1.698**	**1.065**	**1.502**	**1.812**	**134**	**7.399**
Russia		**463**	**369**	**473**	**715**	**868**	**12**	**2.900**
Africa		**37**	**50**	**38**	**51**	**43**	**9**	**228**
South America		**30**	**20**	**35**	**48**	**37**	**17**	**187**
Arabic Countries		**4**	**5**	**12**	**2**	**5**	**3**	**31**

Table A 16: Table of patents found related to ES per country and year

The following table includes the keywords used for patent and Web research.

Sector	Keyword	Patents
AUTOMOTIVE/AVIONICS	avionics	241
	driver+assistance	90
	antilock+braking+system	46
	automotive+system	22
	automatic+landing	19
	unmanned+aerial+vehicles	10
	drive+by+wire	7
	guidance+computer	5
	inertial+guidance+system	4
	automatic+take+off	3

Sector	Keyword	Patents
	fly+by+wire	2
CONSUMER ELECTRONICS	digital+camera	5205
	digital+video	4899
	video+camera	4408
	PDA	3040
	digital+audio	2858
	personal+digital+assistant	1863
	joystick	1105
	digital+tv	977
	cd+player	672

Sector	Keyword	Patents
	dvd+player	664
	digital+receiver	349
	mp3+player	263
	home+automation	248
	digital+music	225
	video+projector	221
	electronic+music	177
	digital+photo	128
	personal+information+manager	65
	multifunctional+printer	27
	videogame	23
	infotainment	20
	photocopy+machine	16
	intelligent+home	7
	multifunction+wristwatch	4
	minidisk+player	4
	intelligent+house	3
	electronic+speaking	2
	electronic+synthesizer	1
	chip	11636
	electronic+device	9508
	microcontroller	3062
	digital+signal+processor	2438
	firmware	2076
	electronic+controller	1449
	lcd+display	1180
	microchip	972
	image+detector	571
	spectrum+analyzer	569
	programmable+logic+controller	544
	oscilloscope	534
	computer+peripheral	460
	digital+device	330
	photometer	302
	digital+controller	287
	digital+clock	184
	rs232	179
	logic+analyzer	156
ELECTRONICS	rs+232	151

Sector	Keyword	Patents
	embedded+processor	146
	electronic+locking	123
	circuit+emulator	96
	digital+decoder	95
	embedded+microprocessor	59
	digital+compass	33
	digital+appliance	21
	digital+voltmeter	21
	digital+watch	21
	digital+motor	15
	flash+drive	13
	embedded+electronics	10
	embedded+cpu	7
	digital+wattmeter	1
E	automatic+teller+machine	437
	sensor	11642
	actuator	11366
	sensors	10831
	robot	7820
	transceiver	7688
	microscope	6753
	actuators	6098
	card+reader	3730
	usb	3486
	mobile+device	2273
	rfid	1940
	digital+communication	1439
	digital+output	1205
	digital+input	1157
	sim+card	954
	laser+printer	880
	pcmcia	694
	digital+interface	676
	surveillance+system	614
	man+machine+interface	559
	digital+storage	495
	handheld+device	476
	image+projector	364
GENERAL	angiography	344

Sec-tor	Keyword	Patents
	laser+pointer	343
	smartcard	301
	distributed+control+system	256
	answering+machine	228
	information+appliance	182
	watchdog+timer	169
	IRDA	168
	wearable+computer	155
	passive+safety	115
	information+acquisition+device	103
	laser+projector	101
	embedded+computer	70
	system+on+chip	53
	firewire	47
	embedded+network	35
	windows+CE	21
	java+card	12
	wireless+sensor+network	10
	zigbee	8
	UAVs	5
	ambient+intelligence	1
	transputer	1
MEDICAL	x+ray	9096
	magnetic+resonance	4866
	endoscope	4724
	tomography	2566
	pacemaker	852
	biochip	658
	ultrasonography	79
	digital+thermometer	58
	biometric+system	44
	electrocardiography	33
	blood+pressure+manometer	15
	encephalography	5
	digital+blood+pressure	3
	electromagnetic+epilepsia	1

Sec-tor	Keyword	Patents
	magnetoscope	1
	laparascope	1
MIL	scanner	8634
	radar	5716
	missile	1230
	MMI	224
	scatterometer	41
	electronic+weapon	1
OS	real+time+operating+system	170
	embedded+operating+system	43
	j2me	6
	javaos	5
	embedded+linux	4
SE	image+processing	9075
	digital+signal+processing	1855
	DCS	458
	mobile+computing	382
	embedded+system	310
	embedded+systems	182
	embedded+software	76
	embedded+java	11
	dedicated+system	10
Telecommunication	modem	6716
	gps	6587
	mobile+phone	6536
	router	5446
	gsm	2552
	global+positioning+system	1859
	umts	1390
	gprs	1031
	cell+phone	1019
	digital+telephone	324
	general+packet+radio+service	229
	universal+mobile+telecommunicatio	179

Table A 17: List of key word used to filter out patents related to ES (2005)

B Data on Funding Programmes

Using the methodology described in A.2.2 the funding programmes of Europe, US, Japan, China, India, Taiwan and Australia were categorised. Based on the categorisation (Table A 12) and the budget allocated for the funding programmes the estimation on the public funding related to ES is derived for each country.

Usually only the funding programmes of the sectors in IT, communications and electronics were presented, as the other funding programmes were all of category A, e.g. not relevant for ES. From the funding programmes analysed the ones related to ICT were specially marked to allow a comparison of funding for ES with funding for ICT.

B.1 Europe

In Europe public funding is available on the European and national level. On the European level funding is issued through the 5th Framework Programme and via the Eureka Programme, mainly through MEDEA [MED2005] and ITEA [ITEAW05]. For the national level the funding programmes of all European countries have to be analysed. Fortunately the list of all ICT funding programmes of 23 European countries with a description of the programmes and data on the duration and budget had been compiled in a previous study by CISTRANA [CIS2005].

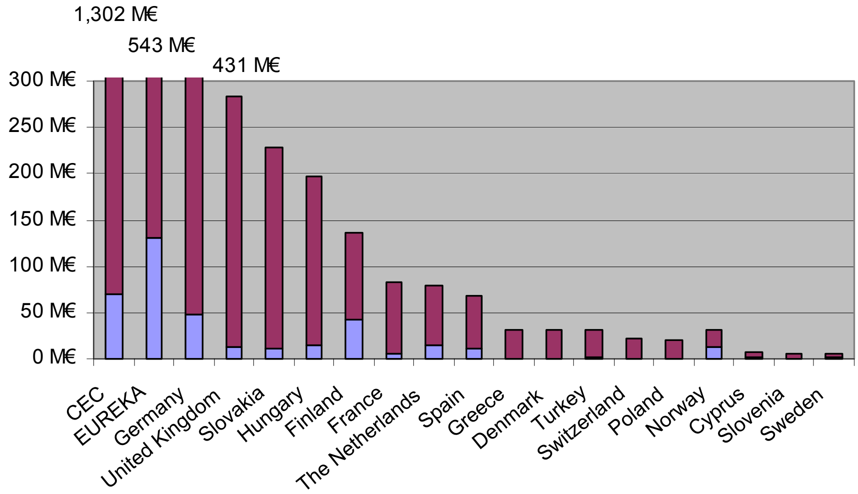


Figure B 1: Budgets in FP for ES in Europe estimated for 2004

Using the classification scheme described in annex A.2.4 each of the 122 funding programmes from CISTRANA was classified. The average budget of each programme per year was calculated and multiplied with the relevant factor as listed in Table A 12.

The classification can only be as precise as the description of the funding programmes. For countries with only one funding programme, like UK, the category B was chosen, thus estimating a flat 5% for all research within that programme being relevant for ES.

As for all European countries the conversion factor for PPP (see Table A 8) is close to 1 the conversion was not deemed necessary, given the large error margin of the estimations.

A graphical representation of the funding situation for ES in Europe is shown in Figure B 1 and in tabular form in Table B 1.

The analysis of the funding programmes reveals that public funding is mainly granted on the European level. On the national level the main performers are Germany and Finland.

ID	Country	R&D-ICT Based on Cistrana [CIS2005]	R&D-ES Using categories for each FP	R&D (ES/IT)
FR	France	77.93 M€	5.00 M€	6%
CH	Switzerland	21.58 M€	0.78 M€	4%
CY	Cyprus	5.10 M€	1.91 M€	38%
CZ	Czech Republic	1.32 M€	0.26 M€	20%
DE	Germany	431.37 M€	47.12 M€	11%
DK	Denmark	30.26 M€	0.50 M€	2%
ES	Spain	56.65 M€	3.70 M€	7%
FI	Finland	128.47 M€	43.22 M€	34%
GR	Greece	30.58 M€	0.58 M€	2%
HU	Hungary	182.60 M€	14.00 M€	8%
LV	Latvia	0.17 M€	0.00 M€	0%
NL	The Netherlands	64.20 M€	15.58 M€	24%
NO	Norway	18.01 M€	13.40 M€	74%
PO	Poland	21.12 M€	0.00 M€	0%
RO	Romania	1.74 M€	0.00 M€	0%
SE	Sweden	4.00 M€	1.10 M€	28%
UK	United Kingdom	270.00 M€	13.50 M€	5%
SK	Slovakia	216.67 M€	10.83 M€	5%
SI	Slovenia	4.07 M€	0.89 M€	22%
TR	Turkey	30.00 M€	1.50 M€	5%
EU	EUREKA (MEDEA & ITEA) [ASRA2005], [MED2005], [ITEAW05]	542.92 M€	130.00 M€	24%
	CEC (5th Framework Programme, 5th Call)	1,301.70 M€	70.00 M€	5%
		3,404.30 M€	381.74 M€	11%

Table B 1: R&D budgets in FPs for ICT based on Cistrana and data from CEC and EUREKA. Estimates for the R&D budget for ES are based on a classifiation of funding programmes. Average yearly spending for 2004 were calculated.

B.2 USA

The funding situation in US is rather complex, as many ministries (agencies) contribute to budgets of specific funding programmes, which therefore are reference in many places. Fortunately the Network and IT R&D Programme [NITRD2005] compiled a list of all funding programmes related to IT and networks across all agencies, which was used to get a consolidated picture. In addition to the consolidated data from NITRD the budgets allocated by the Department of Defense (DoD), as far as published in DARPA, can be added. Note that there are other public expenditures from DoD, which are not published and do not appear in this list.

The total budget for ICT and ES has to be compiled by adding the two tables.

2003			Relvant for	
Name	**NITRD-Programmes**	**CAT**	**ITC**	**ES**
HEC-I&A	High End Computing Infrastructure and Applications ((I&A) of super computers	A	0.58 b€	0.00 b€
HEC-R&D	High End Computing Research and Development ((R&D) algorithms for complex simulations	A	0.32 b€	0.00 b€
MCI&IM	Human Computer Interaction and Information Management (HCI&IM) from smart floors to multimedia systems for disabled people and recognising robots	B	0.33 b€	0.01 b€
LSN	Large Scale Networking in high performance, secure and scalable networks	E	0.33 b€	0.30 b€
SDP	Software Design and Productivity experiments in new visions for SW-design for multidisciplinary distributed and dependable software development (ES)	E	0.21 b€	0.19 b€
HCSS	High Confidence Software and Systems reflect the central role played by software in the overall reliability, security, and manageability of the Nation's most complex and critical computing and communications systems	E	0.13 b€	0.12 b€
SEW	Social, Economic and Workforce Implications of IT and IT Workforce Development is concerned with HR education, IPRs and dynamics of IT impact	A	0.10 b€	0.00 b€
			1.99 b€	0.62 b€

Table B 2: Public R&D programmes for networks and IT in US in 2003 in PPP

Additionally the DARPA program of the Department of Defense funded some activities related to Embedded Systems.

2003 in PPP	DARPA	Budget		Relevant for ICT	Relevant for ES
Basic Research	Defense Research Sciences	0.16 b€	A		
Applied Research	Computing Systems and Communications Technology	0.37 b€	C	0.37 b€	0.07 b€
	Embedded Software and Pervasive Computing	0.05 b€	E	0.05 b€	0.05 b€
	Biological Warfare Defense	0.15 b€	A		
	Tactical Technology	0.16 b€	A		
	Materials and Electronics Technology	0.39 b€	B		0.02 b€
Advanced Technology Development	Advanced Aerospace Systems	0.23 b€	C		0.05 b€
	Advanced Electronics Technologies	0.15 b€	D		0.08 b€
	Command, Control and Communications	0.11 b€	D	0.11 b€	0.05 b€
	Sensor and Guidance Technology	0.21 b€	E		0.21 b€
	Marine Technology	0.02 b€	B		0.00 b€
	Land Warfare Technology	0.16 b€	B		0.01 b€
	Classified DARPA Programs	0.25 b€	B		0.01 b€
Management Support	Small Business Innovative Research	0.06 b€	A		
	Management HQ	0.10 b€	A		
		2.58 b€		0.50 b€	0.55 b€

Table B 3: R&D programmes by the department of defence (DARPA) in 2003 in PPP

B.3 Japan

An extensive Web research of the official publications of the ministry of education, culture, sports, science and technology [MEXT2005] only allowed the collection of qualitative data on the vision, goals and results of funding programmes, but no quantitative data on budget.

Using the general data on GERD and the data on fields of sectors for engineers one can assume that only 24% of all researchers (see Table B 4) are active in fields that are likely to engage in R&D for ES. Without further data a category B with a flat 5% for ES was estimated for the R&D work of these researchers.

2002 Researchers in Organisation Field of science	Total	Business enter-prises	Non-profit inst-itutions	Public organisations	Universities and Colleges
Total	**769,822**	**461,962**	**14,035**	**35,992**	**257,833**
Natural sciences and engineering total	**675,116**	**458,417**	**12,368**	**33,480**	**170,851**
Physical sciences total	**126,864**	**89,758**	**3,193**	**8,223**	**25,690**
Mathematics and physics	33,899	19,950	463	2,044	11,442
Chemistry	70,402	60,909	1,112	3,586	4,795
Biology	13,597	5,598	976	1,558	5,465
Geology	1,482	635	304	543	-
Others	7,484	2,666	338	492	3,988
Engineering and technology total	**398,703**	**337,642**	**6,828**	**9,660**	**44,573**
Mechanical engineering, shipbuilding and aeronautical engineering	124,528	113,247	1,085	2,629	7,567
Mechanical engineering, shipbuilding and aeronautical engineering	186,265	168,425	2,026	2,229	13,585
Civil engineering and architecture	21,208	10,988	2,273	828	7,119
Material	17,786	14,501	257	1,110	1,918
Textile technology	3,308	2,878	40	390	-
Others	45,608	27,603	1,147	2,474	14,384
Agriculture sciences total	**40,870**	**15,079**	**1,497**	**12,519**	**11,775**
Agriculture, forestry, veterinary and animal husbandry	26,506	6,693	1,170	8,739	9,904
Fishery	4,465	1,300	157	1,861	1,147
Others	9,899	7,086	170	1,919	724
Medical sciences total	**108,678**	**15,937**	**850**	**3,078**	**88,813**
Medicine and dentistry	78,600	684	626	1,289	76,001
Pharmacy	19,640	13,749	136	1,135	4,620
Others	10,438	1,504	88	654	8,192
Social sciences and humanities, Other sciences	**95,908**	**4,747**	**1,667**	**2,512**	**86,982**

Table B 4: Researchers by field of science (headcount, 2002)

Assuming average annual personnel costs of 130 k€ results in an indirect measure of the expenses for the sectors.

2002	Total	Business enterprises	Non-profit institutions	Public organisations	Universities and Colleges
Total personal costs for researchers	100.08 b€	60.06 b€	1.82 b€	4.68 b€	33.52 b€
Percentage of electrical and telecom engineers	24%	36%	14%	6%	5%
Personal costs for electrical and telecom engineers	24.21 b€	21.90 b€	0.26 b€	0.29 b€	1.77 b€

Table B 5: Personal costs of researchers in electrical and telecom in 2002 in PPP

B.4 India

The Department of IT published the annual plan for 2005-06 [ITIN2005].

	Department of Information Technology Annual Plan 2005-06	PPP b€	Cat	PPP b€	Rs.[8] Crore
I. R&D PROGRAMMES	1 Society for Applied Microwave Electronics Engineering and Research (SAMEER)	0.0195	A	0.0000	20
	2 Microelctronics & Nanotech Development Programme	0.0390	D	0.0195	40
	3 Technology Development Council	0.0166	A	0.0000	17
	4 Convergence,Communication & Strategic Electronics	0.0058	E	0.0058	6
	5 Components & Material Development Programme	0.0097	A	0.0000	10
	6 Centre for Development of Advanced Computing (C-DAC)	0.0585	E	0.0585	60
	7 Electronics in Health	0.0136	B	0.0007	14
	8 Technology Development for Indian Languages	0.0068	A	0.0000	7
	9 IPR Promotion Programme	0.0010	A	0.0000	1
	10 E-Commerce & Info-Security	0.0078	A	0.0000	8
	11 IT for Masses (Telemedicine)	0.0078	D	0.0039	8
	12 Media Lab Asia for the benefit of the poor and needy.	0.0010	A	0.0000	1
II. INFRASTRUCTURE DEVELOPMENT	13 Vidya Vahini & Gyan Vahini Programme Community Information Centers	0.0015	A	0.0000	1.5
	14 Standardization, Testing & Quality Certification (STQC)	0.0409	B	0.0020	42
	15 Software Technology Parks of India (STPI) & Electronics Hardware Technology Park (EHTP)	0.0039	A	0.0000	4
	16 Digital DNA Park	0.0097	A	0.0000	10
	17 Electronic Governance	0.2925	A	0.0000	300
	18 IT Act / Certification & Network Security	0.0068	E	0.0068	7

[8] A crore is 10 million. One Rs crore is approximately 210,000 US$ or 1 million PPP €.

	Department of Information Technology Annual Plan 2005-06	PPP b€	Cat	PPP b€	Rs.[8] Crore
	19 Community Information Centres (CIC)	0.0487	A	0.0000	50
	20 Setting-up of Megafab	0.0097	A	0.0000	10
III. HR-DEVELOP	21 Training Centers (DOEACC)	0.0097	B	0.0005	10
	22 Manpower Development	0.0195	A	0.0000	20
	23 Sp. Manpower for VLSI Design	0.0127	E	0.0127	13
IV. OTHERS	24 Headquarter (Secretariat & Bldg.)	0.0095	A	0.0000	9.7
	25 Semiconductor Complex Limited (SCL)	0.0001	E	0.0001	0.1
	26 National Informatics Centre for Internet Infrastructure (NIC)	0.2535	A	0.0000	260
	Grand Total	**0.9060**		**0.1106**	**929.3**

Table B 6: Annual plan for 2004 and 2005 from the Ministry of IT in PPP

B.5 China

The government of China publishes statistical data at a online portal [CN2005]. The data on the China Statistical Yearbook 2004 within that portal is split into twenty-five chapters. The data in chapter 21 on "Basic Statistics on Scientific Research and Development Institution" (No. 21-34)[9] is shown in Table B 7:

Item	2000	2001	2002	2003
Expenditure on R&D *)	26.05 bYuan	25.80 bYuan	28.85 bYuan	35.13 bYuan
Conversion (0.52 Yuan/PPP€)	13.62 b€	13.49 b€	15.09 b€	18.37 b€
Percentage for ICT **) (10.4%)	1.42 b€	1.40 b€	1.57 b€	1.91 b€
Percentage for ES **) (3,9%)	0.53 b€	0.53 b€	0.59 b€	0.72 b€
Category C (20%)	0.11 b€	0.11 b€	0.12 b€	0.14 b€

Table B 7: Statistics published at the online portal of the government of China converted into PPP

Since all research is done in laboratories, the description of the laboratories was used to classify them into categories related to ES or ICT. Assuming a uniform split of budget across all 154 laboratories [MOST2005] the factors of 10.4% for ICT and 3.9% on ES were derived.

[9] *) 21-34 Basic Statistics on Scientific Research and Development Institution from China Statistical Yearbook 2004 [CN2005].

**) from percentage of the list of laboratories

2004	Key Laboratories in China	ICT	Nano	ES
154	Count on Laboratories	16	8	6
100%	Percentage of Laboratories	10.4%	5.2%	3.9%
1	State Key Laboratory of Ultrafast Laser Spectroscopy			
2	State key laboratory of solid State microstructures		x	
5	State Key Laboratory of Applied Optics		x	
8	State Key Laboratory of Superconductivity		x	
43	State Key Laboratory of Silicon Material		x	
45	State Key Laboratory for Advanced Technology of Materials Compositization		x	
60	State Key Laboratory of Computer Software Engineering	x		
63	State Key Laboratory of Intelligent Technology and System	x		x
64	State Key Laboratory on Machine Perception			x
65	State Key Laboratory of Pattern Recognition	x		x
67	State Key Laboratory of Information Security	x		
68	State Key Laboratory for Novel Software Technology	x		x
69	State Key Laboratory of Resources and Environ mental Information System	x		
83	State Key Laboratory of functional materials for informatics		x	
85	State Key Laboratory of High performance ceramics and superfine microstructure		x	
101	State Key Laboratory of local area fiber optic and all-optical communication networks	x		
105	State Key Laboratory of microwave and digital communications	x		
106	State Key Laboratory of automobile safety and fuel conservation			x
114	State Key Laboratory of Theoretica and computational chemistry	x		
135	State Key Laboratory of Mechanical Manufacturing Systems Engineering	x		
140	State Key Laboratory of Theory and Chief Technology of Itegrated Services Networks	x		
141	State Key Laboratory of Broadband Optical Fiber Transmission and Communication System	x		
142	State Key Laboratory of Software Development Environment	x		
145	State Key Laboratory of Advanced Metalsand Materials		x	
148	State Key Laboratory of Switching Technology & Telecommunication Networks	x		
149	State Key Laboratory of Information Engineering in Surverying, Mapping and Remote Sensong	x		x
153	State Key Laboratory of Automobile Dynamic Simulation	x		

Table B 8: List of relevant key laboratories in China of total of 154 laboratories

B.6 Taiwan

The public funding can be split into three groupings: the **academic research** in national labs and universities, the **general funding** and a **special program for Science and Technology** [YBTW2004].

Subsequently a list of all research programmes in Taiwan is given and each programme is **rated with respect to its dedication towards Embedded Systems**. The category ranges from A (no ES) to E (fully dedicated to ES).

Academic Research 2003	Characteristics of the Program	Funding in PPP in billion €	ES in PPP in billion €	Cat
Engineering	Civil, Automation, Avionics, Communication, Computer Science, Power, Control, Micro-electronics, Optics, Industrial, Chemical	0.258	0.039	C
Natural Science	Mathematics, Physics, Chemistry, Biology	0.249	0.000	A
Medical Sciences	Physiology, Public Health, Microbiology, Genomic medicine, Pharmacy research, Nutrition..	0.160	0.000	A
Humanities & Social Science	Chinese Literature, History, Philosophy, Education, Art, Law, Economics, Political Science, Geography	0.142	0.000	A
Science Education	Education, e-Learning	0.048	0.000	A
Agricultural Science	Agronomy, Machinery, Plant protection, Soil, Forestry, Fisheries, Food	0.042	0.000	A
National Science and Technology Programmes	**Characteristics of the Program**	**Funding in PPP in billion €**	**ES in PPP in billion €**	**Cat**
SiSoft National SoC	design automation, silicon IP,	0.092	0.092	E
Nanoscience	nanotechnology platform	0.140	0.000	A
Genomic medizin	understand genome	0.124	0.000	A
Telecommunications	urban broadband and wireless LAN via mobile	0.113	0.000	A
Pharmaceuticals, biotechnology	biochip detector	0.076	0.000	A
Hazard Mitigation	flood models plus map	0.032	0.000	A
Agriculture, biotechnology	technology transfer	0.027	0.000	A
e-Learning	nationwide e-Learning	0.027	0.000	A
Digital archives	open access to digital archives	0.016	0.000	A
Government S&T Domain Projects	**Characteristics of the Program**	**Funding in PPP in billion €**	**ES in PPP in billion €**	**Cat**
Aerospace	accelerate technology transfer, competitive electronics	0.141	0.028	C
Electronics	CMOS design and production technology, micro-electromechanic, nanometer elctronics, System-on-chip	0.054	0.011	C

Academic Research 2003	Characteristics of the Program	Funding in PPP in billion €	ES in PPP in billion €	Cat
Machinery	industry value chain, focus on breakthrough inventions	0.048	0.010	C
Common Technologies	industrial revitalization, high-tech parks, recruiting overseas S&T personal	0.043	0.002	A
Energy	renewable energy	0.036	0.002	A
Infrastructure Projects	multi-application laboratories	0.026	0.001	A
Materials	highly-competitive key electronic materials and components	0.023	0.001	A
Biotechnology, Health S&T	neuro-science, vaccine research, research on cancer	0.019	0.001	A
Agriculture	international rationalized agribusiness	0.017	0.001	A
eBusiness	operating models for eCommerce	0.014	0.001	A
Information	quickly get products to mass production, digital content of Chinese culture	0.003	0.000	A
Textiles	innovative products (low volume, high-price) high-tech textiles	0.570	0.000	B
Environmental Protection	maintain quality of life	0.094	0.000	A
Transportation	rail, automotive, ship and bicycle	0.071	0.000	B
Animal Husbandry	reducing production and sales costs	0.060	0.000	B
Atomic Energy	nuclear safety controls, fuel cells	0.060	0.000	A
Science Education	interdepartmental, inter-collegiate goal oriented	0.059	0.000	A
Opto-electronics	Adv. and basic research on core technology, acquisition of hi-tech from oversea	0.056	0.000	B
Automation	info management systems, transformation of conventional electronic machinery	0.042	0.000	B
Chemical engineering	key materials for opto-electronics	0.037	0.000	A
Pharmaceuticals	Chinese herbal medicine	0.035	0.000	A
Forestry	remote sensing technology, forest management	0.032	0.000	B
Food Science	functional and vegetarian food	0.023	0.000	A
Fisheries	strengthened restoration of resources	0.020	0.000	A
Meteorology	improvement of forecasting	0.016	0.000	B
Geology	Earthquake forecasts	0.013	0.000	A
Resources	flood and drought prevention	0.012	0.000	A
Civil Engineering	fire safety in high-rising buildings	0.009	0.000	A
Communication	new products integrating services	0.008	0.000	B
Ocean Science	recreation and safety	0.003	0.000	A
Humanities and social studies	future of domestic manufacturing, integration of global resources	0.003	0.000	A

Table B 9: Public funding for academic research [YBTW2004] in 2003 in PPP

B.7 Australia

The Australian Government's Innovation Report 2004-05 [AUInno2005] gives a description of the national funding programmes. The categorisation of the programmes into ES-categories is shown in Table B 10.

A total of 56 million € were invested into research for Embedded Systems. The bulk of the investment was handled by the National ICT Australia Limited (NICTA) [NICTA2004] a union of national laboratories with a strong focus on software engineering for dependable, intelligent systems and human-machine interaction.

Programmes 2004	Description (budget in Australian $)	Funding in 2004	funding related to ES	Cat
Advanced Networks Programme	$21 million is being provided over the next three years to extend the Australian Government's Advanced Networks Programme until 2006–07, to continue and intensify research and to explore opportunities to commercialise leading-edge broadband applications.	0.005 b€	0.000 b€	A
CSIRO National Flagships Initiative	The Australian Government is providing an additional $305 million over the next seven years to the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to enable the development of large-scale collaborative research partnerships, which reflect the National Research Priorities. Flagship Programms in Health, Environment, Energy and Light Metal.	0.031 b€	0.000 b€	A
Extension of Regional Protection Funding	The Australian Government is providing $12.4 million over the next four years to extend Regional Protection Funding that helps regional universities to maintain and build their capacity to carry out research, which is of benefit to regional Australia.	0.002 b€	0.000 b€	B
Health and Medical Research - Overhead Infrastructure Support	The Australian Government will provide $200 million over the next seven years for overhead infrastructure costs for independent medical research institutes.	0.020 b€	0.000 b€	A
Information and Communications Technology (ICT) Centre of Excellence: National ICT Australia	The Centre of Excellence will receive an additional $126.3 million from the Department of Communications, Information Technology and the Arts, and $124.7 million from the Australian Research Council (ARC). This brings the total funding from the Australian Government for the five years from 2006–07 to 2010–11 to $251 million to continue building Australia's competitive advantage in ICT with the ICT Centre of Excellence.	0.036 b€	0.036 b€	E
International Science Linkages	The Australian Government is providing $55.5 million over five years from 2006–07 to continue building Australian links to global research and technologies.	0.020 b€	0.010 b€	D
National Collaborative Research Infrastructure	The Australian Government is providing $542 million over 2004–05 to 2010–11 to continue to provide researchers with access to major infrastructure, link infrastructure funding more directly to Australia's	0.001 b€	0.000 b€	A

Programmes 2004	Description (budget in Australian $)	Funding in 2004	funding related to ES	Cat
Strategy	National Research Priorities and foster greater research collaboration and the collaborative use of infrastructure.			
National Competitive Grants Programme	The Australian Government is providing an additional $1189.2 million for the Australian Research Council (ARC) to maintain the doubling of funding for the National Competitive Grants Programme achieved by *Backing Australia's Ability*.	0.147 b€	0.007 b€	B
Quality and Accessibility Frameworks for Publicly Funded Research	The Australian Government is providing $2.8 million over the next two years to establish Quality and Accessibility Frameworks for Publicly Funded Research.	0.001 b€	0.000 b€	A
R&D Tax Concession	An estimated $390 million is being provided over five years from 2006-07 to continue the new elements of the R&D Tax Concession programme introduced in *Backing Australia's Ability* – the Tax Offset, the 175% Premium R&D Tax Concession and effective life treatment for R&D plant. This funding is in addition to the tax expenditure on the 125% R&D Tax Concession, which is up to $360 million per year (2006–07 estimate).	0.056 b€	0.003 b€	B
Research Infrastructure Block Grants Programme	The Australian Government is providing an additional $554.5 million between 2006-07 and 2010-11 to maintain Research Infrastructure Block Grants (RIBG) support at 20 cents for each dollar of Australian competitive research grant income.	0.133 b€	0.000 b€	A
Research Support for Counter-Terrorism	The Australian Government is providing $7.2 million over the next four years to coordinate and focus research and development to support Australia's counter-terrorism needs.	0.001 b€	0.000 b€	A
sum		0.454 b€	0.056 b€	

Table B 10: Backing Research in Australia 2004-5 [AUInno2005] in PPP

C Results of the Online Questionnaire

Total number of responses:	249

Please tick the areas for which you want to view the detailed results.
For which of the following organisations do you wish do see the results?
Industry or Consulting [117 responses] University or Research Organisation [113 responses] Funding Body or Governmental Organisation [25 responses]
For which of the following sectors do you wish do see the results? (you may select none or several sectors)
Automotive [121 responses] Avionics & Aerospace [65 responses] Health / Medical Equipment [50 responses] Household Appliances and Consumer Electronics [81 responses] Industrial Automation [93 responses] Telecommunitations [91 responses]
For which of the following engineering fields do you wish do see the results? (you may select none or several fields)
Hardware (sensors, actuators, peripherals, power supply, digital hardware) [95 responses] Platform software / firmware / middleware / operating system [158 responses] (Application) software [143 responses] Communication infrastructure (protocols, busses) [88 responses] Systems Engineering [134 responses]

C.1 Industry or Consulting

1. General	
What is the type of your organisation?	
start-up (< 3 years)	7%
small or medium enterprise (SME < 250 employees)	27%
large enterprise	62%
non-profit	4%
What is your role in the organisation?	

technical expert	28%
department/program manager	36%
executive manager	28%
shareholder	0%
other	7%

2. Products/Services						
Estimate what percentage of costs in your products/ services could be attributed to Embedded Systems in the past?	Ø	2000 47%	2001 48%	2002 49%	2003 51%	200 4 51%
In your opinion, what is the likely percentage of costs in your products/ services caused by Embedded Systems in the future?	Ø	2005 51%	2006 52%	2007 52%	2008 53%	200 9 53%
Does your organisation develop Embedded Systems on its own?						yes 78%
Does your organisation buy and integrate Embedded Systems?						yes 68%

3. Research						
Estimate what has been the share of overall R&D investments in relation to the total turnover for your organisation in the previous years (not specific to Embedded Systems)?	Ø	2000 20%	2001 20%	2002 20%	2003 19%	200 4 20%
In your opinion, how will the share of overall R&D investments in relation to the total turnover of your organisation evolve in the future (not specific to Embedded Systems)?	Ø	2005 19%	2006 19%	2007 19%	2008 20%	200 9 20%
What is your organisation's research focus in Embedded Systems? (You may select more then one area.)						
hardware						56%
software						85%
tools						50%
engineering methodologies						55%
user interfaces (e.g. display)						32%
sensors, actuators						33%
communication & network						57%
security						41%
Estimate what has been the share of R&D investment for Embedded Systems in relation to the organisation's annual turnover in the past?	Ø	2000 19%	2001 19%	2002 20%	2003 20%	200 4 19%
In your opinion, how will the percentage of R&D for Embedded Systems in relation to the organisation's annual turnover evolve in the future?	Ø	2005 19%	2006 20%	2007 20%	2008 20%	200 9 20%

4. Education and Training		
Estimate what percentage of developers in your company received training in embedded system within the last 5 years through the following schemes?		
courses		Ø 29.04%
internal seminars		Ø 42.63%
in-house courses		Ø 37.87%
lectures at universities		Ø 11.65%
workshops at universities or research institutes		Ø 13.63%
How much interest exists to send employees to courses at the university?		
	Ø Importance (1=low..4=high)	#responses
block courses	2.18	89
part-time study (in addition to work)	2.29	88
In your opinion, which is the most efficient transfer of knowledge between the university and the industry?		
	Ø Importance (1=low..4=high)	#responses
workshops	3.20	90
seminars at the university	2.83	90
Internet portal	2.51	83

5. Customer concerns		
Please assess the importance of the following concerns of your customers according to importance in your domain within the next 5 years:		
	Ø Importance (1=low..4=high)	#responses
dependability (reliability, safety) of systems	3.81	97
information security	3.37	95
improvement of human-machine interface	3.10	98
compliance with policies & regulations	3.17	97
environmental concerns	2.62	96
improved comfort	2.71	95
more features	2.98	94
mobility	2.90	97
self-organising systems	2.23	96
customisation/individualisation	2.86	97
high performance	3.40	98
low cost	3.51	97
lowest power devices	2.68	97
miniaturisation	2.45	96
adaptability to individual user	2.60	96

dynamic reconfiguration	2.84	97
fault tolerant systems	3.24	96

6. Certification	
Does the fulfillment of certification criteria play an important role in your company?	yes 76%

C.2 Universities and Research Organisation

1. General	
What is the mission of your organisation? (selected/total, multiple selections were possible)	
education	69%
basic research	58%
applied research	81%
How many researchers are employed in your organisation? (Please do not include students)	Ø 368
How is your organisation funded? (average percentage)	
public (flat)	38%
projects (public)	32%
private (flat)	4%
projects (private)	19%
public/private partnerships	7%

2. Education	
What is the current number of students?	Ø 3169
Do you have a special curriculum for Embedded Systems?	yes 37%

3. Research						
What is your current research focus in Embedded Systems? (You may select more than one area.)						
hardware	31%					
software	67%					
tools	52%					
engineering methodologies	62%					
user interfaces (sensors, actuators)	21%					
communication & network	37%					
security	24%					
Estimate what percentage of costs in your products/ services could be attributed to Embedded Systems in the past?	Ø	2000 29%	2001 32%	2002 34%	2003 37%	2004 37%
Please assess the importance of the following user needs according to importance in your domain						

within the next 5 years:		
	Ø Importance (1=low..4=high)	#responses
dependability (reliability, safety) of systems	3.75	122
information security	3.15	122
improvement of human-machine interface	2.98	120
compliance with policies & regulations	2.85	120
environmental concerns	2.46	119
improved comfort	2.64	119
more features	2.84	117
mobility	3.14	121
self-organising systems	2.79	119
customisation/individualisation	2.91	119
high performance	3.15	121
low cost	3.12	120
adaptability to individual user	2.81	117

What are the future topics for research in Embedded Systems? (You may select more then one area.)	
hardware	40%
software	72%
tools	59%
engineering methodologies	66%
user interfaces (sensors, actuators)	40%
communication & network	50%
security	48%

In your opinion, how will the percentage of researchers for Embedded Systems evolve in the future?	Ø	2005 24%	2006 26%	2007 30%	2008 32%	2009 35%

Are you involved in research for industry in Embedded Systems?	yes 80%

4. Evaluation/Publications						
Estimate how many publications in general did your institute have in the last years?	Ø	2000 166	2001 172	2002 178	2003 182	2004 181
Estimate how many patents in general did your institute have in the last years?	Ø	2000 4	2001 4	2002 5	2003 5	2004 5
Estimate what was the percentage of publications on or about Embedded Systems?	Ø	2000 0%	2001 20%	2002 22%	2003 26%	2004 28%
In your opinion how will the percentage of publications on embedded system evolve in the future?	Ø	2005 29%	2006 30%	2007 30%	2008 30%	2009 31%

future?						

Is there any cooperation or coordination of research with other research institutes? (You may select more than one.)	
no	1%
within institute	67%
on a national level	84%
within your region (EU, America, Asia, Australia)	69%
internationally (outside your region)	50%
Is there any cooperation or coordination of research with private industry? (You may select more than one.)	
no	15%
on a national level	77%
within your region (EU, America, Asia, Australia)	45%
internationally (outside your region)	27%

C.3 Governmental Organisations or Funding Bodies

1. General		
What are the main policies for public funding? (Please select the three main policies.)		
strengthen specific sectors		32%
strengthen innovation of companies		84%
strengthen basic research in technology		64%
strengthen cooperations to enable knowledge transfer		72%
create clusters to enable start-ups		32%
strengthen certain regions		12%
strengthen education		4%
attract foreign know-how and investors		12%
How has the ratio public/private funding changed?	increased	19%
	unchanged	19%
	decreased	50%
	don't know	12%
Has the focus/mission of public funding changed?	yes	42%
	no	42%
	don't know	15%

2. Importance of Embedded Systems	
What are the funding sources for R&D for Embedded Systems?	
public	23%

Private	54%
public-private partnership	23%

3. Programmes for Embedded Systems						
For the next questions please state your reference scope.						
one funding programme						40%
all funding programmes of your organisation						30%
all funding programmes of your country						30%
Estimate what percentage of funding in the past was for Embedded Systems within your reference scope?	Ø	2000 22%	2001 37%	2002 37%	2003 33%	2004 30%
How do you think the percentage of funding for Embedded Systems of your reference scope will evolve in the future?	Ø	2005 30%	2006 34%	2007 39%	2008 39%	2009 35%
Organisation that implements the funding programme (decides on funding, monitors the programme).						
public						67%
private						7%
public/private consortia						27%
Which sectors frequently participate in funding programs? (Please tick the five main sectors.)						
aerospace						47%
automotive						65%
household appliance and consumer electronics						47%
industrial automation						53%
telecommunication						65%
transport						12%
chemical						0%
finance						0%
media						6%
military						41%
medical						76%
environmental						12%
energy						6%
government						18%
education						29%
What are the current topics of research in Embedded Systems? (You may select more than one area.)						
hardware						38%
software						75%

tools	50%
engineering methodologies	56%
user interfaces (sensors, actuators)	50%
communication & network	63%
security	25%
What are the future topics for research in Embedded Systems? (You may select more than one area.)	
hardware	43%
software	71%
tools	50%
engineering methodologies	64%
user interfaces (sensors, actuators)	64%
communication & network	57%
security	64%
Who is eligible to participate?	
university or research center	82%
start-up (< 3 years)	65%
small or medium enterprise (SME < 250 employees)	71%
large enterprise	71%
Are single organisations funded or do organisations have to form a consortia?	
single organisation	41%
national consortion	76%
international consortia	41%
Are there regional cooperations?	
by projects	75%
by common infrastructure	33%
by programme creation	8%
Are there international cooperations?	
by organisations or bodies	56%
by joint ventures	19%
by research centres	38%
by conferences	63%
only individually	44%

4. Programme evaluation/transfer	
Is the programme evaluated?	yes 83%

If yes, what are the criteria for success?	
deliverables	73%
business generated	53%
publications	60%
patents	40%
jobs generated	40%
Have there been any publications regarding the projects or results?	
by the programme	59%
by projects	65%
no	12%
What has been done for general transfer of knowledge?	
Publications	71%
Workshops	76%
Conferences	65%
seminars / training courses	53%
cooperations in projects	71%
What has been done to transfer knowledge in Embedded Systems to other sectors?	
cross-sectorial road shows	7%
focus on applied research in sectors	53%
publications in applied journals	40%
broader education	33%
multy disciplinary projects	60%

Which is the most efficient transfer of knowledge between the university and the industry?		
	Ø Importance (1=low..4=high)	#responses
workshops	3.44	17
seminars at the university	2.41	17
Internet portal	2.38	16

C.4 Automotive Sector

Please rank the following specific techological trends of your domain according to the importance within the next 5 years:		
	Ø Importance (1=low..4=high)	#responses
human-machine interface (e.g. enhanced sensors, displays in the cockpit)	3.18	111

driver assistance and passive safety (e.g. lane departure warning, pedestrian protection)	3.44	110
infotainment (e.g. in-car entertainment)	2.86	110
telematics (e.g. navigation to next free parking spot)	3.08	110
improvement and interconnection of control systems (e.g. advanced stability controls, advanced electronic suspension, powertrain control for hybrid vehicles)	3.57	110

C.5 Avionics Sector

Please rank the following specific technological trends of your domain according to the importance within the next 5 years:

	Ø Importance (1=low..4=high)	#responses
human-machine interface (e.g. enhanced sensors, displays in the cockpit)	3.06	50
unmanned aerial vehicle (UAV) and surveillance technology	3.24	51
multi-vehicle coordination	3.06	50
multi-vendor software integration on one computing node	3.21	51
integration of mission / enterprise systems and vehicle control systems	3.23	50

C.6 Health Sector

Please rank the following specific techological trends of your domain according to the importance within the next 5 years:

	Ø Importance (1=low..4=high)	#responses
enhanced surgical systems		
in general	3.31	41
enhanced surgical tools (e.g. providing tremor compensation or navigation features)	3.00	40
surgical robotics	2.94	41
enhanced medical imaging systems	3.55	43
augmented reality (e.g. for micro surgery)	3.14	42
intracorporal devices		
in general	3.24	40
for monitoring	3.44	39
for therapy (e.g. pacemakers, drug infusers)	3.20	41
communication with extracorporal devices	3.15	40
intracorporal RFID devices	2.88	39
extracorporal networked devices		

in general	3.43	38
for monitoring	3.66	39
for therapy	3.21	37
integration into everyday gadgets (glasses, watch, clothes)	3.14	38
communication with remote supervision facility	3.41	38
extracorporal RFID devices	3.00	37
Interoperability of medical devices		
hardware level (standardised buses / protocols)	3.28	39
application level (e.g. standardised health data record)	3.47	39
mobile healthcare (e.g. mobile access to patient data)	3.54	41
micro electro-mechanical systems	3.28	40

	Ø Agreement (1=disagree..4= agree)	#responses
Medical equipment is a domain that will significantly influence innovation in general embedded technologies.	3.26	44
Europe is in a leading position when it comes to embedded medical equipment technology.	3.00	43

C.7 Consumer Electronics Sector

Please rank the following specific technological trends according to the importance within the next 5 years:		
	Ø Importance (1=low..4=high)	#responses
multifunction equipment / devices	3.43	78
micro electro-mechanical systems / nano-devices	2.97	78

C.8 Industrial Automation Sector

Please assess which field buses are most used in your sector:		
	Ø Importance (1=low..4=high)	#responses
Profibus	2.65	75
CAN(open)	2.94	84
Ethernet	3.27	83
wireless (WLAN, Bluetooth,..)	2.77	76

Please rank which field buses will become important in the future:

	Ø Importance (1=low..4=high)	#responses
Profibus	2.32	62
CAN(open)	2.71	70
Ethernet	3.59	77
wireless (WLAN, Bluetooth,..)	3.56	78

Please rank the following specific technological trends of your domain according to the importance within the next 5 years:		
	Ø Importance (1=low..4=high)	#responses
multifunction equipment / devices	3.09	82
remote control	3.20	84
micro electro-mechanical systems / nano-devices	2.96	82

How do you judge the decomposition of monolithic solution blocks in individual elements for easier change of production lines	
Important	89%
Not relevant	11%
Importance will increase	94%
Importance will decrease	6%
How much data do the Embedded Systems in your domain manage? (in MB)	745.83 MB

Which of the following standards and concepts are important in your organisation? (You may select more then one.)	
CIP (Common Industrial Protocol)	18%
IEEE 802.11	79%
Bluetooth	47%
ZigBee	26%
IEEE 802.15.4	37%
RFID	43%
JFLEX (wireless concept of I/O-Modules for 3.5"-CPU-Boards)	5%
XML	58%
IEC61131-3 (Standard for programming)	30%
Standard 1288 (European Machine Vision Asssociation, EMVA)	8%

C.9 Telecommunication Sector

Please mark the importance of the following communication network standards for the upcoming 5 years:

	Ø Importance (1=low..4=high)	#responses
GSM	2.82	77
GPRS	2.99	73
HSCSD	2.40	63
EDGE	3.00	67
UMTS	3.48	72
WLAN	3.72	77
Bluetooth	3.11	74
IrDA	2.05	68

Are you involved in the research in Embedded Systems for industry?	yes 84%

Please rank the following specific technological trends of your domain according to importance within the next 5 years:		
	Ø Importance (1=low..4=high)	#responses
multifunction equipment / devices	3.36	68
micro electro-mechanical systems / nano-devices	2.78	70

C.10 Hardware Experts

Please assess the following trends in hardware technologies according to the importance in your domain within the next 5 years:		
	Ø Importance (1=low..4=high)	#responses
use of standard hardware (e.g. Intel x86, PowerPC)	2.95	81
System-on-a-Chip	3.48	84
miniaturisation	3.24	79
improvement of sensor technology (accuracy, cost, size, ...)	3.39	81
intelligent sensors	3.38	81
micro-electronic/mechanical devices (MEMS)	3.09	78
improved processor/DSP performance	3.31	81
secure networking	3.36	79
power supplies/power management	3.20	79
advances in RFID technology	3.03	77
software-defined radio (SDR)	2.57	74
adaptation of COTS (Commercial off-the-shelf) technology (e.g. WLAN 802.11 networks)	3.00	81
technology (e.g. WLAN 802.11 networks)	3.14	77
high-reliability networks (e.g. FlexRay for automotive, TTA for avionics)	3.17	79

low power consumption	3.48	81
centralisation (use of centralised processing platform, as opposed to network of autonomous electronic control units)	2.30	76

Advances in Embedded Systems generally require a combination of several new technologies. Please assess the influence on innovations and relevance of the technological solutions in your field of application		
with respect to power supplies / power management:		
	Ø Importance (1=low..4=high)	#responses
new battery / accumulator technology (e.g., Lithium polymers)	3.22	80
new sources for energy (e.g., fuel cell)	2.97	79
high efficiency voltage converter	2.84	79
better power management IC's	3.29	77
with respect to digital hardware:		
	Ø Importance (1=low..4=high)	#responses
increase of computational power (e.g., 32/64bit, higher clock rates)	3.16	81
increase of available storage (both ROM and RAM)	3.31	81
availability of high-level functionality (e.g., multi-threading, multi-kernel)	3.33	82
hardware support for signal processing / DSP-extensions for microcontrollers	3.26	81
better power management IC's	3.23	80
increased number of capture and latch registers	2.53	79
new storage technologies (e.g., flash, MRAM, ...)	3.08	80
ASICs	2.78	79
FPGAs	3.09	81
with respect to peripherals:		
	Ø Importance (1=low..4=high)	#responses
intelligent sensors (system-on-a-chip sensors including pre-processing)	3.44	82
multi-functional sensors (sensor capable of measuring several parameters)	3.28	82
micromechanical sensors or actors (e.g., piezo-electrical valves or pumps)	2.97	81
new sensor technology (e.g., contact-free measurement)	3.27	81
"plug and play" sensors or actors (requires standardisation of interface definition)	3.26	81

C.11 Application Software Experts

What programming languages/environments are currently used in your organisation for the development of Embedded Systems?	
AWL / IL	6%
C	97%
C++	83%
Java	66%
Assembler	33%
What programming languages/environments will be used in the next five years in your organisation for the development of Embedded Systems?	
AWL / IL	2%
C	94%
C++	80%
Java	71%
Assembler	25%

Please assess the following trends in software technologies according to the importance in your domain within the next 5 years:		
	Ø Importance (1=low..4=high)	#responses
improved image processing algorithms	2.79	116
improved voice recognition	2.53	118
advances in peer-to-peer technology	2.59	118
integrated data models	2.91	119
flexible service discovery and execution frameworks (e.g. OSGI for automotive)	2.95	117
dynamic reconfiguration	3.28	120

C.12 Platform Software Experts

How do you judge the relevance of the concepts stated below for Middleware?		
	Ø Relevance (1=low..4=high)	#responses
object / component oriented	3.27	141
service oriented	3.27	141

Please assess the following trends in platform technology according to the importance in your domain within the next 5 years:		
	Ø Importance (1=low..4=high)	#responses
porting existing software execution platforms and associated tools (e.g. Java, .NET) to embedded, real-time domain	2.78	141

middleware and module technologies (e.g. AutoSAR in Automotive, AADL, IMA in Aerospace)	3.23	135
certified/high reliability compilers/OSs/middleware	3.35	139
flexible service discovery and execution frameworks, peer-to-peer (P2P) technologies, and similar (e.g. OSGI for automotive)	2.89	137
adaptation of COTS (Commercial off-the-shelf) technology	3.10	139
specialised educational programmes	2.79	131

Advances in Embedded Systems generally require a combination of several new technologies. Please assess the influence on innovations and relevance of the technological solutions in your field of application		
with respect to operating systems:		
	Ø Importance (1=low..4=high)	#responses
non-proprietary operating system (e.g., OSEK, Windriver, APEX)	3.08	132
embedded-specific operating system (e.g., APEX, OSEK)	3.06	130
networking capability (e.g., OSEK-COM)	3.26	130
real-time extensions (e.g., OSEK-Time)	3.23	131
open source (e.g. embedded Linux)	3.41	97

C.13 Communication Infrastructure

Advances in Embedded Systems generally require a combination of several new technologies. Please assess the influence on innovations and relevance of the technological solutions in your field of application		
	Ø Importance (1=low..4=high)	#responses
high-volume buses or protocols (e.g., MOST, UMTS)	2.96	73
high-reliability buses (e.g., TTP, Flexray, package-oriented protocols)	3.30	73
real-time-capable buses (e.g., TTCAN, TTP, Flexray)	3.45	73
buses with dynamic/spontaneous integration (e.g, MOST, FireWire, Bluetooth)	3.08	73
wireless networks	3.23	75
time triggered architectures	3.08	70

C.14 Systems Engineering

Advances in Embedded Systems generally require a combination of several new technologies. Please assess the influence on innovations and relevance of the technological solutions in your field of application with respect to software development:		
	Ø Importance (1=low..4=high)	#responses

high-level model tools (e.g., Simulink, ASCET, Rhapsody, ARTiSAN, Rose RT)	3.40	112
efficent code generation (e.g., ASCET-SD, TargetLink)	3.07	112
domain-libraries (e.g., MSR-MEGMA, Simulink Domain Libraries)	2.86	110
standard architectures (e.g., ITEA-EAST/EEA)	2.80	111
standard middleware (e.g., AUTOSAR, ARINC)	3.05	109
formal verification	2.98	111
test automation	3.41	112

Please assess the importance of the following challenges in software development methodology according to the importance in your domain within the next 5 years:		
	Ø Importance (1=low..4=high)	#responses
composability	3.37	101
standardisation	3.40	106
dependability (reliability, safety, security, certification)	3.74	106
integrated tool support of complete development process	3.43	107
product line engineering	3.00	104
life cycle management	3.11	106
improvements in software maintenance/reengineering	3.30	105
requirements engineering	3.25	105
model-based design and synthesis of executables	3.50	106
systematic design of large dependable control systems out of components	3.13	103
testing	3.45	103
validation	3.50	103
model-based design tools (e.g. Simulink, SCADE, ASCET)	3.39	106
code generators (e.g. targetlink, real-time workshop, SCADE)	3.15	107
adaption of COTS (commercial off-the-shelf) tools/compilers (e.g. Java technology)	2.97	105
distributed systems	3.51	108
dynamic environments	3.14	104
hardware/software co-design	3.24	105

C.15 For all

Please give your opinion to the following statements:		
ecological effects		
	Ø Prediction (1=disagree..4= agree)	#responses
The use of Embedded Systems reduces the energy consumption of a system.	2.78	205

With Embedded Systems, the efficiency of the respective superordinate systems can be improved (e.g. improvement of gasoline-operated engine).	3.48	201
Embedded Systems lead to more electrical losses.	1.95	202
social effects		
	Ø Prediction (1=disagree..4= agree)	#responses
Do you think Embedded Systems will be another revolution like the Information Society?	2.82	204
Do you think your government is supporting the development of Embedded Systems sufficiently?	2.20	203
If you disagree, what further support is needed?		
Do you think that your products will be more reliable due to Embedded Systems?	3.20	199
Do you think Embedded Systems will be used to enhance the biological capabilities of humans?	3.19	176
Do you think Embedded Systems will increase the quality of life?	3.31	200
Are you afraid of the risks of future developments of intelligent dust and self-organising embedded networks?	2.03	202
education effects		
	Ø Importance (1=low..4=high)	#responses
lack of qualified engineers capable of developing Embedded Systems	3.37	202
broad system perspective required	3.55	202
knowledge of dependability issues not disseminated properly	3.20	197
designers of Embedded Systems work seldom systematically when considering interdependencies between critical and non-critical (sub-) systems, e.g. air conditioning corrupts vehicle network, toilet control influences critical general bus, corrupting critical function and so on.	3.05	202
need for proper understanding of standards	3.16	201
the exchange of experience and incidents not properly performed (confidentiality prohibits learning from incidents)	3.13	196

List of Abbreviations

3G	3^{rd} Generation Mobile Phone Technologies
AADL	Architecture Analysis & Design Language (formerly: Avionics Architecture Description Language)
AAGR	Average Annual Growth Rate
ABS	Antilock Braking System
ADAS	Advanced Driver Assistance Systems
ANF	Asia Nano Forum
API	Application Programming Interface
ARIB	Association of Radio Industries and Businesses (Japan)
ARINC	Aeronautical Radio, Inc.
ARPU	Average Revenue per User
ASIC	Application-Specific Integrated Circuits
ASSP	Application-Specific Standard Products
ARTEMIS	Advanced Research and Technology for Embedded Intelligence & Systems (a Technology Platform)
AT	Automation Technology
ATP	Advanced Technology Program
AUTOSAR	Automotive Open System Architecture
BAIKA	Bavarian Innovation and Cooperation Initiative for the Automotive Suppliers Industry (Germany)
BERD	Business Expenditures on R&D
CAGR	Compound Annual Growth Rate
CASE	Computer Aided Software Engineering
CE	Consumer Electronics
CEE	Central and Eastern Europe
CERN	European Organization for Nuclear Research
CCiBT	Convergence communications & broadband technologies
CISTRANA	Coordination of IST Research and National Activities
Chess	Center for Hybrid and Embedded Systems (US)
CoC	Centre of Competence
CoE	Centre of Excellence
CORBA	Common Object Request Broker Architecture
COTS	Commercial off-the-Shelf
CRC	Cooperative Research Centres (Australia)
DB	Databases
DSL	Digital Subscriber Line

DSL	Domain-Specific Language(s)
DSP	Digital Signal Processing
ECU	Electronic Control Unit
EIB	European Investment Bank
EIS	European Innovation Scoreboard
EIU	European Intelligence Unit
EMEA	Europe, Middle East and Africa
EMBL	European Molecular Biology Laboratory
EPO	European Patent Office
ERA	European research Area
ES	Embedded System(s)
ESI	Embedded Systems Institute (The Netherlands)
EU	European Union
EUCAR	European Council for Automotive R&D
EUREKA	A pan-European network for market-oriented, industrial R&D
FDI	Foreign Direct Investment
FMC	Fixed-Mobile Convergence
FP7/ FP6	Seventh / Sixth Framework Programme (EU)
FPGA	Field-Programmable Gate Array
GDP	Gross Domestic Product
GERD	Gross domestic Expenditure on R&D
GOVERD	Government Expenditure on R&D
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
HCS	Home Control System
HERD	Higher Education Expenditure on R&D
HIS	Hersteller-Initiative Software (Automotive OEM Software Initiative)
HMI	Human Machine Interface
HSDPA	High-Speed Downlink Packet Access
HW	Hardware
IC	Integrated Circuit
ICT	Information and Communication Technology
IDL	Interface Description Language(s)
IEEE	Institute of Electrical and Electronics Engineers, Inc.
IMA	Integrated Modular Avionics
IMEC	Interuniversity MicroElectronics Centre (Belgium)
IN	Intelligent Network
IP	Integrated Projects
IP	Internet Protocol
IP	Intellectual Property
IPR	Intellectual Property Rights

ISDN	Integrated Services Digital Network
IT	Information Technology
ITEA	Information Technology for European Advancement
ITU-T	International Telecommunications Union, Telecommunication Standardization Sector
IWT	Institute for the Promotion of Innovation by Science and Technology in Flanders
J2ME	Java 2 Platform, Micro Edition
JTI	Joint Technology Initiative
LCD	Liquid Crystal Display
LE	Large Enterprise
Linux	Operation System by Linus Torvalds
M2M	Machine-to-Machine
MDA	Model Driven Architecture
MEDEA	Microelectronics Development for European Applications
MEMS	Micro-Electro-Mechanical System
MISRA	Motor Industry Software Reliability Association
MSC	Multimedia Super Corridor (Malaysia)
NASA	National Aeronautics and Space Administration (US)
NASCOM	Indian National Association of Software and Service Companies
NIST	National Institute of Standards and Technology
NITRD	Network and IT R&D
NoC	Network on Chip
NoE	Network of Excellence
NSF	National Science Fundation (US)
NSFC	National Natural Science Foundation (China)
OECD	Organisation for Economic Cooperation and Development
OEM	Original Equipment Manufacturer
OMB	Office of Management and Budget (US)
OMG	Object Management Group
OS	Operating System
OSGi	Open Service Gateway Initiative
P2P	Peer-to-Peer
PC	Personal Computer
PDA	Personal Digital Assistant
PIM	Platform-Independent Model
PLC	Programmable Logic Controller
PNGV	Partnership for a New Generation of Vehicles
PPP	Public-Private Partnership
PPP	Purchasing Power Parities (related to currency conversion)
PROGRESS	Programme for Research on Embedded Systems (The Netherlands)
PSM	Platform-Specific Model
QoS	Quality of Service

R&D	Research and Development
RE	Requirements Engineering
RFID	Radio Frequency Identification
RoW	Rest-of-World
RTOS	Real-Time Operating System
S&T	Science and Technology
SDR	Software-Defined Radio
SCL	Semiconductor Complex Limited
SE	Systems Engineering
SEE	South East Europe
SEMATECH	Semiconductor Manufacturing Technology
SIM	Subscriber Identification Module
SME	Small and Medium-Sized Enterprise
SMT	Surface Mount Technology
SoC	System-on-Chip
S&T	Science & Technology
SW	Software
TP	Technology Platform
UAV	Unmanned Aerial Vehicles
UML	Unified Modelling Language
UMTS	Universal Mobile Telecommunications System
US	United States of America
USPTO	United States Patent and Trademark Office
VC	Venture Capital
VCR	Video Cassette Recorder
VHDL	Very High Speed Integrated Hardware Description Language
VLSI	Very-Large-Scale Integrated (chip design)
WAPI	Wired Authentication and Privacy Infrastructure

Glossary

Term	Short	Explanation
Activity		An activity is part of a process and describes what needs to be done to manufacture a product. An activity is assigned to a role.
Aeronautical Radio, Inc.	ARINC	A commercial standards group governing connectors, connector sizes, rack and panel configurations, etc, primarily for airborne applications. Connectors, which conform to ARINC specifications are sometimes referred to as ARINC connectors. Thus, the term “ARINC” is often used for the specification for system partitioning and scheduling, which is often required in safety- and mission-critical systems, particularly in the avionics industry. The current ARINC 653-1 specification became a standard in October, 2003. ARINC 653 defines an APplication EXecutive (APEX) for space and time partitioning that may be used wherever multiple applications need to share a single processor and memory, in order to guarantee that one application cannot bring down another in the event of application failure. ARINC standards allow aircraft manufacturers to ensure that new installations are compatible and interchangeable. The study "The Economic Impact of Avionics Standardization on the Airline Industry" from Georgia State University's Aviation Policy Research estimates annual savings by the airlines industry of more than $239 million p.a. through the use of ARINC standards.
Application Programming Interface	API	A specification of a set of definitions how a piece of software communicates with another. It is a method of achieving abstraction, usually (but not necessarily) between lower-level and higher-level software.
Applied Research		Creative research aiming at obtaining new knowledge on a specific objective or target. Purpose of applied research is to identify the possible use of results from basic research, or to explore new (fundamental) methods or new approaches. Results of applied research are expressed in the form of scientific papers, monographs, fundamental models or invention patents. This indicator reflects the exploration of ways to apply the results of basic research.
Architecture Analysis & Design Language	AADL	Architecture description language aimed at real-time systems. In the current version it covers embedded real-time systems in various domains and is not specific to the avionics sector anymore.
Automotive Open System Architecture	AUTOSAR	Partnership of automotive manufacturers and suppliers in order to develop and establish a de-facto open industry standard for automotive electric/electronics (E/E) architectures. The project defines a software infrastructure, which provides the runtime

Term	Short	Explanation
		facilities for interconnected AUTOSAR software components.
Autonomy		"The assumption that, although we generally intend agents to act on our behalf, they nevertheless act without direct human or other intervention, and have some kind of control over their internal state." [WJ1995]
Basic Research		Empirical or theoretical research aiming at obtaining new knowledge on the fundamental principles of phenomena of observable facts to reveal the nature and law of movement of objects and to acquire new discoveries or new theories. Basic research takes no specific or designated application as the aim of the research. Results of basic research are mainly released or disseminated in the form of scientific papers or monographs. This indicator reflects the original innovation capacity of knowledge.
Business Expenditures on R&D	BERD	Part of GERD that is invested by the private industry. Consists of all R&D expenditures of the private industry within the country and funded from abroad. Excludes expenses for R&D performed abroad.
CASE Tool		Computer aided tool for Computer Aided Software Engineering (CASE). Main components include: graphical user interface, specification/design methods (especially structured analysis (SA), entity-relationship-principle, OO-design), editor(s) for the production of models, code-generator(s) and a repository for all created documents.
Commercial off-the-shelf	COTS	Ready-made, identical software or hardware products, which are usually sold in great numbers. The opposite of COTS products are in-house solutions developed individually for a specific customer.
Common Object Request Broker Architecture	CORBA	CORBA is an architecture and specification for creating, distributing, and managing distributed program objects in a network. It allows programs at different locations and developed by different vendors to communicate in a network through an "interface broker." CORBA was developed by a consortium of vendors through the Object Management Group (OMG), which currently includes over 500 member companies. Both the International Organization for Standardization (ISO) and X/Open have sanctioned CORBA as the standard architecture for distributed objects (which are also known as components). CORBA 3 is the latest version.
Communication Network		Interconnection of communicating entities. Communications networks permit a temporary or continuing information transport between spatially separated communication partners (humans, machines). The information can consists of language, sound, text, data, graphics, still and moving pictures, etc. They are sent along a fixed or variable path (channel) from a source to one or several sinks. The interaction between the communicating entities takes place on the basis of communication protocols.
Communication Protocol		Set of rules governing the exchange of information between communicating entities in a communication network.
Component		Reusable software unit with clearly determined interfaces and defined behaviour.
Configuration Management		Regulation of all tasks to the arranged administration of all results resulting in the expiration of a project and/or necessary units. These tasks cover generally also the administration of error

Term	Short	Explanation
		messages and requests for modification, which refer to delivered products. The principal purpose of configuration management is the documentation and the production of transparency of the current configuration of a product and the pertinent conditions of the technical and functional requirements. A further goal is that each editor receives the correct and complete information at each time in the software life cycle.
Continuous System		In signal processing, a continuous-time signal is one in which time is represented as a continuum. Signals based in continuous time are usually also non-quantized, making them analog signals. These systems are described in particular differential equations (in the time interval), Fourier-transforms (in the frequency range), or transfer functions. Continuous systems are implemented either by analogue computers, similar circuits or by discretisation on microprocessors (usually DSPs). Sample applications are filters in the communications technology and regulations. The contrary to continuous systems are discrete systems (time discrete or event-controlled).
Criticality		A relative measure of the consequences of a failure mode and its frequency of occurrence.
Dependability		Dependability of a computing system is the overall ability to deliver service that can justifiably be trusted. Dependability is typically defined as a combination of safety, security, and reliability concerns.
Design		The phase during the software engineering process in which the main system design (architecture and properties) is determined according to a given (requirements) specification, without being involved in details. Also the product of this phase.
Digital Signal Processing	DSP	Digital signal processing refers to various techniques for improving the accuracy and reliability of digital communications. The theory behind DSP is quite complex. Basically, DSP works by clarifying, or standardizing, the *levels* or *states* of a digital signal. A DSP circuit is able to differentiate between human-made signals, which are orderly, and noise, which is inherently chaotic. All communications circuits contain some noise. This is true whether the signals are analog or digital, and regardless of the type of information conveyed. Noise is the eternal bane of communications engineers, who are always striving to find new ways to improve the signal-to-noise ratio in communications systems. Traditional methods of optimizing S/N ratio include increasing the transmitted signal power and increasing the receiver sensitivity. (In wireless systems, specialized antenna systems can also help.) Digital signal processing dramatically improves the sensitivity of a receiving unit. The effect is most noticeable when noise competes with a desired signal. A good DSP circuit can sometimes seem like an electronic miracle worker. But there are limits to what it can do. If the noise is so strong that all traces of the signal are obliterated, a DSP circuit cannot find any order in the chaos, and no signal will be received. If an incoming signal is analogue, for example a standard television broadcast station, the signal is first converted to digital form by an *analog-to-digital converter (ADC)*. The resulting digital signal has two or more levels. Ideally, these levels are always predictable, exact voltages or currents. However, because the

Term	Short	Explanation
		incoming signal contains noise, the levels are not always at the standard values. The DSP circuit adjusts the levels so they are at the correct values. This practically eliminates the noise. The digital signal is then converted back to analog from via a *digital-to-analog converter* (DAC). If a received signal is digital, for example computer data, then the ADC and DAC are not necessary. The DSP acts directly on the incoming signal, eliminating irregularities and thereby minimizing the number of errors per unit time.
Digital Subscriber Line	DSL	Family of technologies that provide a digital connection over the copper wires of the local telephone network. It allows an ordinary phone line to provide digital communication without blocking access to voice services.
Discrete system		A discrete system or discrete-time system, as opposed to a continuous-time system, is one in which the signals are sampled periodically. It is usually used to denote an analog sampled system, rather than a digital sampled system, which uses quantized values.
Distributed System		A distributed system consists of components that are distributed spatially or conceptually and help to secure the functionality of the higher-ranking system (coupled or networked).
Electronic Control Unit	ECU	Electronic device reading sensors and using the information to control a process (e.g. fuel injection) via actuators.
Embedded System	ES	An ES is an electronic programmable software-/hardware unit that is generally an integral part of a larger heterogeneous system and connected to it over sensors and actuators. This integration of electronics and software in a higher ranking system to control and interact with this system results in the expression "embedded". An embedded system is dedicated to performing specific functions of its encapsulating hardware component.
Environment		The objects of the world and information that are relevant the system but, which are not part of the system.
EUREKA		An intergovernmental initiative supporting European innovation.
Event		Each sending and/or receiving of a message in a system run. We differentiate explicitly between sending and receiving events. Events occur instantly, i.e. do not take up time. The temporal expansion of a transmission of messages and/or a processing activity is modelled by a sending and a receiving event, which specify beginning and end of the transmission of messages and/or the beginning and end of the activity.
Experiments and Development		Systematic activities aiming at using the knowledge from basic and applied researches or from practical experience to develop new products, materials and equipment, to establish new production processes, systems and services, or to make substantial improvement on the existing products, process or services. Results of experiment and development activities are embodied in patents, exclusive technology, and monotypes of new products or equipment. In social sciences, experiment and development activities refer to the process of converting the knowledge from basic or applied researches into feasible programmes (including conduct of demonstration projects for assessment and evaluation). There are no experiment and development activities in the science of humanities. This indicator

Term	Short	Explanation
		reflects the capability of transferring the results of Science&Technology into technique and products, which is the materialized measurement of Science&Technology pushing forward the economic and social development.
Failure		Departure of a system from its required behaviour that is visible to the users or customers.
Fault Tolerance		If it is not sufficient that after the occurrence of an error a system is brought into a defined condition, it must be designed fault tolerant: For example, an airplane in air after the loss of a safety-relevant component can not switch immediately to a safe state. Here fault tolerant controls are necessary, which can resume their original task correctly, also after recognition of an error.
Feature Interaction		Reciprocal effect, which results from interrelations between the functionality (service attribute) of activated services and/or additionally activated capability characteristics (auxiliary services), which stand in connection with the desired operation of a service. The reciprocal effects can have undesired effects on the flow of the service. Feature interactions are especially common in telecommunications, because all features are modifying or enhancing the same basic service, which is real-time communication among people.
Field Bus		An industrial digital data communication system that connects numerous field devices such as sensors and actuators with a control device. Some examples for field buses are Profibus, Interbus, ControlNet or CAN. IEC61158 is a worldwide standardisation for field buses.
Fixed-Mobile Convergence	FMC	Increasingly similar technologies are used and services provided by fixed telephone and mobile telephone systems. This type of convergence opens up prospects for operators to propose the same services to all users, regardless of the technology or networks they use.
Formal Method		Mathematically based technique for the specification, development, and verification of software and hardware systems.
Functional Requirement		A functional requirement specifies a function, which a system or a system component has to make available. Functional requirements include the description of: • input and output data • external interfaces (to other systems) • the user interface • hard and software interfaces • functional input and output behaviour
Global System for Mobile Communications	GSM	The Global System for Mobile Communications is the most popular standard for mobile phones in the world. GSM phones are used by over a billion people across more than 200 countries. The ubiquity of the GSM standard makes international roaming very common with "roaming agreements" between mobile phone operators. GSM differs significantly from its predecessors in that both signalling and speech channels are digital, which means that it is seen as a second generation (2G) mobile phone system. This fact has also meant that data communication was built into the system from very early on. GSM is an open standard, which is currently developed by the 3GPP.

Term	Short	Explanation
Graphical User Interface	GUI	A graphical user interface consists of a visual display unit as well as windows, pictograms, menu-based interaction forms and showing aids.
Gross domestic expenditure on R&D	GERD	The gross domestic expenditure on R&D (GERD) is the total intramural expenditure on R&D performed on the national territory during a given period, that includes R&D performed within the country and funded from abroad but excludes payments made abroad for R&D. Consists of private and public expenditures. The first are also defined as Business Expenditures on R&D (BERD). The latter consists of direct and indirect funding for R&D and expenses for higher education (HERD).
Gross Domestic Product	GDP	The gross domestic product (GDP) of a nation is the total value of all goods and services produced within that nation within a specific year. It is usually taken as a measure of the economic power of a nation.
Higher education expenditure on R&D	HERD	The part of the gross domestic expenditure on R&D (GERD) that a county invests into the system of higher education. Usually the government is by far the largest source of funding, additional funds may arise from industry and p
Human Machine Interface	HMI	Also referred to as “Man Machine Interface”, HMI denotes the “layer” that enables an interaction between the user and a system. HMI consists of a physical section (electro-acoustic, electro-optic transducer, keys, switches *etc.*) and a logical section dealing with functional operation states.
Hybrid System		System, which works with analogue as well as with discrete data and/or interacts with their surrounding over continuous time periods as well as at discrete points in time.
Implementation		Both the activity, which leads from a given design of a system to a functioning version of this system and the result of this activity.
Integrated Modular Avionics	IMA	General term describing a distributed real-time computer network aboard an aircraft, which consists of a number of computing modules capable of supporting numerous applications of different criticality levels.
Integrated Services Digital Network	ISDN	Digital communications network, which makes several communication services available over a universal, standardised connection for participants and offers comfortable service attributes. The transmission of the intelligence signals on the line and their switching happen in digital form.
Intelligent Network	IN	Architectural concept for the functional separation of call/connection control and service control for auxiliary services for the flexible production and supply of extended telecommunication services. Services are furnished by cooperating service entrance knot (SSP), service control computer (SCP) and service management system (SMP) on real time conditions. The service entrance knot (SSP) is closely linked with the basis call control and can recognize the activation of an auxiliary service, and for treatment, pass on to the service control computer (SCP). The concept of intelligent networks is standardized by ITU-T.
Interface		Any named boundary across which two or more separate elements (e.g., classes, components, hardware devices, subsystems, systems) interact (e.g., service requests with

Term	Short	Explanation
		potential exceptions raised, physical connections) with each other.
International Telecommunications Union, Telecommu-nication Standardization Sector	ITU-T	ITU is an international union from organisations to the compilation of standardisation recommendations, formerly CCITT. The Telecommunication Standardization Sector is responsible for the investigation of technical, operational and tariff questions and compiles recommendations for a worldwide standardisation of telecommunications. (www.itu.ch/aboutitu)
Java Microcontroller Edition	J2ME	Developer platform developed by Sun Microsystems. J2ME is the implementation of the Java programming language for so-called “embedded consumer products”. The J2ME technology consists of a virtual machine and a set of APIs suitable for providing tailored runtime environments for consumer and embedded electronics.
Mechatronic		If electronic is linked spatially closely to mechanical system components we talk of mechatronic systems. Mechatronic systems increasingly contain hierarchically ordered, coupled Embedded Systems.
Micro-Electro-Mechanical System	MEMS	Integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. While the electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar, or BICMOS processes), the micromechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices.
Modularity		Characteristic of a system such that it consists of modules. Structuring of systems into functional units (modules) facilitates project engineering, construction, production, and handling as well as maintenance and increases thus their economy. In addition, the module structure of a product makes the supply of an all-covering pallet of derived products possible by exchange or modification of individual modules (“unit construction system”).
Module		Logically matching and in itself final part of a larger overall system. It accepts, regarding contents and structure, well-defined inputs, implements a well-defined quantity of processing actions and produces well-defined output regarding contents and structure. A system is called modular (see modularity), if without disturbing system functionality, individual modules can be removed, added or replaced by others. In the context of programming, a module describes a logical functional unit, which results from summary of data types and algorithms and satisfies the following conditions: • each module consists of a, from external view, visible interface and an invisible implementation • by the interface it is described, which services are usable by other modules (export part) and which requirements are to be fulfilled (import part) • the services defined in the export part are provided by the module implementation. Thus software components, function libraries, etc. represent

Term	Short	Explanation
		examples for modules. Under the criterion of reusability, modules permit the efficient conception and realization of systems by relying on already existing and proven functional units.
Non-Functional Requirement		A non-functional requirement specifies a restriction on a system or a system component or on its development. Non-functional requirements include: • performance • cost • user support • documentation • security • maintenance • flexibility • portability
Object Management Group	OMG	Union of over 700 organisations (among them most of the important international software enterprises, many large companies and some universities) with the goal to create a standard architecture for distributed, object-oriented systems.
On Demand Services		Superordinate term that describes services, which are activated at the request of the user. For example, video on demand describes a service where at the request of the user a video signal is played, in contrast to the conventional television distribution service.
Open Service Gateway Initiative	OSGi	The OSGi Alliance is a non-profit industry consortium, which defines a standardised, Java-based, component-oriented computing platform for networked services. An OSGi framework can be added to a networked device (embedded or server) and provides an environment in which loadable services can be executed.
Open Source		All kinds of software of which the source code is freely and publicly available. Usually, open source software may be obtained, copied, distributed and used for free.
Operating System	OS	Basic software layer, which allows utilising a computer. The OS administrates all hardware resources and devices such as memory, CPU, IO-devices, and controls the execution of programs.
Product Line Architecture		A software architecture, which defines a group of different products sharing a common set of features by deriving the individual products from a common basis.
Programmable Logic Controller	PLC	A programmable logic controller or programmable controller is a specialised computer used for automation of real-world processes, such as control of machinery on factory assembly lines. Where older automated systems would use hundreds or thousands of relays and cam timers, a single PLC can be programmed as a replacement. The functionality of the PLC has evolved over the years to include also sophisticated motion control, process control, distributed control systems and complex networking.
Prototyping		Comprehensive term of different kinds of fast producing of executable code for the evaluation of requirements or design

Term	Short	Explanation
		decisions for a system, which can be provided. Apart from the prototyping for requirements, prototyping is used also for the evaluation of design decisions.
Public-Private Partnership	PPP	Public-private partnership is a variation of privatization in which elements of a service previously run solely by the public sector are provided through a partnership between the government and one or more private sector companies. Unlike a full privatization scheme, in which the new venture is expected to function like any other private business, the government continues to participate in some way.
Purchasing Power Parity	PPP	In economics, purchasing power parity (PPP) is a method used to calculate an alternative exchange rate between the currencies of two countries. The PPP measures how much a currency can buy in terms of an international measure (usually dollars), since goods and services have different prices in some countries than in others.
Quality Costs		Costs, which are caused by measures of fault prevention and quality inspections as well as due to external and internal errors.
Quality of Service	QoS	Term for individual quality criteria concerning one end-to-end connection. Covers for example cell loss rate, delay duration, or fluctuation of the delay duration.
Radio Frequency Identification	RFID	Method of storing and remotely retrieving data using devices called RFID tags or transponders. An RFID tag is a small object that can be attached to or incorporated into a product, animal, or person. RFID tags contain antennas to enable them to receive and respond to radio-frequency queries from an RFID transceiver. Passive tags require no internal power source, whereas active tags require a power source.
Reactive System		A reactive system transforms input events (whose occurrence in time usually cannot be predicted) into output events, often under time restrictions.
Real-Time Constraint		Constraint regarding the maximally permitted time between production of a system answer and occurrence of the external stimulus. If the intended arithmetic performance of the controlling system is not sufficient for the computation of all system answers requested at the same time, a real time failure occurs. On the basis of the effects such a failure causes, one differentiates between hard real time conditions (e.g. with endangerment of human life, destruction of the system, which can be controlled) and soft real time conditions.
Real-Time Operating System	RTOS	An operating system (OS) specially designed for use in real-time systems. RTOS guarantees a certain capability within a specified time constraint. In what is usually called a “hard” RTOS, if the calculation could not be performed at the designated time, the operating system would terminate with a failure. In a “soft” real-time operating system, the system would continue to function but the result might be sub-optimal. Some real-time operating systems are created for a special application and others are more general purpose. To some extent, almost any general purpose OS can be evaluated for its real-time operating system qualities. That is, even if an OS doesn’t qualify, it may have characteristics that enable it to be considered as a solution to a particular real-time application problem. In general, real-time operating systems are said to require:

Term	Short	Explanation
		• multitasking • process threads that can be prioritised • a sufficient number of interrupt levels. Real-time operating systems are often required in small Embedded Systems that are packaged as part of microdevices. Some kernels can be considered to meet the requirements of a RTOS. However, since other components, such as device drivers, are also usually needed for a particular solution, a RTOS is usually larger than just the kernel.
Real-Time System		System that must observe real-time constraints.
Reliability		User-oriented quality as shown by failure behavior of a system. Reliability is also a software metric expressing the probability that software will not cause the failure of a system for a specified time under specified conditions.
Research and Development	R&D	Systematic and creative activities in the field of science and technology aiming at increasing knowledge and using the knowledge for new applications. R&D includes 3 categories of activities: basic research, applied research and experiments and development. The scale and intensity of R&D are widely used internationally to reflect the strength of Science&Technology and the core competitiveness of a country in the world.
Reusability		Characteristic of a product in the development of a system regarding the renewed employment within the development of new systems. The re-use of already existing and proven products permits the efficient development of reliable systems. Here the possibilities for the re-use extend over all phases of the development process (e.g. specifications in the analysis, design, modules in design and implementation). However the respective subjects of the re-use must be adapted usually more or less extensively to the new development and differ thus in their reusability.
Roadmap		A roadmap is a structured representation of a plan to reach a goal. The goal of a roadmap is to identify (critical) milestones and place them on a timeline.
Robustness		Robustness is a special aspect of the system reliability. A software system is robust if it reacts to all unexpected, i.e. not explicitly permitted inputs reasonably, i.e. that any faulty operation by the user is recognized by the system and rejected with an understandable error message. In addition, processing of user inputs may take place only if no errors were recognized in them.
Safety		Prevention of or protection against events being harmful to the system or its environment and caused by malfunction of the system.
Scientific and Technological Activities	S&T Activities	Organised activities, which are closely related with the creation, development, dissemination and application of the scientific and technical knowledge in the fields of natural sciences, agricultural science, medical science, engineering and technological science, humanities and social sciences (referred to as scientific and technological fields). S&T activities can be classified into 3 categories: research and development (R&D) activities, application of R&D results, and related S&T services. This statistical definition is made by UNICHIEF for scientific and

Term	Short	Explanation
		technological activities to meet the need of carrying out statistical work in this field for its member countries, in particular developing countries.
Security		Prevention of or protection against malicious attacks.
Service		The set of behaviours characterising the use of a system for a specific purpose. Describes functional aspects from the user's view.
Service Control		Functions or processes in a communication network, which guarantee the flow of a special telecommunication service.
Software Metric		Defines a standard way of measuring some attribute of the software development process. For example, size, costs, defects, communications, difficulty, and environment are all attributes. Examples of attributes in the physical world are, mass, length, time, and the like. "Kilo-lines of executable source" illustrates one metric for the size attribute. Metrics can be primitive (directly measurable or countable, such as counting lines of code) or computed (such as noncomment source statements / engineer / month).
Software-Defined Radio	SDR	A software-defined radio system is a radio communication system, which uses software for the modulation and demodulation of radio signals. An SDR performs significant amounts of signal processing in a general purpose computer or a reconfigurable piece of digital electronics. The goal of this design is to produce a radio that can receive and transmit a new form of radio protocol just by running new software.
Specification		The first phase of the software engineering process, in which the designers are to describe in a simple though precise way what the software is intended to do and/or what the purpose of the software is. Also the result of this phase.
Strategic Research Agenda		The strategic research agenda is the key deliverable of a European Technology Platform. It should set out research and technological development priorities for the medium to long term, including measures for enhancing networking and clustering of the RTD capacity and resources in Europe.
System-on-Chip	SoC	Also referred to as "System-on-a-Chip", SoC is an idea of integrating all components of a system into a single chip. It may contain digital, analog, mixed-signal, and often radio-frequency functions – all on one chip. The key concept in SoC design is that a chip can be constructed rapidly using third-party and internal IP, where IP refers to a pre-designed behavioral or physical description of a standard component. SoC designs usually consume less power and have a lower cost and higher reliability than the multi-chip systems that they replace.
Technology Platform	TP	Technology Platforms are public-private partnerships conceived at the Lisbon European Council in 2000 as a tool to provide a means to foster effective public-private partnerships involving as appropriate public research, industry, financial institutions, users, regulatory authorities and policy-makers.
Testing		Process of exercising an implementation to verify that it satisfies the specified requirements and to detect faults.
Trend		The general direction in which something tends to move.
Universal Mobile Telecommunicati	UMTS	Universal Mobile Telecommunications System is one of the third-generation (3G) mobile phone technologies. It uses W-CDMA as

Term	Short	Explanation
ons System		the underlying standard, is standardized by the 3GPP, and represents the European/Japanese answer to the ITU IMT-2000 requirements for 3G Cellular radio systems.
Usability		Comprehensive term for user comfort and in particular management of programs. For the examination of usability, different procedures are used (e.g. heuristic evaluation, user questioning, empirical tests, etc.).
Validation		Activity of confirming that the developed product meets the user needs and requirements.
Verification		Activity of ensuring that the developed product is consistent, complete, and correct at the different steps of the life cycle.
Very High Speed Integrated Hardware Description Language	VHDL	IEEE standardized hardware description language. VHDL supports the description of digital hardware on system-level, register-transfer-level and gate-level. Each component description in VHDL consists of an interface description and a behaviour description. Behaviour descriptions cover algorithmic, data flow-oriented and structural formulas.

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