HTSM Roadmap Embedded Systems 2018

Laying the foundation for intelligent high-tech systems and applications

Document
Version 1.0
February 26th, 2018

Roadmap team
Hans Geelen, Océ
Herma van Kranenburg, STW
Frans Beenker, ESI
Wouter Leibbrandt, ESI

Author/Editor
Hans Geelen, Océ
Arjan van der Hoogt, Océ
Wouter Leibbrandt, ESI
Frans Beenker, TNO-ESI

Contributors
This roadmap signifies a mid-term limited update with respect to the Embedded Systems Roadmap 2015.

Table of Contents

MANAGEMENT SUMMARY

This document represents the *Roadmap for Embedded Systems 2018* (HTSM-ES roadmap), which is a limited update to the HTSM-ES roadmap 2015. This update was done to align with the societal challenges as set down in the "kennis- en innovatieagenda 2018 – 2021"[28].

The HTSM-ES addresses short- and medium-term industrial needs for design and engineering of high-tech and embedded systems by summarizing strategic focal points for innovation.

The 2015 roadmap has been developed and reviewed by about 40 persons from industry and academia, representing key stakeholders in the Topsector HTSM, using a structured analysis process that is identified as 'line of reasoning'. This emerges from the societal and economic needs that drive new industrial activity. The associated innovation needs, especially those for high-tech product design and engineering, act as driver for new technology and scientific research. Together these form the foundation of the current HTSM-ES roadmap. The 2018 limited update was conducted by the roadmap core team.

A key concern underlying this roadmap is the fact that the ever increasing complexity of high-tech system design cannot be dealt with by the current, mainly mono-disciplinary design methods, techniques and tools. As a result, a more fundamental basis of embedded systems engineering is required to improve the efficiency, effectiveness, quality and costs of the design processes.

To create the required breakthroughs, not only new embedded technologies are needed, but also new design paradigms. This roadmap addresses these topics by analyzing product innovation challenges at business level, the (functional, non-functional, process) challenges in system design and engineering, as well as challenges related to human capital. The corresponding technology and scientific challenges define the HTSM-ES research roadmap for industry and academia, where the latter is expected to provide the general direction and innovative inroads for future technologies and applications.

This document contains separate chapters that: (i) discuss the context in which the HTSM-ES stakeholders operate, (ii) analyze key roadmap drivers and needs, (iii) summarize the operational and financial plans and programs that are available in the context of the Topsector HTSM.

1. INTRODUCTION

The high-tech industry in the Netherlands requires access to an open innovation ecosystem that strongly facilitates strategic innovation. The Topsector HTSM has been established to facilitate this ecosystem. A large number of application- and technology-based roadmaps form the heart of HTSM, of which the embedded systems roadmap represents an important building-block.

This document represents the *HTSM Roadmap for Embedded Systems 2018* (HTSM-ES roadmap). which is a limited update to the HTSM-ES roadmap 2015. This update was done to align with the societal challenges as set down in the "kennis- en innovatieagenda 2018 – 2021"[28].The current roadmap further provides an extension to the HTSM-ES roadmaps for 2012 [1] and 2014 [2]. It follows a structured process that emerges from the *societal drivers and economic needs* that drive entrepreneurial activity in high-tech industry, identified as the HTSM-ES 'line-of-reasoning' (LOR). This is important since industrial products act as the tangible enablers of both societal and economic needs. In a next step of the LOR, the associated *industrial needs* and *high-tech product challenges* are expressed. In turn, these challenges drive the *technological and scientific challenges* that embody the key building-blocks of the embedded systems roadmap.

The document consists of six chapters.

Chapter 2 analyses the *general context, market and application domain* in which innovations for high-tech and embedded systems take place. It has been divided into sections that present a definition of embedded systems, elaborate on economic and societal challenges, and discuss key trends in market, product, technology, human capital and open innovation.

Chapter 3 contains the *elaboration of the line-of-reasoning*. It is structured along six individual steps, respectively, an analysis of the (i) societal challenges, (ii) economic drivers, (iii) industry needs, (iv) high-tech product challenges, (v) technology challenges, (vi) scientific challenges. Together these represent the short- and medium-term knowledge needs for the engineering of high-tech embedded systems.

Chapter 4 presents an overview of the *public-private partnerships*, *programs and funding* that are available to the participants in the context of the HTSM open innovation community for embedded systems. This includes the European programs that are relevant for this roadmap.

Chapter 5 summarizes the *partners and stakeholders* involved in the development process of the embedded systems roadmap.

Finally, in Chapter 6 a (best guess) summary of the overall Dutch *investment* in embedded systems R&D for the year 2015 is presented.

2. SOCIETAL, ECONOMIC AND TECHNOLOGICAL CONTEXT OF THE HTSM-ES ROADMAP

Embedded systems are at the heart of most technological advances. Healthcare diagnostics, traffic management, security provisions, manufacturing and many others- they all rely on this core technology. In this chapter, a general introduction of the trends and developments that drive the application of the embedded systems technology is presented.

A large variety of definitions of embedded systems exist. In this roadmap, a generic *definition of embedded systems* is used, that incorporates individual devices, high-tech systems, as well as system-of-systems (Section 2.1). As system architecting, design and engineering are the predominant professional disciplines for developing these devices, systems and applications, these disciplines receive considerable attention in this roadmap. This includes activities such as requirements capturing, functional analysis, key technology choices, system partitioning and architectural decomposition, design-space evaluation, analysis of design trade-offs, cost/benefit analysis, etc.

This chapter identifies the context in which embedded systems technology is being deployed. In Section 2.2, we identify how this roadmap addresses the *societal challenges* and in Section 2.3, the key *economic trends* are identified. Section 2.4 summarizes the *market, product and technology trends,* while Section 2.5 considers developments in regard of *human capital.* Finally, in Section 2.6 we discuss the key characteristics of the knowledge ecosystem for *open innovation*, as this represents the context for the HTSM embedded systems roadmap.

2.1 A definition of Embedded Systems

Embedded systems (ES) are defined as integrated hardware/software systems (computer technology, software, semiconductors, control, actuators, sensors, etc.) built into systems and devices that are not necessarily recognized as computerized devices or computers[1]. Embedded systems comprise platforms of hardware and software that allow decision power and intelligence to be added to almost any product, system, infrastructure or service. As a result, embedded systems define and control the functionality and quality of these products and applications. They form an integral and indispensable part of complex high-tech systems. For this reason this roadmap pays special attention to the architecting and design of high-tech embedded systems.

Embedded systems are typically not monolithic and may consist of applications running on multiple processing units and sub-systems that communicate through buses, wired/wireless networks and/or telecom infrastructures. The systems and system components range from tiny battery-powered intelligent sensors and actuators, to large multiple-rack computing devices, information-centric systems-

[1] It is estimated that only about 4% of the computer chips that are produced globally will end up in a ‘normal computer’, the remaining 96% is used to become part of a hidden computerization in the form of embedded systems [42].

of-systems (SoS), or even highly distributed cyber-physical system configurations (CPS)[2]. This definition of embedded systems implies that the technology and methods, as developed on the basis of this roadmap, will find application in a wide variety of products, applications and technology infrastructures.

The key concern for embedded applications is that they have to fulfill a wide variety of strict resource constraints, ranging from limited energy-usage, memory-footprint, limited processing or bandwidth resources, to space and weight constraints. At the same time, they have to fulfill strict requirements regarding (real time) performance, dependability, data privacy, security and integrity, (networked) integration and system interoperability. These limited resources and strict non-functional requirements distinguish embedded systems technology from ICT in general. The design of embedded system applications is intrinsically a multi-disciplinary activity, requiring skills from computer science, electronics, communication technology, mechatronics and control, data and information, as well as a thorough understanding of- and interaction with the application field in which these systems are being deployed.

2.2 Societal challenges

As explained in more detail in section 4.2, the HTSM-ES roadmap is technology-oriented, acting as a roadmap in itself but also servicing the application-oriented HTSM roadmaps and some roadmaps of the other topsectors. Through this, the HTSM-ES roadmap indirectly addresses basically all societal challenges as laid out in the 'Kennis- en Innovatieagenda 2018-2021' [28], as they are addressed by these application-oriented roadmaps.

The advances of embedded systems do not limit themselves to industrial high-tech products. With few exceptions, most solutions for societal challenges incorporate embedded applications in one form or another to improve quality-of-life, or enhance effectiveness and efficiency of service. Societal sectors that are effectively incorporating embedded system technology are, among others, health and wellbeing, transport and logistics, safety and security, energy and environment, but many others could be mentioned. The common denominator within all of these areas is that societal innovation has become ever more reliant on deployment of embedded technology applications.

A significant number of direct connections between the HTSM-ES roadmap and several societal challenges can be identified:

<u>Health and Care</u>

Every step of the care cycle, from home monitoring, diagnostics imaging through treatment and surgery to after-care is increasingly relying on highly digitized, complex cyber-physical systems and highly interoperable systems (system-of-systems) that sense, analyze, and report on personal care

[2] Cyber-physical systems (CPS) are configurations of collaborating computational elements that control physical entities. In other words, they are mostly 'distributed' configurations of embedded systems [5]. The key concerns for CPS configurations are identical to those for traditional definition of embedded systems, with the added observation that more emphasis is placed on (wired or wireless) networking, communication, system interoperability, and aspects of ubiquitous computing [9].

aspects. The design and maintenance of such systems faces increasingly complex issues in aspects such as functionality, robustness, safety, security, and performance. The HTSM-ES roadmap addresses such issues and supports the efficient realization of robust, performant, maintainable and upgradeable cost effective equipment. Examples of such systems are X-ray imaging systems, guided-surgery systems, alert systems for home care, etc. Through this, it contributes in a significant way to improved healthcare, prevention of illness, earlier diagnosis and treatment, and reduced cost of healthcare.

Safe and secure society

The HTSM-ES systems roadmap addresses technologies that are instrumental in enabling the solutions for the societal challenges addressed in the HTSM security roadmap; e.g. those concerning cyber-security and operational security challenges to society. In addition, the HTSM-ES roadmap directly couples to the safe and secure society challenges along two lines:

1. Physical safety: addressing safety aspects of mission critical systems like autonomous vehicles and traffic management systems. The HTSM-ES roadmap addresses the challenge of how to ensure safety at the system and system-of-system level while preserving requirements on for instance performance, reliability, robustness and cost.

2. Digital security and safety: how to ensure system security and reason on security by design of cyber-physical systems and system-of-systems.

Mobility and transport

Intelligent Traffic Systems and the development of autonomous transport of people and goods, are identified as priority for the mobility and transport challenges. These directly couple with the HTSM-ES roadmap. In applications such as truck platooning, V2X communication, and parcel handling and delivery the HTSM-ES roadmap analyzes how to overcome the challenges set by system complexity in ensuring system reliability, performance, availability, safety, security, and affordability.

Agriculture and food

This societal challenge very explicitly calls for the rapid introduction of smart technology; e.g. required for smart farming systems, systems for sensing and monitoring environmental factors and crop, etc. Such technology requirements directly translates in an accelerated adoption of digital and cyber-physical systems in agriculture and food domain. This in turn raises the need to address the associated system complexity problems using methodologies covered by the HTSM-ES.

Inclusive and innovative society

The Netherlands is home to some of the most advanced and world-leading high-tech industries. Common denominator is that they all engineer and maintain highly complex systems and they all rely on the availability of the most advanced and state-of-the art system architecting and (embedded) systems engineering competence. The Netherlands is recognized to be world leading in this competence. The HTSM-ES roadmap aims at pushing the envelope in this area, securing our world leading position, thereby strongly contributing to being an innovative society.

2.3 Economic trends

Today, embedded systems technology plays a prominent role in most state-of-the-art products, applications and services, e.g., in cars, mobile phones, advanced manufacturing systems, medical equipment and public infrastructures. Embedded systems technology enables companies to differentiate from other companies by providing a unique customer experience (USPs). The fact that embedded systems technology often represents a sizable and important part of a company's value proposition is demonstrated by the product development investment being allocated to it. It is not unusual that this represents more than 50% of total development costs with continuously rapid growth of this percentage over time.

This universal application of embedded systems technology in all segments of industry and society has created challenging new opportunities. New industrial products, with enhanced functionality and better cost-performance ratio represent a key element of the competitive position of our high-tech industry. New manufacturing processes, such as discussed in "Industry 4.0" [3] and "Actieagenda Smart industry" [4], have become a key component of competitive positioning and new services and business models emerge that deploy all of these technology advances. We will address some of the aspects of these agenda's in Section 3.4.

As already mentioned in the Section 2.1, a further key trend is that of cyber-physical (CPS) applications. More and more standalone systems are integrated and connected by means of intelligent networks, wireless communications and data processing capabilities to perform value added user functions and work-flow processes [5] [6]. This provides for entirely new applications and services, such as for real-time road traffic monitoring and control, distributed energy provisions, outbound patient care and highly adaptive emergency services. With an ever-growing dependency on these applications, for our personal, societal and economic needs, embedded systems design capabilities have become the key enabler of the emergent CPS domain.

2.4 Market, product and technology trends

The size of the Dutch *embedded systems* market is difficult to measure as such, as embedded systems are an inherent part of a wide variety of high-tech products. The turnover in the field of high-tech products in the Netherlands is estimated at 73 B€/year, and has shown the highest growth levels of all Dutch Topsectors. Although not the largest in size, the high-tech systems market is among the largest in terms of export value in the Netherlands (about 32 B€/year). The public R&D investment amounts to 2.2 B€ in 2009, and will rise to 3.5 B€ in 2020. According to the 'Artemis embedded systems roadmap' [11], embedded system technology represents the fastest growing sector in Information Technology.

The accelerating development of science and technology is at the foundation of almost all new products and applications, where the technology to create ever miniaturized electronic components with previously unimaginable processing capabilities has provided one of the most powerful drivers. With several decades of exponential growth in hardware capabilities, the bottleneck for future products no longer lies at producing smaller, faster and more powerful electronic circuits. Instead, it is shifting toward the deployment of these components into highly intelligent, well-performing and adapting systems, where embedded software acts as the key integrating discipline. Moreover, as all of these systems are increasingly being integrated into larger (networked) functions and applications, entirely new challenges and possibilities emerge, such as for cooperative work-flow, system interoperability and data security.

Furthermore, globalization has significantly changed the characteristics of the high-tech industry. In the past, OEM companies realized the entire product developments 'in-house'. Today these enterprises rely on specialized technology providers and manufacturers of critical components & subsystems, regularly outsourced to new/emerging economies. As a result, many OEMs are positioned at the higher end of the value-chain, typically with overall market and product responsibility, and to a significant extent, globally sourced engineering and manufacturing. This has caused the needs for knowledge and professional skills of these OEM industries to focus away from non-strategic capabilities, processes and components, while increasingly addressing system-level engineering and value management across the supply-chain, as key capabilities. For product development, this translates into a shift from basic engineering towards a need for enhanced capabilities for overall system architecting, design and integration, as well as technology coordination of a highly diversified and globalized supply chain. This implies that the SME's that act as supplier, partner or co-developer, must be engaged in this sourcing process in such a way that their specialized know-how and capabilities are incorporated in the design process, but also that they have a (working) relationship that allows them to advance their own capabilities and skills.

A further key development is found in the way in which companies position themselves in the value chain. The traditional business model of 'selling boxes' is steadily becoming obsolete. Today's market requires products that satisfy a broad variety of customers, can be tuned and configured to specific needs, and flawlessly integrate with other (networked) products and applications, often from other manufacturers. This means that today's product must be designed for adaptability to individual needs, allow flawless interoperability with other products and services, and be sufficiently future-proof to accommodate changing needs during its operating lifecycle. A further step in this evolving business position is that companies not only provide these products to their customers, but also are expected to deliver total integrated solutions.

As a result of the above developments, and the speed at which today's innovations take place, a continuously growing gap has emerged between the available technologies and the professional capabilities to effectively leverage those. This requires special attention to be paid to system engineering practices for product innovation (analysis, design, integration, test, validation), the accommodation of requirements from operational use (dependability, adaptability, networked integration, service, etc.), but also to education and (life-long) training of knowledge workers as is elaborated in Section 2.5. A further elaboration of these needs, as expressed in terms of the Embedded Systems Roadmap, is presented in Chapter 3.

2.5 Human capital

In high-tech industry, next to the battle for profit, a battle for talent is taking place. High-tech companies not only need to address the consequences of an aging workforce, with the ever changing technology base they must also try to attract the best brains worldwide [25]. Consequently, R&D

groups within the Dutch high-tech industry have developed into one of the most internationalized workspaces around.

Practice shows that poor decisions in the earliest product development phases have significant impact on product function, quality, costs and time-to-market. As these decisions are mostly taken by product architects and system designers, a significant need emerges for top-specialists that understand the complexities of the system design and the associated system engineering processes, and have insight in latest technologies, methods and techniques. This requires highly qualified embedded systems architects and engineers i.e., people who can deal with the increased level of abstraction and multi-disciplinary aspects of product development.

This requires systemic investment in education at all levels, not only to become less dependent on just a few people who know it all, but also to improve the broader capabilities in design of state-of-the-art embedded systems. Special attention needs to be given to training for system architecting and engineering, as companies need to accelerate the relevant learning curves of their staff, and maintain state-of-the-art capabilities for their (aging) workforce. With the quickly changing technology base, only life-long learning programs will be able to address these needs.

2.6 Open innovation

All applications of embedded systems technology in the various industrial and societal fields, rely on comparable technology building-blocks, methods and techniques. Because the management of complexity, functionality and interoperability of embedded systems is almost always at the heart of a technology concern, it is of utmost importance that new knowledge is not only generated for individual products or applications, but that opportunities for synergy and knowledge exchange are taken into account. Such a coherent approach leads to a faster and more efficient build-up of knowledge, with sharing of solution strategies, architectures, platforms, design techniques, best practices, training and education, et cetera. This provides benefits to all parties through a knowledge and investment multiplier.

In consideration of the above, the creation of an open innovation knowledge ecosystem is generally seen as one of the best ways to address the challenges in the area of innovation and exploitation of new technologies [36]. This is true for the Netherlands, the rest of Europe, and globally, as the complexity and costs of problems that need to be addressed are beyond the scope of individual organizations and industries.

For the Netherlands, the combination of a globally operating high-tech industry and world-renowned academic groups and research institutes provides an excellent basis to strengthen our national economy and pursue societal improvements. The Topsector HTSM, of which the roadmap for embedded systems is part, provides a sound basis for participation in an open ecosystem of public and private partners in order to develop and exchange valuable knowledge and experiences, strengthening both the economic infrastructure (cooperation with industrial parties), societal functions (cooperation with societal users) and address scientific challenges (cooperation with academia).

Participants in the open innovation ecosystem have access to the newest knowledge in the area of embedded systems engineering. Typical channels available for cooperation are through: (i) academic research programs funded by NWO or STW, (ii) European funded research through program such as H2020, Ecsel and Itea, (iii) applied research projects co-funded in public-private research partnerships with GTI's or TNO, (iv) participation in public activities and programs, (v) through direct B2B research and knowledge dissemination projects between any of the (individual or multiple) participants in the ecosystem. Also in European context there are various possibilities to leverage the open innovation model. Chapter 5 presents more details for these programs within the Netherlands and Europe.

3. ROADMAP DRIVERS

The roadmap for embedded systems is based on a structured analysis process of 6 steps that is identified as 'line of reasoning' (Section 3.1). It emerges from the societal (Section 3.2) and economic drivers (Section 3.3) that lie at the foundation of our society. These act as key drivers for industrial activity, whereas industrial products represent the physical enablers for these societal and economic needs. The strategic industrial needs (Section 3.4) drive the high-tech product challenges (Section 3.5) where, in the end, the results of these needs and challenges can be expressed in terms of technology challenges (Section 3.6) and scientific challenges (Section 3.7). The latter two challenges represent the core of the embedded systems roadmap.

3.1 Structure of reasoning-line

This section summarizes the line-of-reasoning as depicted in Figure 1. It comprises the following distinct elements:

1. **Societal challenges.** The key societal challenges and public drivers in which high-tech systems technology is expected to provide a solution.
2. **Economic drivers.** Economic drivers represent a key focus area for the high-tech industry, and therefore the financial prosperity of The Netherlands.
3. **Industry needs.** Most of the societal and economic needs are realized through technology products or services provided by commercial enterprises. This emphasizes the importance of our high-tech OEM industry and networks of SME's. This means that industry needs, especially those in the field of high-tech products and services, represent one of the most important drivers for the embedded systems roadmap as a whole.
4. **High-tech product challenges.** This is an elaboration of the needs of the high-tech industry in regard of their product innovation challenges. These are categorized into: (i) *product/application challenges*, addressing functional and non-functional challenges in design and engineering of high-tech systems, (ii) *design process challenges*, addressing challenges for innovation processes, methods and techniques, as well as the challenges for the development of the required human skills and competences.
5. **Technology challenges.** These are the technology related challenges that play an important role in the design and engineering of high-tech products. They represent the immediate needs that industry has for product innovations. These challenges form the key elements of the embedded systems roadmap, and also provide an important source of inspiration for the more fundamental 'scientific' challenges.
6. **Scientific challenges.** Scientific challenges provide the fundamental foundation for future technology innovation. The scientific challenges are expected to provide the general direction, solutions and ideas that will find their way into future products. As such they represent the medium- and longer-term agenda for the development of new applications and services, thereby providing an important contribution to our future societal needs and competitive positioning.

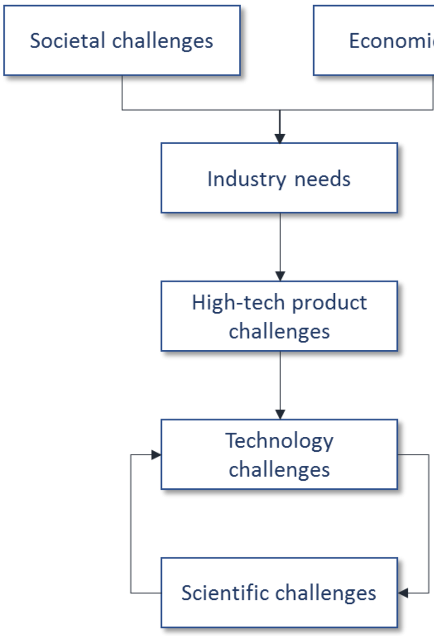

Figure 1: The line of reasoning that is followed to create the foundation of the embedded systems roadmap.

In the following sections, each element of the reasoning line is outlined in more detail, while a summary of the 2015 update of the reasoning line is presented in Appendix A.

3.2 Societal challenges

As discussed in section 2.2, the HTSM-ES roadmap links tightly to most of the societal challenges. The category 'societal drivers' represents key societal advancements that (directly or indirectly) act as key drivers for the embedded systems roadmap [11]. In each of the domains, 'Energy and CO_2, 'Agriculture and Food', 'Health and Care', 'Climate and Water', 'Circular economy', 'Mobility and Transport', 'Safe and Secure Society' and 'Inclusive and Innovative Society', embedded systems technology is used as a predominant enabler for the associated societal needs. As an illustration of the societal challenges in the reasoning line, we mention a few examples:

1. A safe and secure inner city requires threat detection, early warning and safety monitoring;
2. Secure maritime and airspace transport can be supported by dedicated systems for traffic monitoring and control;
3. Efficient logistics requires systems that monitor and optimize the flow of goods;
4. Road safety and efficient use of road infrastructure can be optimized through advanced driver assistance systems (ADAS), car-to-infrastructure (C2I), vehicle-to-roadside (V2R) and car-to-car (C2C) communications;

5. Leisure & lifestyle applications that incorporate mobile computing and communication, home entertainment and home automation (domotics) applications;
6. Improved preventive healthcare, better diagnostics and treatment, and lower cost-of-care is enabled through innovations in healthcare systems and services;
7. Enhancing home-care and well-being of the elderly through technology provisions;
8. Performant, dependable and secure (tele-) communications;
9. Cost-effective, reliant and environment friendly energy or food production and distribution;
10. Sustainable and clean environment and lower carbon footprint.

The embedded systems roadmap provides an important contribution to these ever evolving societal needs, mainly through new high-tech products and services. It also contributes through capabilities for integration of technology systems (i.e. information-centric systems-of-systems) to support value added end-user functions or work-flow support. These systems address specific societal needs, such as the ability to improve inner-city security, optimize road traffic efficiency, or provide better maritime safety and security.

A number of the application-oriented roadmaps of the HTSM Topsector, such as for the roadmaps for *security* (addressing national security & safety provisions), *automotive* (addressing smart mobility and future power-train), *lighting* & *solar* (addressing lighting and energy needs) and *healthcare* (addressing provisions for preventive care, diagnostics and treatment) explicitly specify these societal drivers. Other technology-oriented roadmaps from the HTSM Topsector, including those for *nanotechnology*, *semiconductor equipment*, *printing, components & circuits*, address the societal drivers more indirectly, but nevertheless are of key importance to a successful realization of these drivers.

The separate *cross-domain ICT roadmap* addresses the relevance of ICT for the various Topsectors, thereby addressing also embedded systems, amongst others for "ICT for monitoring and control" and "ICT one can rely on" [8].

3.3 Economic drivers

The economic drivers in the reasoning line all emerge from the fact that a thriving and capable high-tech industry is a core asset to a modern society. Both Dutch societal and economic stakeholders share their interest in a thriving national industrial base, where value-creating economic activities take place that provide growth in GDP and a competitive export position. In other words, a globally leading OEM industry that is well-integrated with an effective and efficient supply chain of specialized high-tech SME's and a capable and competitive workforce, are a key asset to our national economy. In this regard, the Topsector HTSM plays an important role in ensuring that these strategic technology and knowledge needs are appropriately addressed.

The economic drivers for the high-tech industry can directly be translated into the industry needs for their core products and markets and be elaborated into the technology and scientific challenges.

3.4 Industry needs

A wide variety of high-tech industries operates in the Netherlands. They are expected to operate at the leading edge of technology innovation and at the forefront of the global economy. The needs of most of these industries are well represented by the roadmaps of the Topsector HTSM - see Section 4.2.

The most prominent objective of high-tech industry is to develop discriminating and impacting product offerings that addresses rapidly and continuously changing customer needs (the right product/service at the right time and place). This not only requires an efficient, cost-effective, and predictable product creation process, incorporating the latest innovative technologies (or to be a creator of that), but also flexibility, adaptability and strong customer intimacy. To a large extent the technology challenges (Section 3.6) and scientific challenges (Section 3.7) are a reflection of those needs.

In addition to this, the high-tech companies need a highly qualified workforce with leading professional capabilities for design and engineering, an effective and efficient (global) supply chain, appropriate and adequate regulations and standards, and an open innovation ecosystem that strongly facilitates and supports strategic innovation.

This chapter addresses key industry needs in the context of the HTSM-ES roadmap. In Section 3.4.1 we discuss a strategic trend that drives the need for new product and services, in Section 3.4.2 we analyze the general research and development needs, while in Section 3.4.3 we discuss the needs for knowledge and investment sharing.

3.4.1 A changing market paradigm

Many companies observe a strongly *shifting business paradigm* [10] [11], that drives the need for new technologies, processes and techniques. This can be summarized as follows:

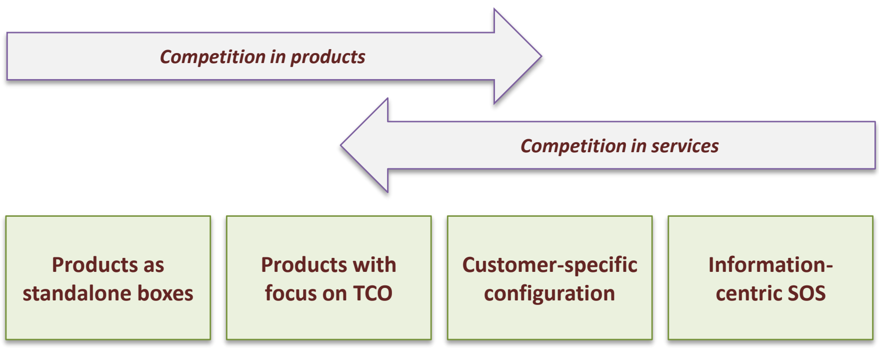

Figure 2: Companies undergo a market paradigm shift, by adapting their mix of products and services.

1. **Changing market paradigm.** The evolution of globalized markets, combined with the emergence of companies that focus on information-centric value-added services, have forced OEMs to adapt

their strategy. As depicted in Figure 2, focusing on stand-alone (often high-performant) products (boxes) only, has become less and less a viable business proposition. Today's products must not only provide the required level of functionality, performance, and a competitive level of total cost-of-ownership (TCO) with severe requirements on product quality and reliability, they increasingly must be adaptable to individualized customer needs, provide flawless integration and cooperation with other products and end-customer processes and applications, and preferably be sufficiently future-proof to accommodate continuously changing operating requirements during their lifecycle.

2. **A changing technology paradigm.** Within the shift from stand-alone products toward value-added services, the emerging application field of 'information-centric systems-of-systems' has become increasingly important. As is depicted in Figure 3, information-centric SoS require a merge (or integration) of technologies from the fields of high-tech systems, ICT & communication infrastructures, user interaction and data-processing & information services. This poses entirely new product design challenges, requiring innovative strategies and processes to develop such products and services. It also drives new knowledge needs, requiring access to- and in-depth understanding of latest high-tech system-, communication- and ICT-innovations[3].

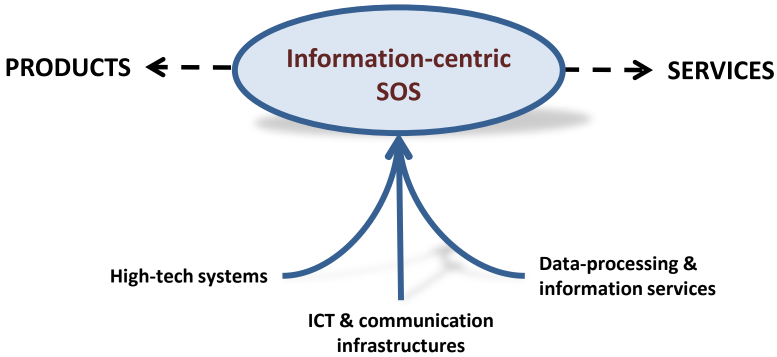

Figure 3: The emerging role of information-centric systems-of-systems for integrating products and services.

3.4.2 Research and development needs

To address these paradigm shifts a number of key innovation areas need to be addressed.

- **Multidisciplinary architecting and design.** Design and engineering of complex high-tech systems currently relies on fundamentals and models developed in computer science, physics, mathematics, mechanical engineering and electrical engineering over recent decades. This state-of-the-art practice, however, fails to meet current and future requirements, as the ever increasing complexity of these high-tech systems cannot be adequately dealt with by current, often still mono-

[3] These innovations are also being addressed in the Dutch roadmap for ICT [8], addressing topics, such as cooperative networks, interoperable ICT systems, information fusion, big data analytics, web-based services, net security, privacy, etc.

disciplinary, design methods and tools. As a result, the engineering discipline is in strong need to address the heterogeneity and multi-disciplinary aspects of product architecting and design.

- **Efficient and effective product innovation process.** There is a significant need for a more fundamental basis of embedded systems engineering to improve on the efficiency, effectiveness, quality and costs of the design/development process. Emerging techniques for product design have a strong quantitative basis, involving modeling, analysis, virtualization and simulation to achieve the desired results, with an integrated system view that makes interdependencies between the disciplines and technologies more explicit and manageable. The main needs are summarized as follows:
    a. *Speed of development*. Quality and speed of innovation may be the difference between being market leader and missing a window of opportunity. An improvement of just 1% in efficiency in product innovation can represent a saving of millions of Euros.
    b. *Lean and flexible innovation process.* With the ever increasing need for customer intimacy, also the need for product adaptability, personification and integration in a continuously changing user context increases. This requires an agile product innovation process that caters for quickly changing customer needs with short feedback cycles that incur minimal costs.
    c. *Dependable products and services.* Industrial cost of non-quality (recalls, after sales, brand damage, etc.) can easily amount to 2 - 3% of a company's turnover. Societal costs for non-availability or redesign of public infrastructures, can amount to many millions of Euros. As a result there is significant need for processes and techniques that contribute to a considerable improvement in product (or service) quality and reliability.
    d. *Effective deployment of design assets.* The cost of innovation is not only determined by an efficient and effective development process, but also by the ability to re-use (or efficiently adapt, rejuvenate or refactor) these design assets to generate different products or product versions. Also, a value-added upgrade and life-cycle business requires processes and designs that emerge from a well-established technology platform and configuration management strategy.
- **Human capital.** In terms of human resources, based on the points mentioned above, there is a significant need for competent professionals with the required level of knowledge and skills. As is also invigorated by an aging workforce, there is a growing need for systemic investment in education and training to support life-long learning to develop and maintain the broader capabilities of high-tech knowledge workers. In the area of embedded systems, this translates into a special need for education in the area of system architecting and multidisciplinary engineering to accelerate the relevant learning curves.

3.4.3 Knowledge and investment sharing

The HTSM-ES roadmap enables the creation of an open innovation eco-system on embedded systems knowledge and competence development, in which industry, academia and knowledge institutes can work on problems, cross fertilize and share results. These possibilities are especially important, as the investments to develop the required competences and knowledge building-blocks may surpass the capabilities of individual industries and organizations. An open innovation process that facilitates a shared knowledge and investment multiplier therefore is of paramount importance.

3.5 High-tech product challenges

As has been described in Section 3.4, most high-tech companies experience a shifting market paradigm that drives a need to adapt their mix of products and services, with a focus on value added end-user applications with a high level of integration in a user's work-flow. Key to this change is the continuously advancing capabilities for integration of high-tech systems with communication technology and information services. As is depicted in Figure 4, the move from stand-alone products toward client-focused solutions has significant impact on the high-tech product challenges. Apart from an appropriate level of product functionality, user interaction, performance and dependability, companies now need to address capabilities for system adaptability, context awareness and data-privacy and integrity.

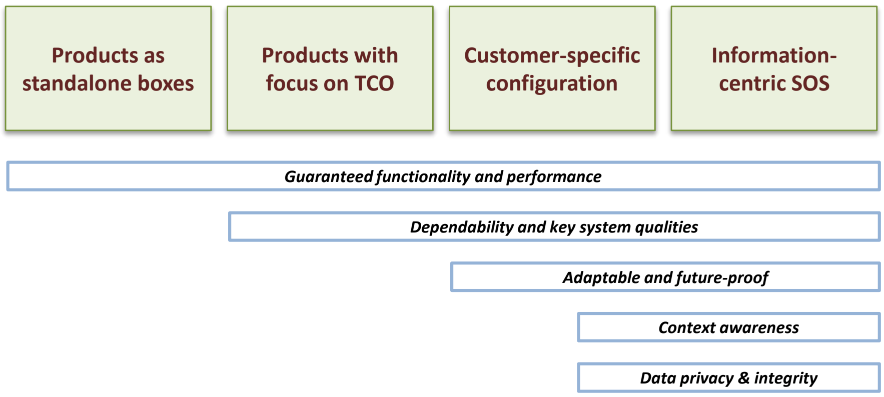

Figure 4: The emerging role of information-centric systems-of-systems for integrating products and services.

These capabilities address a number of high-tech product challenges that are grouped into two key categories, (i) at *product/application* and (ii) *design process*.

1. **Product/application challenges**. The high-tech product related challenges primarily address product innovation, i.e. the processes, methods, tools, and techniques that are used to conceptualize, architect, design and engineer a system. Product requirements are expressed in terms of *functional and non-functional* requirements which, to a significant extent, will determine the user experience and product appreciation in the market. However, this multi-disciplinary design process is considered one of the most complex challenges that needs to be addressed.

   The following system-level high-tech product challenges are considered key drivers for the embedded systems roadmap:

   a. *Architecting/design for key system qualities*. Most systems and applications continuously grow in functionality and technological complexity. At the same time they are further integrated into networked data-driven environments. In this context it has become a major challenge to design systems that comply with the required levels of performance, dependability and efficiency, without compromising on privacy, security and scalability.

b. *Adaptable systems.* Product designs that are *configurable* to customer needs and that can be adapted or tuned to a specific user need, user environment and/or application over time. The challenge with such capabilities is not only to support a wide variation of use cases, but to do so under strict requirements for quality, performance and dependability. A further level of adaptability incorporates *s*ystems that are context-aware, as well as self-organizing and plug-and-play, so that they provide the required functional capabilities, also in situations that are not a-priori known.

c. *Technology platforms.* Technology platforms with efficient re-use of design assets can provide for significant development and operational cost savings. It requires special attention to be paid to the product's architectural starting-points, such as for system decomposition, abstraction of interfaces, platforms to facilitate reuse of design assets, as well as the ability to efficiently and effectively apply for software refactoring or code rejuvenation techniques.

d. *Future proof systems.* Design and implement systems that are future-proof in such a way that technical and functional changes can be accommodated during the operating life-cycle of the system. This implies that it must be possible to change or upgrade operational systems.

e. *Open systems.* The design of the system has to provide an adequate level of interoperability, portability and open software standards to allow it to be integrated in a varying user-context, exchange feedback with its environments, analyze that feedback, adjust internal systems as needed to achieve the system's goals.

f. *Data security.* Systems that are secure and safeguard the correct level of data-privacy and data-integrity, as they are protected against external threats, such as hacking and viruses, or misuse, both intentional and unintentional.

g. *Target platform diversity.* Methods and techniques to implement applications on a variety of hard- and software platforms with minimal extra efforts. This includes methods and techniques for code-generation/synthesis and systems programming, taking into account resource constraints, and architectural considerations for portability of applications.

h. *Human factors and user interaction.* The ergonomics of a system must maximize ease-of-use, safety, human well-being and occupational health. This requires the design of man-machine interactions that represent an optimal 'fit' between the user, product characteristics, information and operating environment.

i. *System interoperability.* Design and implementation of systems that provide the appropriate level of interoperability between the products or services to which they are connected (by means of intelligent networks, wired/wireless communications), including their joint capabilities for information management and ubiquitous computing (see next points).

j. *Data analytics, information mining, cloud computing.* The process of gathering, storing, mining, inspecting, processing analysis and visualization of data [26], with the goal of discovering useful information and supporting the decision-making process. This also incorporates analysis technique that focus on knowledge discovery rather than purely descriptive purposes.

k. *Pervasive computing.* Systems that enable pervasive or ubiquitous data-processing and computing applications require novel architectures and solution patterns, including in-depth understanding of information flows, processing flows and system health.

2. **Process challenges.** The process challenges related to high-tech products concern the design processes and leadership in design & engineering. The following design process challenges enable the high-tech product challenges:

   a. *Multidisciplinary design teams.* Product development processes that support the control of the multi-disciplinary aspects of the system and the design as a whole.

   b. *Distributed design teams.* Product development processes that cater for co-development (multi-party/multi-site), with global design partners and a network of suppliers.

   c. *Design virtualization.* Strong emphasis on virtual prototyping (less physical models) and design digitalization, model-based analysis, including model-based verification and test. This implies an increased use of simulations, 3D models, virtual realities, etc. Design virtualization will also enables effective and efficient design-space exploration and optimization strategies.

   d. *Product-families and design re-use.* Development processes for products or product-families that are platform-based and ready for future needs, to achieve proper cost-benefit through re-use of hardware, software, and design building-blocks among products and across product generations (evolutionary design following reference architectures).

   e. *Multidisciplinary design tooling*. The challenge to deal with high-level tooling and their interoperability, but also to integrate tooling from various disciplines (multidisciplinary processes) and from various subsystem suppliers into one design process.

   f. *Agile design processes.* An agile product development process promotes adaptive planning and an evolutionary development process. It incorporates a release policy that supports early delivery, thereby allowing for continuous system integration, system improvement and rapid response to change[4].

   g. *Professional capabilities and skills*. To accelerate the relevant learning curve and cope with the challenges mentioned in this roadmap, special life-long learning programs are needed that not only accommodate the quickly changing *technology base*, but emphasizes on training and education for system architecting, system engineering and multi-disciplinary system design.

[4] Design virtualization will be a catalyst *and* prerequisite for this.

3.6 Technology challenges

This section translates the challenges in high-tech product design, as discussed in the previous section, into more specific technology challenges and design practices that need to be addressed to stay ahead in the innovation curve.

The following technology challenges are essential for system-level innovations of high-tech products and services:

1. **System design with focus on system qualities.** Methods and techniques to conceptualize, design and implement systems that certify key system dynamics, most notably *the functional requirements*, but also the non-functional requirements (or system qualities) such as *system performance* and *dependability* (reliability, availability, etc.). This incorporates, depending on the application, also topics such as energy usage, security, privacy, and scalability.

   To address these challenges, technology solutions can be found in terms of 'solution patterns', 'reference designs' and 'model-based' techniques. These approaches are especially useful for analyzing non-functional behavior in terms of performance, reliability and adaptability, allowing for early design verification. They also support a much better understanding of the system's functional capabilities. These approaches must ensure that the system (or component) properties are fully preserved during the system's operational life-cycle (see also 'future-proof systems').

   A further key challenge is found in the need for the design models to be well-aligned and well-integrated in the overall design process and to have a sufficient level of mutual interoperability. This is tightly coupled to the product challenge of design virtualization.

2. **System integration and test.** Over the recent years, a number of innovative new techniques and approaches for system test have been developed. However, design for system integration has been a largely unexplored area[5]. Novel techniques and approaches for early system integration, such as model-based approaches that simulate sub-system or component behavior, are required. These approaches must aim to minimize the need for re-design and re-engineering activities that regretfully are happening all too often during the system integration phase. Especially underexplored are the integration and test techniques that are needed for highly configurable and adaptable systems-of-systems that operate in a larger context. Such systems are not under control of a single system integrator and are subject to continuous change.

   A further challenge is to limit the number of physical prototypes and/or system configurations that is needed for system integration, system test and training. This is especially important for products that require very high levels of capital investment but can also be used in situations where there is much to gain by automating integration and test activities.

3. **Future-proof systems.** There is a strong need to design systems that allow for ease of change and upgrade during its operational life as many business revenue models are based on such a capabil-

[5] Policies for system integration often incorporate techniques based on ERP, planning and tracking, and less so techniques from architectural reasoning.

ity. The technology challenges associated to this need are huge and, amongst others, require the following:

a. *System modularization.* Future-proof systems require a level of modularization that allows for system updates (hardware, software) to be executed under the condition of full 'system integrity'. This requires new architectural decomposition approaches and interfacing concepts, including extended plug-and-play capabilities in devices.

b. *Design for re*-use. Re-using design assets require a clear definition of such assets and their interfaces. This is narrowly coupled to the system modularization.

c. *Product upgrade.* Product (field) upgrade strategies are needed that cater for the rapid changing technology and new product functionality. This requires new techniques for architecting in a life-cycle context.

4. **Adaptive systems.** The technology challenge for adaptive systems addresses both the design-time and run-time topics that need to be addressed in order to incorporate capabilities for a system to adapt itself to specific user needs, operating environment or application context. These concern, amongst others:

a. *System configurability.* Product designs that are configurable to specific (widely varying) customer needs. The technology challenge is not only to support a wide variation of use cases, but to do so under strict requirements for quality, performance and dependability.

b. *Context awareness.* Context-aware and adaptive operations are needed for systems to function in situations that were not addressed or known at design time. The technology challenge is to realize embedded intelligence to observe both the system's own operations and that of its environment, to be able to reason on both, and to decide about how to adapt itself and optimize its system level capabilities

c. *Self-organizing, self-learning systems.* These systems base their operation on an algorithm learning process that is based on trial and error. By making changes in operation and simultaneously monitoring results, the system can judge whether these changes were favorable with respect to the control goals. This allows the system to make changes until 'best results' are achieved or until the control process starts to deteriorate.

5. **System health monitoring, diagnostics and preventive maintenance.** Systems must ensure continuous operation and need to be diagnosed and repaired whenever problems are expected or arise.

a. *Runtime techniques.* New runtime techniques for system-level integration and test are needed for systems with continuous operation.

b. *System maintenance.* Maintenance & service strategies are required that address efficient field-service problem diagnostics. Also prognostic techniques for timely identification of preventive maintenance are needed.

c. *System health detection.* The purpose of a system health monitor is to detect any error states (i.e. exceptions, disappearing processes, deadlocks) in the system to take appropriate (preventive) action. Each component in a systems-of-systems configuration needs an inner notion of the health of its own and the others' operations. This incorporates mechanisms to safeguard against effects of communication failures, delays, faults, and intentional misinformation or misuse.

6. **Data-privacy and data-integrity.** Systems must ensure active and passive *data-privacy* and *data-integrity*. The technology challenges required for these innovations are, amongst others:
   a. *Architecting for data-privacy and security.* This requires novel means to fulfill system operation in distributed configurations with minimal sharing and storing of information.
   b. *Monitoring and prevention.* The means to detect an (attempted) breach of privacy or integrity and the capability to respond and rectify the situation.
   c. *IP protection*. Build-in IP protection for software and hardware (e.g. source code, VHDL).
7. **Cross-domain system interoperability and interaction.** The challenge in interoperability and interaction is to fuse embedded systems technology with network and communication technology and integrate with high-level information processing (e.g. big-data, cloud-based, ubiquitous computing, etc.). These large-scale CPS systems provide very specific challenges in terms of timeliness, safety, security, privacy and adaptability.

   The technology challenges required for these innovations are, amongst others:
   a. *Inter-system communication.* Systems-of-systems operate beyond the current level of well-defined communication that adheres to standards or was defined during design-time. Instead, smart interpretation of communication becomes necessary to allow for flexibility to co-operate in unforeseen ways in a robust manner, adapting to differences in protocols and syntax as well as semantic interpretations.
   b. *Data-driven capabilities.* From data collection to information management and decision support. New run-time (embedded) methods and techniques to access, search, interpret (big) data, methods for data driven prognostics/diagnostics and capabilities for the system's to base decisions and take actions on the interpretation of data.
8. **Small heterogeneous systems.** Small heterogeneous systems, such as systems-in-packages or systems-on-chips, incorporate an increasingly wide variety of components, sensors, actuators, processing units and network interfaces. The design challenge is to combine and integrate these components into single (component) solutions, providing faster calculations, lower power consumption, more precise sensing, reduction in physical dimensions and lower overall costs. The development in this area is inherently multi-disciplinary, requiring entirely new technologies, such as for physics, new materials and manufacturing processes. Please refer to the HTSM roadmaps 'Nanotechnology' and 'Components and circuits' for further details.

9. **Model-based systems (of systems) design and engineering.** Currently, a wide variety of technologies is available for model-based design, computational science, simulation, test and verification. Aspects thereof have been discussed above. There is a strong need for better mutual alignment and integration of this large diversity of (mainly mono-disciplinary) techniques. This translates into the following technology needs:

    a. *System-level insight.* Novel ways are required to control the variability of systems, components, their operations and interactions. Without such support, no system architect, designer or engineer will be able to understand and manage the impact of (even small) design decisions on the total system behavior[6].

    b. *Structured design support.* Support is needed to sustain critical design reasoning and design decisions through time and product evolutions. This requires methods and tools to systematically track design decisions and their interplay, and couple those to the assumptions and boundary conditions on which these decisions were based. This not only allows system level reasoning, it also provides the development organization with communication and learning capabilities. Finally this helps the organization to consolidate design decisions and their reasoning for future reference. In the domain of system-of-systems engineering, where systems are independent of operation and organization, this leads to the additional challenge of engineering within a scope that is no longer under control of a single design team. Such methods and tools will provide a reference point for the system design, to be used as the 'single point of truth'.

3.7 Scientific challenges

The scientific challenges can be clustered along the same lines as the system level challenges indicated in Figure 2: (i) guaranteed functionality and performance, (ii) dependability and related system qualities, (iii) configurable and future-proof systems, (iv) context awareness, data privacy & integrity, (v) virtualization of design process.

1. **Guaranteed functionality and performance.** This addresses many challenges such as requirements capturing, trade-off analysis, key technology choices, resource budgeting, system partitioning and assessment of alternatives. The current state of the art techniques are often either too coarse (spreadsheet-type analysis) or too detailed (implementation level, fully functional prototyping) to allow for extensive, multi-objective design-space exploration. They are insufficiently tailored to users from different application domains and to multi-disciplinary use and relationships between models of different disciplines are usually unclear.

    Research on these topics addresses a number of main challenges:

    a. The codification of solutions in terms of best practices or reference architectures, generically, or for specialized classes of systems, e.g., architectures for data-intensive systems, or for real-time systems

[6] Through the diversity and complexity of today's systems, it becomes almost impossible to foresee all possible consequences of these decisions in future implementations, configurations, situations and operations.

b. Finding solutions under new and advanced requirements, e.g., in the context of systems of systems, or for systems with mixed criticality
c. Hardware-software trade-offs and hardware/software co-design
d. Incorporating legacy and third party components and (sub-)systems
e. Resource planning and scheduling to deal with an increasing degree of parallelism (e.g., in multi-core CPU's, GPU's, heterogeneous platforms, or on FPGA's)
f. The use of software engineering and programming techniques to generate efficient yet maintainable code, incl. software refactoring to create state-of-the-art coding structure that can be deployed on a large scale on a variety of hardware devices
g. The generation of code for resource-constrained devices (e.g., regarding memory, processing power or energy)

2. **Dependability and related system qualities.** The term dependability is used in relation to the availability, reliability and maintainability of a given system and coupled to the complete lifecycle (from requirements, specification, design, hand-over, operation, and final decommissioning) of a product. The dependability of a system can be influenced by external factors such as worn-out or broken components (life-time failures), internal factors such as compromises in the quality caused by humans, and organizational factors, e.g., wrong design-time decisions.

   Dependability is an essential n-functional requirement of a system. Non-functional requirements include constraints and *system qualities*. System qualities are properties of the system that its stakeholders care about and will affect their degree of satisfaction with the system. Examples of system qualities include cost, size, performance, reliability, context awareness, security, power consumption, environmental footprint, etc.

   The objective for dependable systems is to ensure that a system both meets the required functional- *and* non-functional needs. This not only requires cross-functional, multidisciplinary, system-level thinking, but especially proven architecting principles that are well-defined, both in theory and practice.

   Research on these topics addresses a number of main challenges:

   a. Understand and quantify the relationship between architecting, design and requirements
   b. Systematic analysis of a design for key system values (e.g. performance, reliability, robustness, security, availability, …)
   c. Incremental system integration techniques (focus on 'are we building the right product'), including integration-driven design, design for integration, and making use of hardware-in-the-loop and software-in-the-loop techniques.
   d. Adaptive/learning control methodologies
   e. Verification techniques (focus on 'did we build the product right'), including model-based testing, test automation, execution flow analysis and making use of virtual prototypes

f. Fault diagnosis (what is the root cause of failure) and prognosis/health monitoring, including data-driven prognostics, data-driven diagnostics and remote monitoring

g. Techniques for system-health monitoring, failure analysis, prognostics, or more specifically data-analysis and mining techniques to predict system operations in terms of quality, performance, reliability and need for preventive maintenance.

h. Techniques to monitor critical resources like threads, processes, and memory conditions in the system and describes actions which can be taken to address problems.

3. **Configurable, future-proof systems and re-use of design assets.**

   1. *Model-based design, platform-based design and re-use of design assets.* This comprises architecting and system design methodologies, including those that emphasize the systematic re-use of design assets. Such designs are based upon platforms of design components or libraries of compatible hardware and software virtual component, intended to maximize re-use and thereby reduce development risk, costs and time-to-market.

      Research on this topic addresses a number of main challenges:

      a. Analytical and computational models
      b. Model-based design approaches and design model interoperability
      c. Synthesis-based design approaches with design/implementation level separation
      d. System heterogeneity, management of diversity
      e. Platform architecting, validation and virtualization
      f. Meta-modeling (frameworks for expressing different models and their interoperation)
      g. Architecting for large-scale component/sub-system re-use
      h. Design automation and code generation techniques for re-use
      i. Legacy systems and software refactoring

   2. *Future-proof systems.* The phrase future proofing describes the exclusive process of trying to anticipate future developments, so that action can be taken to minimize possible negative consequences. Systems need to be future proof to allow progressive (functional and technical) updates and enhancements to prolong their useful economical life. Being future-proof is a system property that relates strongly to how a system is designed and therefore, as a matter of fact, to the design-time methods and techniques being deployed.

      Research on this topic addresses a number of main challenges:

      a. Structured approaches for design decomposition and interface definition
      b. Platforms and modular architecting approaches (amongst others forward and backward compatibility)
      c. Strategies for system configurability and adaptivity
      d. Run-time optimization of systems

e. Adaptive and learning control methodologies

f. Exploration of the impact of different design options (being future-proof)

g. Analysis of sub-system and component interdependencies

h. Architecting in a life-cycle context

i. Product upgrading techniques

4. **Context awareness, data management, security, privacy & integrity**

1. *Context awareness.* Context awareness is regarded as an enabling technology for ubiquitous computing systems. It is concerned with the acquisition of context (e.g., using sensors to perceive a situation), the abstraction and understanding of context (e.g., matching a perceived sensory stimulus to a context) and application behavior based on the recognized context (e.g. triggering actions based on context). Context-awareness is used more generally to incorporate impact by the physical environment, such as lighting, noise level, the presence of people, traffic or external threats, but also of availability of services, such as mobile networks, energy provisions, utilities or information. Context awareness can also comprise social interactions.

Research on this topic addresses a number of main challenges:

a. Sensing/actuator techniques to observe and react on external conditions

b. System interoperability

c. Integral security (support in OS, HW, languages, …)

d. Dynamic adaptation to changing contexts

e. Incremental system integration and testing to evolve towards the targeted setup

f. Decision and control in uncertain and changing contexts

g. Mobile agents

2. *Data management and analysis.* The process of gathering, storing, mining, inspecting, processing and analysis of data, including analysis techniques that focus on knowledge discovery.

Research on this topic addresses a number of main challenges [26]:

a. Data architectures and design

b. Data management, i.e. methods for data definition, collection, modeling, analysis and processing

c. Data analytics for structured, semi-structured and unstructured data

d. Data governance and security

e. Data visualization techniques

f. Data mining

g. Hybrid search engines

h. Bayesian network modeling

3. *Information privacy and integrity.* Information privacy, or data privacy (data protection), is the relationship between collection and dissemination of data between systems. It is strongly influenced by public expectations of privacy and the legal/political issues surrounding them. Data integrity refers to maintaining and assuring provenance, accuracy and consistency of data over its useful life-cycle and is a critical aspect to design, implementation and usage of any system which stores, processes, retrieves and exchanges data.

   Especially for cyber-physical system configurations, i.e. systems that are integrated in large, information-centric, distributed, and multi-owner systems of systems, data privacy and integrity issues are a key concern.

   Research on this topic addresses a number of main challenges:

   a. Reliability of information

   b. Data ownership, data security

   c. Physical and logical data integrity

   d. Integrity constraints and rules (entity integrity, referential integrity, domain integrity)

   e. Data and information fusion, semantic alignment (shared interpretation of information)

   f. Data retention

5. **Virtualization of design processes**

   Traditionally, a high-tech product design process relies on the development of (partial) physical prototypes of the system design. These physical prototypes are constructed to test and evaluate functional and non-functional characteristics of the system. Typically, these systems are used to manage project risks by providing early proof of correctness of the design decisions. The weaknesses that are detected during physical testing of the prototype serve as drivers for redesign, allowing faults to be corrected as early as possible in the design stage.

   Design virtualization addresses the techniques to create a virtual (as opposed to physical) version of the system design. This is done by creating computer generated models that accurately represent key (functional, non-functional) characteristics of the system with the objective to simulate its behavior and performance in the real world. This allows key design decisions to be validated before committing a physical prototype or the product itself.

   1. *Model-based design techniques.* When deciding on the best approach to implementing virtualization techniques in a product innovation process it is important to have a clear understanding of the different virtualization solutions and their benefits. Research on this topic addresses a number of main challenges:

      a. Capturing of knowledge in (domain-specific) models

   b. Combining different approaches from different disciplines in system-level models[7]
   c. Assess design alternatives and the impact of choices on product aspects such as cost, quality, and performance (design space exploration)
   d. Capturing of 'specific' knowledge in (domain-specific) models
   e. Model-based testing and test-based modeling techniques

2. *Design space exploration.* Design space exploration (DSE) refers to the activity of exploring design alternatives before going to actual implementation. This process, usually combined with techniques for model-based design optimization and/or rapid prototyping, allows the system architect to explore the boundaries of the design and the trade-offs between critical design criteria. Research on this topic addresses a number of main challenges:
   a. Methods and techniques for analyzing a design space with attention to multi-disciplinary and multi-aspect analysis of design trade-offs
   b. Strategies for design space reduction (as design space analysis can become extremely large and complex)

3. *Multi-model analysis and integration*. Design virtualization is based on the creation of computer generated models that represent one or more key characteristics of a system. This creates a multitude of virtual designs in which the mutual relationships and dependencies between these models must be managed. Research on this topic addresses a number of main challenges:
   a. Traceability of design decisions and reasoning throughout the design process
   b. Multi-disciplinary architecting integration, to manage key design criteria
   c. Functional design model integration, i.e. the coordination of calculations between models, as to manage mutual interdependencies
   d. Deep model integration, i.e. generation of new models on the basis of two or more given models
   e. Engineering model integration

[7] E.g., mechanical, electrical, optical and software engineering designs to be combined with domain specific formalisms, such as for magnetic resonance, ink-jet technology, electromagnetic lenses technology, etc.

4. PROGRAMS AND FUNDING

4.1 Available funding

The Topsector High Tech Systems and Materials (HTSM) aims to facilitate structural collaboration between Dutch industry, academia and research organizations. The roadmaps form the heart of HTSM. These contain medium-term plans in which the reasoning and topics for research and innovation are described and that are realized in cooperation between industrial enterprises, academia and research organizations.

To support the realization of the plans, a mixture of fundamental and applied R&D programs is put into place, with funding from industry, academia, NWO/STW, TNO, the Dutch government and the European community. These comprise the following:

- Industrial and academic investments in plans and programs (direct and co-funded participation).
- NWO funding (executed by academic partners).
- STW funding (executed by academic partners in cooperation with industry and/or other research organizations).
- European Union funding (executed by individually participating organizations such as industry, academia or research organizations) - see also Section 4.3.
- TNO co-funding (executed by TNO-ESI or other TNO research groups in cooperation with industrial and/or academic partners).
- B2B funding (research organizations or academia on the basis of assignments).
- TKI innovation funding. Under certain conditions, the Dutch government adds 25% to an industry cash investment in research in the form of a 'TKI toeslag'. These TKI funds are assigned to participating academic groups or research organizations.

4.2 Positioning ES roadmap in HTSM context

The Topsector HTSM comprises a set of application-oriented roadmaps (semiconductor equipment, printing, lighting, solar, healthcare, security, automotive, aerospace, space, advanced instrumentation) and technology-oriented roadmaps (high-tech materials, embedded systems, photonics, mechatronics, components & circuits, nanotechnology, ICT). As is depicted in Figure 5, the embedded systems roadmap basically services all application-oriented roadmaps in the area of *embedded systems engineering*. This also applies to other topsectors where embedded systems know-how plays an important role, such as *logistics* and *energy*. In this regard the Embedded Systems roadmap plays an important cross-roadmap role, similar to the ICT roadmap.

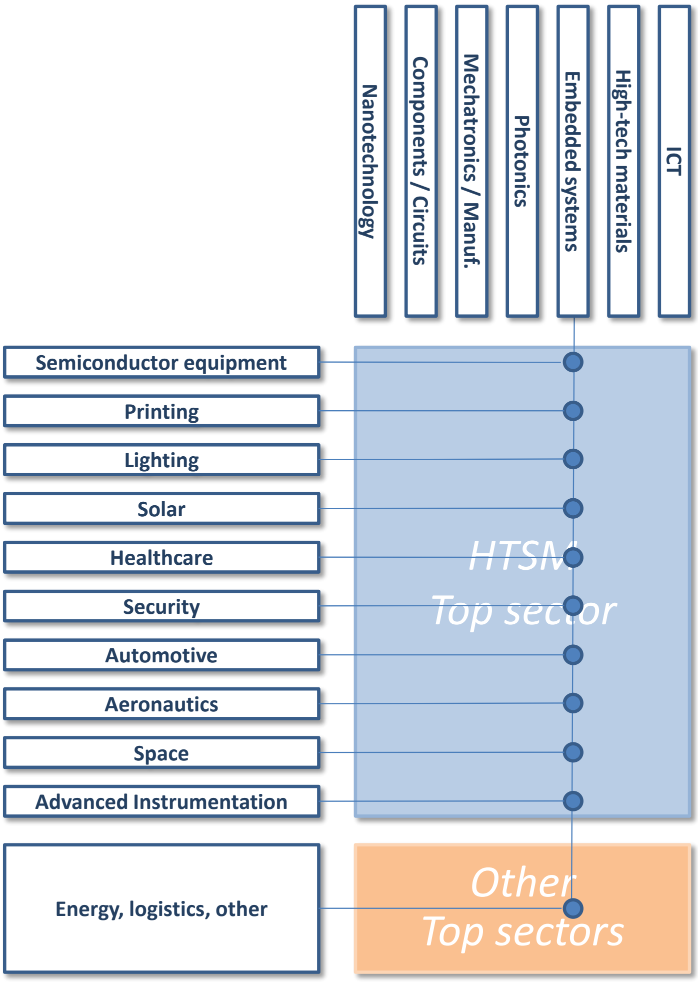

Figure 5: Roadmaps that are part of the Topsector HTSM

4.3 European programs (Horizon 2020, EUREKA)

European programs provide an excellent opportunity to firmly connect to- and cooperate in the international innovation community. Aligning with these programs will enable us to create a knowledge- and investment multiplier for the HTSM Embedded Systems roadmap.

There are two European programs that are closely related to the HTSM-ES roadmap:

1. **Horizon 2020.** This is part of the Europe 2020 program that defines the EU's growth strategy for the coming decade.

   The Horizon 2020 program is running from 2014 to 2020 with an €80 billion budget. The EU's program for research and innovation is part of the drive to create new growth and jobs in Europe. Horizon 2020 will build leadership in enabling and industrial technologies, with dedicated support for ICT, nanotechnologies, advanced materials, biotechnology, advanced manufacturing systems, and photonics, while also providing support for cross-cutting actions to capture the accumulated benefits from combining several ‘key enabling technologies’, facilitate access to risk finance and provide Union wide support for innovation in SMEs.

The Horizon 2020 program provides important means to internationally anchor the embedded systems activities in the roadmap, as embedded systems technology represents an international playing field, with strong industrial and academic players in countries like Germany, France and Sweden.

Horizon 2020 is implemented through, amongst others, public-private partnerships where the partners commit to research and innovation activities of strategic importance to the Union's competitiveness and industrial leadership or to address specific societal challenges. ECSEL is such a Joint Undertaking and a merger of the Joint Technology Initiatives ARTEMIS (embedded systems) and ENIAC (nanoelectronics).

2. **EUREKA.** This is an intergovernmental industry-led network organization that has the ambition to become the leading platform for R&D-performing entrepreneurs in Europe and beyond. It supports market-oriented R&D and innovation projects by industry, research centers and universities across all technological sectors.

   EUREKA public-private partnership is organized in EUREKA Clusters, developing generic technologies. The two clusters of importance for the HTSM ES roadmap are ITEA (software-intensive systems and services) and CATRENE (micro- and nano-electronics).

4.4 Alignment and cross-over ES roadmap and European programs

Horizon 2020 has set three key objectives, as is depicted in Figure 6:

1. **Excellence in science base.** World class science is the foundation of tomorrow’s technology, jobs and well-being. Education of people and building this foundation are major parts of the HTSM Embedded Systems roadmap.
2. **Creating industrial leadership and competitive frameworks.** The ‘Competitive Industries’ objective of Horizon 2020 targets specifically at strengthening of industrial competitiveness in ICT and key enabling technologies.

   The Strategic Research Agenda (SRA) of ECSEL encapsulates both the SRA of ENIAC and ARTEMIS of which the Artemis SRA shows many cross-overs with the HTSM ES roadmap. The three main ARTEMIS research areas are reference design and architectures, seamless connectivity and interoperability, and design methods & tools. All three areas are major parts of the HTSM ES roadmap.
3. **Tackling Societal Challenges.** The reasoning line of the HTSM Embedded Systems roadmap starts with identical societal challenges as the ones from Horizon 2020.

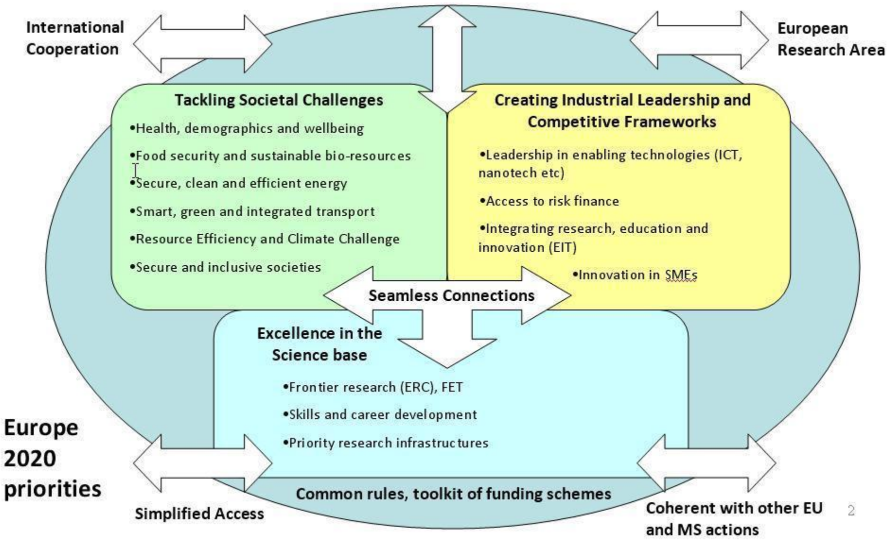

Figure 6: The Horizon 2020 program structure.

The EUREKA ITEA cluster cooperates closely with ARTEMIS/ECSEL which resulted in a shared vision for 2030. Consequently, ITEA can be mapped to the HTSM ES roadmap in the same way.

Conclusion is that there is a clear alignment between the HTSM ES roadmap and the Horizon 2020 and EUREKA programs. This paves the way to work on the HTSM ES roadmap in a European context.

5. PARTNERS AND PROCESS

The HTSM 2015 roadmap for Embedded Systems has been developed in close cooperation with the industrial, academic and institutional R&D community for embedded systems in the Netherlands. Starting point for this roadmap have been the embedded systems roadmaps for the year 2012 [1] and 2014 [2].

On 17 April 2015, a special workshop was organized in which a broad representation of the embedded systems community was invited to comment on- and add to the reasoning line. In this intensive half-day workshop, with more than 30 attendees, many useful comments and extensions were provided. The adapted reasoning line has been redistributed to the embedded systems community for further review and extension. In its current reviewed form, it is presented in Appendix A.

On the basis of the review/update of the reasoning line, the current "HTSM Roadmap for Embedded Systems 2015" has been developed. The document have been put forward to the auditor group (cf. Appendix C). The feedback has been carefully addressed and incorporated as well as possible.

The current approach has safeguarded a broad and strong foundation for the roadmap. It represents a shared vision on Embedded Systems by the majority of the Dutch industry, universities and relevant research organizations.

Figure 7: Pictures from one of the three special workshops during the roadmap review meeting on 17 April 2015.

6. INVESTMENTS

Estimate for overall investment in embedded systems R&D, as applicable to the HTSM-ES roadmap (all figures are in M€ per year):

Roadmap program	2018 (M€)	2019 (M€)	2020 (M€)	2021 (M€)
Industry	1.700	1.734	1.769	1.804
TNO	25	25	25	25
NLR				
NWO	2,5	2,5	2,5	2,5
Universities	62	62	62	62
EC	18	18	18	18
EZ	13	13	13	13
Other institutes	9	9	9	9
Other government				
Grand total (in M€)	**1.830**	**1.864**	**1.898**	**1.934**

TKI program	2018 (M€)	2019 (M€)	2020 (M€)	2021 (M€)
Industry, cash	14	15	16	17
Industry, in-kind	7	7	8	8
TNO	2,0	2,0	2,3	2,5
NLR				
NWO	2,5	2,5	2,5	2,5
Universities	31	31	31	31
Other institutes	4	4	4	4
Other government				
TKI grant				
TKI total (in M€)	**60**	**61**	**63**	**64**

European program	2018 (M€)	2019 (M€)	2020 (M€)	2021 (M€)
Industry	20,5	20,5	20,5	20,5
TNO	5,5	5,5	5,5	5,5
NLR				
FOM				
Universities	4,7	4,7	4,7	4,7
Other				
EU total, projects (in M€)	**30,6**	**30,6**	**30,6**	**30,6**

European program	2018 (M€)	2019 (M€)	2020 (M€)	2021 (M€)
EC	18	18	18	18
EZ	13	13	13	13
Other				
EU total, grants (in M€)	**31**	**31**	**31**	**31**

APPENDIX A - REASONING LINE

Societal challenges
Inclusive and innovative society
Safe and secure society
Smart and green mobility & transport
Quality of life, health & wellbeing and care
Agriculture and food
Sustainable energy and CO2 reduction
Changes in climate and water
Circular economy
Economic drivers
Globally leading competitive position for industry (export, growth in GDP, …)
Reduction of cost of doing business
Minimize economic impact of failing technology
Availability, utilization, performance and quality of the workforce
Industry needs (OEM & Supplier)
Competitive products on the world stage (costs, time, quality, product features)
Right product, right time, right place
Flexibility and adaptability (development, manufacturing, end-user integration)
Effective and efficient supply chains (OEM, suppliers)
Management of installed base (life-cycle management, legacy systems, software rejuvenation, …)
Customer intimacy (distinguishing product features, adaptability, personification)
Collaboration and partnering (3rd party, technology & organization, open innovation)
Certification, regulation, open standards
State-of-the-art knowledge, skills and competent people
High-tech product challenges
1. Product/application
Architectures and techniques to support key system quality attributes
Evolvable, adaptable, platform based systems, product families, compatibility and modularity
System interoperability
Open systems and standardization (e.g. cloud-based)
System-integrated data analytics (mining, analysis, reasoning, presentation, ownership)
Condition-based maintenance
Human factors, user interaction, ease of use
2. Process
Lean agile development (multi-disciplinary, incremental and fast cycles)
Virtual product development (multi-disciplinary, model-based, integrated tooling)
Knowledge-based leadership in design and engineering
Technology challenges
Large scale IoT systems (e.g. cloud-based, ubiquity, legacy, evolution, integrity, …)
Virtual, model-based development (models, tooling, higher abstraction levels, languages, …)
Design for re-use and customer adaptations, incl. adaptability, configurability, flexibility
Autonomous, self-organizing, self-learning (system of) systems
Design of dependable system (of systems)
System (of systems) integration, verification and validation
Architectures for data-intensive system (of systems)
System health-monitoring, diagnostics and preventive maintenance
From data collection to information management and decision support
Build-in IP protection (software, hardware, business control points)
Scientific challenges
Systematic analysis of and design for key system values (e.g. performance, reliability, robustness, security, serviceability, energy)
Multi-disciplinary/aspect model-based design techniques (design, analysis, synthesis)
Design space exploration (e.g. for power consumption, performance, reliability, adaptability)
hw/sw virtualization and multi-model integration
Adaptivity and run-time optimization
Resource planning and scheduling (incl. multi-criticality, heterogeneous platforms, multicore, software portability)
Exploiting hybrid compute platforms, including efficient software portability
Design for low power usage and energy saving
Adaptive/learning control methodologies
Data collection, processing, analytics and visualization
Strategies for system integration
System verification and validation techniques (for functional, non-functional and compliance to standards)
Legacy systems and software refactoring
Integral security (support in OS, HW, languages, …)
System health prognostics and failure analysis

APPENDIX B - APPLICATION FIELDS

The term 'embedded systems' encompasses a wealth of different types of systems, with highly different characteristics and demands. It encompasses a wide variety of system-level views, ranging from silicon-on-chip, high-tech stand-alone systems, to information-centric SoS, or even advanced products or applications that start to emerge in the area of cyber-physical applications. This is demonstrated by the wealth of application related product roadmaps that together comprise the Topsector HTSM.

Innovations in the domain of embedded systems will always need to be tailored to a specific product and market characteristics at stake, as each market requires a different emphasis to be placed on the design trade-offs for the product or application.

Figure B.1. summarizes some of the main product categories, identifying their key market attributes in terms of life-span, lead-time, costs and openness to feature extensions[8]. It shows how these various classes of systems or applications score on criteria related to these key market characteristics, demonstrating why tailored R&D is necessary for individual categories of applications. At the same time it demonstrates why significant synergies between the various product categories exist, validating a generic approach to address specific research topics, with the objective to re-use or re-deploy knowledge that has been developed in an other application domain. This underpins the approach taken in this roadmap, in which generic knowledge needs are addressed, independent of individual embedded system products or applications.

	Consumer electronics	Manufacturing equipment	Medical systems	Mobile Comm.	Automotive systems	Digital printers	Security systems	Robotics
Life Span	Medium	Long	Very Long	Very Short	Long	Long	Very Long	Long
Lead Time	Short	Short	Medium	Very Short	Long	Medium	Long	Long
Volume	Very High	Low	Low	Very High	Very High	Medium	Low	Medium
Cost	Very Low	High	High	Very Low	Medium	Medium	High	Medium
Feature Extension	Growing	Medium	High	Growing	Growing	Low	Growing	High

Figure B1: Key product categories vs. market attributes

[8] The innovation needs for these products and services are extensively discussed in the various application roadmaps of Topsector HTSM.

APPENDIX C - CONTRIBUTORS TO THIS ROADMAP

The list below represents the team that has contributed to the 2015 edition of the roadmap. This 2018 edition signifies a limited update done by the roadmap team..

Universities	
TU/e	Twan Basten
TU/e	Johan Lukkien
UvA	Andy Pimentel
TUD	Koen Bertels
TUD	Arie van Deursen
VU	Guus Schreiber
UT	Gerard Smit
UT	Boudewijn Haverkort
RU	Peter Lukas
RU	Frits Vaandrager
Large OEM	
Océ	Lou Somers
Océ	Arjan van der Hoogt
Philips Research/PINS	Ben Pronk
ASML	John Koster
Vanderlande Industries	Bruno van Wijngaarden
TomTom	Kees Schuerman
Panalytical	Jan van Rijn
Philips Europartners	Ronald Begeer
Philips Healthcare IGT	Eric Suijs
Philips Lighting	Emmanuel Frimout
FEI	Hugo van Leeuwen
NXP	Peter Zegers
Thales TRT	Jimmy Troost
Thales Naval	Maurice Houtsma
DAF	Coco Jongerius
Suppliers	
Devlab	Lex van Gijsel
Altran/Nspyre	Marc Hamilton
Sioux Embedded Systems	Paul Zenden
Technolution	Jacco Wesselius
Prodrive	Korneel Wijnands
VDL-ETG	Ton Peijnenburg
SME	
Hotraco Innovative Solutions	Ger Schoeber
Institutes	
ESI	Reinier van Eck
ESTEC	Marcel Verhoef
Roadmap team	
Océ	Hans Geelen
ESI	Frans Beenker
ESI	Wouter Leibbrandt
NWO-TTW	Herma van Kranenburg

APPENDIX D - BACKGROUND READING

D.1 Previous version of HTSM Roadmap Embedded Systems

The HTSM Embedded Systems roadmap has been built upon previous versions of the HTSM roadmap for embedded systems:

[1] HTSM 2012 Roadmap Embedded Systems, Hans Geelen, Boudewijn Haverkort, Erik Peeters
[2] HTSM 2014 Roadmap Embedded Systems, Hans Geelen, Frank Karelse, Frans Beenker

D.2 International roadmaps and agendas

The HTSM Embedded Systems roadmap aligns very well with a number of international Embedded Systems roadmaps and vision documents:

[3] The German Nationale Roadmap Embedded Systems
Zentralverband Elektrotechnik und Elektronikindustrie, Kompetenzzentrum Embedded Software & Systems, Dec. 2009
[4] Actieagenda Smart Industry
Dutch SMART Industry initiative, Nov. 2014
[5] Strategic R&D Opportunities for 21st century Cyber-physical Systems
Foundation for innovation in cyber-physical systems, NISR-CPS, USA, January 2013
[6] Gartner Identifies the Top 10 Strategic Technology Trends for 2015, Gartner Symposium at ITxpo, Barcelona Spain, 9 – 13 November 2014
[7] FAST, Study of Worldwide Trends and R&D Programmes in Embedded Systems, IT Society, European Commission, November 2005
[8] The Dutch national ICT Roadmap 2015 (to be published)
[9] ICT 2020 - Research for Innovation, German Federal Ministry for Education, Bonn, Berlin 2007
[10] The Global Information Technology Report 2012 - Living in a Hyperconnected World,
World Economic Forum 2012
[11] How smart, connected products are transforming the world, M. Porter, J.E. Heppelmann, Harvard Business Review, November 2014
[12] Horizon2020 Societal challenges
http://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges
[13] The Artemis Industry Association Strategic Research Agenda, 2011
http://www.artemisia-association.org
[14] Recommendations for implementing the strategic initiative INDUSTRIE 4.0
http://www.plattform-i40.de/finalreport2013
[15] USA Common Computing Consortium Cyber-Physical Systems Roadmap
http://www.cra.org/ccc/cps.php
[16] Research Roadmap on Cooperating Objects, CoNET consortium
http://www.cooperating-objects.eu
[17] Hipeac roadmap: high-performance embedded architecture and compilation
http://www.hipeac.net/roadmap, 2011

[18] ITEA Roadmap for Software-Intensive Systems & Services
http://www.itea2.org/itea_publications

[19] The High-level vision ITEA-ARTEMIS 2030,
http://www.artemis-ia.eu/publication/download/publication/783/file/ARTEMISIA_High_level_vision_2030_ITEA2_and_ARTEMIS_v.pdf

[20] Ultra-Large-Scale Systems: The software challenge of the future
Software Engineering Institute, Carnegie Mellon University, 2006.

[21] Boston Consulting Group. The growing importance of embedded software, 2004
http://www.bcg.com

[22] International Policy Conference on Strategies for Embedded Computing Research. March 18-19, 2010, Vienna
http://www.cosine-ist.org

[23] Strategy Report on Research Infrastructures, Roadmap 2010, European Strategy Forum on Research Infrastructures (ESFRI), European Union, March 2011
http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri-roadmap

[24] The Global Market for Embedded Engineer Census and Analysis, Section of Strategic Insights 2013, André Girard, Chris Rommel, M2M Embedded Software & Tools Research Program, 2013

[25] 2014 Worldwide Software Developer and ICT-Skilled Worker Estimates, Al Hilwa, IDC OPINION, December 2013

[26] European Big Data Strategic Research & Innovation Agenda, Big Data Value cPPP, July 2014

D.3 National roadmaps and agendas

A number of national (embedded systems) roadmaps and vision documents have been consulted to write this roadmap:

[27] The 2010 Point-One Emerging Technology Agenda for Embedded Systems, Annual Plan, Feb. 2011
http://www.point-one.nl

[28] Kennis- en Innovatieagenda 2018-2021 – Maatschappelijke uitdagingen en sleuteltechnologie-en
https://www.nwo.nl/documents/nwo/kennis-en-innovatieagenda-2018-2021

[29] The Strategic Research and Innovation Agenda of the IIP Vitale ICT
http://www.ictregie.nl/vitale_ict.html

[30] The Strategic Research and Innovation Agenda for the IIP Roboned
http://www.roboned.nl

[31] The Strategic Research and Innovation Agenda of the IIP Sensor Networks
http://www.iipsn.nl

[32] Strategic Research and Innovation Agenda, Embedded Systems Institute, September 2012,
http://www.esi.nl/research/research-agenda.dot

D.3 Selection of consulted scientific papers

The following is a selection of the consulted scientific papers and background articles:

[33] C. Baier, B.R. Haverkort, H. Hermanns, J.-P. Katoen. Performance evaluation and model checking join forces. Communications of the ACM 53(9): 76-85, September 2010

[34] B. Bailey, G. Martin and T. Anderson, Taxonomies for the Development and Verification of Digital Systems, Springer, 2005

[35] M. Boucher and D. Houlihan. System Design: New Product Development for Mechatronics, Aberdeen Group, 2008

[36] H.W. Chesbrough, The Era of Open Innovation, MITSloan Management Review # 4435/3, Spring 2003

[37] A. Deshmukh and P. Collopy, Fundamental Research into the Design of Large-Scale Complex Systems, in 13th AIAA/ISSMO Multidisciplinary Analysis Optimization Conference, Fort Worth, Texas, September 2010

[38] R. Ernst. Embedded Systems - the Neural Backbone of Society, 18 May 2011. [Online]. Available: http://www.artemisia-association.org/publication/download/publication/539

[39] T.A. Henzinger, J. Sifakis. The discipline of embedded system design. IEEE Computer, Oktober 2007: 32-40

[40] P. van de Laar and T. Punter (eds), Views on Evolvability of Embedded Systems, Springer, Embedded Systems Series, 2011

[41] M. W. Maier. Architecting Principles for Systems-of-Systems, Systems Engineering, vol. 1, no. 4, pp. 267-284, 1998

[42] M. Morales, Intelligent Systems, Connectivity, Cloud and Data, Embedded Research and Education Summit, February 2012

[43] G. Muller, Systems Architecting, A Business Perspective, CRC Press, 2012

[44] G. Ramamoorthy, Hype Cycle for Embedded Software and Systems, 2013

[45] J.A. Stankovic. Strategic directions in real-time and embedded systems. ACM Computing Surveys 28(4): 751-763

[46] J.A. Stankovic, I. Lee, A. Mok, R. Rajkumar. Opportunities and obligations for physical computing systems. IEEE Computer, November 2005: 23-31

[47] T. Tomiyama, V. D'Amelio, J. Urbanic and W. ElMaraghy. Complexity of Multi-Disciplinary Design, Annals of the CIRP, vol. 56, no. 1, pp. 89-92, 2010

[48] R. Valerdi and 11 more authors. A research agenda for systems of systems architecting. International Journal of Systems of Systems Engineering 1(1/2): 171-188, 2008

[49] K. W. Zimmermann and H.-M. Hauser. The Growing Importance of Embedded Software - Managing Hybrid Hardware-Software Business, The Boston Consulting Group, Munich, 2004

APPENDIX E - TERMS AND ABBREVIATIONS

3TU	Federation of the three Dutch universities of technology, TUD, TU/e and UT
ARTEMIS	Advanced Research & Technology in EMbedded Intelligence and Systems European Community funded innovation initiative
ARTEMIS-IA	ARTEMIS - Industry Association
ARTEMIS-JU	ARTEMIS - Joint Undertaking
B2B	Business-to-Business
CATRENE	Cluster for Application and Technology Research in Europe on Nanoelectronics
CPS	Cyber-physical systems
ECSEL	JU on Electronic Components and Systems for European Leadership
ENIAC	JU on Nanoelectronics
EC	European Community
ES	Embedded Systems
ESE	Embedded Systems Engineering
ESI	Stichting Embedded Systems Institute Note: per 1-1-2013 ESI has become part of TNO and is referred to as TNO-ESI
FES	Fonds Economische Structuren Public fund for improvement of the national economic structure
FOM	Stichting voor Fundamenteel Onderzoek der Materie Netherlands Foundation for Fundamental Research of Matter
GTI	Groot Technologisch Instituut Large Technology Institute
HTSM	The knowledge/market domain 'High-Tech Systems and Materials'
HTSP	High-Tech Systems Platform A consortium of the Dutch high-tech OEM industry
IT	Information Technology
ICT	Information and Communication Technology
ITEA	Information Technology for European Advancement
JU	Joint Undertaking - Cooperation between European partners on innovation
KPI	Key Performance Indicator
MinEZ	Ministerie van Economische Zaken Ministry of Economic Affairs, Agriculture and Innovation
MinOC&W	Ministerie van Onderwijs, Cultuur en Wetenschap Ministry van Education, Culture and Science
NOST	Netherlands Office for Science & Technology (previously Netwerk van Technisch-Wetenschappelijke Attache's - TWA)
NWO	Nederlandse organisatie voor Wetenschappelijk Onderzoek Netherlands Foundation for Scientific Research
OEM	Original Equipment Manufacturer
R&D	Research and Development
RWS	Rijkswaterstaat

	Public body for Netherlands transport infrastructure
SME	Small and Medium Enterprise
SoS	Systems-of-systems
SRA	Strategic Research Agenda
TCO	Total cost of ownership
TNO	Toegepast Natuurwetenschappelijk Onderzoek National Research Organisation for Applied Research
TNO-ESI	TNO Embedded Systems Innovation
TTI	Top Technology Institute
TKI	Topconsortium Kennis en Innovatie Topconsortium for Knowledge and Innovation
TKI-labeling	Public-private partnership programs that comply to the HTSM roadmap
TKI-toeslag	Dutch public funding that is assigned to TKI-labelled projects