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Knowledge and Innovation Agenda ICT 2016 - 2019

connect and create

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Introduction to this Knowledge and Innovation Agenda

This Knowledge and Innovation Agenda (KIA) ICT has been created under the auspices of Team ICT. This Team, chaired by René Penning de Vries, has been installed by the Minister of Economic Affairs to stimulate interconnections between the top sectors, to strengthen the industry policy and the let ICT innovations fuel economic growth. According to the Minister: “In the future, ICT will continue to play a major role. Think Big Data, the internet of things, breakthroughs in healthcare, increases in serious gaming and e.g. 3D printing, where in a short time an industry of start-ups and suppliers around it arose. The government, business and education together have the task to utilize the opportunities of such developments. In that way the Netherlands remains a forerunner in the world of the digital economy. Rene Penning de Vries will stimulate and boost these developments with his Team ICT. That benefits both the ICT sector and the Netherlands.” Under the umbrella name ‘dutch digital delta’ Team ICT initiated several high-priority activities: a human capital agenda, a branding initiative, and this KIA ICT.

This KIA ICT contains the ICT challenges and themes of various (top)sectors as well as cross-cutting ICT themes that unite the different sector challenges. Its objective is to identify instances of high-potential ICT innovation in the top sectors and to provide an agenda for public-private partnerships in the 2016 – 2019 period. The agenda forms the starting point for the innovation contracts 2016 – 2017, in which government, NWO, TNO, and top sector teams agree on research and development programming. Investing in public-private partnerships originating from this KIA ICT gives a high return on investment, since each action line is relevant for more than one sector. This KIA ICT also identifies long-term ICT subjects that most likely end up in the National Research Agenda.

This KIA ICT has been created with the input from many. As a first step, public-private teams of stakeholders (see Appendix 1) of (top)sectors have identified the ICT domains relevant to that sector and the ICT breakthroughs required to advance the sector. In this way an ICT agenda is compiled for each sector. These ICT agendas have a close link with the sectorial KIAs, in many cases they are identical as far as the ICT challenges go. This link allows for further integration of efforts and to bring together the ICT-sector/parties with the respective domain experts. The ICT agendas also have a close link with or are a compressed version of other relevant research and innovation agendas, such as smart industry, NCSRA (national cyber security research agenda), and smart farming.

In the second phase, the sectorial ICT challenges have been aggregated into four action lines. These action lines form over-arching themes relevant for more than one (top)sector. The action lines range from use – *inspired fundamental and applied ICT* – research to enabling innovation by the application of modern ICT. In 2012, a first KIA ICT has been compiled, named ‘Roadmap ICT for the Top Sectors’. In addition a ‘Scientific Answer to the Roadmap ICT’[1] has been written. Both documents have been used as input as well. As such this KIA ICT forms a natural extension and actualization of these previous documents (and efforts).

Finally, two large, concerted domains of challenges have been identified to implement the proposed action lines. Both form great opportunities for the Netherlands to be at the forefront of R&D and innovation in the Big Data and security domains, respectively. The Netherlands would claim its position on the global

[1] http://www.ictonderzoek.net/content/ICT+OnderzoekNL/ict+roadmap

stage. The COMMIT2DATA Big Data public-private program aims to strengthen the Dutch knowledge, valorisation and dissemination position in data science, stewardship and technology across the top sectors, with data for life science, smart industry, energy transition and security as important drivers. The Cybersecurity program extends the Dutch knowledge and development position in trustworthiness of pervasive digital infrastructures such as the Internet of Things.

Major stakeholders in the PPP-domain have been involved in the creation of this KIA ICT, such as NWO, TNO, COMMIT/, and industry through the networks of CIO Platform Nederland & Nederland ICT. These actors are well positioned to put their (inter)national connections of ICT innovation into action.

The structure of this KIA ICT has been summarized in the figure below. Overall, a link is made between (top)sector challenges, over-arching ICT themes and societal challenges. The European Commission's aim is to develop new solutions to the societal problems Europe is facing today. Horizon 2020 will tackle societal challenges by helping to bridge the gap between research and the market. Ground-breaking solutions come into being by means of multidisciplinary collaborations, including social sciences and humanities. The Dutch top sector policy is well-connected to the Horizon 2020 approach. In the figure, it is shown that ICT is important to all of the challenges. Chapter 1 will give an overview of the broad impact of ICT in all (top) sectors of society. In Chapter 2, the ICT part of the (top)sector innovation agendas will be summarized. On the basis of this demand-inspiration from each (top)sector, Chapter 3 will follow with a list of relevant ICT themes shared by more than one sector. In Chapter 4, the ICT innovation landscape is described and a line of action is proposed. Finally, in Chapter 5 financial aspects of the implementation of these ambitions are given.

TOPICS	ACTION LINES				SOCIETAL CHALLENGES						
Chapter 2	ICT One Can Rely On	ICT Systems for Monitoring & Control	ICT for a Connected World	Big Data	Health, demographic, change and wellbeing	Food security...	Secure, clean and efficient energy	Smart, green and integrated transport	Climate action...	Europe in a changing world	Secure societies
Healthcare Systems & Services					✔						
Life Sciences & Health					✔						
Smart Citizens & Cities										✔	
(Cyber)Security											✔
Software Industry											✔
Energy Transition							✔		✔		
Smart Industry						✔		✔		✔	
Smart Farming						✔					
Smart Logistics								✔			
Chemical Industry						✔		✔		✔	

Chapter 3

Chapters 4 & 5

Chapter 1

ICT for Economic Growth and Grand Challenges

ICT IN THE NETHERLANDS

dutch digital delta

5.1% share of ICT sector in the economy (GDP 2011)

Added value to the economy: **€ 26.5 bn**

Contribution ICT (-usage) to economic growth: at least **30%**

Contribution of Internet economy to GDP grows with **9%** annually

€ 47.5 bn ICT expenditure
27% households
73% industry

57,000 ICT companies

€ 13.9 bn in ICT investments: software, new media, cloud services, gaming

8700 new ICT companies in 2013

Import / Export ICT goods and services

Export
€ 12.8 bn
(82% re-export)

import
€ 70.7 bn

21% of Dutch companies sell online

13% of total revenue is e-commerce

53% of Dutch companies buy online

The Netherlands is among world leaders:

3rd Digital Economy and Society index

4th Networked Readiness Index

265,000 people working in ICT = **3.6%** of workforce is in ICT

Akamai Internet Speed Ranking **3rd**

11 submarine cables for digital communication via NFIA (of the 15)

669 companies connected to AMS IX

World leading research and education via SURF

95% of households has Internet access

21 million mobile phone connections

4G access for **90%** households

Coverage fast internet nearly **100%**

78% of the Dutch shop online

Global No # 1 internet banking

LABOUR MARKET

37.000 ICT vacancies in the coming years

(a.o. Big Data, Internet of Things, 3D printing, Cloud)

ICT RESEARCH

COMPUTER SCIENCES RESEARCH OF DUTCH UNIVERSITIES IS WORLD LEADING

REGIONS DELFT-EINDHOVEN -AMSTERDAM ARE IN TOP 20 ICT-COMMUNITIES IN EU A.O. BY ICT-R&D

ICT for Economic Growth and Grand Challenges

Digital technology is entering almost all aspects of our daily lives and it is happening at an ever increasing speed. Media, industrial production, healthcare, education and sciences are just a few domains that are undergoing rapid changes, or even being disrupted by the digital revolution.

The process of digitization has been possible through the advancement of Information and Communication Technology, ICT in short. Over the last 50 years tremendous progress has been made through Moore's law of miniaturisation on the hardware side, always-on connectivity on the network side, and intelligent algorithms incorporate into software tools and database techniques.

ICT is a so-called General Purpose Technology. It enables technology development and innovation in many fields. Impressive as the progress in ICT is, the real value economic, societal or science is especially achieved if ICT is applied to an application domain. In doing so, highly innovative solutions in various domains as businesses, education and science have been created. In addition to the impact of hardware and software, we are now entering the next level of disruption due to the explosive growth and pervasive enrichment of big data, the volume of which doubles every 18 months. Recent and upcoming breakthroughs in big data will lead among others to better business intelligence, more informed decision support, better use of scarce resources, a higher degree of product personalization and automation, better understanding of customer behaviour, and a chance to gain deeper insight in root causes of diseases, production defects, and security threats.

The Four Ds of Digitization

Disruptive. ICT and new business opportunities change markets, sectors, business models and coalitions. Services become more personalized and production and distribution processes become more flexible and demand driven.
Deceptive. New developments are suddenly there and pervasive available. New services can grow fast with relative minor costs.
Delocalised. Technology and internet are every-where to connect people and products.
Democratised. Everybody can use data, ideas, knowledge and applications and start new business. Open innovation and software development take place in dynamic interacting networks of stakeholders.

Innovation for economic growth

Recent studies (CBS and Dialogic 2014) show a remarkable contribution of the ICT sector, in terms of productivity, jobs, and percentage of GDP. Digitization is responsible for at least 30% of the economic growth in the Netherlands. The Dutch ICT Sector is an important factor in the Dutch economy and with an annual turnover of nearly € 50 bn it provides more than 5% of the GDP. In addition to the traditional economic top sectors, Information and Communications Technology now constitutes its own business sector, and at the same time is a key enabler for innovation in the economy, society and science.

Grand challenges 2016- 2020

Challenges in the ICT sector are found along three dimensions:

- ICT as an enabler for solutions to societal challenges such as trust in the use of data and healthy living enabled by personal health services and sensors.
- ICT as an enabler for solutions in economic top

sectors and smart industry, for example by ICT software, hardware and data-components for smart grids, smart logistics, smart farming and imaging systems in healthcare.

- ICT as an enabler for scientific discoveries. Here big data is an enabler for rapid digitization of these sciences, making them increasingly quantitative with spin offs in the market (better analytics and predictions of production processes and human behavior).

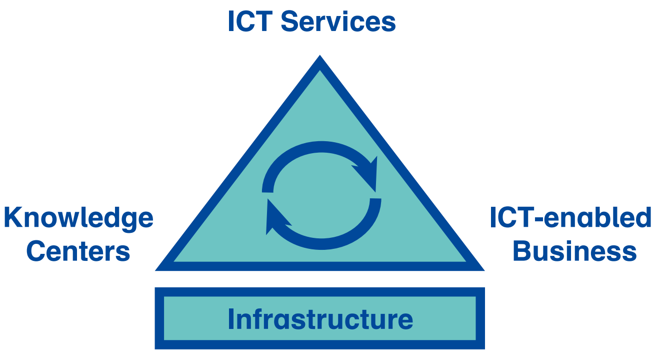


Figure. Growth results from cooperation between knowledge centres, ICT Service and ICT-enabled Business, building on state-of-the-art (communication, computing, software and data) infrastructure. As an example, as an ICT-enabled sector, Smart Industry benefits strongly from innovative solutions, created by knowledge centres and ICT Services, in PPP.

In the last three years, the Netherlands ranked 4, behind Singapore, Sweden and Finland, in the Networked Readiness Index (Networked Readiness Index, World Economic Forum, 2015). This strong position is because of a reliable and comprehensive ICT infrastructure (most European Internet connections pass through the Amsterdam Internet Exchange), an open and business friendly orientation, the quality of science and a highly educated workforce.

To stay in the top 5 of leading ICT nations, dedicated attention is needed to accelerate the absorption of new technologies by businesses and to invest in public private collaboration for ground-breaking research, enhancing the (inter)national flow of knowledge and ideas. The Netherlands is well positioned to benefit from the new opportunities in ICT. Especially the advent of Big Data promises further growth opportunity, which fits well with the ambition of our country to become a Big Data Mainport.

Research and innovation in public private partnerships

ICT is a scientific discipline in itself in which Netherlands scores excellently in terms of R&D quality. Big data and High Performance Computing are also changing the way research is performed and knowledge is shared, as part of a transition towards a more efficient and responsive "Open Science". A grand challenge for further growth in a digital economy is the valorisation of research results, leading to product and service innovation and eventually higher productivity in nearly all top sectors, including small and medium sized companies. For example the smart industry perspective is to produce *just in time and on demand*, cutting back stocks. The results of research and innovation for science and business depend on an ICT sector with impact, an outstanding ICT infrastructure and sufficient ICT professionals on all levels.

ICT sector with impact

The ICT sector consists of hardware and software providers, (cloud) services, telecommunication, as well as gaming, information and social media businesses. This sector counts for 265,000 skilled jobs in the Netherlands. Due to the transformative nature of ICT, traditional companies in sectors such as mobility, travel, and finances are rapidly converting to ICT companies, themselves realizing ICT innovations. The ICT sector enables the Dutch society and industry to improve their operations by means of ICT solutions. The new opportunity here is the usage of Big Data in almost any domain of economy and society. In this Knowledge and Innovation Agenda on ICT big data will be found in almost all domains from Life Science and Health, to Smart Grids, and from Cybersecurity and Creative Industry.

Outstanding ICT infrastructure

ICT networks provide the backbone for digital products and services which have the potential to support all aspects of our lives. The Netherlands has a strong position in physical infrastructure (main ports, roads, waterways and ICT networks). The Netherlands acts as an intelligent digital gateway and virtual hub to Europe and the rest of the world. This is a promising for generating value added services and more profit with ICT. The challenge for success is to generate added value to data by intelligent handling of (inter)national data streams and new applications We see a growing amount of global players choosing the Netherlands for their headquarters, data centres and distribution centres. In order to become a "big data mainport" focus is needed on strengthening big data knowledge and infrastructure for collecting and using data across sectors and government.

SURF is one of the players acting as the national coordinator of the ICT infrastructure for high end research, applications and education in the Netherlands. SURF supports the approach of the KIA ICT. In order to achieve higher return on ICT research together with obtaining sufficient digitally skilled people preserving the quality of the ICT research infrastructure is necessary.

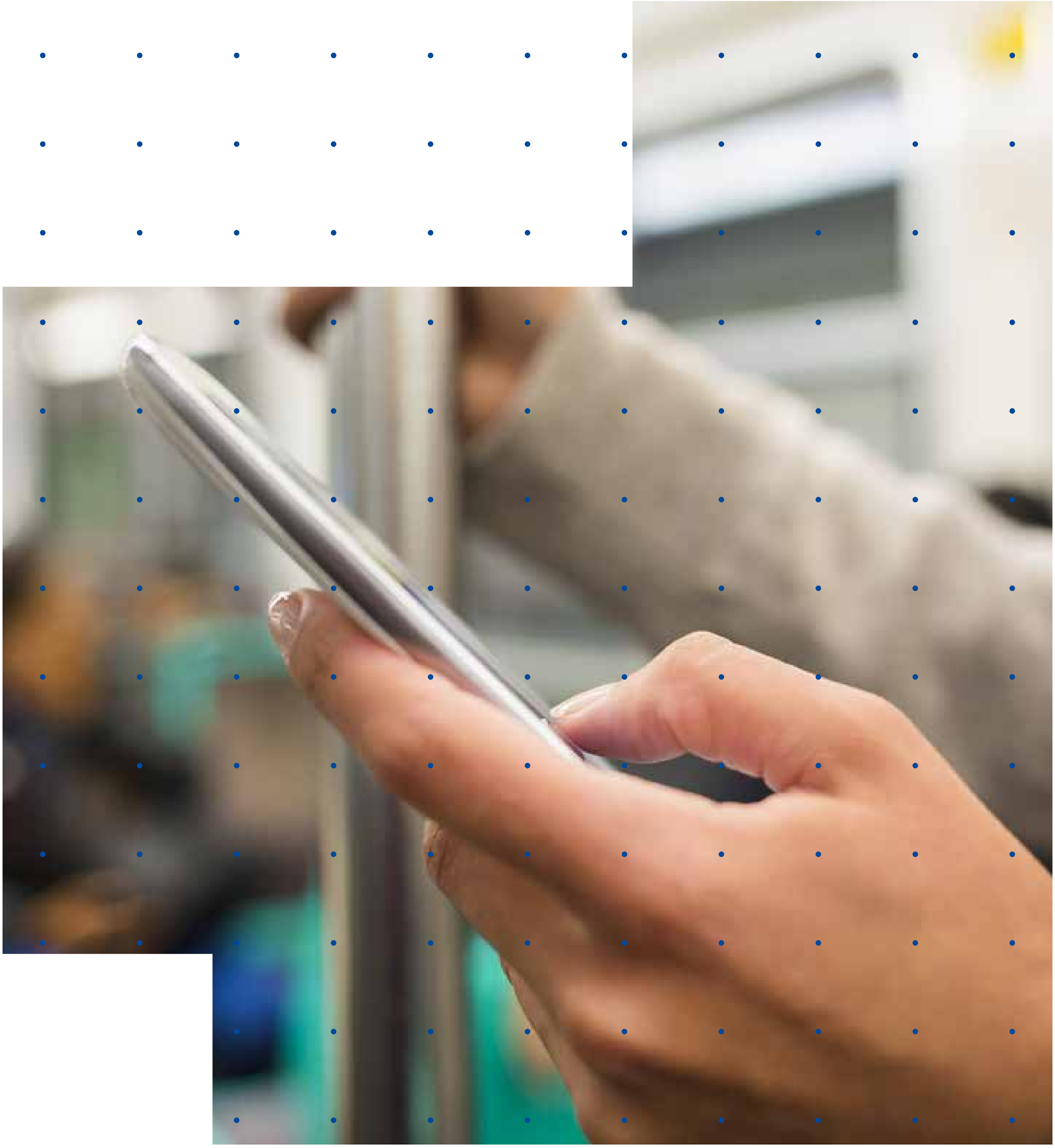
Sufficient ICT professionals

Digital Skills for smart and safe use of ICT and computational skills for understanding the limitations and opportunities of ICT, are gaining more and more importance. However the supply of skilled employees, as well in numbers as in competence (software development, cyber security, big data analytics) does by far not cover the demand for individuals with T-shaped profiles, that create bridges between deep ICT knowledge and application areas. In the years to come 37,000 vacancies are expected requiring highly skilled ICT professionals in Big Data, Internet of Things, cybersecurity, cloud technology and 3-D printing.

In conclusion

To support the growth ambition of the Netherlands, it is a must to fully embrace the digital revolution, especially in the domain of Big Data. Technological innovation is a driver for innovation of businesses, research and social innovation. Exploring the potential of Big Data goes brings us join unchartered territory. How to deal with unlimited access to huge amounts of unstructured data to redesign a business process? How to use Big Data to improve the efficiency of crop growth? How to make the transformation from mass production into customised production? How to make personalised medicine operational? How to allow for localised energy production and consumption, while maintaining the existing grid infrastructure?

Key for addressing such questions, is the cooperative effort between experts in the ICT domain and the experts in the top sectors or application domains. In doing so, it has to be realized that the issue at hand is not just a technological, but in many cases also has a creative and social context, related to data ownership, privacy and security, as well as legislation



Chapter 2

Rolling ICT Agendas in the Top Sectors

Rolling ICT Agendas in the Top Sectors

In this chapter, the ICT challenges and themes of ten (top)sectors are described. Each of the sectors (see table below) was asked to indicate the ICT domains relevant to that sector and the top-3 of ICT breakthroughs required to advance the sector. In this way an agenda is compiled for each sector. Especially those subjects that are relevant to more than one sector deserve high priority in programming research, as in those cases the ICT science and innovation results can be translated from one sector to another. This aggregation of challenges is done in Chapter 3. ICT is a very dynamic sector where new research results, services and technologies may change the landscape overnight. Therefore the ICT agendas in the top sectors are rolling, which implies flexibility for emerging new public-private initiatives in any sector.

For several sectors, such as (cyber) security and smart industry, the information in this chapter is a much condensed version of a larger knowledge agenda. These agendas are referred to in the relevant sections. Not all top sectors are represented in this chapter. This does not imply that ICT is not relevant in those sectors. It only means that at the time of writing no public-private teams of stakeholders have come forward to give input. Given the rolling nature of the agendas this may happen in future editions of the KIA ICT.

TOPICS	ACTION LINES			
	ICT One Can Rely On	ICT Systems for Monitoring & Control	ICT for a Connected World	Big Data
Healthcare Systems & Services				
Life Sciences & Health				
Smart Citizens & Cities				
(Cyber)Security				
Software Industry				
Energy Transition				
Smart Industry				
Smart Farming				
Smart Logistics				
Chemical Industry				

2.1 HEALTHCARE SYSTEMS AND SERVICES

(top sector: LSH and HTSM/RM Health)

ICT Challenges and Themes

Important challenges in the health sciences are to improve healthcare, to promote healthy living and to support active ageing. Healthcare is becoming more expensive as a result of the ageing population (more people requiring health care), a decrease in the number of people available to work in the healthcare sector, and more costly methods of treatment. Smart use of ICT can contribute to solving these challenges.

Two recently written agenda's represent the fundament of this section, the top sector HTSM Healthcare 2015 Roadmap and the Action Plan of the top sector LSH. The unique selling points for the Netherlands selected in the LSH action plan are Healthy aging, Medical devices, Personalized nutrition, E-health and Personalized medicines. Also the importance of further investing in overarching and necessary infrastructure, to improve our overall performance (including biobanks, labs and infrastructure for vaccinology) is underpinned in this action plan. The following core themes for ICT research in health care systems and services were extracted from these agenda's.

- **Context awareness** is an essential property of smart ICT systems and services that aim to support people in their self-management. It enables these systems to provide personalized information representation and coaching solutions at the right time, in the right way. It also enables social support mechanisms by allowing patients to share their context with their social environment.
- **The virtual patient model** seeks to combine available information from a broad range of diagnostic measurements (image data, sensory signals), acquired over time, into a single coherent frame of reference, and make this data available for complex automated processing. This will provide breakthrough capabilities in patient-specific visualization, modelling and treatment planning.
- **Gamification and intelligent interaction** encompass adaptive computer mechanisms for behaviour change support, including appropriate interaction solutions for patients and doctors. It uses profiling techniques on patient and longitudinal treatment progress data to create personalized and situation-dependent interventions (or “intervention support”), in the case of virtual health agent.
- **Trustworthy information infrastructures** is required for computational solutions for Health & Life Sciences require a structural, scalable, and sustainable cross-discipline collaboration infrastructure. The largest challenge for the future will be the creation of a sustainable computational environment for the interplay between medical devices and sensors (patient data) on the one hand, and personal omics and molecular data on the other.

Ongoing programs and new initiatives related to the theme of ICT and Healthcare Systems and Services are: Dutch Techcenter for Life Sciences (DTL Hotel Call for Enabling Technologies); ELIXIR Bioinformatics Infrastructure Initiative (ESFRI); CTMM/TraIT IT project; NFU IT Infrastructure project - data4lifesciences; ISBE (Infrastructure for Systems Biology Europe); EU OpenPhacts project - (semantic) interoperability of pharmacological data resources (molecular databases); COMMIT-2DATA (for life perspective).

ICT Breakthroughs

Theme and Breakthrough	TRL	Innovation milestones
Context awareness	2-4	Behavioural modelling based on sensing, reasoning, interaction and self-management. Context awareness is at the TRL level where the relative simple use cases have been tested and validated in a controlled setting, whereas more complex concepts and use cases are still at a lower TRL level.
Virtual patient model	2-9	Data integration from a broad range of imaging and sensory inputs into a single, image-driven patient model. Real-time visualization and virtual interaction during education, surgery and diagnosis. Computation and simulation of patient dynamics based on available sensory data. Decision support system using personalized prognostic health models. The TRL level of virtual patient model spans a broad range. Individual solution providers have developed demonstrators of data integration and real-time visualization. Simulating dynamics is still in an early stage.
Gamification and intelligent interaction	2-5	Instant signal processing and instant adaptive visual response; treatment and intervention at home (online vs offline); virtual agent therapy support (blended therapy, combination of face-to-face therapy and at home support intelligent virtual health agent). Modern sensor, display, and interaction solutions techniques for medical purposes, including rehabilitation, diagnosis, surgery support, and treatment.
Trustworthy information infrastructures	2-4	Large scale virtualized distributed secure personal data processing architecture. Standards for interoperability, certification. Secure methods for processing sensitive data. Big data exploration tools/methods supporting valid conclusions at population and individual level. Establishing a privacy aware EU centred architecture for handling patient data is still at proof of concept level. Radically different approaches such as homomorphic encryption, or block chain could give a significant boost in the trust and acceptance of patients to provide their data to EPDs.

2.2 LIFE SCIENCES AND HEALTH

(top sector: LSH)

ICT Challenges and Themes

Life sciences and health research has become a data-driven discipline or information science. The ability to generate enormous amounts of data – *for instance with Next-Generation Sequencing* – is quickly outrunning our capacity to store, link and analyse these. Research in the field of personalised medicine increasingly relies on the use of and integration of heterogeneous and multimodal data sets as imaging, medical history, genomics and environmental data, and by doing so is drawing from vast quantities of data. An additional challenge is to enable data sharing of privacy-secured medical data from hospitals, diseases communities and individual patients. Data is often stored in an unstructured way and in different ‘languages’, which challenges their integration and accessibility, also across different institutions.

Challenges are also to combine personal measurements with the relevant context and environmental data, which requires making different sources of information interoperable, putting personal measurements in their context and making them interpretable for the user. The combination of ICT and Data Science is needed to develop algorithms for estimating individual causal effects, as opposed to the classical population-based statistics, to deliver personalized advice for treatment and prevention of diseases.The largest challenge for the future will be the creation of a sustainable computational environment for the interplay between medical devices and sensors (patient and citizen data) on the one hand, and personal omics and molecular data on the other. This interplay will happen at two timescales: (1) a short (say 48-hour) timescale for diagnostics and treatment plans based upon fixed integrated diagnosis and omics measurement regimes, and (2) a longer timescale for research and innovation.

- **Medical devices.** Currently a plethora of different sensoring and monitoring devices are being developed, and these are used increasingly in health care. Technologies and devices used in the health domain include wireless implantable devices and stimulators/actuators for point of care testing, while also devices such as smart catheters are used for diagnosis and therapy "at the tip". Increasingly, clinical omics measurements are becoming used in the clinic for integrated personal diagnosis and treatment plans, such as for example RNA-sequence measurements from blood samples.
- **E-health / healthy aging** applications for self-assessment, quantified self, online therapies, behavioural adaptation and personal health records will increasingly promote healthy aging and health in general. Mobile apps, such as those aimed at reducing sedentary behaviour, will become pervasive. Mobile apps will increasingly be used to collect data about behaviour, environment and exposure as well as provide tailored context-aware recommendations.
- **Personalized medicines/nutrition** (N=1) requires building up a statistical base through far reaching integration of highly multimodal and disperse data, including sensor, imaging, genomic, public and proprietary (anonymized) domain data from different platforms and locations. The virtual physiological human will require fundamental insight into large scale multi- as well as intra-cellular environment-aware molecular network behaviour. Vital aspects relating to N=1 statistics are technologies for improved diagnostics and prognostics at the individual level, requiring machine learning on very high dimensional data (no of features), but a relatively low number of (labelled) samples. These analytics enable long-tail statistics to find driver genes in cancer, and finding driver mutations/events in a specific tumor for guidance of treatment.
- The underpinning **infrastructure** for all of the above activities should be based upon a linked open data structure where data is Findable, Accessible, Interoperable, and Re-usable (FAIR), integrating public knowledge, patient data and HTP-generated data stores (devices/sensors and omics measurements). The data management platform and compute environment should be secure and scalable on demand to allow for advanced statistics, data analytics, intelligent reasoning and modelling technologies with feasible performance.

2.3 SMART CITIZENS AND CITIES

(top sector: creative industries)

ICT challenges and themes

Individual citizens act as smart citizens in the different roles they have in smart society. For example, as traveller or car-pooler in public and private transportation services, as patient or social caretaker in healthcare, as student or neighbourhood teacher in education, as user of government services, or voluntary contributor to the local social eco-system. The evolution of these roles demonstrates how the interaction between the individual, the society and its services and other

ICT Breakthroughs

Theme and Breakthrough	TRL	Innovation milestones
Semantics-based interoperable data infrastructure (FAIR)	3-5	Cloud-based services, implemented electronic health records and digitized registries, integrated with public data and omics data; Use cases demonstrating (a) added value of integrating local high-throughput data with public data on rationalizing complex disease; (b) effect of personalized nutrition on disease outcome; (c) added value of interoperability at this ultimate integrative level. TRL levels indicate local approaches, but no widely adopted standardized solutions.
Data analytics, intelligent reasoning and modelling	4	Prescriptive data-analytics; i.e., proactive rationalized decisions and personalized advice. Proof of concept demonstrating effect on rationalizing complex disease cases. Tangible step towards higher-order cellular or multi-organ integration, towards the virtual physiological human. TRL level reflects that current semantic reasoning generally lack quantitative and approximate reasoning.
Secure and trusted data processing	2-5	Secure and trusted compute environment, close/linked to storage, that is scalable on demand (distributed) and interoperable with external and public databases. Adhering to EU privacy framework. Standardized methods for authentication, secure wireless communication, single-sign on for cohorts of millions of patients. Comparing patient data records in the encrypted domain. Scalable integrated OR information systems and workflow support. TRL shows that there are Many initiatives ongoing, but no user-ready solutions yet.
Prognostic personal (N=1) health	2-4	Integration of longitudinal patient data within linked open data infrastructure (individual molecular/omics data, imaging and sensor data). Deepening insight in cellular/molecular network architecture and causation. Long-tail statistics and advanced statistical and machine learning methods for inference at n=1 level. Learning psychobiosocial health models from life-long behaviour and exposome (including nutrition) data logs.

individuals is radically changing. These changes are triggered by the opportunities of information technology, and even more so by the abundance of data that now appears to facilitate such changes. There is an urgent need to understand how the technology and the citizens interact and how a society of smart citizens is to be. We need to experiment with new designs for the information technology and the way individuals can interact with it in key societal domains, such as healthcare, education, energy, security and transportation.

The empowerment of the smart citizen in developing new products, services, and processes requires the personalized and scalable educational approach, and social inclusion. Game-based technology will likely play a role here. Companies and organizations are struggling how they have to change to meet the needs and expectations of groups of citizens that are already becoming empowered. Much is unknown about the interplay between this innovation in ICT & media technology and societal, economic, and cultural changes. The role of big data is evident. With the massive amounts of digital data being available about the interaction between individuals and the technology they use, it is possible to extract knowledge that helps to know and understand what is going on. Yet when dealing with citizens, we need to ensure that the technology and data are used for the purpose for

ICT Breakthroughs

Theme and Breakthrough	TRL	Innovation milestones
Big data: analysis, interoperability,	3-5	Social sensing: technologies getting insight into activities, drivers, emotions, performances, behaviour by analysing people with bio-sensors, cameras, social media and other offline and online data sources.
Human-assisted processing and visualization of big data	2-4	Technologies for involving human computing, crowdsourcing, and gamification for data creation, visualization and interpretation. Assist hybrid human-machine data processing pipelines.
User modelling and personalization.	2-6	Strategies for modelling and analysing users, to be able to serve them in effective and personalised contexts: humans as “interactive receivers”. Personalization methods: recommendations, personalization, gamification, framing and storytelling, (big) data visualization, ‘digigeren’ (a method to influence online behaviour positively), persuasion, inclusive design.
Enabling technologies, gaming and sensors	3-5	Validated (proven effective) and scalable serious game and interactive media formats enabling social inclusion and policy making.

which they are expected to be used. Privacy is just one of those aspects where technology users want to know and agree on what can and cannot be done with the technology and data.
Trends like the quantified and social self and the quick adoption of wearables with (cheap) sensors make it possible to measure people’s behaviour, emotion, etc. Social sensing will enable us to get insights from all these data. These approaches require solid foundations to be able to apply them at scale and fitting in Dutch contexts and sectors. Applied gaming is an innovative and effective technology that can be used as an interaction strategy. For applied gaming the focus will be on validation and on enabling applied game adoption in other sectors. In the crossover between the creative industry and other sectors, a new economy of (start-up) companies will emerge that offer interactive services.

Some aspects of smart cities and citizens are essentially different from traditional approaches and require solid research. Scale, since many of the approaches rely on processing data “at scale” (massive education, transportation solutions); individualization, since approaches aim for individualization and personalization); diversity in that solutions increasingly address minority groups; and communities where social groups influence society.

ICT Breakthroughs

While most of the ICT & media technology could be developed or applied anywhere in the world, the key to Dutch success is to engineer solutions that work with Dutch people, Dutch companies and organizations, and Dutch contexts. Designing for the “average” Dutch user won’t be successful since this average user does not exist. In order to make sure that ICT enhances individuals’ everyday life’s it is essential to take different user groups with different needs and cognitive and physical abilities into account. Such capability is not targeted at only Dutch per se, but reflects that the solutions are socio-technical solutions that combine technology with local social structures and systems. Fitting with the Dutch and European context, social and cultural inclusion will be a value that is considered essential in system architecture and development.

2.4 (CYBER)SECURITY

(top sector: HTSM/RM Security)

ICT challenges and themes

Security paradigms that were suitable for people and systems just up to ten years ago are now obsolete. Cyber-attackers have become true professionals, as the vulnerability market has reached maturity. The value of our digital assets continues to increase fast, while the hyper connectivity has dramatically increased the attack surface. Critical infrastructures are at risk, with the increased reliance on ICT, notably in the telecom, financial and energy sectors (e.g., smart energy grids, and smart industry). Fuelled by a recent string of high profile attacks on the one hand and revelations about unprecedented cyber surveillance on the other, interest in security is rising - not just among industry and government organizations, but even among individual citizens. High priority has to be given to raise cyber risk awareness, and more importantly to create or improve our risk control or mitigation capability. The building of cyber-capabilities is of national importance in order to protect the digital sovereignty of our country and to maintain the attractive position of the Netherlands as a country for business.

The government is not only responsible for the national security policy, but also steers large organizations for carrying out safety and security interventions. For the Ministry of Security & Justice this involves the physical safety, public order and national (internal) security, including the protection of our vital infrastructure and the prevention and combat of crime. The Ministry of Defence looks after the external (international) security and, at the request of a competent domestic authority, will contribute to internal security as well. The private security sector has shown distinct growth the last years, due to privatisation of areas of government responsibility (outside the monopoly on the use of force) and the focus on and transfer towards the personal responsibility of citizens and businesses. Against this background, there is a good prospect for companies in the security domain to strengthen their economic activities.

Security is a **conditio sine qua non** for a prosperous country, normal economic transactions and healthy inter-human communication and interaction. In order to further trust at the core of social order and economic prosperity in an increasingly ICT-dependent world, a number of ICT challenges need to be faced.

- **Trustworthiness of Internet of Things.** The Internet of Things (IoT) and its unstoppable push towards "smart everything" is exacerbating our security problems. IoT devices will soon control our cyber-physical world, our houses, our industry, our government, and our critical infrastructures. Billions of embedded devices will be simultaneously active, in hostile and hard-to-reach places, where updating and standard maintenance will be challenging. On top of this, IoT devices often have tight resource constraints, precluding the use of standard security solutions. Guaranteeing the trustworthiness of such a hugely vulnerable infrastructure is a major challenge. There is no alternative other than to make security in the IoT one of the top priorities.
- **Privacy and Security of Big Data**. Big Data is a big target. Organizations use, sell, mine, and correlate huge databases of sensitive data, for instance to spot trends, profile customers and target advertisements. The power of big data is tremendous: even genuinely anonymized data, if appropriately correlated, can be used to trace the behaviour of single target individuals. This data is valuable not only to governments and industry, but also to criminals. Guaranteeing security and protecting the citizen's privacy in presence of big data databases is particularly challenging: structural challenges are related to vulnerabilities in information systems, insecure storage or transport, the human factor, etc.; organizational challenges include ensuring that the access to the data does not violate the privacy and integrity of sensitive information.

ICT Breakthroughs

Theme and Breakthrough	TRL	Innovation milestones
Security and trust of citizens and organizations	2-5	Empower citizens and organization to protect their interests in the digital society. Privacy enhancing technologies and privacy by design practices and techniques for managing (digital) identities. New techniques (incl. cryptography) and methods to manage risks and increase resilience in the interconnected and on-demand composed (cloud) systems and services. Objective methods to measure the value of security, which is a prerequisite to the definition of affordable security tools.
Security & trustworthiness of infrastructure	2-5	From SCADA systems to the Internet of Things, the ICT infrastructure is the backbone yet also the weak link of our society. Monitoring systems able to give situational awareness over very complex systems and to detect 0-day malware and targeted attacks. Design and engineering tools to create trustworthy software and system architectures that are resilient to malware and to cyber-attacks. Monitoring and protection tools, testing and attestation techniques to secure cyber-physical systems and critical infrastructure.
Fight against Cybercrime	2-4	ICT capabilities to respond and perform criminal and forensic investigations. Incident response and recovery capability for organizations, including self-protection and self-healing. Digital forensics techniques for Internet of Things, Big Data and cloud based services. Law enforcement capabilities, including botnet takedown, criminal investigations in dark web and on social media.
System of systems & decision making	3-6	Incorporation of state of the art capabilities and novel insights in sensor and actuator technologies, like augmented reality, network and data mining and fusion, with the purpose to improve hyper dynamic decision-making in security operations and to advance process control applications in smart industry operations.

- **System of systems**. The design, development and implementation of sovereign, integrated, networked information systems (system of systems) at a national scale, overcoming stovepipe system limitations, taking into account factors like: crossing borders between countries and between organizations (both in public and private sectors), human nature, ethics and privacy.

ICT Breakthroughs

In line with the most recent National Cyber Security Research Agenda (NCSRA II), the cyber security ICT challenges revolve around the core assets we need to safeguard and what to do if, despite our preventive efforts, attacks or criminal activities do occur.

2.5 SOFTWARE INDUSTRY

ICT challenges and themes

Reliable and flexible software systems are not only required by enterprises across top sectors with a total dependence on software as a result of classical automation, but also by new businesses which have emerged from the ICT/software infrastructure. These enterprises crucially depend on knowledge and skills in the field of software engineering: the efficiency and the effectivity of their core business is governed by the costs and risks of software engineering activities.

Businesses that need reliable and flexible software systems can be found everywhere: high-tech sector, energy sector, health sector, media sector, financial and administrative services sector, the logistics sector, the government sector (taxes, social security, infra-structure), and in the relatively new sectors of personal computing, web, mobile apps and (serious) gaming. All of these examples are uniquely represented here because their existence depends on software, creating a pressing demand for both control of software related risks (reliability) and enabling rapid software-based innovation (flexibility). Reliable and flexible software systems are an essential component of the knowledge-based economy, demanding highly educated personnel, investment in research and development and steep rates of innovation.

Software industry has exceptional opportunities, while challenged by large risks at the same time. The software medium is unmatched in its flexibility allowing swift creation of new markets by product and service innovation. To rise to the challenge businesses need software engineering expertise to bring their ideas to the market before the competition does, with quality assurance and the flexibility to learn and adapt on-the-go.

In older and larger existing markets software-centric enterprises have to deal with lack of control over the growing complexity of long lived and interconnected software (eco)systems. The risks are due to the relatively young age of the field, which is still growing a theoretical foundation, and therefore lacks tools and methods for software engineers to control software processes and product quality.

ICT Breakthroughs

The core themes in which breakthrough are required serve both reliability and flexibility.

- **Domain Specific Model Driven Engineering**. Flexible software analysis, simulation, and synthesis. Flexibility comes from smart modelling of expected future variations and by dramatically decreasing code volume. Quality is achieved by early quality assurance and fast feedback loops and by fully automated domain specific optimization techniques
- **Software Analytics**. Software engineering decisions via empirical evidence. Data on the software development process is acquired

ICT Breakthroughs

Theme and Breakthrough	TRL	Innovation milestones
Domain specific model driven engineering	3-6	Scaling up to general practice of the design. Implementation and continuous improvement of new domain-specific modelling environments. Specialization of languages and interactive development environments, including accurate simulation, verification, synthesis and optimization tooling. High level TRL result exist in some areas but general technological standards and methodologies are lacking.
Software analytics	2-5	Actionable insights from data collected from the continuous software development and deployment process in software ecosystems. Software analytics is a relatively young field and is being pioneered in the Netherlands.
Software assessment	2-8	Reproducible and validated quantification of software product quality in different dimensions: reliability, robustness, security, efficiency, scalability, modifiability, energy, both in absolute terms as well as relatively (benchmarking). TRL varies depending on the chosen dimension. Software quality is only barely measureable. Today software quality is mostly assessed "manually" and informally by either experts and non-experts.

and analysed to drive decision making and continuous improvement. This data is produced in continuous integration and delivery cycles in order to create weekly or even daily opportunities for process improvement.
- **Software Assessment**. (Automated) Measurement and certification of product quality in different dimensions: correctness, compliance, reliability, scalability, flexibility. Methods and techniques which help to formally and indisputably assess quality to enable control over complex software ecosystems and evidence-based decision making.

2.6 ENERGY TRANSITION

(top sector: Energy)

ICT Challenges and Themes

Our energy system is changing in a revolutionary way. An increasing amount of energy generation will be coming from sustainable resources. Resources such as wind and solar are typically producing energy locally, intermittently, and time dependently. Therefore, with the growing demand for electricity, balancing energy supply and demand together with storage becomes more and more important. These developments not only occur in the electricity domain, but also in other energy domains, like gas and heat.

The major aspects of the future energy systems to be tackled are the changing supply/demand matching of energy (demand should follow uncertain supply), the decentralized energy generation, as well as the changing profiles of energy usage (more intense usage of electricity). The energy system therefore has a largely increased complexity as well as several new possibilities. This requires intertwining technological, economic and sociological solutions. Appropriate ICT plays an essential role in keeping the changed energy system working, cost-effective and highly reliable. New opportunities will arise for new as well as existing players, such as ICT companies, ESCOs (Energy Service Companies), distribution and transmission system operators, energy suppliers, consumers, and government. In the coming period, research will especially address developments that allow for large-scale deployment of ICT in various energy systems and services.

Important topics for ICT in the energy domain are the following.

- ICT systems for automated operations and management, allowing for wide deployment. This concerns amongst others demand-side management, energy control via (demand/supply) transactions, congestion management, self-recovery, data management, billing, and balancing/ancillary services in a variety of energy networks (from transmission grids to distribution grids to micro grids) and at end users. Here, scalability, reliability, predictability, risk-reduction, decentralisation, fairness, cost-effectiveness, data-ownership, privacy, security and social acceptance play important roles. ICT systems that (fully) automate these operational tasks in networks and for users are heavily needed.
- ICT systems for hybrid energy system integration. ICT systems are needed for just one energy carrier as well as multiple energy carriers at the same time (heat, power, gas), addressing hybrid energy system integration. Different energy carriers have different properties and can complement each other in the energy system. The latter results in interaction between energy sub-systems for different energy carriers.
- ICT systems for integral simulation and optimization platforms. This concerns simulation of energy systems and complete ecosystems, scenario analysis, technical

ICT Breakthroughs

Theme and Breakthrough	TRL	Innovation milestones
Automated operations and management systems, allowing for wide deployment	2-6	Combining (all or part of) scalability, reliability, predictability, risk-reduction, decentralisation, fairness, and cost-effectiveness in operational ICT systems for a variety of energy networks (from transmission grids to micro grids), especially for hybrid integrated systems with several carriers (electricity, heat, power). For some operational tasks, some solutions exist that satisfy several basic requirements, like basic energy commodity matching. Additional requirements, like scalability, predictability, and fairness need to be met by basic research. For others, first research still has to be carried out.
Integral simulation and optimization platforms	2-4	Simulation and optimization platforms that take sufficiently many of the relevant aspects of the energy infrastructure, energy markets, players/users in the energy system, and social/economic processes into account for reliable simulation and optimization results. TRL reflects that platforms covering sufficiently many aspects of the energy (eco) system are still limited and subject to basic research.
Actionable Data Generation	2-6	Systems that can handle big data in real-time or that acquire knowledge from this in a reliable and decentralized fashion. Data ownership approaches and privacy are also required. TRL shows that for some tasks, solutions exist that satisfy several basic requirements, like basic energy management in homes or visualization of energy usage. Additional requirements, like taking into account dynamic energy prices or hybrid data integration, still need to be met by basic research. For others, first research still has to be carried out.

(real-time) validation with hardware in the loop, energy network planning, and investment support. The associated models include not only (parts of) the energy infrastructure, but also energy markets, players/users in the energy system, social/economic processes, or hardware-in-the-loop as well.

- ICT systems for generating actionable data. These systems deal with the gathering of large amounts of data coming from sensors and meters, located in networks, neighbourhoods, buildings, and homes, and turning these data into data with a purpose, insight or action. (Big) data can be processed and used real-time or for predictive usage, by e.g. network operators, technical or service companies, and users, for management, information, and other services. Apart from the processing issues, privacy and data-ownership issues are important as well.

2.7 SMART INDUSTRY

(top sector: HTSM/RM Smart Industry)

ICT challenges and themes

The concept of Smart Industry[2] reflects the fourth industrial revolution with so-called cyber-physical systems, emphasizing that everything is now digitized and digitally interconnected. This technological innovation will lead to business and social innovation. Traditionally, a product was designed, the bill-of-materials compiled, the parts bought or manufactured and the product was subsequently assembled and sold. Today, however, we see ever-increasing complex products and associated services coming out of value constellations of suppliers, manufactures, and brand owners. In the near future the value chain is yet to experience another shift with the introduction of product personalization and new technologies, such as additive manufacturing. Products themselves are also becoming increasingly intelligent, with embedded computing inside. This not only enriches the intended functionality of the products, but smarter products will also be able to monitor their intended and unintended use, and failure in all phases of the life cycle. This information will be fed back into the value chain. Hence, the days that ICT in industry encompassed merely storing product and manufacturing information are past; in tomorrow's industry life cycle data of every individual product will be stored, used, and shared across the value chain. This will enable production at higher yield, higher quality, lower costs and increased flexibility.

The 2014 Smart Industry Action Agenda[3] formulates an overall plan in order to meet the demands of smart industry. Action line 7 of the agenda calls for creating a Smart Industry R&D agenda. This agenda encompasses many disciplines, from engineering to humanities and social sciences. As part of this R&D agenda, several ICT challenges within Smart Industry have been formulated. At the heart of the ICT challenges are two observations directly from the digitization of production processes. First, secure and reliable connectivity is a growing need. Fall-back mechanisms, multiple connections, fail-safe solutions and new architectures capable of dealing with multiple systems (system-of-systems) with different availability, states, and ownership are needed. With the growing number of parties involved in the production chain, one cannot simply switch off system-of-systems for maintenance, software updates, etcetera. The size and complexity of these man-made systems are large and increasing by the day. Second, big data is rapidly becoming pervasive in smart industry, leading to the demand for solutions to deal with big data and to create new services and businesses using these. These solutions must be based on secure storage and sharing of data beyond the concept of trusted third parties, as the constellation of involved parties in smart industries consists of complex and variable interactions of services, components, and data. Data will need to be shared in order for business to be shared.

ICT Breakthroughs

The knowledge and innovation agenda for Smart Industry formulates a number of ICT-challenges in the domains of secure and reliable connectivity, and big data. A particular requirement in smart industry is that the ICT communication and processing solutions must be able to function under harsh and heterogeneous conditions, and that real-time performance is necessary due to the continuous nature of industrial processes. Energy constraints

[2] http://www.smartindustry.nl

[3] http://www.smartindustry.nl/wp-content/uploads/2014/11/Smart-Industry-actieagenda-LR.pdf

ICT Breakthroughs

Theme and Breakthrough	TRL	Innovation milestones
System architectures and design tools. (smart industry action line 13: software action plan)	2-5	Interoperable systems with reliability, adaptivity and recognition of legacy and (open) standards are needed. The complexity of systems needs to be managed. The software should be affordable to create, simulate, operate and maintain. Possibly formal methods can be put to use.
Algorithms for storing, protecting and analyzing large data streams.(smart industry action line 12: big data – big trust)	2-4	Data streams from manufacturing processes, monitored equipment, and products traced during manufacturing and use can be exchanged and processed in a trusted manner. Properties of the data are incorporated, such as missing or unreliable data (due to sensor failures or transients), and the velocity of the data streams.
Secure, reliable connectivity interconnecting everything and everyone. (smart industry action line 14: cybersecurity)	3-5	The Internet of Things is equally pervasive in smart industry as in other sectors of our "digital society". Here solutions must be able to securely handle real-time sensor data for quality control, process optimization and operator intervention. This includes security and reliability of the communication and the identity of the involved devices.

might have an impact on the solution space.
ICT development will trigger changes in businesses where new entities as data-brokers, third party service providers, etcetera will create new (manufacturing) service players. Smaller (start-ups, spin-outs) get involved in the ICT breakthroughs and implement them as soon as possible. Existing, classical manufacturing companies need the flexibility of these more agile partners who understand ICT research and can adapt it to practical use. Of particular relevance to the ICT breakthroughs are the following field labs:

- Region of Smart Factories (RoSF), focusing on zero-defect production and "first-time right" product and process development. Requires extensive sensory and video monitoring and analysis of big data in real-time.
- Smart Dairy Farming (SDF) monitors milk production processes. Real-time analysis of sensory data, and sharing of data across the value chain.
- Secure Connected System Garden (SCSG) concentrates on the challenge of maximally securing the exchange of data across the complete value chain.
- Campione helps companies in the chemical sector to collect, communicate and analyze data for the purpose of (zero-surprise) maintenance planning.
- Digital Factory aims at optimal interconnectivity in high-tech supply chains. Strong need for secure and reliable communications and system-of-systems architectures.
- Ultra personalised products and services (UPPS) focuses on innovative applications of user data for healthcare and fashion, using automated and parametric design algorithms and applying that to cloud-based user data, gathered with IoT-enabled human-centred sensing, scanning and communication technologies

2.8 SMART FARMING

(top sector HTSM/RM HT2FtW, Agri & Food, Horticulture and Starting Materials)

ICT challenges and themes

The sectors Agri&Food and Horticulture deliver important contributions to solutions for societal challenges such as food supply, health of consumers, and sustainability. The technology sector ICT – *as well as HTSM* – enables the Agi&Food and Horticulture sectors to meet these societal challenges and to improve the sector's competitiveness. Crossovers from ICT to agriculture will lead to better control of production systems, higher product quality, less waste, and more effective production. Further, more information is needed not only for producers for instance to verify compliance to regulations, but also for consumers as so to check for allergies and diet prescriptions[4]. Conversely, the non-uniformity of products, difficult production conditions for instance in crop fields and in stables, complexity of the production and logistics chain, and the push for economically viable solutions demand robust, reliable and safe ICT solutions that are often beyond today's systems' capabilities[5]. A 2015 study[6] of "Study Centre for Technology Trends" describes a number of scenarios based on technological advances that emphasize the cross-overs between Horticulture, Agriculture and Food, and the ICT sector.

The figure below shows that three technological dimensions have been identified involving ICT (and HTSM): Data collection, Data Analysis and Automation. The technological developments are relevant to the sectors horticulture, agriculture, propagation, life stock production, and food industry.

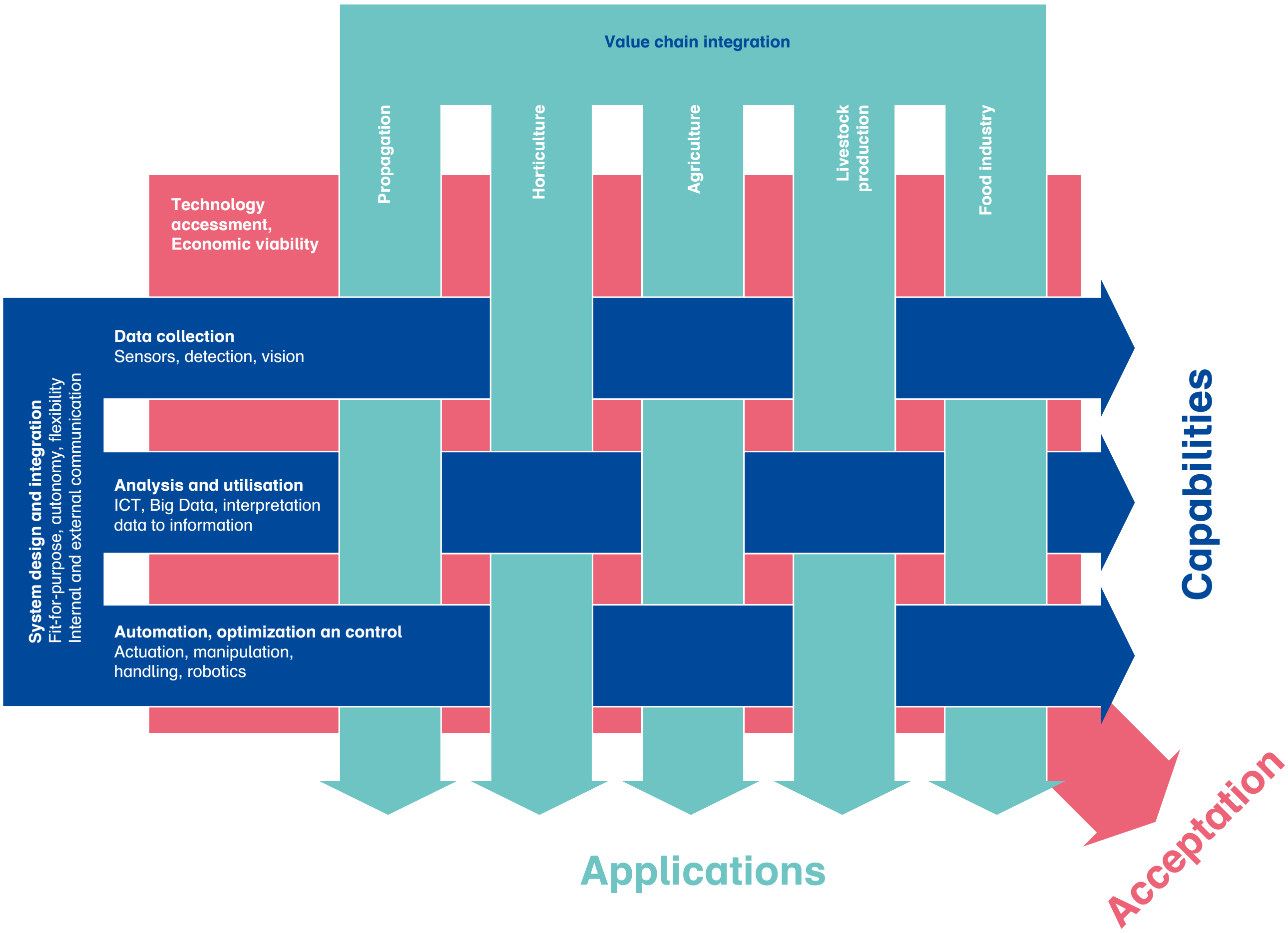
- **Data collection**. Real-time data plays an important role in optimization and automation of processes in the sector. Thanks to improved sensors, for instance to measure local humidity and fertility, processes can be closely monitored which helps to improve the quality of products and preventing plant disease. Sensors will also play a role in intelligent packaging and genotyping and sequencing.
- **Data analysis**. Common practice is to individually analyse few measured parameters relevant to optimization and automation. Much more value can be created if large amount of parameters are analysed simultaneously, factoring in the different qualities, accuracies, and sources of the measurements. New data such as the genome of grown organisms becomes increasingly available for analysis in combination with, for instance, local soil structure.
- **Automation**. Robots play an increasingly important role but need to compete with human intelligence in difficult and highly variable conditions. For instance, careful picking of eggs or peppers is not a trivial task and requires intelligence and vision systems to drive the robot grippers.

Finally, the above components need to be flexibly integrated into robust and safe systems that operate autonomously or in collaboration with humans in a diversity of tasks. A system-of-systems approach is needed in which smart components can cooperate and communicate flawlessly.

4 Eberhard Nacke (CLAAS Group): "No product will be bought without the related data". June 2014.

5 F. Kampers et al.: Cross-over agenda "High-tech to Feed the World". May 2015.

6 Stichting Toekomstbeeld der Techniek: "Van autonome robots tot zilte aardappels, Toekomstverkenning naar de invloed van technologische ontwikkelingen op de agri- & foodsector tot 2050", April 2015.



ICT Breakthroughs

The main ICT breakthroughs needed in the Agri&Food and Horticulture sectors are found in technologies and development of new sensors, data standardization, interoperability, and analysis for decision making and prediction, and robust and flexible system design.

Theme and Breakthrough	TRL	Innovation milestones
Sensor technologies	2-3	High speed, accurate and robust measurements of agri&food and horticulture relevant parameters for instance plant and product quality (e.g. preservability, plant disease detection, morphological properties), in fields, green houses and packages.
Data standardization, interoperability, and analysis for decision making, prediction and prescription[7]	2-4	Data can be transparently exchanged and processed with guaranteed access rights, but secure and private at the same time.Valorisation studies that show added value of big data analysis on specific cases.
Robust and flexible system design	3-5	Open system architecture for sensors, actuators, and embedded computing in the sector.

[7] See e.g. IBM white paper page 4: http://public.dhe.ibm.com/common/ssi/ecm/ti/en/tiw14162usen/TIW14162USEN.PDF

2.9 SMART LOGISTICS

(top sector: logistics)

ICT Challenges and themes

Smart logistics is efficient and effective use of data for physical transport of cargo. Supply chain visibility is conditional for smart logistics: what is the location of cargo, where is it going to, what is its current and what will be their next status. The better it is understood how cargo flows in global supply chains, the better these flows can be managed. Timely access to data creates possibilities for planning and forecasting required transport capacity, which can lead to more efficient, sustainable, and cost efficient transport.

Key element is access to the right data at the right moment. Still (too) many different forms and documents, and different implementations of the same or different (open) standards are in use to support different processes and fulfill different (legal) obligations, for example for customs and tax purposes, import/export declarations are mostly still lodged by companies on paper or captured in proprietary systems. These problems are particularly complicated in large international logistics hubs such as port of Rotterdam or Schiphol, being some of the most important gateways for international trade to Europe. With an increase in volumes, smaller shipments due to eCommerce, increasing competition, and an increasing demand for predictability (speed, quick delivery and time certainty), smart logistics becomes more and more important.

Smart logistics should be about making efficient use of available data throughout a supply chain. An important element is aggregation and nesting on different levels of cargo (i.e. container, pallet, box, individual goods item). A supply chain starts with buying and selling products, packed as items for transport from seller to buyer in for instance a mailbag or on a pallet. Items can be packed together in an U haul or containers for transport by a vessel or airplane. On this level, tracking an airplane or ship, is similar to tracking the items in the mailbags in the container on vessels as long as it is certain that the containers are sealed. Things get more complicated when multiple shipments (i.e. goods of different owners) are packed in one containers. In that case goods tracking and tracing is much more complicated than simply tracking and tracing of the container that contains the goods of the different shipments. Currently, tracking data is captured in different systems, not always easily accessible. Some private companies make use of this lack of transparency, scraping sites from carriers (for example: http://www.track-trace.com/aircargo, www.17track.net). Quality and trustworthiness of these sites sometimes is questionable.

Important themes are:

- **Interoperability and availability** of transport information. How can information be shared globally amongst heterogeneous systems of stakeholders in such a way that, based on aggregated data, forecast and planning tools of each of these stakeholders can be fed to optimize their parts of supply chains
- **Transformation amongst standards**. There are many implementations of (open) standards, but these implementations lead to closed solutions. (Automatic) transformation between these different implementations of standards is key to achieve interoperability. For example for barcodes and RFID tags worldwide supported industry standards are available (GS1, EPCIS).
- **Security**. Interoperable supply networks can be of high value for cyber criminals. In wrong hands, this information can be used to selectively try to get access to the right containers, or hijack the right truck with the most valuable load. Additionally, there is the concern that companies will only use this IT innovation

ICT Breakthroughs

Theme and Breakthrough	TRL level	Innovation mile stones
Data homogenization and seamless interoperability –	3-5	Data can be transparently exchanged and processed with guaranteed access rights.Standardization is probably not the answer to the lack of Interoperability. E.g. if we look at other domains like e-billing the quest for standardizations has failed because of the different reasons. What is happing there is that consolidation platforms (federation of platforms) are developing which are able to connect suppliers and customers quickly. If this can work within the logistics domain should be investigated. If this is achieved then we have the possibility of introducing simulation and gaming so that we can e.g. model the internet of things and transport capacity.
Analysis to improve decision-making and prediction/prescription.	2-4	Automatic access to (a large number of) data sources to improve situational awareness and predict future behavior
Visualization dashboards	2-4	The information should be available for all parties in clear dashboards providing supply chain visibility (descriptive analytics) supported by rule sets to analyze behavior (diagnostic analytics) and potentially take preventive actions. These dashboards, supported by analytics solutions, should not only be available to enterprises, but also for authorities.
Security and privacy of information for exchange in B2B and B2C, controlled data sharing (privacy enhanced technologies)	3-5	Data is safe and privacy is ensured while it is in the cloud or connected to the internet of things. Solutions must be able to securely handle real-time data for quality control, process optimization and operator intervention. This includes security and reliability of the communication and the identity of the involved devices. Fully encrypted, secure network only to be used be trusted parties

to share data in the supply chain, if they can be sure that their commercially sensitive data is not accessible for their competitors, hence strong security is also key to the successful adoption of this IT innovation by companies

- **Big Data**. There is a growing need for exchange of information, including business to government (B2G), business to business (B2B), and business to consumer (B2C). In all cases this information flow is reciprocal.
- **e-Commerce**. Internet trading is growing rapidly and this creates several problems, e.g. security of web shops, logistics efficiency, return logistics, payments (refunds and reimbursement), etc. These are urgent problems or they will become urgent within a short period of time.

ICT Breakthroughs

If the Netherlands manages to create a (global) digital hub for supply chain data, transportation in and out Europe, its position as a(n logistics ICT) distribution country can be improved significantly. Predictable throughput by improved e-customs processes, faster loading and unloading can be achieved by managing data flows.

Managing returns is an important element for eCommerce. Not only managing the physical return flow, but also the VAT and customs regulations are important. Smart logistics should make it possible to easily retrieve taxes, when an item is returned.

Creation of an open system by providing (automatic) transformation between individual systems and seamless interoperability, both for visibility (available capacity, logistic services, location of cargo, etc.) and business transactions constituting the various business documents. Visibility should be provided to all stakeholders participating in chains, both enterprises, consumers, and authorities, in a controlled way. It allows to create mechanisms like smart matching with which we can real time change parameters to establish a logistical chain and thus support synchromodal planning, agility, and supply chain resilience.

2.10 CHEMICAL INDUSTRY

(top sector: Chemistry)

ICT challenges and themes

For decades the chemical industry has made extensive use of ICT systems throughout its value chain, from logistics, to modelling, design, control, monitoring and repair. In addition, the chemical industry is a key provider of materials and technologies that form the basis for many ICT solutions. In the 2015 European Strategic Innovation and Research Agenda[8], ICT challenges have been identified in two domains: smart chemical processes and smart materials.

As chemical products, process and plants become ever more complex and resource usage and performance requirements become tougher, significant ICT-innovation is needed to keep the European chemical industry competitive on the global stage. Process control is a critical factor for sustainability in the production process. Today, the main success factor is the efficient identification of models during normal plant operation. There are many processes, for example batch processes, where non-linear models and non-linear optimization problems must be considered. The main obstacles are the complicated model-building process and a lack of professional software tools. The model-building process for non-linear process models of batch processes requires expensive, time-consuming experiments. Innovative methods to facilitate model-building must be developed to allow the necessary empirical information for parameter identification to be gathered during normal plant operations or with limited testing.

Monitoring methods in the process industry are mainly used for early fault detection and performance monitoring of equipment and for the early detection of anomalies during a production process. In the first class of applications, the aim is to detect problems in equipment and therefore increase the availability of plant by an improved condition-based maintenance strategy. The second class of applications addresses deviations in the chemical production process itself and aims to optimize plant operation by the implementation of early measures to counteract any variations. Current state of the art monitoring methods are based on the analysis of single signals such as vibration measurements or reactor temperatures. More advanced methods like model-based approaches are only used for critical equipment that suffer frequent variations. These models, based on normal plant operations, are either empirical or first principle and are high cost and effort intensive. It is known that incorporating both normal and abnormal data-driven behaviour in models helps significantly to find the root-cause of a process deviation.

The time required from an initial idea to innovation for new smart materials or new process technologies ranges from a few to many years. Based on experience, 10 years or more are

[8] http://www.suschem.org/newsroom/suschem-press-releases/suschem-publishes-new-strategicinnovation-and-research-agenda.aspx

ICT Breakthroughs

Theme and Breakthrought	TRL	Innovation milestones
Secure, reliable communication software interconnecting everything and everyone.	3-5	Internet of Things is equally pervasive in the chemical industry as in other sectors of digital society. Here solutions must be able to handle huge volumes of real-time sensor data for quality control, process optimization and operator intervention, from single products to complete plants and sites.
Data-driven, self-learning, modular modelling techniques and software.	3-5	There is a need for integration of models over time scales and techniques for efficient simulation of multi-domain multi-aspect multi-timescale models. Re-use of model (elements) is key.
Methods for storing, protecting and analysing large data streams.	2-4	Data streams from manufacturing processes, monitored equipment, and products traced during manufacturing and use can be exchanged and processed in a trusted manner. Properties of the data are incorporated such as missing or unreliable data (due to sensor failures or transients), and the velocity of the data streams.

needed to bring new products and processes to implementation. Laboratory and pilot phases are conducted sequentially with occasional iteration loops for adaption and optimization. Work flows and research processes lack a standardized and systematic approach and are based on individual skills and experiences. Concepts enabling simultaneous modelling and synthesis of products and/or design of processes from the initial idea or concept are required. This needs a joint and mutual approach between disciplines including chemistry, engineering and modelling. Standardized tools and procedures to conduct research work more systematically are required to review outcomes and track development including selection ofcase studies with operational relevance to prove concepts.

On the other hand, chemistry has also a lot to offer to the ICT-sector. Smart Materials are materials which enable the development of some important ICT such as nanoelectronics and haptic devices. The chemical industry will also provide the specialty polymers and other materials that will be required for the new 3D printing technologies.

Chapter 3

ICT Research Action Lines

ICT Research Action Lines

This chapter describes the ICT research and innovation themes that are common to the top sectors and grand challenges. Section 3.1 to 3.4 describe the four ICT action lines that emerge from Chapter 2. The four action lines have been chosen as consistently as possible with the 'Roadmap ICT for the Top Sectors 2012' as so to warrant continuity of research and valorisation investments. Yet, they are also updated according to the current needs of top sectors and grand challenges as described in the previous chapter, as well as developments in the ICT sciences[9]. For each of the four Action Lines, the back-connection is made to the desired breakthroughs in the economic sectors and grand challenges in Chapter 2 through the Figure on page 34. The figure shows which sectors in Chapter 2 cross over to which Action Lines in this chapter. Also shown in the figure are the societal challenges relevant to the ICT progress in specific Action Lines for each sector. In this way the figure gives a concise representation of the cross-sectorial and pervasive nature of the KIA ICT. Section 3.5 emphasizes the need for multidisciplinary perspectives on the ICT research action lines. Finally, Section 3.6 connects the current and possible future Action Lines to ICT challenges in the National Research Agenda.

TOPICS	ACTION LINES			
	ICT One Can Rely On	ICT Systems for Monitoring & Control	ICT for a Connected World	Big Data
Healthcare Systems & Services	✔		✔	✔
Life Sciences & Health	✔			✔
Smart Citizens & Cities			✔	✔
(Cyber)Security	✔			✔
Software Industry	✔			✔
Energy Transition	✔	✔		✔
Smart Industry	✔	✔	✔	✔
Smart Farming		✔		✔
Smart Logistics	✔		✔	✔
Chemical Industry	✔	✔	✔	✔

[9] The Scientific Answer to the Roadmap ICT for the Top Sectors", ICT-Research Platform Netherlands, 2014.

3.1 ACTION LINE 1: ICT ONE CAN RELY ON

Computers are part of an enormous network, the largest and most complex man-made system ever: the Internet. Hand in hand with the further penetration of digitization, the vulnerability of our ICT systems is also growing. Cyberattacks can bring down banking and industrial systems, and cybercriminals try to steal our identities or companies' digital assets. Add to this the growing complexity of software, and it is clear that we face huge challenges in creating ICT we can rely on, now and in the future. Within this action line, two main themes are identified. First, complex software and systems addresses architectures and design of technically robust computing and communication infrastructure with guaranteed quality and reliability. Also the monitoring of software and systems while being developed and in operation increasingly plays a role in achieving ICT vitality. Second, (cyber)security addresses solutions to protect our infrastructure against malevolent adversaries, including malware detection and removal, intrusion detection and prevention, trustworthiness of networks and hardware, secure information exchange and sharing, and privacy & identity protection.

3.1.1Complex Software and Systems

Tools, businesses, organizations, media, traffic, finance, education and even law are controlled by software and systems. The growth in software code is astronomical, and systems are increasingly complex as they are turning from homogeneous and stand-alone into heterogeneous system-of-systems. This makes modern digital society vulnerable to lacking software quality and unmanageable system complexity. Complexity causes the risk of failure in governments, businesses and safety-critical systems. Generally speaking: the more code and subsystems, the more dependencies, the more potential errors and the less flexible software and systems. This is conflicting with the rapid changes in society and economic sectors, demanding software and systems to be smart and flexibly adapted to change. Apart from being vital to society, software and systems are also an important factor for the Dutch economy. Several Dutch application vendors rank in the European top fifty. Sector-specific solutions for instance for healthcare, agriculture and media are well positioned.The fundamental challenge is to understand and control complexity. The more features, the more smartness, and the more interaction leads to an exponential growth of states in which a system can be. It then becomes practically impossible to analyse and test every state beforehand. Nevertheless, we still demand correct, safe, reliable, secure, flexible and easy-to-maintain software and systems at reasonable cost. We observe that actions in the field are often triggered by incidents and aborted large software and systems project in government, eroding rather than increasing trust in vital ICT Services. It is therefore important to develop versatile methodologies, formal approaches, and tools to understand and quantify complexity and desired robustness, factoring in that software and system complexity is not solely of technological nature but also defined by people and processes. It then becomes important to analyse the behaviour of existing ICT systems from a technical and socio-psychological perspective, and to feed back this knowledge into the software and system development and maintenance cycle. However, no individual can oversee an entire body of software or system-of-systems as the numerous internal dependencies complicate matters beyond imagination.In order to maintain consistency and in order to keep complexity manageable, efficient development and maintenance methods are crucial. Strategic research topics within top sectors therefore encompass models for software and system design and maintenance, automated code generation, re-use of existing modules, and integrated checks during development and operation. And these methods should not only be applicable to modern plug-and-play software and system components, but also to legacy components, especially when migrating to cloud-based solutions. Finally, made-to-measure solutions and development of new systems from scratch are becoming outdated, because of the enormous component pool already available. This pushes software and system development increasingly towards component-based-integration, where system behaviour can be predicted on the basis of (sometimes autonomously operating) components included in a system-of-systems design approach.

3.1.2 Cybersecurity and Privacy

ICT systems can be attacked by adversaries, for example by means of malware, viruses or a network of infected computers (botnets). This leads to cybercrime or even cyber warfare. These attacks are intended to bring computers into states that are undesirable for the original users. As the intention of an attack is not known beforehand, we also do not know how the system will behave once it enters into one of the undesired states. Unfortunately, in today's world such threats are constantly present to any computer that interacts with the Internet. Cybersecurity is no longer limited to traditional computer systems such as PCs and laptops. Rather, they now also surface in the physical world, from electricity and water supply systems to the health service, from public transport to smart cars, from implants to supply chains, and from banking and logistics to the emergency services. Therefore, addressing cybersecurity involves many disciplines or domains of expertise.

Strategic research directions in cybersecurity address techniques to understand, detect and stop known and unknown cyber-attacks. But we also have to work on prevention, both from a technological and from a legislative perspective. Even more, at a non-technical level we need to better understand the forms and causes of cybercrime, the effectiveness of measures (including law enforcement) and the underground economy, and we need to see where economic drivers for implementing security measures are lacking and where regulation may be needed. The National Cyber Security Research Agenda (NCSRA) plays an important role in defining future strategic public-private research programs.

A particular topic relevant to cybersecurity is privacy, identity and data protection. Already 95% of the Dutch households are on-line via computers and mobiles, and an increasing number of companies connect to the Internet not only for B2C business, but also for B2B dealings. The ubiquity of information technology and data collection in everyday domains of life has opened many new and beneficial possibilities for consumers and citizens, from on-line shopping to wireless payment. But the flip side is that the collected data also reveal something about our behaviour in the digital and physical world, and therefore about our identities. For consumers, protection of privacy and identity is a fundamental need, even if it is not always exercised by the consumers themselves for instance when over-sharing online information. At the same time, companies see more and more possibilities in sharing information for maximizing their businesses, logistics and operations. Governmental organizations are stimulating the re-purposing of their data collections by opening them up as "open data" to society. Sharing company-sensitive information or governmental data comes, however, with similar threats. An individual's privacy and even identity may be compromised by data shared by others. A company's valuable process, customer of other information will have to be protected sufficiently even when partially shared with other companies in the value chain.

Strategic research therefore encompasses solutions for privacy and identity protection, possibly via a nationwide trustworthy, interoperable e-identity infrastructure and following a privacy-friendly and data-minimization approach. Methods for protecting and secure sharing of data are often based on cryptographic or anonymisation techniques. These techniques will have to be improved in the face of the ever increasing computational power available to adversaries, but also because of the undesirable level of overhead some (cryptographic) techniques impose on services. Finally, “privacy and security by design” is an important research topics currently being investigated to deal with privacy and security concerns in ICT applications right from the start of developing a particular hardware or software component or service.

3.2 ACTION LINE 2: ICT SYSTEMS FOR MONITORING AND CONTROL

Control is an important objective of ICT systems, and monitoring and control solutions often have a central position with great impact in high tech systems. Examples are encountered in healthcare, smart industry, utilities, chemistry, agriculture and horticulture. Monitoring is also a key element in the modern world of surveillance and public safety for detecting suspicious behaviour, where cameras and other sensors are pervasive. In developing monitoring and control systems, two main themes are recurrent. First, the physical and digital world need to be “connected” by cyber-physical systems, in particular sensor systems. Sensors (and actuators) measure the state of the world, society, companies, and individuals. The challenge is to embed sensors in all sorts of objects and products, in clothing, in wearables, in surfaces of all sorts, and in a wide range of machinery under often harsh conditions. A highly compact sensor can measure an increasingly large set of parameters, and pass measured data via wired or wireless networks amongst themselves and often connect back to a networked service. The Internet of Things (IoT) is becoming reality thanks to sensors and actuators.

Second, the increasing miniaturization of components puts embedded systems in the centre of high-volume, high-performance, highly-integrated, low-cost- and energy-efficient digital monitoring and control solutions. Yet embedded system complexity is increasing, quality standards and performance expectations are going up, and development time need to decrease, calling for general and modular solutions.

3.2.1 Sensor Systems

By quantifying our environment and ourselves we can potentially make better decisions, live healthier and safer lives, and improve the efficiency of production processes. It is expected that by 2020 – *only 4 years away* – fifty billion sensors and devices will be connected to the Internet, from computers to home automation, cars, building, roads. The quantified self-movement – *already widely spread worldwide and giving rise to exponential growth of measured data* – will undoubtedly be followed by other quantified-X developments. Designing, operationalizing, protecting and understanding the behaviour of a large sensor network is a huge challenge. Sensor systems come with a number of challenges. First, before deploying a sensor network it is important to understand its expected performance and behaviour. This is not trivial given the harsh, uncontrollable and often dynamic conditions under which sensor systems are deployed, leading to unreliable communication and inaccurate or even missing measurements. Data-driven sensor systems therefore often require some level of (predictive) modelling

of the operational environment.
Second, even if millions of sensor in a network can be manufactured and powered cost economically, it is still extremely difficult to deploy and possibly (re-)configure such number of sensors optimally as so to yield desired measurements, especially when not all deployment conditions can be foreseen. Scalability and anticipating deployment uncertainties are important reasons for studying and understanding the complexity of sensor networks. Third, and related to the previous one, there is a growing need for algorithms and applications that efficiently make sense of the measured real-world data. Due to the scale and harsh deployment conditions, often a partially in-network processing solution is desirable, as so to preserve relevant data only, or to avoid inefficient centralized solutions by using autonomous agents. Tools, programming models and development support are the needed in order to come to easy and pervasive deployment and use of sensor networks. This issue is particularly pressing because of the increasing heterogeneity of the sensed data, thus connecting the topic of sensor systems to Action Line 4 of this KIA ICT. Finally, in systems of this order of magnitude, energy-efficiency of communications and processing is a priority through miniaturization and smart software and hardware.

3.2.2 Embedded Systems

Nowadays, ninety-eight percent of all computing chips are embedded in devices that do not look like computers, such as smartphones, cars and pacemakers. Embedded systems are instrumental creating smart cities that will make our lives healthier, our transport safer and our energy consumption more sustainable. Embedded devices range from tiny battery-powered intelligent sensors and actuators to large multiple-rack computing devices. The big challenge in designing embedded systems is to comply with a series of sometimes conflicting requirements such as flexibility, reliability and efficiency in processing power, memory and energy. A key step in the design of embedded systems is the systematic approach to mapping required functions onto hardware, software, and specialized components as sensors and FPGAs. Moreover, a recent trend is to make this process dynamic and determine only on runtime how the actual mapping is done. To efficiently and effectively deal with the many and often conflicting design objectives, novel modelling, simulation and design techniques and tools are needed. These techniques and tools should be capable of dealing with the sheer size of the design space of embedded systems, both in lateral and hierarchical dimension. At the same time they have to be accurate enough to make trustworthy evaluations of design decisions.
Once an embedded system has been designed, it is desirable to verify its correct operation especially in safety-critical applications. Two of the most common embedded software problems are ‘deadlock’ (when the systems hangs because two software processes are waiting for each other) or ‘livelock’ (when the systems hangs because it keeps on running a particular loop). This issue in embedded systems connects well to Action Line 1 (ICT one can rely on) of this KIA ICT.

As mentioned before, energy is a cross-cutting concern for embedded systems, and an embedded system should be designed to save energy in its operation. This is especially true for battery-operated components, but also for high-performance embedded systems, for example because of heat dissipation.
Due to constraints on power consumption, embedded systems use multi-core or even many-core architectures. However, effectively programming and utilizing such systems is a largely unsolved problem.

3.3 ACTION LINE 3: ICT FOR A CONNECTED WORLD

ICT systems can only efficiently exchange digital information among services if the system components are connected via communication networks, and if the services and data are interoperable. The development of interoperability and standards is indispensable when it comes to creating efficient digital business, supply chain, electronic health record, and digital government, for example. Also data exchange must be interoperable, preferably at the semantic level. In a period of under a decade, a myriad of communication services has come into existence. They are immensely popular and vital to society. The availability of communication networks is essential, yet they are soon becoming stretched to the limit. Digital communication systems continuously face new challenges in terms of more bandwidth due to big data, less latency for real-time services, and an exponentially growing number of connections due to the Internet of Things.

3.3.1 Interoperability

A good digital infrastructure requires an efficient information exchange between different ICT systems. Interoperability is a priority for businesses and governments, as well as for science. On an international level, the European Commission is pushing for European ICT standards in innovative products and services. When existing services are interoperable, this stimulates the further uptake of novel services in other application domains. Lacking interoperability is often a cause for high costs in maintaining a particular service. The big challenge is to make sure that ICT devices, applications, data repositories and services will interact seamlessly anywhere, just like the Internet does. Agreeing on the use of standards is an important tool to reach interoperability. It is far from trivial how to develop standards in order to realize interoperability in an unambiguous way. Systematic formalization are needed to determine complete standards for complete complex systems, rather than for only small parts of the whole ICT system. And once an interoperability standard has been set, how do we know that the system works correctly? If it works correctly in one domain, will it also do so in another domain? Can we specify the quality of a standard? These are some of the challenges that need to be addressed in interoperability of systems. Furthermore, the context in which systems and standards work, are not static. As the context changes over time in unforeseen manners, also the standards need to change as so to maintain interoperability. For this reason, open standards are highly preferable for generic ICT-technology solutions coming out of research and ready for market.

At the core of interoperability is the exchange of data. Data can only be efficiently exchanged if the meaning of the data is known. Semantic interoperability emphasizes the need for interoperability of the meaning of the data, rather than its syntax. Yet, if data is collected for one purpose, how can we make sure that it can be repurposed for a completely different application? Common technical solutions to semantic interoperability are adding meta-data, or linking data elements to controlled shared vocabularies. Linked (open) data describes a method of publishing structured data such that it can be interlinked and become more valuable. But such standards will still need to allow for human understanding and interaction when exchanging data. The challenge is to find the optimal cooperation between the cognitive strength of humans, who can understand the meaning of data, and the data processing strength of machines, who have difficulties in understanding the meaning of data in the context of the everyday human world. Standards for realizing semantic interoperability will remain to be of high priority with the further introduction of digital solutions across top sectors.

3.3.2 Communication Networks

New communication techniques, encompassing both novel hardware and smart software designs, will be needed to introduce more efficiency, flexibility and robustness in order to secure further growth of communication requirements in today's ICT systems. Optical fibre communication with its far higher capacity will play a major role in wired connectivity. But without new breakthroughs, its enormous bandwidth will not suffice to deal with tomorrow's data streams. Not only the net capacity needs to be increased, but also the capability to adjust to different traffic patterns on the fly. Already for today's networks, another challenge lies in interaction speed with data. This is relevant for instance for content delivery with very fast response times and thus low latency. But also for machine-to-machine communication where real-time monitoring and control of operation-critical components and services is essential and demands very low latency.

One of the present problems is the immense amount of wireless signals. Although existing communication signals can be repurposed for other applications like position estimation, it is clear that bandwidth for digital communication is scarce. One way ahead are cognitive and software-defined radios; these are intelligent radios that can be programmed and configured dynamically. Its transceiver is designed to automatically detect and use available channels in the wireless spectrum. To achieve maximal flexibility, traditional hardware components like mixers, filters, amplifiers, (de)modulators and detectors are implemented by software.

Complexity is a pervasive issue in ICT systems, and communication networks are no exception to this rule. Present communication protocols such as the TCP/IP Internet protocol are several decades old. Miraculously the internet still functions. A bottleneck in future developments is the capacity to manage and understand the complexity of networks, and to possibly move away from – *in a way* – legacy communication protocols to protocols that meet today's needs of larger bandwidth, less latency and growing number of connections.

The final strategic research direction in wireless communications is the minimization of electromagnetic radiation and reduction of energy consumption. Hardware has already come far and can make further steps with for instance smarter antennas. A prominent role is now reserved for software, through communication protocols which minimize overhead transmission of information, and for energy harvesting for wireless communication of small sensors.

3.4 ACTION LINE 4: DATA³: BIG DATA

All around us, small data is growing to big data. Not just on the Internet, but in science, in industry, and in society at large interactions, sensor data, data sets and growing at an unprecedented exponential rate. When the size of these data sets goes beyond the capabilities of the current database technology, they enter the realm of big data. With the right instruments a lot of insight can be extracted from the data and a lot of value can be created. In the field of big data the route forward is along two themes. First, how to find interesting patterns in the volumes of data, where this data might also be time varying, incomplete and incorrect. Furthermore, having mined the data for patterns, the next level challenge is to determine causality among related data features. And what is more, we also wish computers to learn to assign meaning to the data, mimicking human cognitive abilities. Second, the handling of the sheer size of data brings new challenges in terms of (distributed) computing power, programming languages, but also in terms of maintenance and preservation of big data, and in particularly open data.

3.4.1 DATA EXPLORATION AND MEANING

Data and content exploration is central to many economic top sectors and grand challenges. Society increasingly relies on data and content for a wide range of applications. More and more data is digitized in science, society and industry. Process data, social data, informal data, observed data, structured and unstructured data are just a few examples of how data is encountered. But data does not live in isolation; the more we know about the context of the data, the more useful it becomes in terms of finding and interpreting interesting patterns. Rather than exploring the data items on their own merits, data mining techniques explore association or correlation patterns in the data using statistical methods and machine learning algorithms. If the data set is large, the set of association found is often even larger. The challenge is therefore to present the data miner with small, manageable, understandable, representative and actionable sets of such correlations, that is also relevant in the application context.

Many interesting big data sets are not static. They originate, for instance, from industrial monitoring instruments or from social media, producing continuous streams of data. Single snapshots of data are meaningless, yet it is impossible to store all data, and it is also impossible to continuously re-compute the models that are derived from the data. Incremental reasoning and data mining will be needed to combine earlier results, models, and decisions with the continuous stream of newly arriving data.

The tradition approach to analysing data has been based on querying data bases, relying on complete and correct answers. Finding useful information in big data – *that is often unstructured, and especially open data may be partially incomplete and incorrect* – requires a far more interactive mode of operation, where the user has means to stepwise explore the data deeper and deeper into the database. Such browsing and exploration process makes searching in a database, a document, a collection of data sets, or on the web itself more and more alike. A big challenge in big data is what are the best exploration techniques and what visualization methods are optimally suited for the human data miner? How can we visualize abstract data such that humans can best explore and understand them?

Whereas data mining may find interesting patterns in data, it essentially does not associate a meaning with its findings. Automatically assigning meaning to data is a big scientific challenge. Solving this challenge will lead for instance to semantic search engines for rich and complex data of which speech, images and video are the archetypes. Meaning is also closely related to causality. Even if data mining produces a significant correlation result, we still do not understand what the meaning of the correlation is and if it points to causal relationships. The use of big data for decision support and making predictions can only be successful if causality and a sufficient level of meaning can be established.

Open big data is posing a number of specific challenges. First, it is important that open data models and formats are established that can be understood and processed autonomously. The conversion between models and formats need to be specified and transparently implemented. Second, as open data become free to use, the maintenance of the data is non-trivial. How do we ensure proper stewardship, encompassing authenticity, reliability, trustworthiness and preservation of the open data over very long time spans? Open data is an important driver of big data exploration and understanding, but it is not a temporary project. Data stewardship demands long-term investments because users of the data may lose trust and companies may lose their willingness to invest.

Finally, our ability to assign meaning to the world around us based on observed sensory information forms the core of intelligent behaviour. One of the largest challenges in big data is to develop intelligent algorithms that can do just that. Semantic understanding of images, video, audio, text, and other forms of real-world information is becoming increasingly data-driven thanks to large learning sets available on the internet. And for situations where such learning sets are not yet available, like in industrial processes, self-learning data exploration methods will be needed. These methods have the ability to learn from experience, adapt to new situations, understand and handle abstract concepts, and use knowledge to manipulate the environment. With a growing understanding of the way the human brain learns to recognize patterns, improvements on machine-learning and artificial intelligence techniques will be made.

3.4.2 Cloud Processing and Programming

The storage and memory capacity of computers has grown from kilobytes to gigabytes, and even up to terabytes and petabytes. We tend to expect that in terms of handling and manipulating big data, the evolution is the same, but alas this is not the case. Over the last decades, the speed of processors has gone up from the megahertz to the gigahertz range, but in recent years the processor speed has pretty much come to a standstill. Likewise, the transfer speed of data to and from mass storage media such as hard disks, has not increased as much as the storage capacity. We therefore need breakthroughs in the fields of multi-core data-intensive processing as well as in massive parallel data processing and cloud computing. In particular the challenge is how to optimally distribute data over the available processing units? This becomes even more pressing when data sources, data storage and processing infrastructure are geographically distributed as is typical for cloud computing. The challenge is to use the distributed ICT infrastructures optimally by distributing both data and algorithms. One the one hand this requires automatic schedulers; on the other hand it may also require particular large scale distributed and cloud programming approaches. E-science aims at providing domain-specific processing and programming solutions. Like for other computing and communication technologies, also cloud computing will need to factor in energy consumption, in this case with the objective to minimize the compute centre's environmental footprint.

When running software applications in the cloud, multiple parties (called tenants) use the same cloud. Because of the economy of scale, multi-tenancy often leads to services that at first sight seem to be cheaper. However, it can also create multi-tenancy problems for enterprise users, as the service is often less flexible, less secure and less powerful than in the classical situation where software is rolled out to individual users. Software innovations are needed to deal with the data explosion and the complexity of the underlying distributed computing infrastructure. Modern open source tools as Hadoop MapReduce partially address these challenges. However, these tools need to be extended to deal with more complex big data analysis functionalities such as learning and reasoning. Domain-specific languages are needed to take advantages of the modern infrastructure including adaptive schedulers, on-demand scaling in clouds, and heterogeneous computing architectures including massively multi-core, Graphical Processing Units, and task-specific FPGAs. The rise of big data is also driving the development of new generation databases for business intelligence, process control, and data exploration. The sheer size and complex structure of the data creates query results that are both produced to slow and too large to interpret. New database architectures are needed that can push response times down to almost instantly, and that will allow for interactive exploration of the data.

3.5 Multidisciplinarity for T-Shaped ICT

The Action Lines of Sections 3.1 to 3.4 focus on scientific and technical challenges in ICT. Progress in these action lines depends critically on the excellence of ICT sciences in the Netherlands and innovation of the ICT sector. Yet at the same time, innovation of ICT does not happen in isolation but in the context of application domains and in the context of other disciplines, which gives ICT a strong multidisciplinary perspective especially in the context of top sector innovations. This implies that in implementing the four action lines, we should aim for T-shaped projects, programs and especially the associated human capital agenda. T-shapedness emphasizes that depth of expertise is coupled to breadth of knowledge. In other words, deeply specialized ICT which at the same time is well connected to neighbouring disciplines and applications will not only maximize technological innovation, but also have maximum impact on the interconnected social innovation.

T-shaped research in the context of the sectors addressed in Section 2 means that ICT researchers are sufficiently aware of application domains' characteristics as so the be able to engage in meaningful interaction about, for instance, the sector's specific system robustness requirements and operational condition; or the quality and heterogeneity of data collected when used in data analytics; or even the terminology that may vary widely from sector to sector.

Multidisciplinarity of ICT research is also immediately obvious when realizing that ICT methods and systems always interact with human end users and within legal and economic contexts. For instance, when developing advanced systems the end user is often overwhelmed by the complexity, causing cognitive overload. Without proper design and factoring in the human abilities to deal with certain complexity, the ICT system is doomed to fail. It is important to develop versatile methodologies, approaches, and tools to understand and quantify complexity and desired robustness, factoring in that system complexity is not solely of technological nature but also defined by people and processes.Many ICT challenges contributed by top sectors refer to using data collected via IoT (sections 3.2 and 3.3) for the purpose of data analytics (section 3.4). However, there might be strong legal implications of sensing and collecting certain information, especially when privacy is at stake. Also the use of data may be bound by law or (often complicated) use conditions and informed consent. For that reasons, T-shaping also implies being able to connect to legislative experts especially in contexts of security and privacy-by-design research.

The social dynamics of users plays an important role for instance in smart cities. The use of technology and the way it influences human behaviour, required education, and social innovation is another aspect that ICT researchers should be aware of. In cybersecurity, understanding the behaviour of users (over sharing of information) and adversaries (economic motivations, state threats, etcetera) is inevitably linked to research described in section 3.1.

In conclusion, ICT is transforming the world. The ICT specialist should not be so deep into the forest of knowledge that the consequence of this transformation goes by unnoticed. Education, top sector project and programs that explicitly address T-shapedness will accelerate ICT innovation more, and also yield more interesting and challenging research questions for ICT specialists.

3.6 RELATION TO NATIONAL RESEARCH AGENDA

The National Research Agenda (NWA) collects a number of scientific challenges of importance to (Dutch) science, innovation and society at large. The Dutch ICT community has submitted a number of questions, several of which relate to the four ICT Action Lines and eight themes. The NWA challenges formulated are often more abstract in nature than the breakthroughs demanded by economic top sectors, yet they may serve as an inspiration for future developments in ICT science beyond this KIA ICT 2016-2019. We here summarize several of these questions in the expectation that they may become important for future versions of the KIA ICT.

A first category of questions relates to the effects of ICT at large and in particular the intelligence being developed for sensor systems and big data. Especially because the computing and communication infrastructure is increasingly difficult to grasp for humans in all its complexity.

"We develop computers that are increasingly intelligent, and leave more and more of the decision making to computers. How smart can we (and do we want to) make computers? Which cognitive abilities for processing of the information are inherently human, and which ones can we trust computers to do well for us? Can big data give answers to questions that were never asked? How can we make sure that we remain able to control computers in the long run? How can we determine the trustworthiness of a computer?"

The second category refers to the future of computing and networking technologies. Initiatives like QuTech are taking a first peek into the future. If new technologies materialize, what are the consequences for today's challenges? Which of the four Action Lines and eight themes in the current KIA ICT will disappear and which ones will become ever so important?

"How to develop, manage, and control the ever-growing internet such that it remains open, accessible and trustworthy? The development of conventional computing and networking is coming to an end. Radically new solutions are emerging. How do we make the transition? Can we build an inherently secure internet based on quantum technologies? Will the quantum computer realize artificial intelligence surpassing our own?"

The third category and final set of questions refer to the two sides of analysing and using massive amounts of data now and in the future: can we handle the amount of collected data, and what are potential risks of collecting and analysing big data?

"How will the growing amount of data remain analysable and usable in the future? What solutions does ICT science deliver for extracting information from (big) data without inadvertently revealing secrets? What is the impact on society if information is analysed at massive scale by government and companies? How do we conform big data analysis with fundamental values such as privacy and individual autonomy?"

Chapter 4

ICT Innovation: Actors, Models and Plans

TOPICS	ACTION LINES			
	ICT One Can Rely On	ICT Systems for Monitoring & Control	ICT for a Connected World	Big Data
Healthcare Systems & Services	✔		✔	✔
Life Sciences & Health	✔			✔
Smart Citizens & Cities			✔	✔
(Cyber)Security	✔			✔
Software Industry	✔			✔
Energy Transition	✔	✔		✔
Smart Industry	✔	✔	✔	✔
Smart Farming		✔		✔
Smart Logistics	✔		✔	✔
Chemical Industry	✔	✔	✔	✔

Cyber Security

COMMIT2DATA

ICT Innovation: Actors, Models and Plans

In this chapter the implementation scenarios for the KIA ICT are described. One of the priorities of Team ICT is the stimulation of public-private partnerships. For the implementation of this KIA ICT, many actors have a role to play. They are briefly described below. Several models for implementing public-private partnerships are discussed next. Finally, implementation of this KIA ICT through concrete actions is proposed.

4.1 ACTORS IN ICT INNOVATION

To successfully implement the ambitions of the KIA ICT, the active participation of various stakeholders is a must. The ICT sector and its customers form a diverse landscape with many actors. From small companies to large multinationals. From suppliers and service providers to ICT users. Public and private. Each actor covers a part of the spectrum, with knowledge, questions, resources, etc. In this paragraph several main stakeholders are described in more detail. This is not an exhaustive overview, but it covers the landscape from fundamental and applied research through to commercial use and supply.

Netherlands Organisation for Scientific Research

The Netherlands Organisation for Scientific Research (NWO) is the national research council in the Netherlands. NWO ensures quality and innovation in science and facilitates its impact on society. Its main task is to fund scientific research at public research institutions in the Netherlands, especially universities, with a budget of 625 million euros per year. NWO focuses on all scientific disciplines and fields of research. The funds are allocated by means of a national competition on the basis of quality and independent assessment and selection procedures. NWO plays several roles as a broad, national research organisation that actively contributes to various elements of national science and innovation policy. ICT research funding is mainly addressed by the division of Physical Sciences and by Technology Foundation STW. The NWO institute CWI (Centrum Wiskunde & Informatica) performs ICT research (see below). Other divisions fund ICT-research in a domain context (e.g. in energy, logistics and healthcare).

NWO implements the action lines of this KIA ICT along two lines, both in a national competition: supporting talented researchers & fundamental research and public-private partnerships. Each line will be strengthened by valorisation activities and might be supported by an international component. Given their large impact in society, it is essential to engage other disciplines in the top sector agendas. The impact on the foundations of public and private life is simply too big to leave it to ICT alone. NWO is uniquely positioned to bring together diverse disciplines around a central theme, as has been show for instance. in the cyber security domain in recent years. In both implementation lines this will be actively pursued.

- **supporting talent and fundamental research**
  Supporting talented researchers in their scientific career is a vital condition for scientific innovation. Encouraging the development of groundbreaking ideas is a key aspect of NWO policy. At the same time, reinforcing the knowledge chain from the start at fundamental research will return economic benefit, as countries around us recognize. Therefore, NWO will allocate budget for a free competition and the Talent Line (Rubicon and Vernieuwingsimpuls). Financial commitment from companies will not be required for this implementation line. Establishing active connections between scientists and companies through user committees, for example, is part of these schemes.
- **public-private partnership research programs**
  NWO has a long-standing tradition in public-private partnership programs, the thematic programs such as Big Bang, Big Data and the STW Perspectief program. The goal here is to be inspired and to inspire research. Also, the education of future personnel is a key motivation for the participation of the sector. The implementation in this line is on the one hand by competition where public - private partnerships will be invited to submit a proposal under one of the themes of the KAI ICT. As selection is on the quality of research and the quality of use-inspiration, some themes may have more than one project, whereas other themes may have none. In public-private programs, dissemination is a key activity and part of the budget will be reserved for this. Additional schemes, such as the Take Off Program, may be used for this as well. The industry participation in the use-inspired or insight-inspired research is warranted by an in-kind active or an in-cash contribution of at least 25% of the program. On the other hand, NWO may participate in national, large-scale initiatives such as COMMIT2DATA.
- **international activities**
  Science is international by nature. A strong embedding and benchmarking against international programs will ensure a maximum return for the Dutch science and industry communities. Furthermore, European schemes (EIT, FET, Horizon 2020, ERC) may provide additional financial matching for the national programs. NWO has a co-operation with ministries and science foundations in strong

research nations such as China, India and the United States. These agreements lead to international cooperation through joint workshops, student and staff exchanges and research programs (including public - private programs).

Centrum Wiskunde & Informatica (CWI)

CWI is the NWO national research institute for mathematics and informatics in the Netherlands. The institute was founded in 1946 and is located at Amsterdam Science Park. The institute has a strong international position and is renowned for its high quality research. CWI's strength lies in the discovery and development of new ideas, and the transfer of knowledge to other scientific areas, society at large and trade and industry in particular. Research of CWI is applied for instance in payment systems, cryptography, telecommunications, public transport, smart energy networks and meteorology. CWI concentrates on five broad, top sector-relevant themes: Software, Information, Life Sciences, Logistics, and Energy.

CWI implements the action lines of this KIA ICT through world-class research. With 50 tenured researchers and over 80 PhDs and postdocs, CWI contributes to relevant national programmes. CWI maintains close contacts with the industry and academic world, both in the Netherlands and abroad, cooperating with companies such as Rabobank, Cisco, ExxonMobil, Actian, ABB, ING, Centric and VORtech. More than half of its tenured research staff is also associated with universities as part-time professors.

Netherlands eScience Center

In this digital era, eScience is the developing discipline that provides the domain overarching software instruments (software, workflows and protocols), training and knowledge to support diverse scientific initiatives. It makes possible the creation of new, even unforeseen, applications – with the potential to transform current scientific practice, optimize scientific investments and significantly accelerate scientific discovery. The Netherlands eScience Center (NLeSC) is tasked with coordinating a collaborative scientific program, working as partners with both academia and industry, to conduct funded projects fostering the development of overarching tools and technologies for the benefit of a broad scientific community.

The key competencies of NLeSC are Optimized Data Handling, Big Data Analytics, and Efficient Computing. It focuses on top sector relevant applied research domains: Environment & Sustainability (a.o. climate, ecology, energy, logistics, water management, agriculture & food), Life Sciences & eHealth, Humanities & Social Sciences (a.o. smart cities, text analysis, eBusiness, creative technologies), and Physics & Beyond (a.o. astronomy, high-energy physics, advanced materials, engineering & manufacturing).

NLeSC implements the action lines of this KIA ICT along three lines: with its staff of eScience Research Engineers who work as partners in demand-driven thematic research projects, by providing versatile generic software technologies to all researchers and through coordinating eScience and data research activities. eScience Research Engineers are digital scientists able to work at the interface of a scientific discipline and enhanced ICT. The funding is organized both in technologically and in domain oriented calls. Projects are always a combination of academic staff with eScience Research Engineers. The generic software technology, which aims to avoid fragmentation and stimulates re-use, is managed and disseminated through the open source and open access platform eSTeP.[10]

[10] https://www.esciencecenter.nl/project/estep

SURF

SURF is the collaborative ICT organisation for Dutch higher education and research. SURF offers students, lecturers and scientists in the Netherlands access to the best possible internet and ICT facilities. The SURF organisation consists of the SURF Holding and 3 operating companies: SURFnet, SURFmarket and SURFsara. SURF services are provided by these independent operating companies, each of which has its own field of operation. SURFnet ensures that researchers, lecturers and students can work together in a simple and robust manner using ICT. To enable the most effective use of ICT, SURFnet supports, develops and operates advanced, reliable and interconnected ICT infrastructure networks. SURFmarket is the prime ICT marketplace for higher education and research, and also facilitates the use of ICT. SURFmarket negotiates with ICT providers on behalf of institutions connected to SURF, offering them a selection of software, cloud services, digital content, ICT Services and hardware, and all at competitive prices. SURFsara is the Netherlands' national supercomputing centre. It provides high-quality computing services for academic research and education in the Netherlands. SURFsara also launches initiatives that encourage the transfer of technology to industry. SURFsara supplies high-performance computing (HPC) services, data storage, network research and visualisations to the academic and business communities. Finally, SURF is cofounder of the Netherlands e-Science Center, together with NWO.

SURF is important to the implementation of this KIA ICT by providing the necessary e-infrastructure, and stimulating break-through innovations in this e-infrastructure in public-private partnerships.

TNO

TNO, the Netherlands Organisation for Applied Scientific Research TNO, is an independent research organisation founded by law in 1932 to enable business and government to apply knowledge. TNO connects people and knowledge to create innovations that boost the competitive strength of industry and the well-being of society in a sustainable way. This is the mission and it drives the 3,000 professionals at TNO in their work every day.

TNO believes in the joint creation of economic and social value and works in collaboration with partners. TNO focuses on five transitions that are identified together with stakeholders. These are: Industry; Healthy Living; Defence, Safety & Security; Urbanisation and Energy.
One of the topics TNO focuses on is Networked Information. ICT is essential to our society.
A new information infrastructure is emerging whereby citizens, industry and government will communicate with each other in new ways and will fully employ open data. The impact of this on many societal and economic processes will be considerable, though as yet unknown.

The innovating power of ICT enables us to do things differently: more efficiently, better, faster, smarter and more sustainably. Smart ICT innovations can help solve complex societal issues like climate change, demographic ageing, scarcity, education, mobility, care & safety and Smart Industry. In fact, the smart application of ICT is a precondition for this.

EIT Digital

EIT Digital is a European public-private initiative intended to turn Europe into the global leader in ICT innovation. EIT Digital aims at a sustained transformation in innovation through the integration of education, research, and business

- Breeding entrepreneurial ICT top talent via the transformation of higher education to promote creativity and entrepreneurial spirit;

- Speeding up ICT innovation through ICT Labs for researchers, innovators and entrepreneurs
- Generating world-class ICT business via broader and faster industrialization of research results.

EIT Digital offers a joint program of international Master's schools, doctorate schools and professional schools as well as thematic and business action lines. All action lines integrate the knowledge triangle of education, research and business co-located in 7 nodes in Berlin, Paris, London, Eindhoven, Stockholm, Helsinki and Trento. Core industrial members for the Netherlands are Philips, Siemens, Ericsson, SAP, Deutsche Telekom and France Telecom, where the federation of the 3 technical universities (3TU. NIRICT) also plays a key role.

EIT Digital mobilizes the Entrepreneurial Support Systems as currently organized by the Dutch (technical) universities and research institutes into an international business strategy. In a similar way, EIT Digital leverages educational programs to boost international mobility and entrepreneurship, through its partner network of academia and large enterprises. Public-private research & development projects such as COMMIT, FP7-8 and ITEA2 projects, serve as important carrier projects for the EIT Digital activities, especially in health and well-being, and smart energy systems.

Nederland ICT

Nederland ICT is the trade association for more than 550 IT, telecom, internet and office companies in the Netherlands. Nederland ICT represents a business community with a turnover of almost € 30 billion and over 250,000 employees, making it the foremost advocate and representative of the Dutch ICT sector. Nederland ICT is active in the area of market promotion, advocacy and individual services, for example in the legal domain. Its members form an important group of stakeholders and possible investors in public-private partnerships. Netherland ICT will unlock that potential through its platform function.

CIO Platform Nederland

CIO Platform Nederland is the independent association of CIOs and ICT directors of private and public organizations in the Netherlands. Guideline for member companies and organizations is a turnover of more than € 500 million on an annual basis and / or an ICT budget of more than € 25 million. The CIO is the 'entrepreneur' within the organization that wishes to enhance the value of ICT for the organization in a creative way. Characteristic of this group of top managers is that they are all responsible for the use of ICT in manufacturing companies, government agencies, banking and insurance, utilities, et cetera. So organizations that do not have ICT Services as its core business, but are dependent on ICT. The members of CIO Platform Nederland form an important group of stakeholders and possible investors in public-private partnerships. CIO Platform Nederland will unlock that potential through its platform function.

4.2 PPP MODELS IN ICT INNOVATION

The pervasiveness of ICT in many top sectors has given rise to a wide diversity of users and practitioners of ICT, who have their own skills and priorities in dealing with ICT challenges. Many of them are also involved in ICT-research, be it the usage of ICT or the renewal of ICT itself. Maybe with the exception of high-tech OEMs, the advantages of public-private collaboration in the field of ICT sciences are not always immediately clear to companies ("the research is too fundamental") or to knowledge institutions ("the research is too applied"). Therefore, especially in the field of ICT due to the very large diversity of actors, a one-size-fits-all collaboration model simply does not exist. And over time private parties may well transfer from "try-it-out" small scale collaborations to sustained and intensive collaboration.

The experience of four years ICT research within top sectors as well as the best practices of the COMMIT/ and similar ICT public-private programs have led to a concise mapping of the types and phases of public-private collaboration. The table below gives an overview of the four types, to be expounded next.
The **round table** model is typical for research projects that have a "utilization committee", as well as for some collaborative research projects in COMMIT/. Smaller scale NWO, STW and first-money stream projects involving private partners often take this form. The term "round table" indicates that activities are often focused knowledge development and collaboration between a relatively small number of parties on specific topics of interest. In ICT this is often an innovative system component, a design tool, or a data set. The collaboration is shaped as bilateral inspiration: new opportunities that research provides for the private partners, and use-inspiration of the research due to challenges private partners pose. For many innovative SMEs "round table" collaboration turns out to be mostly prolific as it accommodates a relatively short involvement in a research project of longer duration.

The **joint strategic** programming is seen in most EU collaborative projects (ECSEL, H2020) and in some COMMIT/ projects, where a series of common deliverables is agreed upon. In the spirit of joint strategic programming, TNO is increasingly taking a partnership role through its joint and early research programs. The "work packages" structure shapes the collaboration in the form a sequence of partial joint results towards a common objective, such as realizing an integrated demonstrator, a fully integrated system, or planned steps on a technology roadmap. Since joint strategic programming requires a multiple years' work plan, this model is suitable for larger companies having their own research and innovation departments. In the Dutch ICT landscape there are currently few companies that focus on purely ICT components, product and services research, such as IBM. In most cases, larger companies with ICT research and innovation departments are found in larger top sectors such as energy, health and life sciences, for instance.

	Use-inspired Research	Usage of the Research Results
Involvement of one/few private parties	**Round table** Also known as path-finder. Dynamic partnership within longer term (4-5 years) project. Highly innovative private partners mix and match with knowledge partners based on competences needed.	**Valorisation sprint** Also known as catalyst model. Concrete (partial) results from use-inspired research are developed in short project (6-9 months) to proof-of-concept or demonstra-tor as pre-phase for commercialization.
Involvement of multiple private parties	**Joint strategic programming** Also known as road-mapped research. Structured as work plans and deliverables. Highly innovative private partners team-up for longer period (4-5 years or even more) with knowledge partners to jointly execute common research.	**Dissemination(** 1) Established and new research knowl-edge are transferred to society at large with focus on less tech-savvy private partners. (2) Private partners employ graduates who have carried out research in PPP projects.

Valorisation sprints are implemented via STW valorisation grants/Take Off, COMMIT/ valorisation projects, cyber security SBIR projects, NWO KIEM, and EIT Digital catalyst "added value" projects. Increasingly knowledge institutions are stimulating valorisation projects as means to transfer knowledge to other-than-academic peers. These sprints are fairly short in time, say 6-24 months. In most cases, collaboration is based on results and/ or (low fidelity) proof-of-concept demonstrators that have been achieved in earlier research phases. A valorisation sprint is often characterized by the fact that opportunities for research results are seen or anticipated by an outside party. Partners then take up the earlier science result and begin to factor in fidelity, product and market considerations. This leads to demonstrable prototypes that can show customer and market relevance. Whereas valorisation sprints are still in pre-competitive development phase, they aim to eventually feed into a business development phase, where a commercializing company or start-up takes over. Finally, **dissemination** aims to transfer knowledge to an as-large-as possible audience. Dissemination activities are generally relatively short, from a day to weeks. This includes all forms of interactions between knowledge parties, companies, and society, including but not limited to demonstration events, technology fairs, matching events, thematic workshops, help desks, media appearances, columns and blogs, presentations, and education. Also the knowledge institute graduates themselves who have carried out research in public-private collaborations, are an important form of knowledge dissemination.

In the field of public-private ICT collaboration, all of the above collaboration models occur, and should occur, simultaneously and not necessarily in a linear order to make the ecosystem function. Only in this way connections between the large diversity of actors can be successfully made. Having organizations and programs that drive the different collaboration modalities are essential. Programming and funding of ICT research by public and private organizations must aim to have the ecosystem function as a whole, and parties involved should accept to jump over one's shadow if needed.

4.3 FRAMEWORK FOR ACTIONS

The implementation of the KIA ICT should take place with all relevant actors through all models along the four Action Lines described in Chapter 3. Both a bottom-up and a strategically coordinated approach are required. Financial consequences of these approaches are described in Chapter 5.

- **Bottom-up approach**
  To continually innovate, a bottom-up PPP approach along all four action lines is necessary. This allows scientists together with industry to collaborate on a project per project basis. It offers a flexible collaboration scheme, suitable for both valorisation sprints and the round table model. Various instruments have been developed by NWO, STW and TNO, ranging from very small (e.g. KIEM) to larger (e.g. IPP) scale. These instruments should be continued where possible. They form the foundation of ICT PPP and may lead to new national initiatives in the future.

Furthermore, the interaction between academics and entrepreneurs should be strengthened. For optimal partnerships, it is important that the various parties find each other and learn to understand each other's needs and challenges. A new tool to stimulate exchanges between Dutch companies and research communities are the Public Private Fellowships. The program provides the opportunity for academic researchers to work in companies (temporary and / or part-time). Also, business people (with sufficient background) can get a temporary position at a university or TNO in the context of basic / applied research. The strategy is that with this initiative, a public-private partnership could also benefit in the long run, for example by subsequent participation of the company in a research consortium with in-kind and / or cash contributions.

- **Strategically coordinated approach**
  From the aggregation of individual sector challenges, two important themes emerge in Chapter 3: Big Data and cyber security. Important in the sense that the associated challenges are dominant in most, if not all, sectors. Important also in that they offer the opportunity for scientific breakthroughs and the potential contribution of the Dutch ICT sector (both academic and private).

Although several programs and projects exist that address (part of the) Big Data spectrum, a coherent national initiative is currently lacking. Therefore, Team ICT has decided to initiate a National Initiative Big Data: COMMIT2DATA. COMMIT2DATA, follow-up to the COMMIT FES program, focuses on accelerating economic activities based on big data opportunities, with societal challenges as an important guiding theme. This National Initiative is a public-private partnership (PPP), and is being developed in coordination with NWO. COMMIT2DATA comprises three related program lines that all focus on ICT challenges in data science and data stewardship, and related technological challenges, namely the exponential growth of data and the use and protection of data. The first program line focuses on pre-competitive use-inspired knowledge development. Demand inspiration comes from coordinated and impactful regional / national partnerships. Sectors include Energy, Smart Industry, Security, and Life Sciences & Health. The second program line aims to significantly strengthen the valorisation and in particular entrepreneurship in the field of big data in all (top) sectors. The third program line focuses on accelerating the opening up of big data methods and connecting big data business to in particular SME entrepreneurs through so-called data factories. A more detailed description of COMMIT2DATA is given in Appendix 2.

Cybersecurity is of high importance to many top sectors, in particular HTSM, Energy and Creative Industries. A single, bottom-up created national research agenda has proven to be a valuable instrument to all. As of 2012, based on two subsequent editions of the National Cyber Security Research Agenda (NCSRA), NWO and its partners (in particular the Ministries of Security & Justice, Economic Affairs and RVO) have organized two tenders for cybersecurity research and innovation. Synchronised calls for long term fundamental research and short term product innovation routes (SBIR) in the area of cybersecurity turned out to be a very successful combination. Simultaneous matchmaking prior to announcing these two call types resulted in fruitful cross fertilization. For the 2016-2019 timeframe NWO and its partners intend to deploy several (funding) instruments. A third national cybersecurity research tender will be organized, again with a short term SBIR call and a call for long term research. In the international arena NWO intends to work with the National Science Foundation (NSF), the Department of Homeland Security (DHS), and possibly Japan and Singapore to set up joint research programs. The transfer of knowledge to society is part of NWO's strategy. Parties like the Hague Security Delta (HSD) are providing a relevant podium to bring scientific results and/or SBIR prototypes a next step towards true innovations. The National Innovation Agenda for Security (NIAS), released by HSD, with a number of cybersecurity related spearheads, will be helpful here.

Chapter 5

Financial Aspects of Public Private Partnerships in ICT

Financial Aspects of Public Private Partnerships in ICT

Digital technology has entered almost all aspects of our daily lives and it will continue to do so at ever increasing speed (Chapter 1). Not surprisingly therefore, an abundance of ICT challenges and necessary breakthroughs was identified by the top sectors in Chapter 2. In short, the importance of ICT research and innovation cannot be underestimated. To address these challenges four concerted action lines were described in Chapter 3. A critical success factor for ICT research programming is that it takes place in public private partnerships. Excellent ICT science in collaboration with private partners from the top sectors is the most appropriate way to renew knowledge and the applications thereof at the cutting edge of today's technology. A significant investment in PPPs aligned with the four ICT research Action Lines is required to realise the ambitions put forward in this KIA ICT. These investments concern public and private partners alike. The investments are aligned with the four ICT action lines as so to maximize the lateral translation of research results to innovation in the top sectors, and thus maximize the efficiency of investments. In this KIA ICT, two large-scale public-private program initiatives are proposed: cyber security and the follow-up to the COMMIT FES program: COMMIT2DATA (Appendix 2). In addition to these larger programmed initiatives, bottom-up programming is proposed to strengthen PPP in all four action lines. To increase interaction between public and private partners, a new instrument is proposed: public private fellowships (Chapter 4). Finally, it is important to invest in PPPs of the future: the emerging lines among others resulting from the National Research Agenda (NWA).

This table outlines the initial estimates of current investment levels in the various action lines of the KIA ICT (Oktober 2015). To fully achieve the ambitions of the KIA ICT, a steady growth of these numbers is aimed for. The innovation contracts for knowledge and innovation that are signed every other year (next one on October 5, 2015) are the basis for strengtening Public Private Partnerships.

<table>
<tr><th></th><th colspan="8">Funding Type (M€ / year)</th></tr>
<tr><th>Themes</th><th>Private</th><th>Govt.</th><th>NWO</th><th>NLeSC</th><th>TNO</th><th>EU</th><th>Regional</th><th>Knowledge Institutes</th></tr>
<tr><td>ICT One Can Rely On</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cyber Security</td><td>3</td><td>3.5</td><td>1.5</td><td></td><td>3.5</td><td></td><td>1</td><td>3</td></tr>
<tr><td colspan="9">Data3: Big Data</td></tr>
<tr><td>COMMIT2DATA</td><td>6</td><td>3</td><td>10</td><td>1.5</td><td>3</td><td>3</td><td>1</td><td>6</td></tr>
<tr><td colspan="9">All Action Lines & Emerging Themes</td></tr>
<tr><td>KIA ICT Calls</td><td>1</td><td></td><td rowspan="3">1</td><td>1.5</td><td rowspan="3">3.6</td><td></td><td></td><td>1.5</td></tr>
<tr><td>Public Private Fellowships</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Emerging Themes Calls</td><td></td><td></td><td></td><td></td><td></td><td>1</td></tr>
<tr><td colspan="9">Total</td></tr>
<tr><td></td><td>10</td><td>6.5</td><td>12.5</td><td>3</td><td>10.1</td><td>3</td><td>2</td><td>11.5</td></tr>
<tr><td>Grand Total (excluding knowledge institutes)</td><td colspan="8">47.1</td></tr>
</table>

In this table, 'Government' includes the contributions from TKIs (a.o. 'TKI toeslag'). NWO includes the contributions from CWI. Both the NWO and TNO numbers include activities that are governed by other top sectors. EU refers to budget acquired directly in connection to funded COMMIT2DATA activities through EIT Digital, H20202 calls, and the EU Big Data PPP. The budget listed as "knowledge institutes" refers to first money stream research matching of (applied) universities needed to be able execute the PPP programs. In overall terms, the PPP programs of the KIA ICT aim at 25-30% private funding.

Appendix

Appendix 1 - Contributors

Contributions:

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Appendix 2
COMMIT2DATA

Introduction

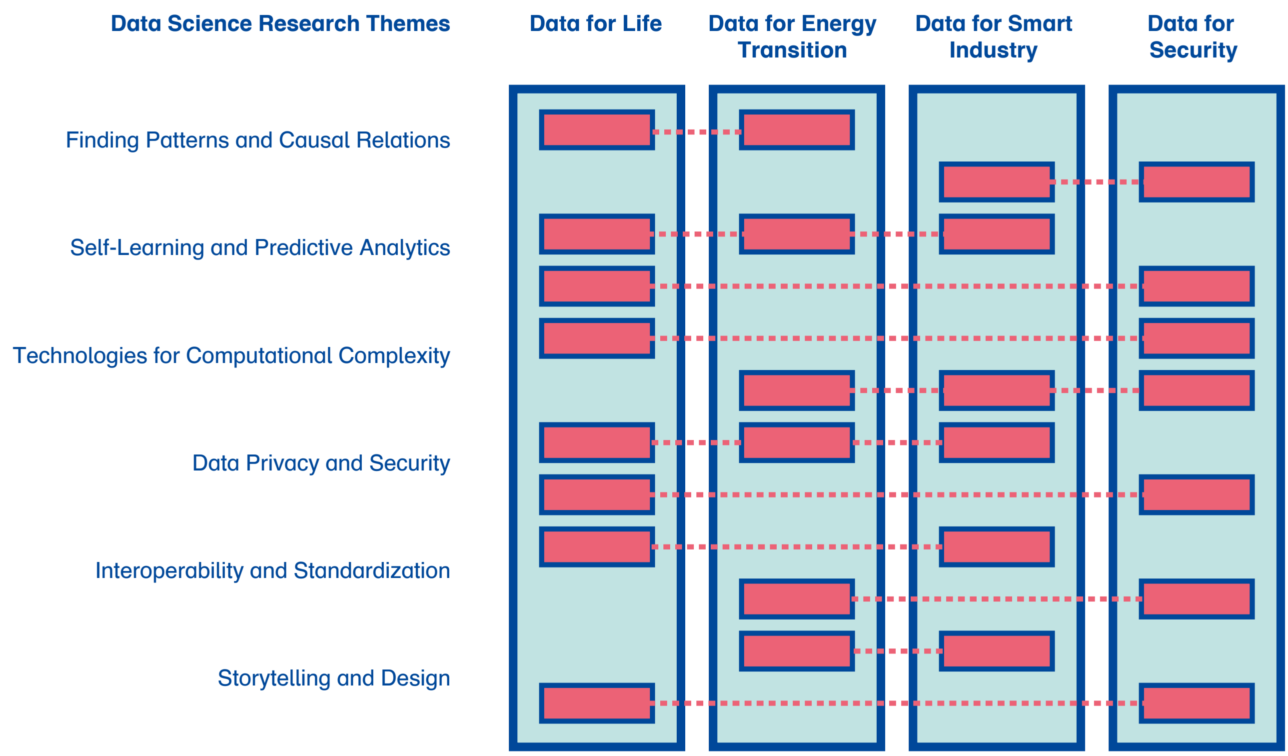
The COMMIT2DATA national public-private program (PPP) program aims to bring together knowledge institutes, government and companies within a number of strong sectors: data for life; data for energy transition; data for smart industry; and data for security. The aim herein is to jointly maintain and strengthen the Dutch top-5 knowledge position in data science. The economic and societal sectors that COMMIT2DATA builds upon have been selected based on data science urgency expressed in the Knowledge and Innovation Agenda ICT 2016, and their susceptibility to innovations with information and communication technology (ICT) sciences. The collaborative and coherent effort across top sectors drives focused data science research, maximally leverages use-inspired research results, maximizes the valorisation opportunities for research results in different sectors, and ensures the optimal use of private and public research investments.

One important big data breakthrough that is consistently mentioned is the unearthing of patterns in the data as so to acquire hindsight, insight and foresight in a particular application domain. Another notable breakthrough is the storage, interconnection and protection of big data across multiple sources, users, companies, and even geographic locations. More details on the data science, stewardship and technology challenges is given in the Appendix to this short note.

Data science across domains

The structure of the COMMIT2DATA program is shaped by the observation that any big data public-private program must bring together (1) excellent data science knowledge with (2) specific application domain inspiration and knowledge. The first dimension considers data properties and objectives. If the focus is on the **volume**, **velocity**, and **heterogeneity** of the data, the challenge is to find algorithms for efficient, massively parallel, robust and cognitive processing that disclose the deeper meaning of the data. If the **quality** of the data is a dominant issue because (uncontrolled) data is exploited that is external to the service – *such as self-reported or social media data* – the challenge is to establish the reliability and trustworthiness of the conclusions arrived at. If **theft**, **privacy**, **access** and **longevity** of sensitive data are the main considerations, then data science focuses on data management and protection. And finally, the **impact** of the data can be an economic value or intellectual insight. Each of these data aspects comes with its own body of knowledge and scientific challenges. Together they define the science of data, stewardship and technology in any application using big data.

The second dimension is the **application** domain and **context** in which big data is used. Big data does not exist in isolation, there is always a context in which the data is generated. In order to successfully reap the value of big data – *be it economic value or intellectual insight* – some degree of contextual information is needed; one needs to understand the specific properties and limitations of the data and its intended use. Applications may be very different because of the dissimilarities of the sectors themselves. But the underlying subset of data science challenges is often very similar indeed. Hence, COMMIT2DATA aims at a maximally effective program by seeing application needs and development as well as the data science research challenges from the perspective of commonalities in the properties of the big data.



COMMIT2DATA action lines

In order to realize the ambitions and results mentioned above, COMMIT2DATA has been structured as three integrated action lines: a use-inspired research action line, a valorisation sprint action line, and a dissemination action line.

- **Action line 1: Use-inspired research**
  The COMMIT2DATA use-inspired research action line is the program's main vehicle. It aims at high-tech and high-science academic research impact on companies delivering advanced technology and services. This action line brings together the data science, stewardship and technology challenges from four major economic sectors and societal challenges. The challenges have been formulated by teams of company and academic stakeholders in each sector. The context, background, anticipated impact, and required action of these research challenges have been developed in close collaboration with representative organizations from each of these sectors. Research projects will be formed by combining data science research challenges across different sectors. These joint academic-company research projects will typically run for 4 to 5 years and provide the main basis for developing new data science knowledge. Direct valorisation will be generated with founding private project partners in the four sectors.
- **Action line 2: Valorisation sprint**
  The COMMIT2DATA valorisation sprint action line provides the vehicle for joint research and transfer of data science results to companies and organizations beyond

those that are founding program partners and beyond the four founding sectors. Such partners see opportunities for valorisation of science results achieved in one or more projects of COMMIT2DATA partners. They jointly develop an activity that leads to a "golden demonstrator" that factors in fidelity, product, usage and market considerations. In this way, COMMIT2DATA projects serve as a catalyst for focused demonstration and pre-development projects in a wide range of sectors and businesses. This model has shown to be successful in EIT ICT Labs (now EIT Digital), the STW valorisation program "Take off", and COMMIT's over 50 valorisation projects. Valorisation sprints aim to attract companies to COMMIT2DATA research as early as possible, and thus provides dynamics among the participating companies. The sprints result from open calls, and are typically run for a relatively short period of, say 6 to 24 months. While activities in valorisation sprints themselves are still in precompetitive development phase, they aim to eventually step into the business development phase, where a commercializing company or start-up fully takes over. The effect of valorisation sprints is a rapid transfer of high-tech and high-science results into technology and services-focused companies and organizations across a maximally broad spectrum.

- **Action line 3: Dissemination**
  Finally, the COMMIT2DATA dissemination action line delivers big data knowledge to an economic and societal audience that is as broad as possible. This action line aims explicitly at organizations, SME companies and other stakeholders that are owners and users of big data, but do not have the objective and/or knowledge to develop high-tech or high-science services themselves. Quite different from the traditional dissemination model of broadcasting result, the COMMIT2DATA dissemination action line moderates hands-on interaction between COMMIT2DATA (knowledge and business) partners and external stakeholders using concrete big data sets. Awareness meetings, public demonstration events, and in particular data factories – *a concept developed in the "ICT doorbraakproject big data"*— will be organized to efficiently disseminate cutting-edge knowledge on big data.

Appendix: Data Science, Stewardship and Technology Challenges across the Sectors

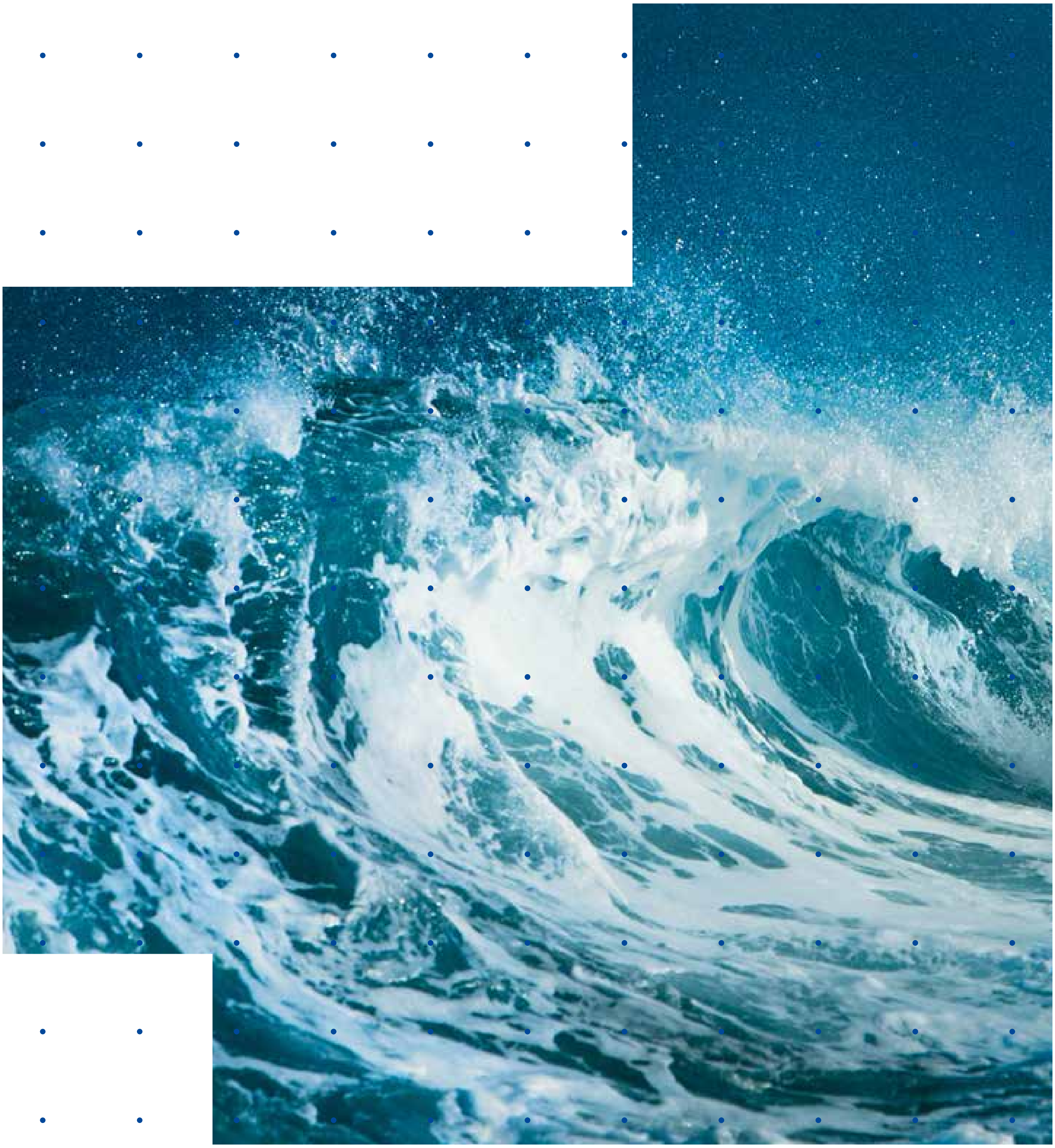
- **Finding Patterns and Causal Relations.** How can machines find patterns and causal relations in heterogeneous data sets, and in which way can machines learn from humans to understand these data? Isolated data are meaningless, they must be embedded in context in order to find meaningful patterns and to interpret these patterns semantically. Therefore machines must be able to deal with heterogeneous and often uncertain data including measured numbers, words, documents, sounds, images and video. Yet the number of patterns that exist in these data may be endless; algorithms will be able to intelligently select those that are interesting, meaningful, and actionable in a particular application context, mimicking human data analysis. Progress on this challenge requires COMMIT2DATA expertise in machine learning, pattern recognition for images, language and other media, content and web technology, interaction, visualization, statistics and process/data mining.
- **Self-Learning and Predictive Analytics.** How can we create self-learning algorithms, that learn from past experiences and learn continuously as data becomes available, and that are able to make predictions on events that have not occurred before? The

use of predictive analytics gives rise to new observations. How well did the predictions match the later observations? Did processes and users behave as predicted, and if not, how will the algorithm learn from its mistakes, possibly instructed by explicit or implicit user feedback. Processes underlying observations often change over time. For instance populations, preferences, consumption patterns, and performance are parameters in data analytics that are dynamic. How to deal with these continuous changes without freezing time and without operating on outdated or legacy data? Big data collections may be rich, but rare events may not be present in the data. Nevertheless, these events may be of high relevance in case they require, for instance, specific actions of human operators. Can data science make predictions on such events (in real-time) based on inferred causal models? In order to address these challenges successfully, COMMIT2DATA needs expertise in the fields of statistics, deep learning, process mining, modelling, and artificial intelligence.

- **Technologies for Computational Complexity.** How do we deal with the complexity of big data? The traditional approach to analysing data was based on querying databases, relying on complete and correct answers. Finding useful information in unstructured, incomplete and partially incorrect big data requires a far more interactive mode of operation, where the user has the means to stepwise explore the data deeper and deeper into the database. Big data not only drives the development of new databases for business intelligence, process control, and data exploration. Also software innovations are needed to deal with the data explosion and the complexity of the underlying distributed computing infrastructure. Modern open source tools as Hadoop MapReduce partially address these challenges. However, these tools need to be extended to deal with the above more complex big data analysis functionalities such as learning and reasoning. Progress in new data science and technology is needed to deal with the complexity of big data; this requires contributions to COMMIT2DATA from the fields of databases, visualization, software engineering, programming languages, and computing architectures and hardware.
- **Data Privacy and Security.** Data analytics relies on the availability of rich data containing patterns. By implication this collected data also reveals something about behaviour in the digital and physical world, about identities, and about critical and sensitive business processes. How can an individual's privacy and company's trade secrets be protected while at the same time allowing for data analytics to do its work? New data science and stewardship solutions will need to be developed based on improved data anonymisation and data encryption techniques. Also discrimination- or manipulation-aware mining techniques will be needed that aim to make results more fair. Such techniques will have to face the ever increasing computational power available to adversaries, but also find solutions to the undesirable overhead that cryptographic techniques impose on data analytics algorithms. Expertise in COMMIT2DATA is needed in the fields of (cyber-)security, identity management, information protection, security- and privacy-by-design, applied cryptography, and efficient algorithms.Interoperability and Standardization. In order to find, access, exchange, integrate and maintain big data – *including open data and data in federative environments* – in the long run, interoperability needs to be guaranteed. Semantic interoperability emphasizes the need for interoperability of the meaning of the data. Yet, if data is collected for one purpose, how can we make sure that it can be repurposed for a completely

different application? Common standardization approaches to semantic interoperability are adding meta-data, or linking data elements to controlled shared vocabularies. Linked (open) data describes a method of publishing structured data so that it can be interlinked and become more valuable. But such standards will still need to allow human understanding and interaction when exchanging data. Optimal cooperation is needed between the cognitive strength of humans, who can understand the meaning of data, and the data processing strength of machines that have difficulties in understanding the meaning of data in the context of the everyday human world. For COMMIT2DATA to deliver progress on this challenge, expertise is needed in the field of information systems, information and system architectures, software engineering, and standardization processes.

- **Storytelling and Design.**
  The ultimate goal of data analytics and prediction is to identify patterns in the data that are actionable, and leads to intellectual or economic impact and value. Efficient mechanisms and designs are needed to communicate, explain and interact with these patterns. Visualization of the results of data analysis are becoming integral part of data science challenges. But also framing results as well-designed stories or game play are essential methods for data scientists to interact with non-specialists. To that end, COMMIT2DATA needs expertise on graphics and visualization, language technology, serious playful interaction, gamification and user-centred design, and simulation and animation.



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