## Deliverable 2.3

Technology and Application Roadmap

<table>
<thead>
<tr>
<th>DISSEMINATION LEVEL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU</td>
<td>Public</td>
</tr>
<tr>
<td>PP</td>
<td>Restricted to other programme participants (including the Commission Services)</td>
</tr>
<tr>
<td>RE</td>
<td>Restricted to a group specified by the consortium (including the Commission Services)</td>
</tr>
<tr>
<td>CO</td>
<td>Confidential, only for members of the consortium (including the Commission Services)</td>
</tr>
</tbody>
</table>
The Road2CPS project is co-funded by the European Community’s Horizon 2020 Programme under grant agreement no. 644164.

The author is solely responsible for its content, it does not represent the opinion of the European Community and the Community is not responsible for any use that might be made of data appearing therein.

---

1 R=Report, DEC=Websites, patents filing, etc., O=Other
2 PU=Public, CO=Confidential, only for members of the consortium (including the Commission Services)
## Change Control

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Change History</th>
<th>Author(s)</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>2016-07-20</td>
<td>Finalisation Intermediate Roadmap</td>
<td>Carsten Rückriegel</td>
<td>SEZ</td>
</tr>
<tr>
<td>1.1</td>
<td>2016-10-16</td>
<td>Updating structure, introduction, methodology, conclusions</td>
<td>Meike Reimann</td>
<td>SEZ</td>
</tr>
<tr>
<td>1.2</td>
<td>2016-10-31</td>
<td>Integration of updates by all partners</td>
<td>Meike Reimann, all</td>
<td>SEZ, all</td>
</tr>
<tr>
<td>1.3</td>
<td>2016-11-11</td>
<td>Finalisation Application Part</td>
<td>Juan Alonso</td>
<td>ATOS</td>
</tr>
<tr>
<td>1.4</td>
<td>2016-11-15</td>
<td>Finalisation Autonomy, HMI, Transport parts</td>
<td>Murray Sinclair</td>
<td>LU</td>
</tr>
<tr>
<td>1.5</td>
<td>2016-11-21</td>
<td>Finalisation Platforms part</td>
<td>David Servat, Daniel Stock</td>
<td>CEA</td>
</tr>
<tr>
<td>1.6</td>
<td>2016-11-25</td>
<td>Finalisation Big Data part</td>
<td>Juan Rico</td>
<td>ATOS</td>
</tr>
<tr>
<td>1.7</td>
<td>2016-11-29</td>
<td>Finalisation M&amp;S and Safety and Security part</td>
<td>Claire Ingram</td>
<td>UNEW</td>
</tr>
<tr>
<td>2.0</td>
<td>2016-11-30</td>
<td>Finalisation Final Roadmap</td>
<td>Meike Reimann</td>
<td>SEZ</td>
</tr>
</tbody>
</table>

## Distribution List

<table>
<thead>
<tr>
<th>Date</th>
<th>Issue</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-10-16</td>
<td>Updated version</td>
<td>Project consortium</td>
</tr>
<tr>
<td>2016-10-30</td>
<td>Updated version with partner contributions</td>
<td>Project consortium</td>
</tr>
<tr>
<td>2016-11-15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016-11-29</td>
<td>Final version</td>
<td>Project Consortium</td>
</tr>
<tr>
<td>2016-11-30</td>
<td>Submission</td>
<td>EC</td>
</tr>
</tbody>
</table>

## Consortium Information

<table>
<thead>
<tr>
<th>Name (and contact data)</th>
<th>Institution (incl. address)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. Reimann <a href="mailto:reimann@steinbeis-europa.de">reimann@steinbeis-europa.de</a></td>
<td>Steinbeis-Europa-Zentrum Erbprinzenstrasse 4-12, Karlsruhe, DE</td>
</tr>
<tr>
<td>M.J.D. Henshaw <a href="mailto:m.j.d.Henshaw@lboro.ac.uk">m.j.d.Henshaw@lboro.ac.uk</a></td>
<td>Loughborough University Ashby Road, Loughborough, UK</td>
</tr>
<tr>
<td>J. Fitzgerald <a href="mailto:john.fitzgerald@ncl.ac.uk">john.fitzgerald@ncl.ac.uk</a></td>
<td>University of Newcastle King’s Road, Newcastle upon Tyne, UK</td>
</tr>
<tr>
<td>David Servat <a href="mailto:david.servat@cea.fr">david.servat@cea.fr</a> @cea.fr</td>
<td>Commissariat à l’énergie atomique et aux energies alternatives, Paris 15, 75015, FR</td>
</tr>
<tr>
<td>Daniel Stock, Ursula Rauschecker</td>
<td>Fraunhofer IPA</td>
</tr>
</tbody>
</table>
Authors

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meike Reimann</td>
<td>Steinbeis-Europa-Zentrum</td>
<td><a href="mailto:reimann@steinbeis-europa.de">reimann@steinbeis-europa.de</a></td>
</tr>
<tr>
<td>Carsten Rückriegel</td>
<td>Steinbeis-Europa-Zentrum</td>
<td><a href="mailto:rueckriegel@steinbeis-europa.de">rueckriegel@steinbeis-europa.de</a></td>
</tr>
<tr>
<td>Murray Sinclair</td>
<td>Loughborough University</td>
<td><a href="mailto:murray.sinclair@me.com">murray.sinclair@me.com</a></td>
</tr>
<tr>
<td>Carys Siemieniuch</td>
<td>Loughborough University</td>
<td><a href="mailto:C.E.Siemieniuch@lboro.ac.uk">C.E.Siemieniuch@lboro.ac.uk</a></td>
</tr>
<tr>
<td>Michael Henshaw</td>
<td>Loughborough University</td>
<td><a href="mailto:m.j.d.Henshaw@lboro.ac.uk">m.j.d.Henshaw@lboro.ac.uk</a></td>
</tr>
<tr>
<td>Paul Palmer</td>
<td>Loughborough University</td>
<td><a href="mailto:P.J.Palmer@lboro.ac.uk">P.J.Palmer@lboro.ac.uk</a></td>
</tr>
<tr>
<td>Claire Ingram</td>
<td>University of Newcastle</td>
<td><a href="mailto:4claire.ingram@newcastle.ac.uk">4claire.ingram@newcastle.ac.uk</a></td>
</tr>
<tr>
<td>John Fitzgerald</td>
<td>Claire Ingram</td>
<td>University of Newcastle</td>
</tr>
<tr>
<td>David Servat</td>
<td>CEA</td>
<td><a href="mailto:david.servat@cea.fr">david.servat@cea.fr</a></td>
</tr>
<tr>
<td>Ursula Rauschecker</td>
<td>Fraunhofer IPA</td>
<td><a href="mailto:ursula.rauschecker@ipa.de">ursula.rauschecker@ipa.de</a></td>
</tr>
<tr>
<td>Daniel Stock</td>
<td>Fraunhofer IPA</td>
<td><a href="mailto:4daniel.stock@ipa.fraunhofer.de">4daniel.stock@ipa.fraunhofer.de</a></td>
</tr>
<tr>
<td>Benjamin Götz</td>
<td>Fraunhofer IPA</td>
<td><a href="mailto:4benjamin.goetz@ipa.fraunhofer.de">4benjamin.goetz@ipa.fraunhofer.de</a></td>
</tr>
<tr>
<td>Dolores Ordóñez</td>
<td>Anysolution SL</td>
<td><a href="mailto:dom@anysolution.eu">dom@anysolution.eu</a></td>
</tr>
<tr>
<td>Nuria de Lama</td>
<td>Atos España SA</td>
<td><a href="mailto:nuria.delama@atos.net">nuria.delama@atos.net</a></td>
</tr>
<tr>
<td>Juan Alonso</td>
<td>Atos España SA</td>
<td><a href="mailto:juan.2.alonso@atos.net">juan.2.alonso@atos.net</a></td>
</tr>
<tr>
<td>Juan Rico</td>
<td>Atos España SA</td>
<td><a href="mailto:juan.rico@atos.net">juan.rico@atos.net</a></td>
</tr>
</tbody>
</table>
# Table of Contents

1. **Introduction** ................................................................. 8
   1.1 Background and Aims of this Document .............................. 8
   1.2 Methodology ................................................................. 10
   1.3 Structure of the Deliverable .............................................. 11

2. **Technology Roadmap** .................................................. 12
   2.1 Introduction ..................................................................... 12
   2.2 Platforms, REF Architectures, Interoperability & Standards ................................................. 13
   2.3 Modelling & Simulation .................................................. 21
   2.4 Safety, security, and privacy ............................................. 28
   2.5 Big Data / Real Time Analysis ......................................... 38
   2.6 Ubiquitous autonomy, forecasting .................................... 47
   2.7 HMI / human & machine awareness ................................. 57
   2.8 Conclusion ...................................................................... 68

3. **Application Roadmap** ................................................... 69
   3.1 Structure of the Chapter ................................................ 69
   3.2 Smart Health ................................................................. 69
   3.3 Smart Manufacturing .................................................... 78
   3.4 Smart Transport ............................................................. 82
   3.5 Smart Energy ................................................................. 95
   3.6 Smart City ....................................................................... 105
   3.7 Conclusion ...................................................................... 109

4. **Summary and overall Conclusions** ................................. 114

5. **References** ................................................................. 117
Executive Summary

The term **Cyber-Physical System (CPS)** describes hardware-software system, which tightly couple the physical world and the virtual world. They are established from networked embedded systems that are connected with the outside world through sensors and actuators and have the capability to collaborate, adapt, and evolve. In the ARTEMIS SRA 2016, CPS are described as ‘**Embedded Intelligent ICT Systems**’ that make products smarter, more interconnected, interdependent, collaborative and autonomous. In the future world of CPS, a huge number of devices connected to the physical world will be able to exchange data with each other, access web services, and interact with people. Moreover, information systems will sense, monitor and even control the physical world via Cyber-Physical Systems and the Internet of Things (HiPEAC Vision 2015).

Cyber-Physical Systems find their application in many highly relevant areas to our society: multi-modal transport, health, smart factories, smart grids and smart cities among others. The deployment of Cyber-Physical Systems (CPS) is expected to increase substantially over the next decades, holding great potential for novel applications and innovative product development. Digital technologies have already penetrated day-to-day life massively, affecting all kinds of interactions between humans and their environment. However, the inherent complexity of CPSs, as well as the need to meet optimised performance and comply with essential requirements like safety, privacy, security, raises many questions that are already beginning to be explored by the research community. Road2CPS aims at accelerating uptake and implementation of these efforts.

The **Road2CPS Technology and Application Roadmap** aims at identifying and describing the relevant underlying technology fields and related research priorities to fuel the development of trustworthy CPS, as well as the specific technologies, needs and barriers for a successful implementation in different application domains.

The Roadmap at hand was established through an interactive, community based approach, inviting over 300 experts from academia, industry and policy making to a series of workshops. Visions and priorities of recently produced roadmaps in the area of CPS, IoT (Internet of Things), SoS (System-of-Systems) and FoF (Factories of the Future) were discussed, complemented by sharing views and perspectives on CPS implementation in application domains, evolving multi-sided eco-systems as well as business and policy related barriers, enablers and success factors. From these workshops and accompanying desk research recommendations for future research and innovation activities were derived and topics and timelines for their implementation proposed.

During the 2 years of activities, a clear consent on different technological and non-technological priorities as well as enablers and barriers could be identified, while some other themes remained more open and need further thorough discussions.

Amongst the technological topics, and related future research priorities ‘integration, interoperability and standards’ ranged highest in all workshops. The topic is connected to digital platforms and reference architectures, which have already become a key priority theme for the European Commission and their Digitisation Strategy as well as the work on the right standards to help successful implementation of CPSs. Other themes of very high technology/research relevance revealed to be ‘modelling and simulation’, ‘safety and dependability’, ‘security and privacy’, ‘big data and real-time analysis’, ‘ubiquitous autonomy and forecasting’ as well as ‘HMI/ human machine awareness’, which are all described in detail in the Technology Roadmap chapter. Next to this, themes
emerged including ‘decision making and support’, ‘CPS engineering (requirements, design)’, ‘CPS lifecycle management’, ‘System-of-Systems’, ‘distributed management’, ‘cognitive CPS’, ‘emergence, complexity, adaptability and flexibility’ as well as work on the foundations of CPS and ‘cross-disciplinary research and CPS Science’.

Non-technological priority themes, needed for successful implementation were particularly seen to be **CPS education, training and skills** and **business models** accompanied by recommendations to address the ‘human in the loop’, and further invest in **community building and networks** and **collaboration** on a regional, national and global level as well as across domains and value chains. **Demonstrators and living lab** are seen as essential to alleviate concerns and **regulatory and legal issues** (incl. Single Digital Market) to ensure a reliable framework. **Societal dialogue and awareness raising** as well as **ethics** are seen as crucial elements of future CPS development, because of the pervasiveness of CPS into everyday life. Further recommendations included to focus EC incentives on open approaches such as **open data**, open platform building, supporting open innovations as well as open source solutions.

Regarding the **application perspective**, five domains have been analysed for their specific needs, the advantages CPS can bring and barriers that have to be overcome for successful CPS deployment. Many similarities could be detected, especially for the underlying technologies, but also domain specific differences between **smart manufacturing**, **smart energy**, **smart transport**, **smart city**, and **smart health** could be observed due to a variety of different legislative and regulatory framework conditions. Common requirements for a better market adoption of CPS technologies include:

- Elaboration of regulatory and legal frameworks for the different domains
- Training and educating labour force and strategies to attract talent to the EU
- Implementation of open solutions and standards to enhance interoperability and facilitate the integration of SMEs and innovators into the ecosystem
- Address security and privacy issues, providing technical tools and IP protection
- New business models and a culture of innovation/entrepreneurship

Main barriers needed to be overcome, are missing **interoperability, integration and standards**, the **fragmentation** of initiatives and across application domains and missing **skills** (knowledge, competences, IT Education, interdisciplinary). Mastering **complexity**, terminology, semantics and overcoming concerns regarding **safety and stability** will be crucial for the success of future CPSs. A major show-stopper, next to **high implementation costs** and **missing demonstration** are concerns regarding **security, privacy and confidentiality**.

Business related barriers include missing **business models**, missing **openness** (open data) and vendor lock, missing **legal frameworks**, **regulation**, **IPR** protection, **liability and concerns** regarding **multiple ownership**. **Conservatism** and **resistance** to change in some sectors and countries and missing **entrepreneurial thinking** are barriers together with difficult access especially for **SMEs**. Moreover, **social acceptance and awareness needs to be ensured** and **ethical concerns** need to be overcome.

In summary, progress in key technological and non-tech fields identified, will help to fuel the development of trustworthy CPS, broaden their applications and enable new business. A cross-disciplinary, multi-domain and inclusive approach should be followed, to best benefit economy and society as a whole.
1 Introduction

1.1 Background and Aims of this Document

The miniaturisation of sensing, actuating, and computing components together with the increasing number of interacting (mostly embedded) systems in our strongly connected society and industry, and the growing overall complexity of such systems have triggered a paradigm shift and the need to enhance the classical view in systems engineering. These emerging networked embedded systems are encompassed by the term Cyber-Physical Systems (CPSs). Recent developments in CPSs aim to manage the increasing challenges for system implementations, e.g. with regard to system complexity and flexibility, and to decreasing life cycle times.

Digital components are increasingly integrated and embedded into products and services that are in everyday usage. In the future, CPS will become natural in managing complex systems (e.g. smart grids, transport, water management systems and manufacturing) and will make everyday objects intelligent (e.g. homes, offices, cars, trains, cities and clothes). The CPS community foresees large potential in creating a competitive edge for Europe, serving existing and new markets across different industries and sectors. CPS will bring a step change in the way industry designs, produces and generates value from products and related services.

CPSs find their application in many highly relevant areas to our society: smart manufacturing, smart energy, smart transport, smart city, and smart health among others. The inherent complexity of CPSs (and related complexity management), as well as the need to meet optimised performance and comply with essential requirements like safety, privacy, security, raises many questions that are already beginning to be explored by the research community.

Although major successes could already be achieved within specific areas, there is still a huge gap between theoretical concepts, technical developments and prototypes, and successful implementation and industrial application. Additionally, there are considerable differences with regard to the propagation and maturity of CPSs amongst the application domains, the actors along the value chain, academia and industry, and between the multiple disciplines contributing to this complex field. Strategic action is necessary to bring the relevant stakeholders together to: i) enable application domains to benefit from state-of-the-art technological developments; and ii) focus research efforts into those areas that will enable visions on future application scenarios to be realised.

The Road2CPS project has been conceived to respond to this situation by

- Analysing the impact from past and ongoing projects, identifying the gaps and bridging efforts towards impact multiplication
- Developing technology, application and innovation strategy roadmaps for CPSs to serve as a catalyst for early adoption of CPS technologies
- Building a CPS constituency by bringing together the key players (from academia and industry) from a broad range of application domains, and across the value chain, to contribute to the Road2CPS action plan
- Enhancing CPS implementation and demonstrating business opportunities through case studies (particularly targeting SMEs in established CPS application domains as well as scouting for ‘new domains’)
- Developing recommendations for future research priorities as well as implementation strategies
Road2CPS project is a 24-month coordination and support action (02/2015-01/2017), co-funded under the European Union’s H2020 Research and Innovation Programme in the area of Smart Cyber-Physical Systems. The project aims at carrying out strategic action for future CPS through roadmaps, impact multiplications and constituency building. Road2CPS is coordinated by Steinbeis-Europa-Zentrum, Germany and supported by six other partners from four European countries (Loughborough University, UK; Newcastle University, UK; CEA, France; Fraunhofer IPA Germany, AnySolution and ATOS Spain) pursuing the following objectives:

![Road2CPS - Objectives](image)

The document at hand focusses on the development of a Roadmap for Cyber-Physical Systems (pillar in the middle), building on outputs from the other pillars and feeding into the Road2CPS recommendations for future research priorities and innovation strategies.

This Technology and Application Roadmap presents the vision, challenges, research and innovation priorities for a set of highly important CPS technologies as well as the impact and deployment of CPS in five application domains. The main aim of the roadmap will be to highlight the benefits of using a CPS approach (related to the market needs) and provide users with the most relevant technical trends that will help to implement this CPS approach. The document aims at giving support to the European Commission in structuring the future CPS related Research Programme, as well as at giving researchers in the field and decision-makers from industry, academia, and policy making of the related domains a broad perspective on developments and implementations in the field of Cyber-Physical Systems.
1.2 Methodology

The roadmapping methodology initially follows a parallel technology-push and market-pull approach, to be combined into a strategic innovation roadmap towards the end of the project:

1. **A technology-driven approach**, which will identify priority research results and research field with a high potential for a technological breakthrough. A special focus was put on the following themes: i) integration, interoperability, and standards; ii) architectures ii) modelling and simulation iii) safety, security and privacy iv) big data and real-time analysis v) ubiquitous autonomy; and forecasting vi) human and machine awareness.

2. **A market-driven approach**, which will identify socio-economical needs, barriers and important application domains for CPS with a special focus on the following application domains: smart manufacturing, smart energy, smart transport, smart city, and smart health.

3. **A strategy roadmap** will combine technology push and market pull perspective to derive strategies for future research and innovation priorities and their implementation.

![Figure 2: Overview of the Road2CPS approach](image)

The generation of technology and application roadmaps started with an early roadmapping workshop to compare and validate existing roadmaps and to find consensus on priority themes to be further elaborated (resulting in the technology chapters of this document). The activities were accompanied by internet search and interviews adding relevant content during the roadmap building process, leading to 3 stand-alone deliverables (D2.1: Report on scientific and technological challenges and D2.2: Report on market requirements and socio-economical needs D3.2 Intermediate Technology and Application Roadmap). Moreover, results from other project activities fed into the roadmapping activities (gap and impact analysis, cases studies, constituency building workshops). The roadmaps were completed and validated within two further roadmap workshops and derived this document (D2.3 Road2CPS Technology and Application Roadmap). The results and finding from the two
perspectives were combined in a fourth roadmapping workshop on innovation strategies and recommendations for a successful implementation of CPS (D2.4 Strategy Roadmap).

Following a participative approach over 300 experts were involved in 4 roadmapping workshops (consensus roadmapping WS, Paris June 2015; CPS visionary scenario WS, Stuttgart Jun 2016; CPS technology and application roadmap WS, Newcastle October 2016; strategy roadmapping WS, Brussels November 2016) and 3 constituency building workshops (future platforms, Turin October 2015; ICT-1 cluster event, Vienna May 2016; smart destinations, Mallorca October 2016).

1.3 Structure of the Deliverable

The current roadmap is divided into a technology and an application chapter followed by overall conclusions. The technology chapter consists of sub-chapters describing the priority technologies/research themes in detail:

- Platforms, reference architectures, interoperability and standards
- Modelling and simulation
- Safety, security, and privacy
- Big Data and real time analysis
- Ubiquitous autonomy and forecasting
- HMI / human and machine awareness

These technology topics were validated and ranked with highest priority within the first roadmapping workshop held in Paris on 23rd of June in 2015. All technology sub chapters include the following sections:

- SoA, Situation of technology and funding today – Where are we now?
- Time horizon and vision – What is the vision?
- Impact of the technology – What would be the impact?
- Challenges – What are the gaps and barriers?
- Research, Development and Innovation – What RD&I is necessary?
- Conclusions and Recommendations

The application chapter is separated into the following five domain sub-chapters:

- Smart health
- Smart manufacturing
- Smart transport
- Smart energy
- Smart city

These application domains were chosen by the consortium within the description of action and extended by the health domain to address another interesting field of CPS application. Each of the domains sub-chapters comprises aspects regarding requirements, non-technological elements, mapping of requirements and technology, and a timeline for further domain-specific developments in terms of CPS.
2 Technology Roadmap

2.1 Introduction

The term Cyber-Physical System (CPS) describes hardware-software system, which tightly couple the physical world and the virtual world. They are established from networked embedded systems that are connected with the outside world through sensors and actuators, acquiring data streams from the physical world, establishing and continuously updating a virtual twin of the physical world – and with the capability of interacting with the physical world, following instructions from the virtual sphere. Furthermore, CPSs are not merely networked embedded systems but software-intensive, intelligent systems with the capability to collaborate, adapt, and evolve. CPS can be considered to be the technological foundation for the Internet of Things in which every physical object has a virtual representation and in which the physical and virtual reality form a continuum.

CPS combine challenges from a variety of domains, including large distributed systems, sensor and actuators devices, critical infrastructures, system of systems. Their pervasiveness in our environment makes some of these challenges tangible even for non-specialists when faced with e.g. interoperability issues between systems, device obsolescence or limited battery lifespans. The advent of software intensive systems taking over a growing number of tasks (unmanned vehicles, high frequency trading, energy efficiency building policy, surveillance of field crops, etc.) is a source of both fascination and anxiety for a large part of society.

Among the main topical technical challenges are:

- need to mitigate openness and security in these systems,
- promote certification schemes to build trust,
- enable recovery and resilience mechanisms for these systems which are bound to be constantly running
- and master the technological evolution of the hardware and software artefacts which constitute them over time.

Some fundamental questions are cross-domain such as the emergence of unintended behaviour due to unforeseen interaction schemes between increasing number of entities. Hints to harness this problem may lie in delegating even more decision control to the systems themselves as shown by recent experiments in the cyber-security field – see works at MIT Computer Science and Artificial Intelligence Lab where AI learning system circumvents cyber-threats, 2nd IEEE International Conference on Big Data Security on Cloud (DataSec 2016).4

---

3 Following the concept of CPS as described in the study Geisberger, E./Broy, M. (2012), agendaCPS – Integrierte Forschungsagenda Cyber-Physical Systems (acatech STUDIE), Heidelberg u.a.: Springer Verlag 2012.
2.2 Platforms, REF Architectures, Interoperability & Standards

2.2.1 SoA, Situation of technology and funding today – Where are we now?
CPS intensively use the globally available information in its various formats and communications network for an extensively automated exchange of information in which production and business processes are matched. In such a broad environment, a large number of models, systems and concepts from an extremely wide range of domains play an important part in shaping that structure. Increasing networking of previously extensively autonomous systems, for instance in the fields of production, logistics, power supply and building management, is expected in the near future and leads to the creation of systems of systems. A special difficulty arises here for terminology and standardization. To make this possible in theory, it would be sufficient only to define the additional level of integration and its emergent behaviour. But to do that, the existing system landscape would first have to be coherently and completely defined in a globally standardized manner. This is not always the case. Against this background, the relevant models of the classical architecture require integration and rounding off and the attached standards need to be attuned, consolidated and complemented. Standards create a secure basis for technical procurement, ensure interoperability in applications, protect the environment, plant and equipment and consumers by means of uniform safety rules, provide a future-proof foundation for product development and assist in communication between all those involved by means of standardized terms and definitions.

As mentioned in the ARTEMIS 2016 Strategic Research Agenda it would be « futile trying to tackle this complexity challenge with a pure bottom-up development approach. In order to be competitive we have to establish generic reference architectures and platforms on all relevant implementation levels to meet the development requirements of future CPS ».

What is exactly referred to by the term « reference architecture »? A generally accepted definition is the following: a reference architecture provides a template, often based on the generalization of a set of solutions. These solutions may have been generalized and structured for the depiction of one or more architecture structures based on the harvesting of a set of patterns that have been observed in a number of successful implementations. Further, it shows how to compose these parts together into a solution. Thus in the software domain, this notion is strongly related to the specification of interfaces between components and provision of several cross-cutting services by an underlying execution layer, facilitating the development of application without having to re-develop entire communication, data sharing, security, registry or transaction mechanisms.

Reference architectures have flourished in a variety of domains, serving as a tangible means for extracting key concepts in a domain, exchanging operational solutions between field specialists from various organizations, and later one canvas for standardization or interoperability protocols which have shaped long-term impacts: see AUTOSAR for the automotive industry, SGAM for the smart grid domain, the ANDROID for smart phones, RAMI or IIRA (Industrial Internet Reference Architecture) for smart manufacturing. These examples show that reference architectures may be supported by various

8 IIRA industrial internet consortium, information from http://www.iiconsortium.org/vertical-markets/manufacturing.htm
stakeholder groups: AUTOSAR was industrially-driven, SGAM was initiated by a mandate from the EC, ANDROID was pushed by Google which then released it as open-source, RAMI is a German initiative driven by the Industrie 4.0 platform (with Bitcom, VDMA and ZVEI as main leaders) and IIRA has been elaborated by the Industrial Internet Consortium (IIC). The Industrie 4.0 platform consists of a number of working groups regarding important topics like business models, standardization and IT architectures, where the platform members, also encompassing the most important industrial partners, discuss research topics and requirements for standardization, which is handled by the VDI for example. Part of these initiatives have been funded by the EC or national authorities either directly or indirectly through collaborative projects targeting architecture platforms improvement. For instance, while the work of the IIC is privately funded by the consortium members, RAMI4.0 has had an extended history of public funding by the German Government through various research programs since 2006, which amount to around 400 million € as of today. At European level, the EC and the ARTEMIS/ECSEL JU have had an important role in the advent of reference architectures with targeted funding within both FP7 and Horizon 2020. These were supported in part by the construction of dedicated associations or programs (PPPs, JUs, etc.) e.g. NESSI open service framework for service-based IT systems, EFFRA and the FoF program for manufacturing, the EERA joint program in Energy Systems Integration, or dedicated calls such as those fostering cooperation with countries outside EU (see January 2016 EU-Korea call on the federation and interoperability of IoT platforms). Lately the access to reference architectures and platforms was further supported by the Smart Anything Everywhere and I4MS programs. These initiatives have offered running Innovation Action projects the capacity to organize open calls (fuelled with cascade funding) to seek experimentations, case studies and involve more actors, especially among SMEs. This has had an important effect in helping ecosystems to thrive anchored to platforms sustained by these projects.

2.2.2 Time horizon and Vision – What is the vision?

In the short term (2016-17) we expect to witness a similar evolution that has been affecting the manufacturing industry in all major industries. In the last decade indeed, a raised pricing pressure due to low-pay countries and the possibility to order and ship goods globally at a keen price level, induced a steady evolution of manufacturing processes. One of the results of this challenge is the specialization on core business, and the forming of complex manufacturing value networks, which usually contain many different companies and systems. As a consequence, the effort of coordinating the production has risen and made manufacturing more inflexible. This contrasts with the decrease of product lifecycles, small batch sizes even down to just one part and the increasing number of product variants, as well as life-time involvement in products (circular economy and servitisation), which requires responsive manufacturing and logistics processes supported by Cyber-physical systems.

In order to achieve these contrary demands in the middle term (2018-19), it is necessary to build up collaborative networks and integrated cyber-physical production systems, which take a different approach regarding the management of production processes in Europe. To achieve this it is necessary to reduce efforts needed for the integration and usage of services of various existing platforms by providing tools and support for standards and interoperability and thereby overcome the lack of interoperability between manufacturing and logistics platforms. This will allow companies to

---

9 SGAM documents, from CEN-CENELEC, [http://www.cencenelec.eu/standards/Sectors/SustainableEnergy/SmartGrids/Pages/default.aspx](http://www.cencenelec.eu/standards/Sectors/SustainableEnergy/SmartGrids/Pages/default.aspx)
participate in several value chains and exchange planning and production data without the need for one specific platform. Additionally, it will be possible to switch between the platforms and to integrate new IT solutions of other software vendors easily. This means each company of the value chain is no longer bound to a specific software or service vendor. This will reduce the level of vendor lock-in. Further down the road (2020-21), even SMEs will be able to participate in various value chains if those are grounded on the multi-sided platform approach. This will help SMEs to avoid high costs and efforts running two or more platforms in one company. Last but not least, the lowered vendor lock-in effect makes it easier for SMEs trying to enter existing value chains because they are no longer forced to use the same platforms as the major enterprises of the value chain.

These changes pervade outside the scope of the manufacturing domain. In reaction to this digital revolution, some inflexions in the development of reference platforms are already perceptible and will definitely be promoted in the coming years.

In the short term 2016-17 we can foresee a continuation of the current trend which sees the convergence of reference architectures to extend or consolidate their coverage. For instances RAMI and IIRA are pushed towards a common framework for manufacturing and industrial grade IT systems. While RAMI 4.0 is a detailed architecture for manufacturing systems, incorporating important industry standards like IEC 62264 Enterprise Resource Management (ERP) Integration, IEC 628920 (Lifecycle Management), IEC 61512 (Batch Control), IIRA is more aimed at providing a framework to build future platforms for any industrial domain (energy, healthcare, manufacturing) and to ensure interoperability, standards and security by design between the components and the domains itself. The same should be occurring with EU and international reference platforms and standards, as seen
for instance in the attempt of extend RAMI with some of the OMG\textsuperscript{10} (Object Management Group) standards related to software development methods and business process modelling\textsuperscript{11}.

In the middle term (2018-19) the promotion of the access to such reference architectures to a large industrial sector and particularly to SMEs and mid-caps should be established. In this matter the EC has taken a prominent role with the launch of the ambitious Smart Anything Anywhere and I4MS initiatives. These provide funding for dedicated use-case-oriented projects where SMEs and mid-caps will gain access to know-how and technology platforms via a mentorship program provided by regional competence centres. The scheme is currently tested throughout H2020 Innovation actions in the FoF program where existing technological platforms are being refined and adapted to the needs of industrial end-user requirements.

In the long term (2020-21) reference architectures will be part of the industrial landscape and the challenges will be to: 1) to avoid a proliferation of different reference architectures whose core foundations are largely redundant and rather promote cross-fertilizations; 2) to make their access easier to a growing number of industrial actors. To this aim competence centres which have contributed to their construction have a key role to play.

2.2.3 Impact of the Technology – What would be the impact?

CPS are evolving as the basic infrastructure for lots of vital social, business and economic processes, as shown in several pioneering domains. Nowadays, a lot of infrastructures would not function properly if their CPS systems would break down. The ISTAG report\textsuperscript{12} on « Orientations for EU ICT R&D & Innovation beyond 2013 » mentions the prominent role of CPS-related technology in such challenging enterprises as e.g. urban planning, transport and logistics, crime and risk prevention or health care.

As a result, one of the main important point is to guarantee a universal access to robust, « trustworthy and secure infrastructure services, and standards and open interfaces will become crucially important ». It is also believed that such technology is also a disruptive force in itself, « having a pervasive and transformative impact on society ». This is already shown in the opportunities brought by communication infrastructure for business and work management depicted in the previous section and the increasing servitisation of complete sectors of the economy such as banking, transport, buying of goods by consumers or government services.

Meanwhile component interoperability is still perceived as a major concern by companies, which migrate legacy systems, integrate COTS products, and assemble modules from disparate sources into a single application. While middleware is available for this purpose, it often does not form a complete bridge between components and may be inflexible as the application evolves. What is needed is the explicit design information that will forecast a more accurate, evolvable, and less costly integration solution implementation. Moreover, if common standards and interoperability concerns are considered from the start, the possibility of vendor lock-in is greatly reduced. Vendor lock-in is also a concern of many manufacturing companies, since many emerging industrial platforms often create this effect, involuntarily by the lack of standards and interoperability or deliberate. Collaboration between organizations in business platforms requires new approaches for data interoperability. It’s necessary to

\textsuperscript{10} OMG standards specs, from http://www.omg.org/spec/
\textsuperscript{11} http://business-process-management.cioreview.com/cxoinsight/cyberphysical-systems-implement-now-using-existing-omg-standards-nid-14488-cid-144.html
take away barriers that prevent interoperability through novel and real-time architectures. There are various concepts which can be further improved when applied in conjunction with cyber-physical systems, like for example semantic technologies (e.g. semantic web and ontologies) and new (cloud-based) technologies for data sharing, security by design and governance (e.g. the block chain concept for transaction management). This should lead to new open specifications for interoperability.

This new infrastructure can be built on top of existing investments (existing systems and platforms) and build on the capabilities provided by new solutions such as cyber physical systems, IoT and M2M-communication. New functionalities will be provided using advanced data analytics based on the resulting unlocked new data. An example is the electronics test bed where this data is to be used for zero-defect manufacturing and tracing of processes over multiple production sites and organizations.

Reference architectures are valuable as long as they lower entry barriers, provide open interfaces and up-to-date specifications and ‘how-tos’. They should alleviate system developers with maintenance of common services, which should be ideally supported by a reference architecture consortium (e.g. large open-source foundations assume such a role in a variety of software domains), while accommodating various business models and IPR management to allow for a variety of situations.

Technologies evolve towards ensuring cross-cutting qualities for systems which rely on them: availability, dependability, security, maintainability, etc. This will have a major impact on the way applications will be developed. Ideally the platform should be able to deliver applications assurance of executing policies (as seen nowadays for cloud-based systems), maintenance facilities and safety/security certificates. As mentioned in the ARTEMIS 2016 SRA « we can expect that future CPS with stringent real-time and safety requirements will be augmented with further intelligence from the cloud. Such Systems of Cyber-Physical Systems can only be realised if the services in the cloud, the software of the CPS and the associated communication services are well aligned and developed according to common architecture principles ».

Impacts will be important when the so-called “human-in-the-loop” concept will pervade in the architecture platforms, which requires significant advances in term of situation awareness capabilities, adaptability and accessibility to ensure a trustworthy and gratifying interaction between human end-users and CPS applications.

2.2.4 Challenges – What are the Gaps and Barriers?
Emerging research has shown that interoperability problems can be traced to the software architecture of the components and integrated application. Furthermore, the solutions generated for these problems are guided by an implicit understanding of software architecture. Current technology does not fully identify what must be made explicit about software architecture to aid in comparison of the architectures and expectations of participating entities within the integrated application. Thus, there can be no relief in the expense or the duration of implementing long-term reliance on middleware. With regards to the technical integration of platforms, it has to be considered that there are already various manufacturing IT solutions developed and applied on factory level (e.g. PLC, MES, ERP systems) as well as on manufacturing value network level (e.g. SCM or EDI solutions which focus on the exchange of business documents among supply chain partners). Each of these solutions brings its own data models, IT services and security measures. However, in general they are not foreseen to be integrated with other platforms or services. This is why one of the major activities in developing a holistic multi-sided platform ecosystem is the development of an integration framework, which
supports the seamless exchange of data, information, and services. Interoperability has to be addressed on multiple levels:

- data level (connectivity among platform contents)
- information level (semantic mapping between individual platform’s information models)
- service level (mapping of service functionalities and utilisation conditions)

This concern for data and information exchange was confirmed by the results of the 1st Road2CPS Roadmapping Workshop, where the following top priorities for CPS platforms and technologies were outlined:

- Integration, interoperability and standards
- Safety, reliability, resilience and fault tolerance
- Architectural tools
- Open, modular, flexible platforms
- Facilitated involvement of SMEs
- Reduction of vendor lock-in
- Multi-sided markets

The number of solutions is really high and covers individually many domains. The problem resides in the lack of interoperability and potential collaboration among those solutions. In this sense, the development of open and horizontal platforms which is currently one of the priorities of EC in the different calls, represents a key driver for the expansion of CPS technology and what is more important to the development of synergies among strategical sectors.

The domains addressed by CPS are usually critical environments which require special protective measures to guarantee that data collection, analysis and storage processes are robust against attacks. However, due to their relevance there are a lot of attacks which implies that CPS must be resilient to cyber-attacks.

Finally, the provision of tools that facilitates the integration of new elements into current CPS will facilitate the deployment of CPS technology. These tools will provide a methodology for assessing the new components but also for the evaluation of the impact that the new changes will have over the existing ones. The combination of real deployment and simulation will facilitate a seamless integration and growth of current CPS technology deployments and also accelerate the adoption of CPS to those who have not done it yet.

2.2.5 Research, Development and Innovation – What are the R&D&I is necessary?  
The overall goal of the research is to extract and make explicit the information needed to define and build cyber-physical systems technology and frameworks to incorporate this technology into existing platforms. Research needs to focus on identifying, classifying, and organizing characteristics that help to define an architectural style by using abstraction, semantics and design patterns. To do so, first of all the benefit of multi-sided platform ecosystems has to be outlined and aligned throughout all involved stakeholders. This is achieved by providing frameworks for business model alignment among multi-sided platform ecosystem stakeholders, which follow common standards, i.e. various platform applications and operators, platform and services hosts and providers. These frameworks need to
include guidelines for the distribution of responsibilities (risks, warranties, etc.) and finances throughout stakeholders, as well as for the negotiation and definition of common regulations with regards to data privacy policies, legal contexts and related contractual issues.

The current heterogeneous environment which is a clear barrier also provides several opportunities as solution to this problem. On the one hand the rising of horizontal open platforms whose main asset is the integration and interoperability aspects will facilitate the operation of multiple systems in the CPS ecosystem. On the other hand, the development of components that bridge the differences among platforms are also required and could impact notably the market.

2.2.6 Conclusions and Recommendations
Europe is currently positioned as the most important industrial CPS provider. To maintain this position against emerging stakeholders and markets, there are some steps that have to be taken:

1) Increase reliability of CPS systems – this opens the door to the certification of secure systems, the creation of validation methodologies and the impact of these activities into the different standardisation bodies

2) Implementations of full CPS systems in different domains – currently there are very good solutions for individual parts of systems like smart grids, but there is a lack of a full deployment that allows the validation of the whole CPS subsystem. The provision of such facilities in this and other environments will strength the position of Europe and its technology providers.

3) Sustaining the evolution of reference architectures and platforms - currently, much research and innovation has been carried out regarding interoperability; the focus for the near future should be to consolidate and integrate platforms and frameworks w.r.t data semantics and promote their access to a wide audience of companies

4) To promote this current synergy in the long run, we need to integrate reference architectures and platforms in the curricula of engineers and technicians, and encourage a change of mindset in traditional slow-paced industries towards more agility which one assigns generally to digital industries

5) Improvements of standards are possible, incorporation of emerging standards and reference architectures should be considered, encouraging convergences initiated by standardization bodies (like RAMI 4.0 or IIRA).

In summary, the market is ready and waiting for innovative solutions based on CPS technology, but this will not be exploited in its full potential until existing concerns are addressed.
To best address the above-mentioned challenges and R&I needs, Road2CPS recommends to consider the following R&I sub-topics in the field of ‘Platforms, REF Architectures, Interoperability & Standards’ in the up-coming work programmes (2016-17, 2018-20, beyond 2020):

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Enhancing platforms with cross-cutting system properties support (security, energy management, etc.), seeking reusable mechanisms across domains</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Identifying gaps in relevant and established standards and consolidating domain specific reference architectures convergence (e.g. RAMI/IIRA)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Empowering devices with smart monitoring and diagnosis (self-X) functions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Ensuring easier, safe-by-design integration of heterogeneous execution models and/or mixed-criticality systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holistic interoperability solutions spanning all communication channels and interfaces (M2M, HMI, machine to service) in e.g a factory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Achieving means of analysis of cybersecurity and trust issues stemming from cross domain and interdisciplinary standards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Establishing methodological guidelines for the clustering of standards and their interoperability (Meta-Platforms, model semantics)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elaboration of reference architecture building blocks by applying current industrial standards and protocols</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Achieving complete autonomous system building platform</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exploring the challenges of new computing architectures (quantum, bio-inspired) w.r.t. programming languages, execution platforms, simulation, etc.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.3 Modelling & Simulation

2.3.1 State of the art in technology and funding

Computer-based modelling & simulation techniques have become the norm when building an engineered system. Computer models can be constructed that describe a system mathematically, with enough accuracy and rigour that predictions can be made about the final system behaviour. This allows designers to adjust the design before the first prototypes are built, and the process of building and testing mathematical models can improve development time, costs and design quality significantly. A CPS includes elements that offer computational complexity along with elements that interact with the physical world. Consequently, notations and paradigms from (at least) two disciplines are needed in order to design a CPS, including in the modelling phase. Elements of the system which interact with the physical environment – usually designed by engineers - are typically modelled using “continuous-time” (CT) notations which describe the system’s behaviour using differential equations. In contrast, software-oriented systems are typically modelled using discrete event (DE) mathematics. Unfortunately, these two mathematical approaches are difficult to integrate, and whilst each approach excels at capturing information necessary for its own purposes, each is poor at capturing the information necessary for other types of modelling. This heterogeneity means that it is computationally difficult to simulate global CPS behaviour (Branicky & Mattsson 1997, Fishwick 2007, Sonntag 2009). This is a well-known open challenge in the design of CPSs; integration between the two types of modelling approach would allow computer scientists and engineers to communicate more effectively at an early stage in the design of CPSs, allowing misunderstandings and design problems to be identified early in the design process. It would also allow designers to explore the impact of key design decisions quickly and inexpensively (e.g., by executing simulations of the complete CPS). For this reason there is currently considerable interest in modelling approaches and tools that could support greater integration between different modelling paradigms.

Aggregate modelling techniques are one approach that could be deployed to solve the problem. Commercial tools for simulating dynamic behaviour in notations which are drawn from a range of disciplines are gradually becoming available; these include Dymola\textsuperscript{13}, and gPROMS (Oh & Pantelidis 1996). There are several academic formalisms with well-established semantics, such as hybrid automata (Henzinger 1996), hybrid Petri Nets (David & Alla 2001) which can support switching between different modelling dynamics, as well as hybrid process theories (e.g., Cuijpers & Reniers 2005, Beek et al 2006). Formalisms and simulation tools are often designed specifically for a particular domain (Fishwick 2007, Sonntag 2009, Dessouky & Roberts 1997, Mosterman 1999, Breitenecker et al 2010, Goldsman et al 2010, Sonntag et al 2012).

Automated model transformation is an area under active research currently; this requires a mapping between different formalisms, where semantics are preserved. Examples of this approach have been developed for platforms such as Modelica (2010), gPROMS (Oh & Pantelidis 1996) and EcosimPro (Jorrín et al 2008). The transformation typically maps a number of models to a common modelling language. Major challenges include coping with the contrasting representations of time across different modelling formalisms, and coping with very feature-rich notations. Typically, a model of a CPS and its interactions with the real-world have real-time requirements. “Real-time” implies that functionality can only be considered correct if it delivers the expected results within an expected time

\textsuperscript{13} http://www.3ds.com/products-services/catia/products/dymola/
frame; failure to meet a deadline is a failure to produce correct functionality in a real-time system. CT notations used for modelling physical systems are capable of capturing and reasoning about timing, but many DE modelling notations for reasoning about software and/or control algorithms cannot meet the needs of hard real-time systems. In addition, some modelling notations are feature-rich, capable of capturing complex, specialist information. However, it can be challenging to incorporate a feature-rich notation into an automated transformation scheme, since it becomes increasingly difficult to find accurate ways to capture and express the same information in target notations which are not designed to support the same features. In an effort to provide a common model exchange format, several languages have been developed, including:

- **DEVS (Discrete Event System Specification)** (Zeigler et al 2000) is an exchange format for discrete event models
- **SysML (Huang et al 2007)** is a customization of UML for systems engineering applications with hierarchical high level models
- **UML extensions (Berkenkotter et al 2004)** with hybrid model representations
- **ModelCVS (Kappel et al 2006)** enables ontology-based tool integration
- **Modelica (Larsson 2006, Siemers et al 2009)** for exchange of equation-based models

Collaborative modelling (“co-modelling”) and collaborative simulation (“co-simulation”) can also be employed to solve the problem of heterogeneous modelling requirements. Typically a co-modelling environment allows CPS designers employing different formalisms to construct models representing different aspects of a CPS system, each working in their preferred specialist tools and environments. Simulations can be executed with the different models side-by-side, using a co-simulation tool to exchange enough information that predictions can be generated about the final behaviour of the CPS. Co-simulation techniques therefore enable multiple design teams to collaborate on a design for the CPS. Allowing designers to continue working in their own domain-specific modelling notation and tools allows specialised features from mature simulation tools to be applied where necessary.

Academic co-simulation frameworks include the Simantics Open Simulation Platform\(^{14}\), TrueTime\(^{15}\), CHEOPS (Schopfer et al 2004), and SIMCAN (Núñez et al 2012). However, these frameworks are domain-specific and some lack key features needed for large-scale industrial deployment. Commercial frameworks are also available, targeted at specific domains, such as dSpace SystemDesk\(^{16}\), qTronic Silver\(^{17}\), SKF\(^{18}\), CAPE-OPEN\(^{19}\), OPC\(^{20}\) and TISC\(^{21}\). The Crescendo\(^{22}\) co-simulation tool combines the domain-independent 20-sim\(^{23}\) for CT modelling, and VDM\(^{24}\) for DE modelling (Fitzgerald et al 2014). Ideally, co-simulation frameworks that are both general purpose and industrially relevant are built on

---

\(^{14}\) [https://www.simantics.org/]
\(^{15}\) [http://www.control.lth.se/truetime/]
\(^{16}\) [https://www.dspace.com/en/pub/home/products/sw/system_architecture_software/systemdesk.cfm]
\(^{17}\) [http://www.qtronic.com/en/silver.html]
\(^{18}\) [http://www.skf.com/]
\(^{19}\) [http://www.colan.org/]
\(^{20}\) [http://opc.co.uk/]
\(^{22}\) [http://crescendotool.org/]
\(^{24}\) [http://overturetool.org/method/]
frameworks and open standards which are already common-place in industry, and are ideally supported by relevant standardisation bodies. These include:

- **Functional Mockup Interface (FMI)**, developed by EU project MODELISAR, provides an open tool-independent standard for co-simulation of hybrid dynamic models (Blochwitz et al 2011). FMI only supports continuous dynamics in ODE form. Well-established tools such as Dymola and OpenModelica (Chen et al 2011) support FMI. The INTO-CPS25 project aims to integrate a number of existing industry strength tools, based around FMI-compatible co-simulation (A. Bagnato et al 2015, Fitzgerald et al 2015).

- **Simulink** is a tool for modelling and simulating nonlinear dynamic systems (Dabney & Harman 2003). Discrete event models can be integrated using Stateflow and SimEvents, and acausal components can be added using the SimScape toolbox. Simulink uses the s-function interface that must be implemented by external software components to be integrated into Simulink models.

- **HLA (High Level Architecture)** (IEEE 2010) is an IEEE standard for distributed simulation. HLA establishes a framework in which simulation components interact via services from the Runtime Infrastructure (RTI).

- **CRYSTAL** (CRitical sYSTem engineering AcceLeration), is a project establishing an Interoperability Specification (IOS) and a Reference Technology Platform (RTP) as a European standard for safety-critical systems. This standard will allow loosely coupled tools to share and interlink their data based on standardized and open Web technologies that enables common interoperability among various life cycle domains.

Major funding bodies – such as the European Commission and ARTEMIS-IA - have an important role in this sphere, by pressing for standardisation and/or interoperability between different modelling approaches and tool platforms, and by encouraging sharing of best practice between domains which may be quite disparate and disconnected. Funding initiatives currently dedicated to improving standardisation and interoperability include: ECSEL pilot programs, PPP such as FoF, I4MS; platforms such as CESAR, CRYSTAL; application-specific initiatives, such as initiatives examining low energy computing such as EMC2; initiatives to encourage connectivity and interoperability, particularly in IoT technologies autonomous systems; and initiatives designed to stimulate innovation amongst SMEs, particularly to encourage SMEs to adopt new platforms emerging from this work, e.g., The Smart Anything Everywhere initiative.

Heterogeneity in modelling notations is not the only open challenge facing modelling and simulation in CPS engineering. Many CPS domains have high requirements for fault tolerance, resilience and dynamicity, and many also involve significant interactions with humans or complex autonomous and third party systems. Many domains therefore would benefit from improved support for, and training in, probabilistic modelling techniques, for reasoning about (for example) unpredictable behaviour from humans, unexpected events in hostile environments, or fault tolerance and error recovery rates. There are few modelling techniques currently available which support analysis of CPS system design alongside this type of probabilistic modelling technique. There’s also a need for frameworks and

25 http://into-cps.org/
26 http://uk.mathworks.com/products/simulink/
27 http://www.crystal-artemis.eu/
modelling approaches that allow other types of model to be constructed and shared between stakeholders collaborating in a CPS (who may be independent from each other). This includes accessible, readily-understood models for analysing complex socio-technical issues such as security threats, traceability, data privacy and governance.

2.3.2 Time horizon and Vision – What is the vision?

2.3.2.1 Vision

Although CPSs are found in very many, highly diverse, application domains, there are some key underlying principles that apply to CPSs across domains. Underpinned by collections of inter-operative devices, in the future CPSs should be easy to assemble quickly to deliver highly flexible, adaptive systems but retaining the capability to deliver high-quality global services. CPSs “will enable cooperative systems to be designed and to form statically or dynamically, while providing desired properties such as end to end performance, security and evolvability” (Bensalem et al 2014). This allows CPS owners to adapt to changing requirements or circumstances quickly. CPSs allow many separate constituent systems to be connected to deliver new functionalities: “An application will no longer be localised in a single device but distributed over a range of devices interconnected even on a large distributed geographical area” (ARTEMIS 2016). Modelling and simulation tools are particularly important to achieve this vision, because models and simulations are an important step for building confidence that the desired global behaviours will be produced by a planned CPS which consists of separate constituent systems.

Because CPSs are capable of connecting many sensing devices, performing complex analysis of the data generated and then taking action using connected actuators, future CPSs will be able to react quickly and intelligently to highly complex environmental data to improve performance or flexibility. This could include changing the current strategy for e.g., managing vehicles in a traffic system to reduce the impact of a blockage, or it could mean, for example, reconfiguring a manufacturing line to adapt to new requirements. CPSs “will utilize new networking and distributed systems technologies and standards that need to encompass heterogeneous communication requirements, and techniques for guaranteeing quality of service and negotiation.” (Bensalem et al 2014).

2.3.2.2 Time horizon

In the short term (2016-17), we expect to see an increasing number of tools for model management, and some advances in efficient modelling and simulation of large-scale heterogeneous complex systems (Thompson et al 2015). Tools under active development include verification and validation methods and tools for complex systems, environments and lifecycle management, and simulation will support design space exploration (ARTEMIS 2013); early results from these developments will start to be available in this time frame.

In the medium term (2018-19), CPS should be capable of supporting semi-autonomous systems, including virtual engineering and design space exploration of semi-autonomous CPS (ARTEMIS 2016). Multi-modelling tools such as INTO-CPS are expected to deliver pilot products in 2018. Support for the development of control strategies and methods for decision making will facilitate reconfiguration and partial autonomy of system elements (Thompson et al 2015).

In the longer term (2020-21), CPSs are expected to begin offering features for fully autonomous capabilities, including bio-inspired approaches for modelling self-configuring CPS with complex human interactions. Formal verification should include novel techniques (e.g. stochastic) (ARTEMIS 2013).
2.3.3 Impact of the Technology – What would be the impact?
Advances in modelling and simulation technologies for CPS can lead to significant reductions in CPS development time and/or cost. Integration of a wider variety of heterogeneous models enables complementary engineering disciplines to cooperate at an early stage in the design process, exploring and testing designs without expensive prototyping (Verhoef et al 2014). This provides opportunities to identify design errors/improvements at an early stage, and allows engineers to explore the ramifications of design decisions on global system performance, gaining feedback quickly. Effective support for heterogeneous model-based CPS design could therefore result in shorter development times for new CPSs, better quality designs, and/or lower development costs.

Tools and techniques supporting a wide range of verification and validation techniques are essential for the development of trustworthy and fault-tolerant CPS, and for supporting certification through rigorous testing and simulation (ARTEMIS 2016). Provision of novel techniques for model verification and validation will facilitate dependable and robust CPS. Availability of probabilistic modelling techniques and cross-domain, cross-discipline frameworks for reasoning about socio-technical system aspects, such as security, shared data and governance, will result in improved ability to deliver safe, secure, privacy-respecting CPSs. Development of metrics, guidelines and notations that support analysis of energy efficiency could help to ensure that CPSs of the future deliver improved energy usage, which is increasingly important as Europe moves closer to a decarbonised energy economy.

2.3.4 Challenges – What are the Gaps and Barriers?
Whilst work has been done to combine complementary formalisms, a much wider class of formalisms relevant to CPS should be incorporated in co-models, such as agent-based models (Bonabeau 2012) or economic models. Since one CPS may require a collection of models in varying formalisms to describe different system properties or behaviours, there’s a need for effective model management. Tools must continue to build on existing techniques to track past, current, and planned systems configurations at an architectural level, and provide connections to any associated models. There should be a capacity for semantic linking of concepts among collections of heterogeneous models (Thompson et al 2015).

Uncertainty in the environment, security attacks, and errors in physical devices make ensuring overall system robustness, security, and safety a critical challenge. Methods and tools for designing fault-tolerant and resilient CPS are essential (Rajkumar et al 2010, Fitzgerald et al 2014), and are only partially addressed by current research projects and developments. For example, current techniques only offer limited capabilities to analyse emergent behaviour, which is produced when separate constituents interoperate together (COMPASS 2014). For many CPSs, it’s necessary to be able to ensure that the required emergent behaviour is produced, as well as ensuring that there is no undesirable, unexpected emergence. This includes an ability to reason about emergent behaviour in the face of evolution and dynamic reconfiguration. Integrating stochastic formalisms to describe probabilistic phenomena is important for supporting analysis of human behaviour and fault tolerance (Fitzgerald et al 2014). The gap between formal methods and testing should be bridged to overcome the challenges of verification and validation (V&V) of CPS models, and model-based V&V must be incorporated into certification regimes for CPS (Rajkumar et al 2010). Whilst simulation can be used to create evidence about properties of CPS, the quality of this evidence is limited by the quality of the underlying test set. There will be significant pressure to ensure that CPSs – like all other devices – are as energy efficient as possible as Europe moves closer to a decarbonised energy economy. Modelling and simulation techniques can be helpful here by allowing engineers to analyse the impact of design decisions on energy consumption for various scenarios. Metrics and benchmarks are required for this,
as well as tools and techniques to provide guidance and allow for this aspect of a CPS to be modelled and understood by engineers from different disciplines. CPS modelling necessarily crosses disciplines. There’s a need for analysis techniques which are both meeting the requirements for their own discipline, but also accessible to engineers trained in another discipline. Software modelling (for example) is commonly viewed as a complex skill that requires specialist training. There’s a need to improve accessibility and usability of modelling techniques to ensure that conclusions and analysis results can be understood and interpreted by engineers from varied disciplines (COMPASS 2014).

2.3.5 Research, Development and Innovation – What RD&I is necessary?

Methods and tools for embedded system design must be built upon to facilitate multi-domain, multi-dimensional, and multi-objective specification and modelling (ARTEMIS 2016), incorporating formalisms for the expression of a much wider class of paradigms of than those currently supported by a co-modelling approach, such as models of economy or human behaviour (Fitzgerald et al 2014, ARTEMIS 2016). Establishing standards for interoperability will enable integration of a sufficiently rich set of methods and tools, necessary for system-wide virtual engineering of CPS. Methodologies should not only support semantic integration of heterogeneous models, but also encourage re-use of models at different stages of the design process (ARTEMIS 2016). Model management support should receive attention to ensure ease of use. Modelling tools should provide a semantic link between a diverse collections of models, including legacy systems.

Enabling technologies need to be augmented so that they are able to provide confidence in the safety and security and support certification of CPS (Rajkumar et al 2010), with support for model-/software-/hardware-/system-in-the loop simulation and testing (ARTEMIS 2016). Whilst some initial projects are beginning to address this challenge, the techniques and tools must be sufficiently robust to handle autonomous systems, dynamic reconfiguration and evolution, environmental uncertainty, and properties such as real-time constraints and service level guarantees. System-wide simulation techniques should aid in detecting emerging behaviour, and in system optimisation (Thompson et al 2015). Open standards across the entire value chain are essential for the development of CPS, given the importance of interoperability for modelling and simulation tools and techniques (ARTEMIS 2016).

2.3.6 Conclusions and Recommendations

- CPSs are required in many cases to offer reliable behaviour in challenging conditions, constructed from multiple constituent systems, operating in different domains, and different engineering disciplines, developed by many separate organisations. Existing modelling techniques are poor at simulating and predicting the global behaviour that will be produced by such systems. New approaches are required that build on the very mature and well-understood techniques that are already used in separate disciplines and fields, and allow engineers to integrate aspects of them to produce accurate predictions and simulations.

- There is a skills gap, with not enough engineers and computer scientists available with sufficient understanding of each other’s’ fields

- Good quality tools should be matured, industry-ready, capable of supporting traceability and model management

- In the short-term, industry-led joint undertakings should be building on, or initiating, open frameworks and standards for model interoperability, to support integration of heterogeneous models and datasets that includes legacy components.
- Academic-industry collaborations should produce tool support for heterogeneous modelling techniques, including model management and traceability support, and the ability to consider models of different levels of granularity and abstraction in appropriate relationships to each other, in the medium term. In the longer term, as these techniques mature, they can be extended to support other useful types of modelling paradigm to capture, e.g., human behaviour.

- Also in the medium term, academic-industry collaborations can also focus on combining formal verification and simulation technology, to produce system-wide simulation techniques that aid in detecting emergent behaviour and in system optimization. In the longer term, these can be extended to cater to systems that experience long-term evolution or short-term dynamic reconfiguration.

To best address the above mentioned challenges and R&I needs, Road2CPS recommends to consider the following R&I sub-topics in the field of ‘Modelling and Simulation’ in the up-coming work programmes (2016-17, 2018-20, beyond 2020):

<table>
<thead>
<tr>
<th>MODELLING &amp; SIMULATION Sub-topics</th>
<th>Short term 2016-17</th>
<th>Med term 2018-20</th>
<th>Long term 2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open frameworks and standards for model interoperability, to support integration of heterogeneous models and datasets, including legacy components.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combining formal verification and simulation technology, to produce system-wide simulation techniques that aid in detecting emergent behaviour and in system optimization, particularly for systems that experience long-term evolution or short-term dynamic reconfiguration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Better tool support for heterogeneous modelling techniques, including model management and traceability support, and the ability to consider models of different levels of granularity and abstraction in appropriate relationships to each other</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support for the development of control strategies and methods for decision-making to facilitate reconfiguration and partial autonomy. Modelling and simulation approaches to support development and creation of fully autonomous CPS, including e.g., bio-inspired approaches for modelling self-configuring CPS with complex human interactions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Techniques that support incorporation of wider range of formalisms into CPS co-modelling techniques (e.g., agent-based models, probabilistic modelling, economic or human factors models), or incorporation of architectural features into models (for analysis of e.g., security or fault tolerance).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Big-data analytics modelling via machine learning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPS curriculums for engineers and computer scientists, to produce a skilled workforce with knowledge bridging the discipline gap</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model-based verification and validation techniques to be incorporated into certification regimes for CPS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.4 Safety, security, and privacy

CPSs are increasingly viewed as a key enabling technology for improving delivery and performance of important infrastructures – including civil infrastructures, as well as infrastructures and systems used in domains as varied as architecture, agriculture and manufacturing. As a result, the ability of existing CPS technology to guarantee certain key properties is becoming a concern. Safety is important because, by definition, a CPS can affect the physical world, and in many cases will therefore need to be classed as safety-critical. Security and privacy are important because of the large amount of valuable data about persons and organisations which is potentially collected by CPSs, and also because an inability to protect CPS data or systems decreases safety. Safety and security are closely related, for example because a security violation can pose a safety hazard in many CPS systems. However, there are some specialist terms and concepts for each, so we discuss safety and security/privacy issues in separate sections of this chapter.

2.4.1 State of the art in technology and funding

In general, the cross-disciplinary nature of many CPSs demands that approaches to both safety and security take into account potential hybrid threats – such as security attacks which exploit hardware vulnerabilities to reach software (or vice versa), or safety threats arising from unexpected hardware/software interactions.

2.4.1.1 Safety

It’s not usually possible to guarantee that a system is completely “safe”. Instead, safety-critical system design aims to improve confidence that a system performs as expected. State-of-the-art techniques include notations used to present safety cases (e.g., Goal Structuring Notation (GSN) (Kelly 2004)) which collect evidence and structure it into arguments to support safety assertions. These techniques are used to demonstrate that high confidence in system behaviour is justified, and often form part of a safety-critical assessment and certification process. However, safety assurance for CPSs is a challenge, in part because CPSs are generally required to be adaptable, easy to connect together, and updatable (Trapp et al 2013). Other challenges facing CPS safety assurance include the following (these are also common to e.g., distributed real-time embedded (DRE) systems, or systems of systems (SoS)):

- Fault tolerance strategies must support mixed-mode fault tolerance, since separate components may be employing different strategies to achieve dependable operation (Rubel et al 2007).
- CPSs typically include some components which require a fault-tolerant infrastructure, as well as others which employ non fault-tolerant infrastructures (Rubel et al 2007). For example, some parts of the system may be replicated and require group communications (to communicate with a group of replicas) whilst other components do not.
- Because they interact with the real world, CPSs typically have real-time requirements, which may be hard or soft (Kopetz 2011). Fault tolerant strategies must be capable meeting real-time requirements (Rubel et al 2007). Some strategies for achieving fault-tolerance carry a performance overhead.
- Overall, a CPS has potentially a very long lifespan. Because a CPS interacts with the physical environment, it is sensitive to environmental changes and will be required to adapt & evolve over time. Fault tolerance must work within a changing environment (Rubel et al 2007).
However, assessing the safety of a system, checking its adherence to regulations or standards, and delivering certification, is a long and expensive process and, in many fields, must be carried out afresh each time a system changes. The requirement for many CPSs to deliver adaptability is therefore at odds with their requirements to deliver safety.

- A CPS interacts with its environment and so attention must be paid to the particular characteristics of the domain. E.g., a medical infusion pump has very specific domain requirements (Banerjee et al 2012) and regulations, which do not apply to vehicle design or smart grids, and vice versa.

- Consideration must be given to “interaction safety” between the separate elements (Banerjee et al 2012).

- Safety properties are not compositional. This means that separate independently-contributed sections of a CPS which have been certified or assessed as delivering high standards of safety separately, cannot simply be connected together to deliver a new safe system. Safety must be considered at the systems level. This hinders the CPS marketplace, which benefits from ready availability of low-cost modular devices and services which can be quickly assembled into new offerings.

There’s a need to consider safety at the systems level, so that interactions between aspects of hardware and software can be considered globally. In this respect, there’s a considerable overlap between SoSs and CPSs, both of which can involve systems composed of constituent components contributed by a variety of stakeholders or suppliers. Andrews et al (2013, 2014) propose an approach to model the progression of a fault within an SoS. Identifying where responsibility for the performance of a CPS lies is important; techniques proposed by Andrews et al can help to document this.

Many safety-critical systems implement fault tolerance properties in order to ensure safety. A fault-tolerant system is capable of detecting faults and taking some action to recover or restore correct behaviour. Fault tolerance techniques are already common in both software and hardware design (Rushby 1994), although techniques between the two fields differ in some aspects, and there’s a shortage of designers familiar with both fields. For example, CPS devices will need to cope with transient faults (faults appearing temporarily due to electromagnetic interference or other unpredictable physical phenomena (Rushby 1994)), and devices and hard components need to be inspected, assessed and replaced regularly to cope with routine wear, or unexpected damage. However, although hardware designers are familiar with these types of challenge, software designers are not. Due to differences like this between the two fields, different approaches have gradually evolved for design of fault tolerant hardware and fault tolerant software (Rushby 1994).

State of the art techniques include a range of techniques for fault detection and recovery. Detecting a fault in a live system is itself not trivial. Example techniques could include generating multiple independent results for a calculation and comparing the results, using internal consistency checks (Rushby 1994), or running replicas of an application (perhaps on separate hardware, or separate virtual machines). Once detected, a range of strategies for coping with the fault can be employed, depending on architecture and fault type. These strategies include: fault isolation and containment; error recovery (erroneous state is “replaced by an acceptable valid state” (Rushby 1994)); fault masking or error compensation; and/or fault diagnosis repair. One approach, modular redundancy (called n-version programming when applied to software) relies on availability of separate components to perform computations independently; outputs are compared to produce a “vote” between the
separate modules. Modular redundancy is helpful for CPS design, since modules can take into account varying combinations of hardware and software implementations to ensure a high degree of statistical independence between the independent modules, increasing designer confidence that randomly-arising transient faults will not affect all modules.

2.4.1.2 Security

Safety and security in CPSs overlap significantly. A system which is not secured cannot be assured as safe, since many of the assumptions made by a safety engineer could be invalidated by a malicious attacker. CPS engineering, with systems straddling the hardware/software boundary, there’s a need to look at “end-to-end security” (Sperling 2016). CPSs with many smaller sensors or devices using wireless protocols for communication will provide a greater number of access points than a traditional system. CPS designers will need to develop an improved understanding of how security is implemented in different disciplines (Mo et al 2012) to counter the possibility of hybrid attacks (attack vectors that could exploit vulnerabilities in hardware in order to affect software or data, or vice versa).

In software design, security is often broken down (e.g., see Gollman 1999) into three concepts: confidentiality (preventing undisclosed information), integrity (preventing authorised modification to a system) and availability (preventing unnecessary withholding of information or resources). Because “security” already includes consideration of preventing unwanted disclosure of data, privacy and security are closely related.

Key security priorities for CPS engineering include:

- **Confidentiality** of data transmitted between distributed devices must be preserved. This could include information such as patterns of usage. As a general rule, the security of a system should not depend on secret software (Mo et al) (although software may be kept confidential for other reasons, such as intellectual property).

- Maintaining the **integrity** for a CPS system is vital; if data transmitted between distributed systems within a CPS is modified or falsified, then an attacker could influence equipment in the physical world, which could have implications for safety.

- Because CPSs are often driven by real-time requirements, it’s important that data and services are available when required and that delays are not introduced.

New attack vectors are being uncovered as interest in CPS fields grows and designers begin to search for vulnerabilities. Techniques for delivering a secure system differ in hardware design and software design. However, attacks which exploit the hybrid nature of a CPS must also be considered, and so the system level must also be studied. For example, a chip can be attacked by altering the hierarchical privilege levels in its architecture, allowing access to trusted memory locations (Sperling 2016). Although this is an attack vector which has been until mostly of concern to hardware designers, within a CPS it could ultimately allow access to the CPS’s software and computational facilities. It’s already been demonstrated on military chips that “backdoors” could be exploited to extract configuration data, alter keys for data access, modify low-level silicon features, and even cause permanent damage to the device (Sametinger et al 2015, Skorobogatov & Woods 2012). Types of attack vector that are a risk for CPSs include:

- Malicious software injected into the CPS via compromised devices, such as USB devices. One technique for combatting this is **attestation**, in which the “signature” of currently running code
is revealed; injected code or hidden malware can change the signature, allowing it to be detected. This can be implemented in hardware (May et al 2009) or software (Mo et al 2012).

- Network-based attack vectors – e.g., unsecured communications, open and unmonitored network ports, etc. This could include attacks on devices connected to the CPS which are overlooked or considered low-risk – such as peripheral fax machines, or small sensors (Mo et al 2012), or vulnerabilities in common protocols. Vulnerabilities in commonly-used protocols are particularly pertinent for CPS engineering, because CPS constituent systems may be off-the-shelf, running common protocols, and with unsynchronised update cycles which are not very visible to a CPS owner.

- Compromised supply chains, in which devices acquired and incorporated into the CPS are capable of supporting attacks, via hardware or software. For example, Sanger & Shanker (2014) describe an example of radio-enabled devices embedded discreetly into computers, allowing access remotely even when machines are not connected to the internet. This is a particular problem for safety-critical CPSs, where modular redundancy techniques, commonly used for implementing fault tolerance, can result in complex extended supply chains which are difficult to secure.

- Improperly-configured links with complex applications (such as databases). For example, a connection may exist to allow a CPS control system to issue an update to a mirror, but a compromised mirror may be capable of incorrectly issuing updates to the control system (Mo et al 2012).

- False information injected. Attackers could exploit this vector to damage internal processes, or to alter e.g., prices and charges (Mo et al 2012).

Many CPSs are deployed to support long-term systems and infrastructures (e.g., manufacturing, power and other utilities, smart city applications). For this reason it’s of utmost importance that systems can be updated, so that security threats which are uncovered can be solved, and so that functionality can continue to grow to suit the system’s requirements over many years. Therefore, mechanisms for deploying updates, patches, etc., must be associated with security policies and technologies to avoid becoming a vulnerability that can be exploited when connected to a wider system (Sperling 2016) and interfaces which have become obsolete must be blocked, so that they do not become forgotten entry points. Manufacturers of secure hardware use various techniques to “hide” the trigger points which are necessary to update a device, by ensuring that the range of values potentially used as triggers is so large that random discovery is highly unlikely (Sperling 2016), other techniques include “power resets, data obfuscation, sequence manipulation and signature cloaking” (Sperling 2016).

There’s a general requirement to be able to distinguish trustworthy communications from invalid ones (including patches or updates), and to ensure that data transmitted over a network cannot be understood by anyone except the intended recipient. These challenges are traditionally solved through software encryption techniques, which can be used to generate public/private keys for encrypting data as well as for verifying identity. However, many CPSs may need to integrate small and low-cost devices which transmit very little information; in some cases, packets are so small, or computational resources and memory so restricted, that fundamental cryptographic techniques cannot be applied (Dohler 2016).

Encryption techniques are usually deployed as protective techniques. Other security strategies which may be corrective (i.e., for resolving security problems or breaches when they arise) or detective (i.e.,
for identifying security vulnerabilities or breaches). If data is accessed by an intruder it’s important to be able to detect this quickly so that the impact of this breach be alleviated. Hardware manufacturers currently use formal verification techniques for this, such as running simulations of the behaviour of the chip (Sperling 2016). It’s important that CPSs owners can detect intrusions or breaches through the CPS, regardless of whether an attacker exploited hardware or software attached to the CPS to gain entry.

2.4.1.3 Privacy

Security issues were described in the preceding section. Privacy is closely related to security (as security generally includes notions of confidentiality) and therefore many of the comments made regarding security will also apply to privacy. However, it’s worth outlining a few issues specific to privacy.

CPSs are often applied to large and important infrastructures, which may be privately owned or operated by public bodies. This includes systems for managing cities, traffic, utilities and manufacturing or processing plants, for example. Systems in these domains are capable of collecting information about private individuals (such as drivers on the roads, pedestrians moving around a city, power consumption patterns associated with specific addresses, etc.) or about organisations (specific information about an industrial process carried out inside a processing plant, for example). In order to render CPSs industrially acceptable, it must be possible to guarantee privacy of corporate data. CPSs which are perceived to be capable of unintentionally “leaking” commercially sensitive information (e.g., through transmissions made by low-power wireless sensors) will not be adopted by industries. Preventing this type of privacy violation relies on adequate security measures and technologies to ensure that data which should remain confidential does so.

In order for CPSs to become socially acceptable, private individuals must be confident that information which is collected about their activities cannot be exploited or acquired for malicious ends. This expectation is strongly protected by many regulations, particularly in Europe. Widespread adoption of CPSs is significant because it’s possible that separate CPSs may be collecting information entirely legally and ethically, but that data could be collected from multiple, unrelated CPSs (e.g., smart tourism applications about the movements and activities of a tourist in a city), and linked together to build a detailed picture of an identifiable person. Furthermore, it’s not always clear to consumers what information is being collected about them. Public confidence in CPSs relies on ensuring that there are clear guidelines and frameworks to ensure that personal information from multiple CPSs cannot be connected quickly and easily for malicious purposes. The public must also be confident that organisations operating CPSs also have complied with rigorous security measures, even if security is not their specialization.

2.4.2 Time horizon and Vision – What is the vision?

In general, achieving real change in these very large areas will take some time. Culture changes, for example, take many years to achieve; safety cultures in particular, which includes certification processes and regulatory changes, take a very long time to adapt. Some domains are increasingly reliant on wirelessly-connected devices, but have not until recently been encouraged to adopt advanced security technologies. For example, the healthcare industry provides a high-profile example (Sameting et al 2015), as does the automotive industry (Sperling 2016). Whilst some techniques and tools are available to address challenges which are still outstanding in these and many other domains, existing techniques cannot necessarily be easily and quickly ported into a new brand domain, due to
constraints imposed by domain-specific regulations and standards, manufacturing and design timescales, availability of specialist trained staff, etc. Below are some changes that could be delivered in shorter timescales.

**2016/2017** EU-funded research projects to study multi-modelling approaches for CPSs are due to deliver results in this timeframe (e.g., the INTO-CPS project funded by the EU, and the CRYSTAL project funded through the ARTEMIS-IA). This includes projects that support multi-modelling, as well as projects that support increasing interoperability standards for tool interchange. This will not fundamentally deliver safe or secure systems, but these advances will be helpful, particularly for advancing understanding of how to reason about CPSs at the systems level. Small advances in systems engineering frameworks are possible in this timescale also; there is an increasing awareness amongst existing projects that systems approaches that allow systematic analysis and viewing need to be integrated with specialist formal and low-level techniques.

**2018/2019** Improvements in the pool of available skilled staff should be achievable in this timescale, with an increasing number of degree programmes, exchanges and PhDs addressing areas that intersect with CPS design, safety and/or security.

**2020/2021** Within five years some types of CPS domain may be in a position to adopt state of the art security and safety practices in their own field.

### 2.4.3 Impact of the Technology – What would be the impact?

CPSs have the ability to deliver significant potential gains in terms of adaptable, efficient critical civil infrastructures (such as smart grids or intelligent traffic management) as well as improving efficiency and production in domains such as agriculture or manufacturing. However, because CPSs involve interactions with the real-world, safety is a real requirement in most CPS domains. This is in contrast to traditional digital-only systems, which are often not safety critical. In addition, the ability of CPSs to collect information about their environment – potentially including data about humans’ habits, preferences and movements – means that privacy and security are very real concerns also.

- Without a convincing approach to deliver safe and secure CPSs, with transparent frameworks that control user data, our ability to benefit from the increased productivity, flexibility and efficiency CPSs can bring may be limited in many domains. There is likely to be significant public resistance to widespread adoption of CPS technologies in key civil infrastructure if clear and transparent, trustworthy policies for guaranteeing security and privacy of personal data are not available.

- Safety assurance programs will not be able to accept CPS technologies if assurance techniques and regulations cannot keep up with the functionality on offer.

- Many domains (e.g., processing and manufacturing, smart buildings) have requirements to ensure that data generated by a live system are not disclosed to unintended parties, so unless the CPS field can deliver a convincing framework for ensuring that data leaks do not occur, many domains may be resistant to adopt CPS technologies.

The growing inter-connectedness of critical infrastructures increases the threats posed by safety and security problems, with the increasing risk that an attack on one system could lead to linked attacks on...
related systems. For example, attacks on power grids can affect many other systems; attacks on road management or transport systems can affect ability to deliver emergency services etc.

2.4.4 Challenges – What are the Gaps and Barriers?

In terms of safety, traditional techniques for analysing a safety-critical system, and assembling evidence for its reliable performance, need to be extended to cope with the additional characteristics of hardware and software. Model-based design and structured notations for assembling arguments are the cutting-edge in this field, but these techniques need to accommodate wider modelling paradigms (see the chapter on modelling and simulation). Certification, regulation and standardisation are important concepts for safety-critical systems; these are generally domain-specific, and although some domains already have well-established techniques for addressing CPS challenges at the systemic level, others have so far neglected some areas (e.g., design of complex medical CPSs or cars has only recently begun to address advanced security concerns). There are few tools and techniques available which can support modelling of dynamic or evolving systems, or processes for certifying them. Better techniques are needed for identifying where responsibility lies within a CPS. There are few techniques to address this as of yet.

In terms of security and privacy, interaction with the physical world introduces significant complexity to CPS compared to entirely digital infrastructures. Attempts to analyse and defend against adversaries requires considering a wide range of combinations of possible events, resulting in a state-space explosion (Mo et al 2012). Analysis tools and techniques are required for addressing this problem, and supporting analysis of security at the systems level. Multi-paradigm modelling techniques can be used to examine the security of a system as well as its safety properties, although the cutting edge is largely focussed on dependability at the current time.

Existing approaches to ensuring security of cyber infrastructures (e.g. techniques for key management, secure communication, secure code execution, intrusion detection systems) are needed for developing secure CPS that also respect privacy. However, these approaches do not take account of the physical aspects of CPS (Mo et al 2012). Systems approaches exist which take physical aspects of systems into account, but these approaches necessarily make abstractions and approximations which can affect the accuracy of analyses. Because of this, system-theoretic approaches introduce nondeterminism when applied to CPS (Mo et al 2012). Security approaches are needed that provide appropriate concepts and abstractions for both software and hardware. In some cases traditional encryption methods will not be available due to limited resources or computing power; alternative, robust methods of verifying identity and privacy for low-powered, low-cost devices will be needed, although there has already been work conducted in this area by the private sector (e.g., credit card chip designers). Existing software security approaches have concentrated primarily on IP protocols and other protocols used extensively by computer scientists, but security approaches to be deployed to other types of protocol that may be used by hardware designers or device manufacturers should also be examined. Mechanisms for deploying updates, patches, etc., must be associated with security policies and technologies (Sperling 2016). Frameworks and certification processes are needed for making these approaches transparent, as well as ensuring that manufacturers ensure updated version of embedded software is installed on shipped or live devices. There has been considerable research into the behaviour of users and how this affects system security. Many CPSs rely heavily on humans as key components of a system, often providing important analytical, validation or decision-making capabilities. There’s a need for research that can examine this aspect of human behaviour in a CPS,
where humans are key components rather than external security threats, and consider how human behaviour affects system-wide CPS security.

2.4.5 Research, Development and Innovation – What RD&I is necessary?

Research into modelling techniques are closely linked to our ability to deliver safe CPSs (see the chapter on modelling & simulation). In addition, flexible but rigorous certification processes are required. An appropriate approach to safety assurance of CPSs should be based on research results of a number of complimentary research communities. Runtime safety certificates are required for safe CPSs, along with runtime validation and verification approaches (Trapp et al 2013). A culture change may be needed in many application domains which are not traditionally part of the safety-critical community. Safety-critical domains have worked for many years to establish strong procedures and cultures of reporting safety risks, conducting evaluations and emphasising recommendations for the future rather than apportioning blame for problems. A similar culture must be established in a wide range of CPS fields.

In terms of security, approaches for managing security will need to be extended to cope with the characteristics of hardware and software. This includes new requirements which take into account models and states of the system, which are difficult to address through information security alone. Instead, both information security and system theory-based security practices will be needed (Mo et al 2012). The security of a CPS depends upon the physical environment, and attacks on the physical environment must be guarded against to ensure the expected functionality (and safety) of the system. If the physical environment to which the CPS is exposed is not itself secure, some mechanism for authenticating sensed values is required (Banerjee et al 2012). Furthermore, the integration of physical processes with complex computation can often lead to unexpected side effects in either the cyber of physical domain, compromising safety or reliability. A lack of appropriate modelling techniques hinders progress in this area (Banerjee et al 2012). Techniques to verify identity or keep information confidential must be shared more closely between hardware and software manufacturers; resilient communications topologies and routing protocols which are resistant to attacks are needed (Mo et al 2012), including techniques which can be deployed in low-resourced devices.

Although awareness of security issues is high for software-intensive systems, awareness is relatively new in many sectors which are coming to have an increasing reliance on devices. Many such devices (e.g., cars and pacemakers) are required to have long lifespans. Training in standard security techniques for CPS developers from a variety of backgrounds will be needed. This requires a culture-change; there needs to be a coherent approach within each application domain which includes key management, time-stamping, analysis and so on. If data is accessed by an intruder it’s important to be able to detect this quickly. Although techniques exist in either hardware or software for identifying some types of unwanted access, future CPS technologies will need to be able to detect breaches, which exploit the hybrid nature of CPS systems.

2.4.6 Conclusions and Recommendations

- As CPSs become more widely adopted in many fields, and connected devices that are capable of affecting the physical world are imbued with greater ability to make autonomous decisions, safety and security in the face of significant complexity will become more and more important

- In terms of safety: we need to improve our confidence that we can deliver systems which behave safely, even when they are fully or partially autonomous, dynamic, distributed, and
surrounded by human users, operators or environments. This requires improved modelling and simulation techniques in the face of systems that are reconfiguring dynamically, potentially experiencing connectivity issues and evolving in the long-term, including taking into account many system aspects such as architecture, ergonomics and stochastic events. Certification processes to cope with dynamicity would aid the emerging markets and product development processes in this field.

- In terms of security: we need to improve our confidence that the security technologies we currently use to secure individual systems can be extended to cover an entire CPS in its end-to-end operations, and that the hybrid, distributed, systems-of-systems nature of a CPS cannot be exploited by attackers. This requires the development of some new techniques to secure low-powered, low-resourced devices and new methods of communications in some cases. It also requires developing a new range of concepts to connect the different approaches employed by device and electronics manufacturers and by software developers, and a wider understanding of security concepts in CPS domains that traditionally have not concentrated on security. There’s room to study the role of the human in CPSs, since in many cases humans are part of the CPS architecture.

- Related to privacy: we need to ensure that both CPS operators, and end-users, fully understand the implications of connecting systems together. Education and frameworks could ensure that it’s transparent to users what data is being collected from and about them.

Road2CPS recommends to

- Use larger research projects with academic-industrial collaboration (e.g., RIA, FET, JU) to progress the state of the art in modelling of the fault tolerance or security aspects of dynamic or evolving systems, and processes for achieving certification of such systems, possibly including techniques for collaborative modelling that allows different types of modelling approach to be combined in usable ways for improved holistic viewpoints

- Encourage and support industry initiatives to extend or develop frameworks and tools that support reasoning about security at the systems level, using e.g., JU, FET, including techniques for ensuring that large capital with long lifespans can continue to evolve and update over many years whilst maintaining high levels of security

- Use research projects (e.g., RIA, FET) to study the role of the human operator in the CPS architecture, where humans are sometimes required to provide some functions (e.g., processing, analysis, decision-making or validation) and how they can affect or enhance security and privacy of the CPS

- Use training schemes and academic-led instruments to encourage efforts to develop shared concepts of security between cyber and physical sides, development of systems approaches, and training for engineers with different backgrounds and domains (Marie Sklowodoska Curie training schemes, competence centres)

To best address the above mentioned challenges and R&I needs, Road2CPS recommends to consider the following R&I sub-topics in the field of ‘Modelling and Simulation’ in the up-coming work programmes (2016-17, 2018-20, beyond 2020):
### SAFETY, SECURITY, PRIVACY

<table>
<thead>
<tr>
<th>Sub-topics</th>
<th>Short term 2016-17</th>
<th>Med term 2018-20</th>
<th>Long term 2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frameworks and tools that support reasoning about security at the systems level rather than exclusively the software or the hardware component level, together with guidelines describing good practices and underlying concepts and tools and techniques for quickly detecting intrusions or data breaches which exploit the hybrid nature of CPS systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tools and techniques which can support modelling of the fault tolerance or security aspects of dynamic or evolving systems, and processes for achieving certification of such systems, including taking into account models and states of the system which are difficult to address through information science alone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modelling approaches that can capture aspects of information systems and physical environments, capable of simulating and identifying unintended side effects resulting from integrating cyber and physical domains</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training resources and expertise for CPS developers, engineers and specialists that are required to design CPSs but are not experts in security, to ensure that engineers from a wide range of CPS fields have an understanding of systems-level security concepts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approaches for studying the role of the human operators, users and participants in CPSs and how they affect the overall system safety and/or security of a CPS, particularly where humans provide important functionality to a CPS such as decision-making, validation or analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Runtime safety certificates for safe CPSs, along with runtime validation and verification approaches.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### EMERGING

<table>
<thead>
<tr>
<th>Sub-topics</th>
<th>Short term 2016-17</th>
<th>Med term 2018-20</th>
<th>Long term 2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frameworks designed to make clear to users when their data is being collected and shared, including education resources on the key underlying concepts, based on cross-disciplinary studies of the legal and socio-technical aspects of CPS data sharing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robust methods, key management and certification processes for verifying identity and privacy for low-powered, low-cost devices which do not have resources to cope with conventional encryption methods and frameworks allowing legitimate CPS owners to manage or track the security and updates status of their constituent systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials to support domain-specific culture-changes, with strong procedures and a culture of reporting and sharing safety risks, conducting evaluations and emphasising recommendations for the future (rather than apportioning blame) is required for a wide range of CPS fields that have safety elements</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.5 Big Data / Real Time Analysis

2.5.1 SoA, Situation of technology and funding today – Where are we now?

Currently Big Data landscape is quite heterogeneous, thus it is quite relevant how the interoperability of these solutions is approached. Moreover, most of the companies that are currently pushing the Big Data technologies are based in the US, therefore Europe needs to promote and develop competitive technologies to increase the presence in this sector.

Real-time analytics provides access to data with near-zero latency between data ingestion and processing, thus the results obtained can be directly applied to the processes that are influenced by the information considered. This technology will directly impact the evolution of CPS technologies in the different sectors analysed by Road2CPS. The digitalisation of infrastructures implies an exponential increase in the amount of data generated in the short term, therefore the evolution of Big Data towards mature and complete solutions will transform industry worldwide.

The roles that are currently defined for Big Data applications and their current needs are the following:

- Data provider – Data management from heterogeneous sources.
- Data processor and Service provider – the ones demanding real time analytics and a variety of data offering for the predictive applications.
- Service consumer – this group requires privacy and anonymization as well as advance visualisation techniques helping decision-making processes.
The European Commission (EC) has a long track record in funding projects related to big data, since the
time big data was not even called this way. In the last calls of the Seventh Framework Programme
(FP7)\textsuperscript{30} there were dedicated ICT calls related to Big Data (Challenge 4 – Objectives 4.1 and 4.2)\textsuperscript{31} among others. Other ICT calls funded Big Data for SMEs, and even funding was allocated in non-ICT
calls that had some big data flavour on it. As a result a bunch of RTD projects, many of them still
ongoing, tackled different aspects of Big Data.

Other funding programmes, such as EIT ICT Labs\textsuperscript{32}, also contributed to that effort. An example is the
development of Apache Flint using funding from different EU and National agencies and from ICT Labs.

Since 2014 most of the funding from the EC is channelled via the Horizon 2020 (H2020)\textsuperscript{33} programme.
This new work programme, heir of FP7, has a strong focus on application of the technology. In the big
data field this means that the EC is expecting project proposals to tackle real-world data problems,
with realistic and huge datasets and focusing of the technology uptake. Two ICT calls have been issued
so far for big data innovation (ICT16-2014) and research (ICT15-2015). See the H2020 ICT work
programme for more details\textsuperscript{34}.

Recently a joint effort between the EC and a number of stakeholders from European industry under
the umbrella of the Big Data Value Association – BDVA-(ATOS among them)\textsuperscript{35}, have joined in a Public-
Private Partnership (vPPP)\textsuperscript{36} in order to cooperate in data-related research and innovation, enhance
community building around data and to set the grounds for a thriving data-driven economy in Europe.
This partnership will provide most of the funding on Big Data in Europe in years to come. The vPPP
aims at strengthening the data value chain, in order to allow Europe to play a relevant role in Big Data
in the global market. The BDVA has issued a Strategic Research and Innovation Agenda (SRIA)\textsuperscript{37} on Big
Data as key input for the vPPP Work programme that is expected to be launched in the last quarter of
2015.

The scope of the topic is to address domains of strategic importance for EU industry and carry out
large-scale sectorial demonstrations, which can be replicated and transferred across the EU and in
other contexts.

In the second wave of H2020, the Commission has created a specific call whose main objective is to
provide clear innovation in strategic sector by means of Big Data application (Call on Big Data\textsuperscript{38} – “Big
Data PPP: Large Scale Pilot actions in sectors best benefitting from data-driven innovation”). The
European Commission has set ambitious goals in this call so as to create a noticeable impact of the
activities developed based on Big Data technologies. The challenge is to stimulate effective piloting
and targeted demonstrations in large-scale sectorial actions ("Large Scale Pilot actions"), in data-
intensive sectors, involving key European industry actors. The Large Scale Pilot actions are meant to
serve as best practice examples to be transferred to other sectors and also as sources of generic

\textsuperscript{30} FP7: http://cordis.europa.eu/fp7/ict/home_en.html
\textsuperscript{32} EIT ICT Labs project Stratosphere (Apache Flink): http://stratosphere.eu/disclaimer.html
\textsuperscript{33} H2020: http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/index.html
\textsuperscript{35} BDVA: http://bdva.eu/
\textsuperscript{37} http://ec.europa.eu/information_society/newsroom/cf/dae/document.cfm?action=display&doc_id=7151
solutions to all data intensive sectors. The ICT-15-2016/2017 call seeks Large Scale Pilots with the following objectives:

- Address domains of strategic importance.
- The projects will propose replicable solutions by using existing technologies or very near-to-market
- Demonstrate how industrial sectors will be transformed by putting data harvesting and analytics at their core

And the expected impact of the projects funded within this call is:

- Increase productivity in main target sector by 20%
- Increase market share of Big Data providers by 25%
- Doubling the use of Big Data
- Leveraging additional target sector investments
- At least 100 organizations participating in Big Data Activities actively

2.5.2 Time horizon and Vision – What is the vision?

The BDVA has defined the innovation roadmap that is show below in order to achieve the general objectives that have been laid out in the Big Data Value Strategic Research and Innovation Agenda\(^{39}\). The timeline is based on the prioritization of the five technical key areas that have been identified in a series of sectorial workshops carried out in the context of the SRIA update process during 2015.

The development of the five technical priorities could be divided into two periods. In the short term, Data Processing Architecture and Data Protection are planned to evolve in Year 2 and Year 1 respectively. The European regulation\(^{40}\) in terms of data privacy and its usage demands quick response to the new requirements so as to avoid blocking the progress of Big Data technology, additionally a final boost for these two categories will arrive after setting all the other areas that will evolve in years 3 and 4. On the other hand, Data Management and Data Analytics have their starting point fixed in Year 3 (Data Analytics development continues during Year 4) and finally the development of Data Visualization priority is planned in Year 4. This does not mean that they will be stopped in the first two years but according to current state of technology and the impact of regulatory aspects, the meaningful boosting for those priorities will arrive after setting a clear architecture framework and data protection techniques.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data processing architecture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Analytics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Protection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Visualization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5 Roadmap for Big Data - Reported by BDVA January 2016


\(^{40}\) http://www.wired.com/2016/07/artificial-intelligence-setting-internet-huge-clash-europe/
2.5.3 Impact of the Technology – What would be the impact?

Big Data is already impacting activities developed in different domains and due to the increasing number of connected elements, it will become more and more relevant in daily operations at all levels. As it will be further explained in the next subsection, Big Data technology includes several different subdomains that completes the Big Data Value chain. The evolution of each individual subdomain will boost the adoption of this technology, and it is required to progress all of them in parallel. The main subdomains are:

![Big Data Value Chain](image)

The Big Data value chain must address the five Vs (Volume, Velocity, Variety, Veracity and Value). Moreover, a prerequisite for Big Data is the provision of stable and scalable solutions for the data ‘6cs’:

- **Data clipping** – variables may be omitted because they are deemed irrelevant to the current needs of the owner organisation; likewise, data outliers may be clipped as being out-of-relevant-range.

- **Data classification** – data items are lumped together into classes, thus losing outliers, and also altering the meaning of individual data items; furthermore, data classes entering may not overlap exactly the data classes within the model.

- **Data condensation** – variables are condensed into super-variables, changing the nature of the relationships between the variables. Note that this may mean that receiving models and organisations may not know which variables are included/omitted.

- **Data confusion** – different organisations have different meanings for variables, and my treat them differently (deliveries ‘on time and in full’ (OTIF) being an example).

- **Data confounding** – Although the models may have been built according to international standards for input and output formats, the standards may have been interpreted differently by the organisations that created both the models and their associated formats, leading to incommensuration problems when data transmission is attempted. This was a prevalent
problem in the early days of automation in factories, particularly when the factory pursued a ‘best in class’ purchasing policy for its process technology.

- Data non-cancellation – ‘old’ data is not over-written (or otherwise replaced) at the appropriate time, and is therefore available for inclusion with other ‘new’ data

The impact of Big Data technologies will change not only the way business operate but also the skills required to the professionals working on them. The new emerging profiles imply a challenge in terms of education and awareness.

A recent study commissioned by demosEUROPA\(^\text{41}\) estimates that the Big Data will contribute to an additional EU-28 GDP of 206 b€ by the year 2020. This represents a growth of the EU economy of 1.9% by 2020. The expected impact per sector in which data driven solutions are introduced is presented in the following figure.

Moreover, the efficiency gains made possible by the exploitation of Big Data technologies have also impact at societal level. The OECD\(^\text{42}\) reports of 380 megatonnes of CO\(_2\) emissions may be saved worldwide in transport and logistics and over 2 gigatonnes in the utility sector.

The applications that rely on the value of data will grow in parallel with its availability and the increasing capabilities of each part of the whole Big Data value chain. The progress in all these domains will help to transform industries and services therefore creating a large number of new opportunities and challenges.

2.5.4 Challenges – What are the Gaps and Barriers?

There are several barriers and obstacles that must be addressed in the following years so as to boost the deployment and foster the adoption of Big Data technologies. Among them the BDVA has identified several groups highlighting the most challenging aspects that must be overcome:

- European Aspects:
  - Europe is decentralized which can lead to disparate policies.

---

\(^{41}\) “Big and open data in Europe. A growth engine or a missed opportunity?” S. Buchholtz, M. Bukowski, A. Sniegocki. WISE institute 2014.

\(^{42}\) „Exploring Data-Driven Innovation as a New source of Growth- mapping the policy issues raised by Big Data“, OECD 2013
Some domains are characterized by conservatism and long innovation cycles. There are few European data analytics solution providers. There are few large companies to lead the market, and many small sized companies that need nurturing.

- **Market and Business:**
  - There is a lack of access to Big Data facilities that make data more easily accessible.
  - There is no visibility of ecosystem service offerings, although first proposals are arriving.
  - It is unclear what data should be preserved, and for how long, in all the different sectors and markets.
  - An important barrier comes from problems for data sharing therefore preventing data availability for issues such as:
    - Commercial confidentiality
    - Intellectual Property Rights
    - Regulatory framework at European and National Level.

- **Technical:**
  - Lack of processable linked data, and of aggregated/combined data.
  - Lack of seamless data access and inter-connectivity, and low levels of interoperability: data is often in silos and data sharing is difficult due to a lack of standards e.g. formats and semantics.
  - Migration of data between systems, versions or partners is challenging.
  - Access and processing of data sets that are too big to be given to the end user.
  - Semantic issues and lack of common and wide adopted data ontologies.

- **Data and Content:**
  - Public data in EU is not available to the extent it should be.
  - The quality of data in open data portals is often very low.
  - The different languages within Europe create a barrier (multilingualism) during data processing.
  - Structural data sources often lack precise semantics e.g. labels from ontologies.
  - Poor and inconsistent use or management of metadata
  - Appropriate measures to deal with Data ‘6Cs’; clipping, classification, condensation, confusion, confounding and non-cancellation.

- **Education and Skills:**
  - There is a lack of specialised education programs for data analysts.
  - There are not enough skilled people to participate in training programmes.
  - Several hackathons have been organised for promoting and showing the opportunities that Big data offers.

- **Policy, Legal and Security:**
  - Legislative restrictions on data sharing decrease availability across Europe and makes European-focused initiatives that address these issues more difficult.
  - Rules and regulations are fragmented across Europe.
  - There are high security demands that can be difficult to address.

- **Usage:**

Europe is not good at analysing and changing consumer behaviour.

Citizen science – how to qualify and use data from citizens.

Providing Big Data (Value) for SME use.

2.5.5 Research, Development and Innovation – What RD&I is necessary?
Activities should be directed to the creation of innovative and inclusive environments. The demonstration activities focusing on large scale actions for measuring the real impact of the application of technology, this will help to discover and develop an inclusive environment where new parties can benefit from the Big Data.

Research action must be directed towards the creation of this eco-system, Big Data implies the collection, processing, storage and visualization, and many players can take part in this scenario. The promotion of activities in each individual field will increase the adoption share of the technology, but the development of integrated actions will clearly boost the evolution of technology by the effect of examples and the construction of real synergies.

The EC has already state that needs in the H2020 ICT-15-2016/2017 call, however the focus on the application and demonstration of already existing technologies do not cover the development of new improved ones based on data availability.

The Big data concept has been used by research and industry communities for some years, however the real implementation of the technology has not yet been fully exploited. In order to leverage the Big Data in its full potential it is required to develop new professionals ready to understand the new opportunities. Furthermore, the technologies themselves are enablers that requires people whose expertise provide added value services on top of the opportunities created by the tools created.

Finally there is a need of data harmonization, currently there are a lot of initiatives contributing to open data, however it is required a consolidation procedure so as to facilitate the access to that information and what is more important, to prevent the data-set configuration dependency of many tools. Currently H2020 ICT-30-2015 call is partially covering this aspect, but much more efforts should be put on that part and therefore strength the European openAIRE44.

The main subtopics that will boost the deployment and adoption of Big Data technologies are, as it has been presented in the Big data value chain, the following.

- **Data generation** – This is how data is collected, it affects mainly to the IoT, the protocols and devices that provide information about specific parameters that will be analysed converting those data into useful information.

- **Data processing** – this category gathers the algorithms that are designed for applying, data analytics, data mining and machine learning techniques. The most effective and efficient these algorithms are, the higher the impact of Big Data will be.

- **Data storage** – the storage of information in Big data is one challenge due to the magnitude of the data to be stored, the reduction in the cost per bit will help to boost the adoption of Big Data in different environments.

- **Data based services and visualization** – Finally the previous categories represent a set of technical challenges, but a key aspect is to break the gap between those processes and the

44 Open Research Data Pilot - https://www.openaire.eu/opendatapilot
delivery of the added value of big data. Increase the number of services and facilitate the digestion of the information is a major issue that will be progressively overcome by the development of novel services.

2.5.6 Conclusions and Recommendations

- Involvement of private funding not only EC
- Embrace innovative solutions for pushing European position in overall Big Data market
- Work towards homogenisation of regulatory frameworks

Moreover, BDVA in its SRIA points four key aspects that should be considered in the implementation strategy. The approach requires an interdisciplinary focus that integrates expertise from different fields and actions. European cross-organisational and cross-sector environments have to be incubated, such that large enterprises and SMEs will create synergies opening opportunities at both sides based on the integration and analysis and then develop working prototypes to test the viability of actual business deployments.

In order to implement the research agenda BDVA proposes four major types of mechanisms:

- Innovation spaces: Cross-organisational and cross-sectorial environments – will allow challenges to be addressed in an interdisciplinary way and will serve as a hub for other research and innovation activities.
- Lighthouse projects: The objective is to raise awareness of the opportunities offered by Big Data and the value of data driven applications for the different services and will act as an incubator for the data-driven ecosystems.
- Technical projects: This group of activities focus on improving and taking beyond the technologies that enable Big Data.
- Cooperation and coordination projects: The cooperation will foster international cooperation for efficient information exchange and coordination of activities.

From the industry perspective and towards the application Big Data technologies and its integration in business processes Atos\(^45\) reports seven best practices that minimise the risks:

- Focus on business insights
- Start small and then grow
- Get inspiration from industry best practices
- Get industrialized and flexible at the same time
- Differentiate with performance
- Constantly leverage innovation
- Think security from the start

To best address the above mentioned challenges and R&I needs, Road2CPS recommends to consider the following R&I sub-topics in the field of Big Data’ in the up-coming work programmes (2016-17, 2018-20, beyond 2020):

\(^{45}\) “Next-generation business analytics and big data: The 7 golden rules for success”, Atos – Ascent, May 2016
<table>
<thead>
<tr>
<th>BIG DATA Sub-topics</th>
<th>Short term 2016-17</th>
<th>Med term 2018-20</th>
<th>Long term 2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Generation, the development of programs that promote the development of data ontologies that facilitates the integration of big data solutions and the replicability of the tools</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data processing first developments of Big Data ecosystems are starting to hit the market, the development of data processing techniques that exploits those machines become necessary to boost the impact of Big Data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Processing Architecture represents a key challenge for the upcoming scenario of Big data, on the one hand, it is required to reduce the cost per bit; on the other hand it is important to identify valuable data to be stored in the cloud and how edge computing modifies current approaches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Analytics; the development of data processing techniques that exploits those machines become necessary to boost the impact of Big Data, moreover the real time requirements imposed demands improvement that must be demonstrated and assessed through different use cases and in different sectors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security is a major aspect that must be developed, Firstly is important to assure the integrity of the data collected, after that the architecture should be prepared for dealing with advanced communication scenarios implementing E2E encryption and robust architectures. Here the key aspects are reliability, security and safety</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data based services and visualization moving from abstract processing algorithms towards services exploiting the full potential of Big Data requires the development of visualization techniques that help to understand potential and value of solutions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.6 Ubiquitous autonomy, forecasting

2.6.1 SoA, Situation of technology and funding today – Where are we now?

There are a number of dimensions on which autonomy can be considered; in other words, given that these dimensions are orthogonal to each other, they can create an envelope in which a cognitive agent can be active. These are described in the next subsections.

2.6.1.1 Level of autonomy.

There is an amount of autonomy that an autonomous agent might have; in other words what is the spectrum of operator control. As an example, Sheridan’s scale is presented below (Sheridan 1980, Sheridan 1994, Parasuraman, Sheridan et al. 2000) albeit replacing the word, “computer” with “autonomous agent”:

1) The autonomous agent offers no assistance, human shall decide all;
2) the autonomous agent offers a complete set of action alternatives;
3) and narrows the selection down to a few, or;
4) suggests one;
5) and executes that suggestion if the human approves, or;
6) allows the human a restricted time to veto before automatic execution, or;
7) executes automatically, then necessarily informs the human, or;
8) informs the human after execution only if it is asked, or;
9) informs the human after execution if the autonomous agent decides to do so;
10) The autonomous agent decides everything and acts autonomously, ignoring the human.

It has been recommended (Parasuraman, Sheridan et al. 2000) that no autonomous system/ cognitive agent/ robot, civilian or military, should be designed to operate above level 6 on this scale; the US department of Defence (DoD), as one of the world’s most prolific users of robotic devices, has expectations for military robot autonomy that are generally at level 5. For civilian scenarios, this could be even more important, particularly in the case of care-giving autonomous agents working with vulnerable people.

A second dimension is Class of function. This refers to the kinds of functions that cognitive agents can perform. There are few issues to do with automated guidance systems and automated sensing systems so that high levels of autonomy are acceptable. On the other hand, the responsibility for deliberately killing a person is deemed a human action that cannot be delegated (Makin 2008). Hence, a robot or other autonomous agent will have different levels of autonomy, depending on what functions are operative at a given time in a given scenario, with different requirements for ethical behaviour and for supervision.

A third dimension is duration. This refers to the period of time over which the cognitive agent is able to exercise its autonomy. This might be for the duration of the agent’s operational life, it might be constrained by a circumstance perceived by the cognitive agent, causing it to refer to a higher authority (for example, in the case of a robot, the arrival of children in the vicinity).
Finally, there is **location**. Using a hospital scenario as an exemplar, ‘You, robot, can use the scalpel in the operating theatre, but nowhere else.’ Thus, the functionality of a cognitive agent will be constrained by the location in which its decisions have effects. For a robot, that location is likely to be very local; for an embedded agent, it might be much more distant and diffuse. Furthermore, there can be severe secondary effects at a distance; for example, the command to a robot to open the sluice gates on a reservoir could be calamitous for the communities downstream in the valley.

It is in defining appropriate trajectories through the envelope of behaviour that pre-occupies the research and implementation of autonomous devices, and which informs the rest of this chapter.

### 2.6.1.2 Situation of technology

Progress in the development of autonomous applications and devices is proceeding at astonishing speed, driven by world-wide interest and accompanying financial commitment, both public and private. In general terms, the physical aspects of autonomy in terms of energy, mass, movement and perception of objects in the environment are at Technology Readiness Levels (TRL) 7 and above; near-market or deployed; autonomous vehicles demonstrate this. However, when control is more virtual than physical, progress at the present time is much closer to TRLs 1-4. This is due to the combined issues of ethics, liability, consumer acceptance and the legal status of autonomous devices, all aspects of considerable importance. Complicating this even further is that most autonomous applications are intended to have lengthy lifecycles and to be deployed almost anywhere in the world, including space, and in a world in which change is always happening, or is about to happen; and following this in time, the legal environment will be changing, too. As a general rule, the more influence that an autonomous application has on human behaviour and societal life, the more difficult it is to develop, deploy and support the autonomous application.

### 2.6.1.3 Funding

An estimate from the Robotics Business Review\(^{46}\) is that global spending on robotics and related services was at €71 billion in 2015 and is expected to grow at a compound annual growth rate of 17% to €17135.4 billion by 2020. This investment is expected to be spread across all sectors on society; agriculture, health, transport, manufacturing and services, partly driven by quality issues, but also by rising labour costs and shortages of skilled personnel. The main locations for this investment are said to be the USA, China, South Korea, Japan, and the EU, albeit with different emphases in each country.

An analogous funding example, often quoted by representatives of the EC, shows in Figure 8 below current global spending on cyber-physical systems (CPS). The areas in blue show the classes that will include autonomous applications and supporting devices.

Similar to funding comments in the sections above, major funding sources (e.g. Horizon 2020 Commission and Jus such as ARTEMIS-IA) – are playing a significant, important role in this field, by pressing forwards in the development of technology and implementations, and by encouraging the sharing of best practice. Funding initiatives currently dedicated to improving the understanding and implementation of autonomy concepts include: ECSEL pilot programs, initiatives such as EFFRA, HiPEAC, FoF, I4MS; and platforms such as 3CCAR, CESAR, and CRYSTAL.

\(^{46}\) [https://www.roboticsbusinessreview.com]
Combined, these funding exercises supporting these systems that are expected by all protagonists to include autonomous components within them indicate the perceived significance for our societies of understanding the technologies that underpin autonomous components.

2.6.2 Time horizon and Vision – What is the vision?
Given the expectation of the incorporation of autonomy in CPS in a multitude of domains, it is not easy to give some idea of time horizons. A brave attempt by Gartner\textsuperscript{47} admired and used by many professionals, is the Hype Cycle, shown below in Figure 9 below.

In the short term (2016-17), we expect to see a rapidly increasing number of applications involving autonomy, particularly in the domains of transport and manufacturing. These applications are likely to be in the form of real-world pilot projects, demonstrating both the potential for autonomous operations in the eight domains identified by ARTEMIS, including agriculture, health, etc. and also identifying and evaluating the necessary societal adaptations necessary for these systems to be fully adopted, covering safety, availability, legal issues, human behavioural responses, etc.

In the medium term (2018-19), CPS should be capable of supporting semi-autonomous systems at high TRLs, including virtual engineering and design space exploration of semi-autonomous CPS (ARTEMIS 2016). Multi-modelling tools such as INTO-CPS are expected to deliver pilot products in 2018. Support for the development of control strategies and methods for decision-making will facilitate reconfiguration and partial autonomy of system elements (Thompson et al 2015).

In the longer term (2020-21), CPSSs are expected to begin offering some features for fully autonomous capabilities, including initial, bio-inspired approaches for modelling self-configuring CPS with complex human interactions. Formal verification techniques will be a high priority area, given that many CPS will not have their configurations fully determined until run-time, thus placing great emphasis on M&S to provide assurance regarding safety, ethical behaviour, etc.

\textsuperscript{47} http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp
For example, this shows autonomous vehicles to be at the peak of expectations in 2015, but with about 5-10 years before this technology is ubiquitous in society. In manufacturing, the use of autonomous systems in production processes is already past the prototyping stage, companies such as FORTISS, Bosch, AirBus and Arcelyk have production facilities that make use of autonomous components and are expected to be profitable. Likewise in health care, currently experimental use is being made of surgical robots, albeit still under close supervision.

As a general statement it seems reasonable to expect that by 2020 there will be an appreciable wave of installed systems that make significant use of autonomy in their normal operations, and by 2030, the reliance on autonomous components within CPS and other systems will be seen as a normal way of doing business.

In part, this will be driven by market competition, but perhaps more importantly, it will be driven by the gradual realisation of the Internet of Things (IoT), incorporating CPS in ecosystems reliant and embodying this network. In addition, there will be societal and governmental pressures arising from the global sustainability agenda, addressing the need to move from a linear to a circular economy of much greater efficiency in its utilisation of resources, predicated on a multitude of sensors, actuators and clear-sighted analysis of the torrents of data emanating from these.

However, while the technology will be developed and implemented, it is necessary to misquote the fitness mantra, “there will be no gain without pain”. The move towards a circular economy incorporating CPS is likely to include a number of missteps and failures; consider, for example, the following quotation:
“Due to the large scale and the complexity of systems of systems, the occurrence of failures is the norm in CPSoS” (CPSoS-D2.4 2015).

This quotation is explained in more detail in 2.7.4, Challenges, below. However, in support of this, there is the precedent of the ‘lights-out factories’, explored by many companies in many countries in the 1990s. Almost all of them turned out to be uneconomic because of their high initial cost and the difficulties of obtaining an appropriate ROI, allied to an insufficient development of the automation technologies and support that this mode of operation required. The same classes of problems are likely to recur, but with the benefit of 20 years of development since those times, we may expect a more sophisticated approach to these problems.

2.6.3 Impact of the Technology – What would be the impact?

The advent of mature, successful autonomous technologies will have a major disruptive effect in all domains in which they are implemented; the status quo will become untenable for many companies and institutions within these domains, placing them in a catch-up mode if they are slow to adapt, but providing many opportunities for growth if they anticipate the future and prepare for it.

The main impacts of autonomous technologies is in their ability to go beyond the familiar advantages of automation (increased quality of performance, tireless performance, speed of decision and operation performance, traceability, reduced variability, etc.). Notwithstanding the quotation above, autonomous technologies can enhance all of these attributes, and add to these by:

- More responsive, finer-grain control over operations, leading to less down-time and fewer mismatches in a changing environment
- Much greater resilience to expected and unexpected events, due to finer-grain control and the use of predictive simulations
- Better traceability and reporting of data from the environment and from operations
- More consistent decision-making that is more appropriate to changing environmental and business scenarios
- Providing the option to move people away from performing tasks that are repetitive, dirty, and dangerous, debilitating, boring, and enlarging their responsibilities and skills by performing supervisory, maintenance, and planning tasks instead.
- As the implementation of the IoT and CPS systems steadily pervades society in general, the expected data explosion from the 30 billion or so sensors expected to be in place by 2050 will provide real issues for analysis to extract meaning, both expected and unexpected. It is likely that extracting information and knowledge from this deluge will only be possible with the aid of ‘smart analytics’. As an example, it was said at an ARTEMIS event that accumulating just quality-related data about just one vehicle type created in just one factory over just one year will generate 9 petabytes of data.
- Predictive, agent-based simulations of the consequences of current decisions
- More flexible, faster-reacting business models
- Reduced set-up and operational costs in transferring to a circular economy philosophy
Better, more ethical and more personalised behaviour in dealings with customers, leading to greater customer loyalty.

In turn, these attributes, suitably deployed (with respect to the quotation above), will aid and enhance the transition to service-oriented approaches to many industrial and commercial domains, especially in relation to the circular economy and to the operations of governments.

There are other consequences of these disruptive technologies. Some of the obvious outcomes are:

There will be displacement of people from their jobs, continuing the loss of manual jobs that has been happening for a century or more; however, there will now be a significant ‘hollowing-out’ of many repetitive clerical and managerial jobs, as the development of autonomous technologies progresses. Undoubtedly, many jobs will remain; as the CPSoS quotation below suggests, there will be jobs necessary within the CPS involved in upgrading, maintenance and recovery:

“A few senior managers will step up into overseeing automated machines. Other workers will step aside, by developing careers in areas machines are not as good at, such as motivation, creativity and empathy. Still other will step in (by learning more about how computers work, and how to improve them), step narrowly (becoming super-specialists), or step forward to develop new systems and technology” (Davenport and Kirby 2016).

We may expect a net loss of jobs, which may result in a shift in the welfare state towards the concept of a basic, state-provided ‘living wage’, sufficient for all individuals to enjoy a reasonable, if spartan, life. This wage would then be supplemented by part-time working or by other endeavours. It is notable that Switzerland is actively contemplating this strategy.

Of course, some classes of jobs will remain as they were; jobs that are people-facing, involving care and support of individuals, or where the jobs are concerned with changing circumstances or unexpected events. Nevertheless, these changes in the nature of jobs and how member states support their citizen are likely to be very disruptive.

Secondly, these changes will impact on educational systems; STEM subjects will be essential for most people, Arts and Citizenship will also become important in people’s lives.

A third consequence may be a growing sense of alienation and impotence within communities; the disappearance of jobs and processes behind computer screens and the inability to understand how to influence or affect these systems may to a loss of self-esteem and self-worth that may in turn lead to political irritability and perhaps instability. There are precedents; the Luddites in the UK who smashed machinery in factories between 1811 and 1816 had a similar reason for their behaviour.

Clearly there will be many impacts from the development of autonomous technologies, many of them of huge benefit to the people and economies in nations around the world. However, there are also many potential unwanted impacts as well; it seems obvious that a careful, multi-faceted, multidisciplinary approach will be needed to bring about the benefits and avoid the unwanted consequences.

2.6.4 Challenges – What are the Gaps and Barriers?

As a general statement, most of the challenges and barriers for autonomous technologies are concerned with the virtual world rather than the physical world. As progress with autonomous vehicles shows, the ability of vehicles to go from point A to point B safely, reliably and with due regard
for other vehicles and moving objects (people, animals, etc.), and with awareness of signs and signals is as good as for human controllers; we may confidently expect this status to improve over the next few years. It is in the behavioural aspects of autonomous technologies as they interact with other entities that most of the problems lie, particularly in areas of regulations, ethics and liability; where the decisions and consequent actions impinge on people, both as individuals and as communities. A selection of the challenges and barriers is discussed below:

2.6.4.1 Legal aspects

As a number of papers have indicated, it is unlikely that robots or other devices will ever attain the legal status of ‘personhood’, until such devices have the concepts of responsibility, empathy, ethical behaviour and punishment built into them (i.e. they become ‘moral agents’), and it is unlikely that this will happen soon.

Given that this legal status is unlikely to be achieved, then autonomous systems will fall under ‘agency laws’, in which these devices must be the responsibility of a human ‘owner’. At this point, two legal principles come into effect:

- MQui facit per alium, facit per se - “he who acts through another does the act himself”.
- Respondeat superior - “Let the master answer”. An employer, in most cases, is responsible for the actions of employees within the course of their employment.

Unfortunately, there are many stakeholders in the design, implementation and operation of autonomous entities, all of whom could be considered as ‘owners’ or ‘masters’ at various times in the lifecycle of these entities, and the legal situation of who is responsible for actions and consequences remains to be clarified. For example, consider a robot equipped with a gripper. Nobody is much concerned if the robot is carrying a water pistol, but this will change if the robot is carrying a hedge-trimmer or a hand grenade.

Finally in this section, if we expect humans to be responsible for the actions of autonomous entities, they must be able to consent to suggestions from these entities and to issue commands to them. These areas of ‘informed consent’ and ‘informed command’ imply that the ‘owner’ has full situation awareness when carrying out these activities. This particular issue is discussed later.

2.6.4.2 Learning

It is widely accepted in robotics research that if we expect autonomous behaviour from these devices, then they must be able to learn about the world in which they are acting, to ensure their behaviour matches that world.

Learning can be of three types:

- Environmental - about the existence of objects, devices and applications with which the autonomous entity must interact
- Performance - enabling incremental improvements to processes and tasks for better efficiency, etc.
- Strategic - enabling the autonomous entity to change its goals, commence or cease its operations, and to refuse commands

All of these classes of learning (especially strategic learning) will have the effect of changing the autonomous entity’s behaviour, and creating the opportunity for surprises for its ‘owners’. This is
particularly the case if these entities are able to exchange learning between themselves. While this may be highly beneficial, it may also lead to unpleasant consequences. There is a need for much better understanding of this issue.

2.6.4.3 Ethical behaviour

Clearly, if autonomous entities could be guaranteed to act in ethical ways, the learning issues (among others) would be mitigated. Furthermore, if autonomous entities are to interact with individuals and communities in ways that directly affect human wealth, welfare, established rights and cultures, it is essential that they act in trustworthy ways according to accepted ethical norms. Unfortunately while many researchers are concerned about this, progress is currently uncertain, slow, and open to much argument.

2.6.4.4 Intercommunication and interoperation

The expectation is that autonomous entities will become components of CPS, which in turn will interoperate with other CPS to form systems of systems, and eventually eco-systems. This raises all the issues discussed above to much higher levels of complexity, especially when these systems span different legal jurisdictions and cultures. An important aspect of this is that there may be no overall control of the whole system; each component may be owned and operated by a separate, independent organisation, meaning that the whole system is held together as an operating entity by agreements and contracts instead of hierarchical control. A particular concern in this scenario, and a barrier to successful operation, is ontological. For reasons of effectiveness, efficiency, reliability, etc., it would be ideal if all the system components operated within a common ontological framework. Unfortunately, this is unlikely to eventuate, giving added potency to the CPSoS quotation given above. There is a real need for further research in this area.

It will be observed that learning complicates this situation even further.

2.6.4.5 Big data and situation awareness.

Much of the discussion above implies that humans necessarily must in charge of autonomous entities and CPS. To exercise this responsibility, these controllers must have situation awareness to carry out informed consent and informed command activities. There is a problem in realising this in future systems. An often-quoted benefit of CPS and CPSoS is the close control of operations through the use of mountains of data from legions of implanted sensors - the Big Data paradigm. Earlier in section 2.6.3 there was a comment about ‘9 petabytes of data’ in the automotive industry. Compressing this real-world data mountain down to human-sized virtual information displays that engender sufficient situation awareness for informed consent and informed command is a hard problem; analytics that enable this compression without losing important details of potentially aberrant behaviour is still an unsolved problem. Not only must the analytics be trustworthy, they must be trustworthy to different individuals who might be temporarily in charge on a particular shift.

2.6.5 Research, Development and Innovation – What RD&I is necessary?

In an earlier Road2CPS deliverable, D2.1 ‘Report on scientific and technological challenges’, a number of gaps were identified, based on the findings of 54 EU-funded projects in the area of CPS, coupled with other scoping and review documents in the general CPS literature. This gave rise to some 75 gaps in understanding that would need to be closed (or filled) for CPS technology to be successfully implemented within EU society and communities, as described in deliverable D1.2 ‘Gap analysis’. The
gaps were classified according to the three orthogonal dimensions shown in Figure 8 below, together with links between them (‘closing Gap X contributes directly to closing Gap Y’, and ‘closing Gap X complements and extends the effects of closing Gap Y’). This resulted in a network of related gaps.

The gaps ranged from strategic levels (e.g. Gap 4 ‘Social acceptance of CPS’; Gap 10 ‘Fall-back plans for major CPS failures’) to network connectivity levels (e.g. Gap 74 ‘enhanced distributed data storage for CPS’; Gap 75 ‘IoT interconnection standards’).

Analysis of this network with respect to issues of autonomy produced the table of research issues at the end of this section. While many of the entries in this table are technical in nature, it will be observed that most deal with issues of the acceptance and related adaptabilities that will be necessary as semi-autonomous CPS technology spreads into everyday use within our communities. This emphasis does not ignore the need to improve the pure technological aspects of enhancing the functionality of autonomy within CPS; indeed, this aspect is proceeding at great pace in all domains at the present time towards accepted goals. Rather, these needs refer to the behaviour of CPS once there is close interaction with people in communities across the EU, which has not yet been adequately addressed but which is essential for smooth acceptance.

It should also be noted that many of these gaps also related to the issues explored in Chapter 2.8 HMI/Human and Machine Awareness. For brevity, this table is not repeated in that Chapter.

![Figure 10 The analysis cube utilised in Road2CPS Deliverable 1.1 'State of the Art' for characterizing the results of 53 CPS projects](image)

To best address the above mentioned challenges and R&I needs, Road2CPS recommends to consider the following R&I sub-topics in the field of ‘Modelling and Simulation’ in the up-coming work programmes (2016-17, 2018-20, beyond 2020):
<table>
<thead>
<tr>
<th>UBIQUITOUS AUTONOMY &amp; FORECASTING</th>
<th>Short term 2016-17</th>
<th>Med term 2018-20</th>
<th>Long term 2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Develop techniques for run-time verification and validation (V&amp;V) to ensure that autonomous entities are safe, reliable. This applies both to system components and to the whole CPS, given that its final configuration may not be known until run-time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Improving perception in autonomous agents: fusion of different channels (visual, auditory, haptic); different modalities (gestures, movement, postures, positions) integrated over time to enable comprehensive situation awareness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Develop the theoretical underpinnings of safe, legal and ethical behaviour by autonomous agents as a cross-disciplinary study</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Growing an understanding of both the process, the knowledge required and support needed in order to guarantee reliable, ethical behaviour by autonomous agents</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Develop the theory and practice of ‘Informed consent’ and ‘informed command’; for decisions by autonomous agents and by humans carrying the authority and responsibilities of working with autonomous agents, to ensure conformity with legislation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of Human Avatars as software agents for use in M&amp;S during architecture, design and operations phases of the CPS lifecycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop concepts of dynamic, task-dependent ‘levels of autonomy and authority’ for autonomous agents during operations to ensure that appropriate accountability and responsibility remains with human controllers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop the systems design and operations approach to accommodate autonomous learning by software agents in CPS and CPSoS to control emergent, unsafe and unethical behaviours</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop a secure, regulated approach with experimental ‘real-world’ innovation spaces to accelerate development and test of CPS technologies – similar to DARPA competitions.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop a full theoretical and implementable approach to ensuring trustworthy behaviour, both by autonomous components of CPS interacting with humans, and by humans interacting with CPS components</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.7 HMI / human & machine awareness

2.7.1 SoA, Situation of technology and funding today – Where are we now?
The title of this chapter captures two ideas; firstly the old idea of humans, mainly for the purposes of control, being aware of the performance and operational status of the CPS machines and processes that are entrained to deliver some set of objectives, and secondly, the newer idea of autonomous CPS being aware of the performance and operational status of the humans who are interacting with them.

In respect of the ‘old’ idea, the engineering of the interface between humans and devices has a long history, dating all the way back to when the first human chose a suitable stick to accomplish some purpose. Over the centuries, this interface changed to match the technologies of the time, and grew to include the organization of people and the allocation of tasks in ever-more complex ways to propagate the recent, well-known mantra: ‘Faster, Better, Cheaper’. It was in the 1940s, driven by the exigencies of war, that the design and operation of these interfaces became a science/engineering discipline in its own right. Keeping pace, more or less, with the expansion of engineering into ever more complex fields and systems, it has now become an embraced part of engineering, currently labelled ‘User Experience Engineering (Ux)’. Unfortunately, in requirements engineering it is still seen as a ‘non-functional’ aspect, stemming from the old notion that systems are just physical, ignoring the real-world evidence that all of these systems rely on a range of human capabilities and direction during their lifecycles. This latter fact has been adopted in the engineering and operation of CPS and CPSoS in recent years, and it is on this area that this chapter focusses.

![Figure 11 The Kano diagram (Kano 1992); please see text below. Product design should aspire to the Excitement curve; the design must offer more than the Basic Qualities curve, or the outcome will be uncompetitive. Over time, what is exciting in a product become mundane, and a basic quality.](image-url)
For convenience, we may divide UX into 2 areas. The first is that of consumers; stakeholders in CPS whose interest is in what the CPS can deliver, how well it delivers, and how little irritation (time, cost, effort, etc.) the CPS requires from the stakeholder. The Kano diagram expresses this well; see figure 9. UX plays a very important part in generating the emotion of ‘excitement’. However, for the purposes of this chapter it is the second area that is more important. At the end of section 2.8.1.3 the discussion returns briefly to the interests of consumers.

This second area is the interaction and interoperability of humans within CPS and CPSs in developing and delivering the services for which the CPS is intended. Figure 10 indicates an initial, ideal picture for the rest of this chapter. Starting from the bottom of the figure, devices with embedded software have a presence on the Internet of Things, and are enabled to interoperate through middleware. By entraining these devices and middleware into a business model, an entrepreneur is able to sell services to customers (Business to Customers) or to other businesses (Business to Business), thus forming a CPSs.

![Figure 12](image)

Figure 12 A representation of a CPS-based business, interoperating with devices that have a presence on the IoT, and with consumers (B2C) and/or other businesses (B2B).

However, this is an ideal scenario. It is now widely accepted in the EU that CPS and CPSs will not operate for long (or even at all) without the active involvement of people. There are many reasons for this, such as the absence of ontologies that would ensure that different CPS do not interpret communications as sent by a source; engineers in different companies may interpret standards in subtly-different ways; commercial confidence and the need to protect IPRs may mean that insufficient information about the internal workings of a CPS is provided across the CPS; V&V fails to test some interactions with the real world environment, and designers did not make correct assumptions about the future, etc.). Other indications that less-than-perfect performance can be expected are the following comments:

- “... it is worth noting that the findings from Capers Jones and others indicate that deployed software systems contain approximately 0.4 latent faults per function point. To our
knowledge, this indicator of dismal [operational availability] has improved only about three-fold in the last four decades (Ring and Madni 2005).

- “In one case, we observed an outsourced application with 120 COTS products, 46% of which were delivered in a vendor-unsupported state.” (Yang, Boehm et al. 2005)
- “Due to the large scale and the complexity of systems of systems, the occurrence of failures is the norm in CPSoS”. (CPSoS-D2.4 2015)

Discovering faults, identifying and retrieving the status quo ante, or an approximation to it, is a human capability beyond the capacity of autonomous, embedded systems; while the latter may be competent to deal with local fault causation, it is unlikely that they will be competent for complex-causes-at-a-distance for some considerable time to come.

Furthermore, in restoring CPS functionality, it is likely that updates to CPS applications will be necessary. However, it may be that some of the CPS components that need updating are critical for other services and CPS systems, and therefore cannot be switched off:

“CPS generally support ... critical processes, making it impossible to turn off the system to make changes ... requiring (re-)configuration, (re-)deployment, (de-)commissioning, update, or enhancement during runtime.” (Schätz 2014). This implies a big, significant role for Model-Based Systems Engineering (MBSE) is apparent.

A second implication is evident; following the basic tenets of socio-technical systems theory, people to perform this MBSE work will have to be distributed across the CPS/CPSoS, to save time and to utilize local experience of the processes and the environment.

This leads to a more realistic CPS scenario, with people as co-workers with automated and autonomous components, distributed across the CPS/CPSoS, as shown in Figure 11.

Figure 13  A more realistic vision of a CPS, with co-workers distributed across the CPS to ensure its smooth running and to adapt the CPS as market and the environment evolves.
2.7.1.1 The Co-worker stereotype.

Having raised the concept of the CPS Co-worker, it is time to develop this concept a little further, in order to discuss the interface and interoperation issues of Human and Machine Awareness.

Firstly, it is advisable to consider some common human characteristics.

- Humans have evolved over 800 million generations from the first amoeba to what we are today by natural selection, including through predator-prey relationships.
- As a consequence, humans are very good at sensing, perceiving and making use of the environment – affordances, ‘scaffolding’, dangers, and especially pattern-recognition: “The way is long if one follows precepts, but short and helpful if one follows patterns” (Seneca AD65).
- Evolution has also led to humans becoming social animals as a survival strategy; thus rule-following, responsible, emotional intelligence, ethics, team-working and trust.
- A consequence of this is that humans are variable; no two humans are behaviourally alike – this is both a strength and a weakness.

The first three of these characteristics give people some valuable capabilities within CPS/CPSoS, as indicated below:

- For functionality; for tasks that are not well-defined, or happen in changing environments, or surprises are likely.
- For system resilience, agility, and adaptability in a world of complexity and change; c.f. Heracleitus, BCE 500: “you cannot step in the same river twice”
- For governance, responsibility, & accountability; legal aspects, where CPS meet society.
- For strategy, social responsibility, and ethical behaviour; appropriate, efficient, effective & robust CPS behaviour within society over the whole CPS lifecycle.

However, the last human characteristic, behavioural variability, does pose a problem for customary engineering design; problems of fatigue, distraction, changeable performance, and most worrisome of all to engineers, ‘human error’. However, socio-technical systems theory shows how human behaviour can be made less variable. As Sheridan has said,

“In fact, humans differ enormously from machines, in that they are inherently variable and unreliable in their detailed behaviour, while simultaneously being hyper-adaptable and metastable in their overall behaviour because they perceive and correct their own errors.” (Sheridan 2002).

There are protocols to minimise unreliability and maximize the metastability:

- Well-designed jobs to achieve objectives (meaningful tasks, safe, well-designed operations, satisfying jobs)
- Education & training to know processes, to understand constraints and to minimise bad decisions
- Sufficient time to decide and execute actions correctly, and to realise and retrieve wrong actions.
The variability that remains within the workforce is mainly beneficial; it provides governance, responsiveness, robustness, resilience, and agility, all necessary for CPS/CPSoS operating in a changing world with emergent surprises.

Figure 12 below shows how these precepts come together to create co-worker jobs and roles. The roles are essentially of four types: 

**supervisory co-worker**, carrying out expected tasks under normal conditions; or as **emergence discoverer**, detecting the advent of unwanted conditions and patterns that may lead to failures; as **local resilience managers**, bringing processes back into a safe envelope for operations; and as **designers**, upgrading and updating current processes as required.

For all of these roles it is expected that the co-worker will execute these roles through the tools of the MBSE approach, as indicated on the right of Figure 12, working with the aid of models. In order to be able to do this work, the organization must carry out the functions indicated on the left side of the diagram, including binding in the local CPS operational **nous**; the experience and understanding that guides polished, efficient performance.

There are two implications in the diagram above. Firstly, that new skills will be required for co-workers so that they can operate in a MBSE environment. What skills and to what level depends on the engineering of the interface, which is an engineering responsibility. The less that the interface recognizes the strengths and weaknesses of the workforce, the greater will be the demand on local education facilities and on the recruitment and human resource management functions. Secondly, achieving the goal of a workforce that is optimally adjusted between the four categories of Entrance-level, experienced, Expert and Guru, so that the inevitable churn in the workforce as the years go by and as the world about the CPS evolves does not upset operations is another important consideration in the design of the interface.
2.7.1.2 Sharing awareness between humans and machines.

If it is expected that CPS will contain autonomous components, then there will be a division, or overlap, of decision-making responsibilities between humans and devices. It will become ever more necessary to share situation awareness when data-sensing and authority to decide are differentially allocated between people and autonomous processes in order to achieve good, lasting decisions. This entails the design of suitable interfaces to keep humans and autonomous devices sufficiently aware that on both sides of the interface each can issue informed consents (“yes, no, wait”) to suggestions from the other, and can issue informed commands to each other. A particularly important aspect in this is the development of trust across the interface, a prerequisite for efficient, flexible performance; that humans learn to trust the operations of the hardware and software, and that the processes learn the reliability and characteristics of their human supervisors, especially when instructions are issued when the processes are near the edge of the safe operations envelope (insofar as an envelope can be defined).

Figure 13 illustrates an abstract interface appropriate for the sharing of awareness. This interface presumes that the co-worker is mobile, and will carry out some physical as well as cognitive tasks at different locations. It also assumes that the devices and applications of the CPS must be made aware of the activities of the co-worker for reasons of safety and the prediction of likely commands and consents. It further assumes that both sides of the interface are capable of making decisions that have impacts across the interface. For clarity, this abstract interface also includes situations where the co-worker might be wearing an exo-skeleton in the course of his/her duties. It includes physical transfers of components such as tools, or products as a part of operations. Finally, the mention of Big Data issues is to ensure awareness of the problems of a CPS generating perhaps petabytes of data from a profuse variety of sensors within the CPS and its environment, and then condensing this real-world data set into a visualization artefact that is communicable to the co-worker – bearing in mind that the co-worker will be replaced by a different co-worker at the end of the current shift.
The physical nature of the interface is unlikely to be in the form of computer screens alone; firstly, the geographically-distributed nature of the co-worker’s tasks mean that a mobility-aware interface is required (perhaps a personalized, wearable, secure computing device, enabling the co-worker to operate hands-free) that, with due respect for personal security and privacy, communicates continuously with the CPS EMS to record locations, deviations, delays, errors, etc. as a means of defining future training requirements and support to the individual co-worker. This is a contentious area, for which legislation might be required.

The set of diagrams above represent the state of the art in thinking about the nature of shared awareness, particularly from a socio-technical perspective, and is probably slightly ahead of actual (TRL 5-6) levels of progress in CPS engineering.

Earlier, it was said that the discussion would return briefly to the interface with consumers. It was said that most consumers, in their involvement with CPS, just want the products and services delivered by the CPS to happen with minimum effort (either cognitive, physical or with respect to time). However, some consumers, due to their different wishes, needs and environments may want deeper interaction, perhaps tailoring the products or services. Much of the discussion above then becomes applicable to the interface to these customers, but the liabilities may become more difficult to manage. There are also further problems in ensuring consumers obtain the right support swiftly when the need arises; again much of the discussion above will apply to these individuals as well.

2.7.1.3 Funding

Unfortunately, it is rare for organisations providing funds for the research, development and instantiation of CPS to separate funding for human and system awareness from the overall funding for CPS. Consequently, this document has made an estimate of the funding for awareness, based on the EC’s ‘triangle’ funding diagram, shown below as Figure 6.

As an initial estimate it is thought that about 3% of the funds in each of the blue categories might be allocated to the engineering of awareness. This amounts to about €11B world-wide, and €7.5B for the EU28. In view of the likely importance and impact of awareness, discussed below, it may be necessary for this level of support to be continued for another decade or so, both private and public.

2.7.2 Time horizon and Vision – What is the vision?

In the short term (2016-17), it is likely that attention will be focussed on physical interactions between CPS and people, rather than cognitive interaction (in other words, dealing with physical safety, avoidance of collisions, interpretations of human movements, etc.), necessary so that more complex cognitive interactions can be explored with less risk.

In the medium term (2018-19), CPS research is expected to focus much more on command and control, where issues of informed command and informed consent predominate. Necessarily, this includes situation awareness, both on the part of the CPS and of the humans with which these systems interact.

In the longer term (2020-21), CPSs are expected to begin offering features for fully autonomous capabilities, in which the legal status of autonomous decisions are addressed, together with issues of ethics in CPS behaviour. We also expect that issues in the ‘architecture and networking of trust’ to be explored; how CPS can establish the trustworthiness of decisions made by their human co-workers as well as how CPS should behave to ensure their co-workers will trust them. Complicating these issues
are the effects of contracts between businesses constraining how CPS components shall work, changing configurations of CPS, and many others, all collected together under the banner of ‘new business models’.

2.7.3 Impact of the Technology – What would be the impact?

The impact is huge, and perhaps is best explored from a sustainability perspective. A set of global environmental drivers is the following:

- Population demographics, especially growth and aging
- Food security
- Energy security
- Resource utilisation and re-utilisation
- Emissions and global climate
- Community security and safety
- Transportation
- Globalisation of economic and social activity

This set of drivers have inter-related effects, and are simultaneous in action, as shown in figure 15.

This diagram shows the main driver of unwanted outcomes is population growth, because of the increasing demand on resources of a growing world population – currently estimated to be 7 billion, and expected to reach, by 2050, 9 billion (low estimate), or 9 billion (median estimate), or 13 billion (high estimate).
Fortunately, there are many mitigation strategies available to reduce ‘unwanted outcomes’ to a sustainable level, most of which are being adopted by national governments. Figure 16 illustrates some of the approaches that are being utilized.

An interesting characteristic of this diagram is that the mitigation strategies on the right hand side are all engineering; on the left hand side they are more political and social. Furthermore, the interface between these two cognitive areas runs across the diagram, from left to right, more political/social on the left, and more engineering on the right. Consequently, CPS and CPSoS in particular, will have to deal effectively with a very wide range of individuals with different capabilities, competences and goals for the CPS/CSoS. For this interaction to be smooth efficient, thus reducing the likelihood of unwanted outcomes, it will be necessary for the awareness of CPS, in relation to co-working with humans, to have considerable capabilities for awareness of the world and of the humans with whom it will be interacting.

Around the world, there is already progress in developing awareness in CPS, from autonomous vehicles to banking and financial systems, to energy markets, home appliances and buildings management. However, these are still piecemeal, and a standardized technology is not yet available. However, we may expect significant changes to occur as the technology improves; these improvements are expected to bring about many of the benefits expected of CPS and CPSoS; for example, the requirement of ethical behaviour by systems within the Smart City concept, essential for acceptance of the technologies, will depend on advanced awareness capabilities. Likewise, in Assisted Living scenarios, where for example older patients suffer from increasing dementia as time goes by – the ‘vanishing mind’ – there is a need for autonomous assistants to adjust their behaviour to match the remaining capabilities of the patient as this change slowly happens.

Figure 17 Mitigations for the unwanted effects of the global drivers. Note that to the left are mainly engineering mitigations, whereas on the right the mitigations are mainly social/ political.
2.7.4 Challenges – What are the Gaps and Barriers?

Several challenges can be identified, based on the foregoing discussions:

There is a significant gap between the sensing of data and veridical awareness, for which analytics are required. The capture of data in a continuous, time-varying stream from a host of sensors may be easily accomplished and may result in a multitude of types of data of relevance to machine awareness; however it is the next step of reducing these data to useful meaning in real time that is difficult. Statistical compression of the data may be easy, but most compression techniques lose the fine detail in which important information might lurk. This is a significant challenge.

Ensuring ethical behaviour by a CPS is also a real challenge. There are many researchers hard at work on this problem, treating it as an exercise in engineering and using normal engineering approaches to solve it. This seems to ignore the fact that human awareness and ethical behaviour depends not just on physical inputs; it also depends on emotional intelligence, prior understanding and culture, none of which conform to the world of physics. The need for a different paradigm indicates that progress might be slow; perhaps a decade or so.

The problem of real-time analytics is also a challenge, as discussed above.

Designing interfaces that can efficiently communicate awareness between humans and machines and, from a device perspective can deal with different humans with different awareness’s is another significant challenge; like those above, it will require a multi-disciplinary approach.

2.7.5 Research, Development and Innovation – What RD&I is necessary?

We are approaching a watershed moment, when CPS technologies and implementations leave the laboratories and enter normal community life. For this to represent an improvement to our lives and times, it will be necessary for CPS to behave well in relation to societal requirements. It is here where there is the biggest shortfall in CPS understanding falls. The R&I topics in the table below are aimed at closing this gap in a timely fashion.

To best address the above mentioned challenges and R&I needs, Road2CPS recommends to consider the following R&I sub-topics in the field of ‘Modelling and Simulation’ in the up-coming work programmes (2016-17, 2018-20, beyond 2020):

<table>
<thead>
<tr>
<th>HUMAN MACHINE AWARENESS Sub-topics</th>
<th>Short term 2016-17</th>
<th>Med term 2018-20</th>
<th>Long term 2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Provision of analytics and visualisation tools to improve human understanding of Big Data patterns</td>
<td>✔️</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2. Development of ontologies for human-CPS communication (e.g. SIRI, CORTANA; also gesture/posture, haptics, etc.)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3. Improvements to interfaces, tools and support software for better situation awareness for autonomous systems for better performance</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4. Avatars to model variable human performance in operations, addressing combinations of fatigue, stress, workplace layout, task, job &amp; team design, job satisfaction, etc.</td>
<td>☐</td>
<td>☐</td>
<td>☑</td>
</tr>
<tr>
<td>5. Improved sensing (e.g. motion, position and posture-sensing) capabilities at the human-automation interface, for safety and efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platforms, methods &amp; tools for the design of human roles within CPS (for best use of human intelligence, wisdom, knowledge &amp; capabilities)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop ‘deep’ human-system interfaces with diagnostic and visualisation techniques to enable situation awareness and reachability to fix faults and/or optimise operation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.8 Conclusion

The sections introduce and discuss many issues of importance to the benefit of the EU28 as a whole, to its communities and to its individual people. This is a common feature of each section; all the recommendations about the future and the RD&I needs affect all three levels. Furthermore, from a CPS perspective, the recommendations are complementary, necessary, and implementable.

There are a few overarching conclusions that can be drawn from the text:

- There is a fundamental shortage of professional people in all flavours of engineering, especially electronics, hardware, IT and systems engineering to bring to fruition and deliver good services to the people of the EU. But it is not just engineers that are needed; because CPS will pervade society very deeply, there is a need for other classes of professionals as well, including those from the social sciences.

- Many of the sections allude to the need for more standards, particularly in connection with ontologies, to enable CPS to interoperate to form CPSoS, and to interoperate with human society. These ontologies should ensure coverage across all interoperability layers, from physical interconnection up to strategy and business. Absent these, and we may expect operational failures of steadily greater significance as the failures occur up the interoperability hierarchy.

- The capability to carry out comprehensive modelling and simulation is a sine qua non for the lifecycles of CPS. There is a dearth of tools, architectures, languages, aggregated modelling techniques and capable people to carry out this work. A fundamental barrier in this area that is being addressed but not yet overcome is that the IT industry has worked with discrete time, whereas other engineers have worked with continuous time.

- A particular area of concern for the future is the explosion of data that will be created continuously as CPS and their associated networks of sensors are instantiated in society. This flood may come to threaten the provision of communications, computing and storage capacity to utilise the data to create knowledge and value. This problem exists from the network technologies upwards to people who query the data and interpret the resulting visualisations.

- Taking all these issues together, it seems evident that the near future, we may expect not just disruption to the external environment of business models, consumer habits, established procedures, and legal concepts; there will also be disruptions within the CPS that in theory will deliver a bright new world. With all the simultaneous development that will be happening in so many complementary areas, we may expect “failures to be the norm in CPS”. It seems evident that resilience will become a much-sought-after capability within society in the near future.

- Given the inter-related aspects of the points above, it may be beneficial for future funding of the expected developments to be oriented towards the Smart Community concept, since this embraces all of the points above. In other words, in future ‘No Call stands alone’; any project must show some commitment to the Smart Community concept, and rather than looking inwards, should look outwards to co-operation with other projects. It will also ensure that each project will have to consider the humans who may be beneficiaries and victims of the project.
3 Application Roadmap

3.1 Structure of the Chapter

The application roadmap chapter provides an analysis of the five domains selected by Road2CPS (Smart health, Smart manufacturing, Smart transport, Smart energy and Smart city). Initial contributions came from the project deliverable D2.2 ‘Report on Market Requirements and Socio-economical needs’.

Below are listed the sub chapters that are developed for each domain:

- Introduction
- Revision of requirements (this section provides requirements and needs gathered for each domain)
- Non technology elements (overview of the non-technical drivers)
- Mapping of requirements into technology (this section provides the key enablers that have been identified for each sector)
- Timeline – Definition

Main conclusions of the application roadmap are included at the end of this chapter.

3.2 Smart Health

3.2.1 Introduction

By 2025, the global population will have risen to around eight billion, two billion more than today. Half of the world’s population is already living in urban areas. This trend is set to continue unabated in all countries, resulting in rapid population growth in overcrowded urban centres and an ever-dwindling rural population. The increasing average life expectancy of people in many regions of the world is creating a greater occurrence of chronic illnesses and a growing demand for high quality healthcare services. People’s attitudes to healthcare are changing too: instead of ‘just’ getting treatment for their illnesses, more and more people are placing value on targeted, preventive healthcare. Ambulant healthcare will increase in favour of clinical healthcare.

More (parts of) treatments will be carried out from home. This is also true for cure and care providers; new treatment methods and research findings are extending the range of therapies on offer. But...How can healthcare organizations improve quality through more efficient processes? How can the different stakeholders be networked to create transparency without violating the rights of individuals? How can patient care be made more service-oriented despite increasing cost pressure? Finding good answers to these questions is crucial in order to decrease the inevitable growth of healthcare costs.

Below are presented the key Challenges for Smart Health, some of them have been collected from the Ascent Look Out 2016+ research. In addition, the tables below show key factors to be highlight according to this research.

Table 1 Key Challenges for Smart Health (source: Ascent Look Out 2016+, May 2016)

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>63%</td>
<td>63% believe online is best for booking appointments</td>
</tr>
<tr>
<td>70%</td>
<td>70% using digital channels for medical education</td>
</tr>
<tr>
<td>63%</td>
<td>63% prefer a single app for holding all their data</td>
</tr>
<tr>
<td>10%</td>
<td>Digital may reduce European healthcare costs by 10%</td>
</tr>
</tbody>
</table>

Focus on Patients

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shift toward patient-centred, value-based healthcare</td>
</tr>
<tr>
<td>Patients increasingly using digital for healthcare</td>
</tr>
<tr>
<td>Patient generated &amp; genomic data spurring innovation</td>
</tr>
<tr>
<td>Growing health needs of an aging global population</td>
</tr>
</tbody>
</table>

Improving customer experience. Patients demand get involved and take responsibility for their own wellbeing, so they require new tools and services in order to make informed choices about their healthcare, especially when they have chronic health conditions. For instance, patients are looking for personalized services such as health portals that provide access to information about their illness and have the opportunity to share experiences and information on treatments with other patients.

Business Reinvention. Nowadays treatment processes are more complex, healthcare workers have more real-time data and there is more administration workload. In addition, patients have more information about their health and they are focusing on preventive healthcare. In order to achieve patient’s expectations and challenges, healthcare providers must create a new business model.

Major improvements: The higher level of quality level required of healthcare provider initiates major improvements in the way care is organized among others via care pathways. Furthermore, integral planning will become the standard, which means that patients, rooms, beds, materials and staff are planned in such a way that throughput times for patients are minimized.

Chain optimization: In the research on how to improve the healthcare chain in the shorter term, two factors are crucial: a clear ICT architecture and infrastructure and an outcome-based financing structure. With these two drivers, the co-operation between healthcare providers and other parties can be improved greatly in favour of patients.

IT architecture: To improve information and data exchange, an information infrastructure needs to be set up between healthcare regulators (such as ministries and public authorities), funders (such as statutory health), social and accident insurance providers and service providers (such as hospitals, physicians and pharmacists). The networking of all stakeholders not only improves effectiveness, but also increases transparency.

Trust and compliance: For most patients, there is a concern about the use of personal health information. Healthcare stakeholders, such as legislators and service providers, have to guarantee not only the availability but also the quality of healthcare provision for the population. People, assets and infrastructure must be secured from known and emerging threats across both physical and virtual worlds.
3.2.2 Revision of the requirements

In order to map the requirements into technology, this section presents general requirements and needs that have been gathered from deliverable D2.2. Below are listed these requirements that will be mapped in section 3.2.4 Mapping of requirements into technology.

- **Reducing the incidence of ill-health through better preventive care**, diagnosing problems early for early intervention—stopping emergency or chronic problems from emerging. Digital transformation is a key factor for this purpose, so using suitable technology, a citizen could monitor his/her own health and well-being in order to prevent or reduce the effects of health problems.

- **Giving more power to patients**, especially where long-term conditions are concerned. Given the support, systems and two-way communication they need, they are best placed to monitor and manage personal care. Through the use of multiple channels such as social networks, patients, especially those dealing with long-term conditions will have greater control over their treatment. They will also become more experts at configuring the options to adapt their accurate needs. This not only cuts use of resources and cost in recurring care, but also improves patient satisfaction.

- **Cutting waste through shared services**, using technology to reduce process complexity. In order to maintain and increase care provided to patients it is needed to reduce costs in healthcare systems. This cost reduction will be possible using Telemedicine, Cloud based services or improving Healthcare interoperability.

- **Cutting time and effort from administration**, all while giving clinicians improved information and support at point of treatment. To reduce time and effort, Administration has to be more efficient so will be needed to remove unnecessary stages, improve processes and release resources. This will be possible through the use of Cloud computing and Big data among other technologies.

- **Creating a single ecosystem**, where every agency and care provider can come together, exchange information securely and deliver truly joined-up services—cutting costs while improving outcomes. Using a single ecosystem will improve collaboration and access to patient data at critical moments. In Germany a new health platform will enable authorized service providers from all relevant agencies to work together more effectively. Other solutions give doctors full access to patient data at the bedside whenever they need it.

- **Recognizing that private and public providers can interact to reduce costs**, open access to specialized capabilities and make services more scalable. In order to encourage the collaboration between private and public providers it will be needed to overcome barriers such as legislation and regulation disparity.

3.2.3 Non-technology elements

This section includes an overview of the non-technical drivers that will shape the future of CPS technology adoption in the Smart Health domain. After the revision of Smart Health technologies, some non-technical elements have been identified, however, there are other elements that affect not only a particular technology but also the overall domain. All of these non-technical elements are presented below.
Healthcare legislators, funders and service providers need to develop new scenarios to guarantee the availability and quality of healthcare provision for the population.

- Interoperability and compliance with government regulation
- Security and confidentiality of patient information (A: Cloud computing)
- Legislation to share patients’ data (B: Social Technologies)
- Protection of patient privacy as more information becomes public (D: Big Data)
- It appears that governments are seen as the first uncertainty factor.
- Administration and Private companies
- Regulation disparity

3.2.4 Mapping of requirements into technology

This section includes the key enablers that have been identified for the health sector and the mapping of these enablers into technology. The following figure shows the information collected for this sector. There are three layers that have been described in the previous sections (Challenges, Requirements, and needs and Non Technology elements). After analysing each enabler included in the Technology layer, the results are presented in the last layer “Mapping of requirements into technology”.

Figure 18 Mapping of requirements into technology. Smart Health
Cloud Computing

The use of Cloud computing technologies in the healthcare industry is raised nowadays. One of the main reasons is the increasing pressure to reduce healthcare costs while quality of care provided to patients must be maintained. According with a recent study\(^{49}\) published by M&M Research Company, the cloud computing market in healthcare industry is expected to grow to $5.4 billion by 2017. However, the adoption of cloud computing technologies is held back by security issues and regulatory initiatives.

Besides the demand of delivering higher quality medical services for less money, there are other needs that are forced to change the health care environment such as the increased competitively between health care services. In addition, hospitals, clinics or doctors are also looking for solutions in order to increase daily activities, efficiency and decrease their spending. The implementation and appropriate use of cloud computing technologies give a response to all these needs.

Through cloud computing technologies health care services have the opportunity to share easily information between health stakeholders, to improve operational efficiency, and at the end to improve services for patients reducing cost. More benefits of cloud computing for health industry are presented below.

- Share information between health stakeholders. Information may be needed at the same time in different places, through cloud computing technologies it is possible to share and synchronize information in real time.
- Mobile applications for Easy access to information. By storing in the cloud not only data but also computing power, staff of health care providers have access to information anywhere and anytime.
- Faster access to critical information. By using cloud computing services, doctors, patients and health services providers have faster access to urgent or important information.
- Faster improvement of cloud-based tools. Using cloud-based tools it is possible to upgrade cloud-based tools faster and without service interruption. Cloud-based tools can upgrade and improve their features faster, less expensively and with minimal or no service interruption.
- Privacy standards compliance. Security and privacy are significant concerns in health industry mainly due to the nature of data in health environment, so cloud services providers have to comply with many privacy standards, such as HIPAA (Health Insurance Portability and Accountability Act). However there are some managed cloud providers that offer HIPPA compliance.
- however, nowadays there are several managed cloud providers offering privacy standards compliance
- Reduce costs of hardware infrastructure and maintenance. Health care institutions and doctors will reduce costs because cloud computing providers will take care of these concerns.

Social technologies

Social technologies could improve health quality. Social networks and blogs could be used to better inform patients in order to give them more knowledge and support for health care. This knowledge is very useful for patients wanting to take a greater role in their treatment choice and citizens wanting to proactively take better care of their own health and well-being. Besides this, social technologies can facilitate increased participation, for example through enabling patients to provide feedback on the service they receive or citizens to share information about their fitness programs.

Other advantage of social technologies is the use of data (social media posts), as proposed in a study conducted by University of Pennsylvania researchers. Social media data produced by patients could provide huge insight into overall health outcomes. How the health sector could obtain benefits from these data? The proposal includes a new database that could be used by researchers in order to understand the relationship between certain patients and their health. Of course, patients have to consent to sharing these data.

**Personal health Records (PHRs)**

Personal Health Records (PHRs) are electronic applications through which individuals can access, add to, manage and share their own health information (along with that of others for whom they are authorized) in a private, secure and confidential environment. PHRs have been in existence for nearly a decade, providing consumers with a shareable and portable medical record.

PHRs offer many potential benefits to patients, doctors and health organizations. For customers, one of the most important benefits is greater patient access to a health information, data and knowledge. This information enables patients to improve their health and manage their diseases. For instance, patients with chronic illnesses will be able to track their diseases with their providers, so if a deviation or problem is found, providers will promote earlier interventions. PHRs can help doctors to make better decisions. Patients that enter data into their personal health records are able to submit this information into their doctors’ electronic health records (EHRs), this relevant information enable doctors to make better decisions. PHRs may also cut time and cost for administration. Electronic communications of PHRs between patients and staff of the health care team can reduce the telephone and face to face communications or improve the efficiency of personal contacts between patient and doctor. Finally, potential benefits of PHRs that should be well studied include lower chronic disease management costs, lower medication costs and lower wellness program costs.

**Big data**

The Healthcare industry is significantly increasing the amount of data and knowledge available. In the last few years there has been a progress in digitizing medical records, besides this, providers and health organizations have added research and development data in electronic databases. Meanwhile, public administrations and governments have been opening their huge amounts of healthcare data in order to move toward transparency. All this information is a form of “big data”, not only for the volume of information but also for its complexity and special characteristics.

How can big data bring benefits to healthcare sector? Nowadays technical advances are making easier to collect, analyse and show data from many sources of information. Big data industry has now the availability to work with huge amounts of data, even though the files to be processed have different database structures and technical characteristics. As a result, health stakeholders can now analyse big data to obtain knowledge. For instance, providers and researchers can analyse the relevant data in order to find what treatments are more effective for specific conditions or obtain other information that can help patients and reduce costs. Other benefit that was presented in the Social Technology...
section, it is the use of patients’ social media posts. Using these kinds of data could help to identify health trends in patients.

**Telemedicine**

Telemedicine is defined as the use of medical information exchanged from one site to another via electronic communications to improve the patient’s clinical health status. More appropriately seen as ‘medicine without borders’, telemedicine is far more than just the Remote Sensors and Domotics that will play a key part in improving remote patient care through monitoring vital signs and reacting appropriately. For instance, remote patient monitoring is a service that uses devices to remotely collect and send data to a health agency for interpretation. The kind of data to be collected from homebound patients might include a variety of indicators or specific vital sign, such as blood glucose. Using these services it is possible to reduce the visits of nurses to patients’ home.

Cyber physical systems are a prerequisite for new services and solutions in telemedicine. Through the use of suitable sensors it is possible to process and evaluate medical data in real time. This information allows doctors to provide individual medical treatments do patients with long-term diseases. During the travel in medical emergencies, CPS could give a better support and primary care. Besides these solutions of CPS in the health sector, the the American Telemedicine Association (ATA) mentions four fundamental benefits for healthcare.

- **Improved Access.** Telemedicine has a unique capacity to increase access to new patients located in both rural and urban areas throughout the world. For the last years, telemedicine has been used not only to bring new health services to patients in remote locations, but it also allows doctors and other health organizations to expand their reach, beyond their own facilities.
- **Cost Efficiencies.** Telemedicine can reduce costs of healthcare system and increase efficiency through better management of chronic diseases, reduced travel times and fewer or shorter hospital stays.
- **Improved Quality.** According with some studies, telemedicine services gives the same level of quality than similar services given in traditional system. In some specialties, telemedicine is able to deliver a superior product improving the patient satisfaction and outcomes.
- **Patient demand.** A key factor it is the benefit for patients. Through telemedicine technologies, patients have access to providers and services that might not be available otherwise. In addition, patients’ satisfaction increases due to the reduction of travel time and related stresses.

**ECM Enterprise Content Management**

Enterprise Content Management (ECM) is an industry term that encapsulates the strategies and tools used to capture, store, and manage corporate content. ECM systems could increase efficiency in health organizations by providing a digital repository for patient data. This repository includes different kinds of patient information depending on the solution chosen. Medical history files, Lab results or X-rays are just some usual examples of patient’s information available in these systems. ECM systems also improve search capabilities for medical staff that are able to quickly locate information. This solution saves time and effort in health organizations.

Laserfiche\textsuperscript{51} or Quadax\textsuperscript{52} are just two examples of ECM providers for healthcare industry. ECM solutions can be customizable for each health organization depending on the specific document management needs. These solutions include several document management features, such as scanning, document capture, indexing protocol or workflow.

**Healthcare interoperability**

The HL7\textsuperscript{53} Clinical Document Architecture (HL7-CDA) is a framework for standard XML representations of clinical documents for the purpose of exchange between healthcare providers and patients. CDA documents are distinguished from messages in that they represent a complete document rather than a message between computer applications. All CDA documents are XML documents that can be transformed to an HTML or PDF representation through XMLstyle sheets. A CDA document can contain any type of clinical content such as imaging report, discharge summary, pathology report and other medical information of patients. Regarding benefits, HL7-CDA supports not only the exchange of clinical documents between healthcare organizations, but also the reuse of patient’s information in multiple applications and for specific uses such as public health reporting, quality monitoring, patient safety and clinical trials.

There are also associations that promote healthcare interoperability, such as IHE (Integrating the Healthcare Enterprise). This association includes healthcare professionals, industry and user organizations. General speaking, IHE is an initiative to improve the way computer systems in healthcare shared information. IHE promotes the coordinated use of established standards such as Digital Imaging and Communications in Medicine (DICOM) and HL7 to address specific clinical needs in support of optimal patient care. Systems developed in accordance with IHE communicate with one another better, are easier to implement, and enable care providers to use information more effectively.

**Enterprise Asset Management (EAM)**

Enterprise Asset Management (EAM), including remote sensors, global positioning systems (GPS) and radio-frequency identification (RFID), will play an important part in keeping track of expensive equipment as well as extending its lifespan through pre-emptive maintenance. EAM solutions also facilitate the management and rendering of infrastructure. So using EAM systems, healthcare sector can reduce maintenance costs of infrastructure, facilities and different pieces of equipment.

**Innovation management**

Innovation management will help both healthcare organizations and healthcare technology providers maximize benefits from R&D investments and technological developments by bringing the best ideas swiftly to maturity.

**Application synchronization:** The Health Level Seven (HL7) Context Management Standard (CMS), also known as the Clinical Context Object Workgroup (CCOW), is used to synchronize applications at their point of use. The CMS standard defines a means for the automatic coordination and synchronization of disparate healthcare applications that co-reside on the same clinical desktop. Context Management automatically synchronizes multiple applications in response to a single user gesture directed at any

---

\textsuperscript{51} https://www.laserfiche.com/solutions/healthcare/
\textsuperscript{52} https://quadax.com/ECM/
\textsuperscript{53} HL7 Health Level Seven http://www.hl7.org/
application, using readily identifiable information such as a particular user, patient, encounter, or observation.

**Medical device profiling**

Medical devices can use the Bluetooth Medical Device Profile specification to connect to other medical devices or computing platforms, such as PDAs, mobile phones or computers. The specification covers the details associated with handshaking, security, encryption and criteria for static/dynamic connectivity.

**Exploit CPS to boost the new care provision paradigm and well-being**

The deployment of CPS solution helps in identifying good practices that can reduce costs, concerns and risks. The key aspect is to analyse the new data available and exploit it in a way that the conclusions can be reusable.

**Wearable technology**

Wearable health technologies are increasing their popularity among consumers54. Wearables, smartphones and smart devices will mean that patients are more connected and they can more easily be monitored in real time. Using these technologies medical staff can track nearly everything, from physical activity to sleep or exposure to sunlight. One example is the MC10 Biostamp, which collects very useful data such us body temperature, heart rate, brain activity, and exposure to ultraviolet radiation and more.

Finally, it is important to highlight that the data is collected by unobtrusive wearable sensor, so the benefit for patients is clear.

### 3.2.5 Timeline – Definition

According to the information provided in the aforementioned Ascent Look Out + research, below is presented the timeline definition for Smart Health.

<table>
<thead>
<tr>
<th></th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augmented reality (wearable glasses)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud service integration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet of Things</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile apps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near field communication</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telemedicine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wearable computing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 19 Timeline definition (Smart Health)](image)

Regarding Smart Health, there are some key factors that are currently in progress, such as Augmented reality, Cloud service integration, Near field communication or Telemedicine. On the other hand, there are other key factors that are scheduled to be developed in coming years. That is the case of Internet of Things, Mobile apps and Wearable computing.

---

54 [http://ascent.atos.net/look-out-2016/healthcare/]
3.3 Smart Manufacturing

3.3.1 Introduction

The manufacturing sector is key for the EU economy and has a long successful tradition, albeit in some ways also very conservative. At present, the manufacturing domain is undergoing a fundamental change towards a more and more IT-related production – nevertheless, the automation of the manufacturing processes is not a new phenomenon, but the level and the penetration of IT within this traditional sector is more accelerated than before. The term ‘Industrie 4.0’ proposed by the German government which is referring to a 4th Industrial Revolution shows the paradigm shift. This paradigm shift follows the already happened ‘revolutions’ – mechanization (1st), electrification (2nd), and informatisation (3rd). The melting of mechanical and hardware-related aspects on one hand and IT-related questions on the other hand is also known as IoT technologies or, in case of the Road2CPS project, Cyber-Physical Systems.

Currently, there is a split between the different silos of ‘physical world’ and ‘cyber world’ – this needs to be overcome and shifted to the idea of Industry 4.0. For instance, information is more provided by operators manually as well as through low automatized management processes between cooperation partners within the value chain and even more within different departments of one firm. This lack of standards and interoperability is one big issue in terms of creating a framework for a smart manufacturing sector. Despite the awareness building process still needs to be promoted more and more companies are now aware and willing to take steps to avoid falling behind in terms of CPS. There is also a will to integrate more IT in customer services. The vision in terms of smart manufacturing would be an autonomous production including aspects of servitization, personalisation as well as transparency along the entire production process, but that would only be feasible after 2020.

3.3.2 Revision of the requirements

The major focus for the manufacturing sector at the moment is bringing together two aspects of available ICT technology and the demands of manufacturers to support their need for increased flexibility, scalability, security, efficiency and complexity control, to keep an advantage in the international competition.

The number of reports of security attacks on large enterprises and infrastructure systems is rapidly increasing, along with the level of damage they have wrought. These attacks are better organized, and employ attack techniques of ever-increasing levels of sophistication. The actors in these attacks are becoming more diverse and include anyone from insiders to casual hackers, terrorists and state-sponsored actors. Security for connected manufacturing systems from design, development, and deployment to operations must be heightened to mitigate the increased security risks. To address the concerns of security, trust and privacy in IT for smart manufacturing systems, end-to-end security capability must be provided to harden endpoints, secure device-to-device communications, enable remote management and monitoring, and secure data distribution. This end-to-end security capability with real-time situational awareness should seamlessly span the functional domains, and the information technology and operational technology subsystems and processes without interfering with the operational business processes.

Manufacturing IT systems and technology from multiple vendors who provide heterogeneous components with various levels of security. This is fertile ground for weak links in the assembled
system that must be addressed by integrating security by design rather than the often-tried and often-failed paradigm of including security as by hindsight. Secure design requires establishing the relevant security concerns for endpoints, the communication between them, the management of both the endpoints and the communication mechanisms, and for processing and storing data.

Another general problem is the required interoperability of the building blocks of modern distributed systems and the lack of standards which poses a barrier for integration and interoperability. Subsystems often have only partially compatible data models, so integration mechanisms between them are essential. A smart manufacturing integration mechanism may use a wide variety of available integration mechanisms, including: Syntactical transformation, which requires knowledge about the structure of the data and transformation rules in both manufacturing subsystems. Presence discovery (see below) partially addresses this requirement. Semantic compatibility is also required and can be achieved via an open standards based metadata solution such as ISO 11179. Domain transformation, which converts a data domain based on one protocol to a data domain based on another. Integration mainly serves the purpose of enabling integration across various middleware and application components and supporting functions analogous to conventional ETL (Extract, Transform, Load), typically occurring in the first stages of data transfer, and preceding initial storage.

The manufacturing sector is being shaped by many participants from engineering, design, logistics and production, each with either complex and fast-changing architectures or very slow adaption and low flexibility. To avoid fragmentation and a loss of interoperability, and the concomitant increases in implementation cost and length of development, it is important and urgent to build early consensus among the participants on major architecture questions.

Analytics and advanced data processing transform and analyse massive amounts of data from sensors to extract useful information that can deliver specific functions, give operators insightful information and recommendations, and enable real-time business and operational decisions.

Integrability, interoperability and composability suggests the direction in which smart manufacturing components should be built to support the dynamic evolution of components, including self-assembling components. It also serves as a unifying reference topic for some of the topics, such as connectivity, data management, and dynamic composition and automatic integration. Dynamic composability and automatic integration concerns flexible adaptation to optimize services as environments change and to avoid disruptions as components are updated. Industrial control systems (ICS) have been widely deployed to enable industrial automation across industrial sectors. As we bring these automated control systems online with broader systems in the smart manufacturing and Industrial Internet effort, control remains a central and essential concept of industrial systems. Control, in this context, is the process of automatically exercising effects on physical systems and the environment, based on sensory inputs to achieve human and business objectives. Many control systems today apply low-latency, fine-grained controls to physical systems in close proximity, without a connection to other systems. Because of this, it is difficult to create local collaborative control, let alone globally orchestrated operations.

### 3.3.3 Non-technology elements

Besides the above mentioned requirements non-technological elements are also highly relevant for successful CPS penetration. As stated in many conferences and workshops a need for new and innovative business models that complement the traditional ones was underlined – and these new
business models should be implemented by European companies to stabilize or even extend the market share of European manufacturing firms. Business models will evolve and probably also players outside the current production market will enter this sector in order to gain a big piece of the market – only to mention the google car. The emergence of new business models will result in new value chains and new positions within the traditional value added chains. The car manufacturing, for instance, which is a very relevant industry for Europe is investing in the autonomous car models, which happens to be a data-intensive business, where a lot of ICT is involved. What does it mean exactly? Experts believe that future competitors of companies such as Volkswagen, Volvo, Renault or Fiat (to name a few) will be technology companies such as Apple or Google, rather than other car manufacturers. This is an example of the way a value chain can change, and Europe cannot wait to react to such changes. Therefore, adapting to this new technology landscape is a must, acknowledging the threats but also the opportunities.

As the manufacturing sector is more traditional in terms of business models and application of radical innovations, good practise and success stories are necessary to convince the more sceptical decision-makers. Usually, they need to take the first step of experiencing the usability of the new solutions to be persuaded. The practical applicability of the new way as well as linking with a successful business model could help to overcome this issue. Besides business cases, demonstrators and pilots could promote the transferability of the innovative solutions. The I4MS initiative, for instance, is a way to help SMEs to try and experiment with new technologies, by creating evidence and becoming an example for others. The German initiative Industrie 4.0 has also collected good business cases for large industry. Anyway, the pilot studies should furthermore create an ecosystem especial for SMEs. Small and medium-sized companies have different offerings, tracks for implementation, and different business cases compared to large industry – this fact should also be taken into consideration.

The topic education, training, and CPS Science is highly relevant within the manufacturing sector. Lifelong learning of employees as well as for decision-makers in terms of the applicability of CPS in manufacturing is important to secure a successful implementation of the ‘melting’ of physical and cyber world. The predecessor roadmap of Road2CPS, CyPhERS, underlines that a t-shaped education, which is a combination of specialisation and interdisciplinary competence building, could support the building of skills within the sector. Apart from training in production firms academia and university education need also be adapted to the new CPS paradigm. A common understanding (e.g. in terms of ontology) from academia perspective is relevant to build a strong base for further development. From industry perspective the integration of a human-centric approach should be fostered even more to secure sufficient human-machine interaction. For thus, human machine interfaces should be generated in way that they are easy to use. Furthermore, the topic education is more relevant for industry due to the dependence on skilled and well educated employees. Significant training efforts are needed in order to upskill existing workforce to work increasingly with ICT tools, and to attract new talent in the manufacturing sector.

Regulation aspects and questions of legal frameworks are additionally a potential barrier for implementation of the cyber-physical systems – solutions in this field need to be found by integrating different stakeholders such as law-makers, academia, authorities, and industry for instance.

3.3.4 Mapping of requirements into technology

Some of the requirements can be mapped to already existing technology. Collaborative environments between the actors and engineering solutions can be provided by a number of platforms [Paris Workshop], like Virtual Fort Knox, Fiware Fitman and the Industrial Data Space, which is providing a
reference architecture to connect platforms and endpoints for information exchange and increased interoperability. These platforms can partly support solutions for cloud manufacturing or certain parts can be used to provide Manufacturing as a service or specific technologies to enable MaaS oriented solutions.

RAMI 4.0 and IIRA are the two largest undertakings to provide a CPS or IoT based reference architecture and common framework for manufacturing and other industrial sectors. Their aim is to provide a common understanding for system and platform development to create generic infrastructures, new and different Business Models. The participation of a large number of actors, for example the German government in the case of RAMI 4.0 or around 200 private companies in the case of IIRA, lead to lengthy discussions in a large number of working groups which collaborate on standard drafts, in addition to other reference architectures for the manufacturing industry, like CyPros or Arrowhead.

IIRA, Arrowhead and the Industrial Data Space offer cross domain proposals for a reference architecture in Industrial Internet Systems, which are similar to current IoT solutions, but have increased requirements for security, reliability and stability. These reference architectures try to connect IoT solutions and architectures to manufacturing, but also the interconnection of legacy systems to integrate all data on a platform, or in case of the Industrial Data Space, to connect several platforms into one information meta-hub.

![Figure 20 Mapping of requirements into technology. Smart Manufacturing](image-url)
3.3.5 Timeline – Definition

Production equipment often has a span of life of several decades and very high investment cost. This is why even in technologically advanced countries, which are on the forefront of CPS development, the majority of manufacturers still rely on their machine park with legacy equipment. Especially Original Equipment Manufacturers (OEM) very often have very low profit margins. This can have ambiguous effects, which lead to very slow technological upgrades regarding production machinery on the one side, but many smaller efforts on the technological side regarding digitization of processes, vertical and horizontal integration, IT tools to support new functionality like predictive maintenance and other auxiliary systems to improve flexibility and efficiency, which results in a market advantage improved profit margins. Because of this many research programs like the H2020 programme, have timelines spanning about 6 years, which aim to bring improvements in smaller iterations. The projection is that the 4th industrial revolution will transform traditional factories into high performance, fully optimized plants, by around 2030, which fits the vision of research projects like ARENA2036, which is researching the automotive production of 2036. Gartner (Gartner hype cycle) suggest a timeline of 5-10 years for Smart Manufacturing tools like data analytics and cloud computing to become fully integrated.

<table>
<thead>
<tr>
<th>Technology</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augmented reality (wearable glasses)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autonomy and Context awareness of products and services</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud service integration / Cloud computing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edge computing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identity of CPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interoperability / Integration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machine learning / Big Data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platforms</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retrofitting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time sensitive networks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virtual Production</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wireless communication / 5G</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XaaS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 21 Timeline definition (Smart Manufacturing)

3.4 Smart Transport

3.4.1 Introduction

A quotation from a European Parliament report (Gaggi, Fluhrer et al. 2013) sets the context:

"Currently, some 74% of Europe’s population lives and works in cities and towns, and by 2050 some 82% of the continent’s population will be concentrated in urban areas (UN World Urbanisation Prospects, 2011). Urban concentrations provide impetus for..."
economic and social development, and cities and towns are key drivers of the economy, contributing up to 85% of EU Gross Domestic Product (GDP)."

There are two implications arising from this viewpoint; firstly, that cities and towns must enable good mobility within, so that the economic benefits can be realised and to enable each citizen to live a fulfilling life. Secondly, cities and towns, being ecosystems that must be sustained, must have supply chains reaching locally into each other and into rural areas, and to a lesser extent, reaching out to the rest of the world.

In 2011 the European Commission published a White Paper on the future of transport to 2050 (COM(2011)_144 2011), and an Impact Assessment (EC-Energy 2011), the goals of which can be described as ‘stretch targets’, and are concerned with improving and integrating transportation networks and their utilisation, reducing the emissions associated with transportation and thus moving towards sustainability. This will require the following:

- Improving transportation networks in all domains (air, land, sea) and increasing the level of intelligence within them
- Improving the integration of these networks, and smoothing the usage of them mainly by better implementation of IT resources
- Moving to non-carbon energy sources to power transport

Key goals in this White Paper for 2050 include:

- No more conventionally-fuelled cars in cities.
- 40% use of sustainable low carbon fuels in aviation; at least 40% cut in shipping emissions.
- A 50% shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport.

Attaining all of these goals is expected to contribute to a 60% cut in EU transport emissions by the middle of the century, which at present contribute 40% of total EU GHG emissions.

A 1-page summary of the application roadmap to achieve these goals in given overleaf. The case for this roadmap is then discussed.
The case for these recommendations is divided in two; firstly a discussion about urban mobility (which, for this document, includes suburbs and links to rural communities) and a second discussion about transport modes as that will provide this mobility.

**Urban mobility**

Urban mobility includes travel by walking, cycling, private motorised transport, taxis, buses, trams, light rail, suburban rail, underground rail and occasionally more exotic systems such as autonomous vehicles, monorails, and funiculars. Each of these has specific attributes suited to particular sets of characteristics of cities and towns; urban density; width of streets, traffic lights and other street furniture; infrastructure systems below ground; signalling and space for passenger stops; etc., making a mix of these systems a necessity for mobility. Threading through this mix are the necessary supply systems for the city; freight and public waste management systems; logistics systems for governance, emergencies and resilience, etc.; these are discussed later. Thus, a ‘smart community’ approach is necessary to optimise urban mobility; not just for operating each of these transport systems in parallel, but also providing the information systems that enable their interoperation, journey planning, and future evolution as the urban ecosystem itself evolves. Adding to the complexities is the fact that for all of the systems, there are many legacy issues in that the communities in their built environments (which include existing transport networks) are already in place and are working; they cannot be switched off to enable change.
Two of the fundamental issues to be addressed as priorities are those of emissions and congestion. Both of these can be addressed by changes to the energy provision for transport, by increasing the utilisation of public transport (any mode where lots of people or goods are moved in a vehicle and by packing vehicles more closely), and by moving from long-term private ownership of vehicles to a service approach based on temporary occupancy (leasing, taxis, etc.).

Urban mobility constitutes a system of systems with a tangled and convoluted collection of feedback loops both within and between the systems, with a multitude of different goals for the community as a whole and for the individuals who make up this community. This is a description of a large scale ‘wicked problem’ (Rittel and Webber 1973, deMeyer, Loch et al. 2002, Siemieniuch and Sinclair 2014), and two of the characteristics of wicked problems are firstly that the offered solution to the problem depends on the initial assumptions, and secondly the solution has to be recognised; it is unlikely to be that at which the solution was aimed at the start. Furthermore, given that communities are ecosystems that are continuously evolving, ensuring good-quality urban mobility is a never-ending problem.

Under these circumstances, the best approach is incremental, with constant attention to the interoperation aspects. Each of the systems can gain real benefits from a CPS approach for both vehicles and for the system as a whole; at the interoperation level, there is also large scope for CPS for overall control, safety and resilience; the entire system constitutes all of the identified classes of System of Systems (Dahmann and Baldwin 2008). This is discussed further in the next section, ‘Market requirements and needs’.

Some facts illustrate the scale of EU transport links, with estimates of future demand:

- The EU has more than 4.5 million km of paved roads, 212,500 km of railway lines and 41,000 km of navigable inland waterways.
- The trans-European transport networks (TEN-T), which represent 25,800 km of key European corridors, have nine north-south connections linking the continent, but only four east-west ones.
- A well-performing transport network requires substantial resources. The cost of EU infrastructure development to match transport demand has been estimated at over €1.5 trillion for 2010-2030. An additional investment of a trillion euros in vehicles, equipment and charging infrastructure is needed to achieve emission reduction goals. The completion of the TEN-T network requires about €550 billion by 2020, out of which some €215 billion are for the removal of the main bottlenecks.
- Freight transport activity is projected to increase by around 80% by 2050 compared to 2005.
- Passenger traffic should grow by 51% by 2050 compared to 2005.
- 13.2% of every household’s budget is spent on average on transport goods and services.
- Congestion costs Europe about 1% of Gross Domestic Product (GDP) every year.

Transport modes, supplying communities

Contemplating the goals of the EU at the top of this section, it becomes obvious that reaching these goals will demand a comprehensive response across many sectors elsewhere in this report. For

---

example, not just the development of new transport vehicles and green power-plants for them; better co-ordination of transportation in each sector and across all transportation sectors, but also reducing demand for transport by a wide range of changes happening in manufacturing, in agriculture, and in the organisation of business. As an example, it has been reported that a computer chip, from initial manufacture to its incorporation into a device and subsequent travel to a sales point included 6 air journeys across the Pacific, creating a total of about 100,000 km of travel, when the linear distance between start and finish is under 13,000 km (Sheffi 2005). While it is a high-value, small-volume artefact thus minimising the comparative cost of travel, optimisation of operations within the owning enterprise might reduce the number of journeys, the time, and the costs of documentation.

For convenience, further discussion of transport is divided into the main sectors of transport; air, land and water-borne.

**Air transport**

- EU airports and airlines currently employ 670,000 people, while some 3.2 million people depend directly or indirectly on the air transport sector.
- European skies and airports risk saturation without substantial investment to support the deployment of Europe’s air traffic management system (Single Sky). Air passenger travel is expected to grow by over 50% by 2020, and freight by 125%.
- Over 750 million people – one third of the world market – used EU airports in 2009.
- Travelling from London to Brussels by train produces roughly nine times less emissions per passenger km than a plane journey.
- The new generation of jet engines due on the market in 2020 will cut aircraft emissions by 10-15%. Emission reductions of up to 40% are expected from 2025-2030.

The air transport sector is already undergoing rapid changes as it also grows its markets and its total share of transport in the EU and elsewhere; the EC’s drive towards sustainable air transport and the ‘Single European Sky’ (WP 2011), together with its intentions to introduce an Emissions Trading Scheme (and many other measures) have caused airlines to reconsider their business models: to commence upgrades to their airline fleets to make them more flexible for the routes they fly, to review their strategies for routes, and to concentrate much more on efficiency and sustainability.

Eurocontrol, in its report on ‘Challenges of growth 2013’ (Eurocontrol13 2013), indicates that global growth in air transport will continue; in the EU28 this amounts to about 26% growth by 2035, or about 14.4 million flights, about 1.5 times the number in 2012. Most of this percentage growth is expected to occur in the East of the EU28, and especially in Turkey (which may have joined the EU by then).

Congestion at airports is one of the major constraints on the growth of flights; however, a second is the intended growth of high-speed rail transport between city pairs, likely to affect journeys of up to about 500 miles, with implications for the short-haul market. This may amount eventually to about 54 city-pairs. Fortunately for the airlines, the barriers to increasing high-speed rail transport are numerous enough and significant enough to enable airlines to adjust to the latter constraint in good time. Unfortunately for airlines, increasing the capacity of the infrastructure to accommodate the extra throughput of aircraft is likely to be equally slow; it is expected that congestion will cause the ‘loss’ of flights of about 100,000 now, and about 1 million by 2035.

The proportion of short-haul flights (1-1000km) is expected to decrease by about 10% by 2035 in view of the aging population of the EU (who are less likely to travel by air) and the added competition from
rail transport, but this may be counteracted by an expected equivalent increase of long-haul flights for younger groups.

**Water-borne transport**

- Europe (EU/EEA) has the world’s largest shipping fleet, directly employing some 300,000 seafarers on board merchant vessels and another three million in related jobs. More than 80,000 merchant ships call at European ports every year.
- An EU-registered ship travelling from Antwerp to Rotterdam (150nm, within the EU) can require the same amount of paperwork as a ship travelling to Rotterdam from Panama (6730nm).

This sector covers both maritime and inland waterways; it includes both freight and passenger traffic. Passenger traffic is now fairly much restricted to cruises and ferries; the main focus of operations is on the movement of freight.

**Maritime transport**

Most internationally-traded goods and bulk cargoes still travel by sea and this situation is likely to persist into the future. The trend to ever-larger ships is likely to continue, bringing with them some size and momentum issues in the Suez and Panama canals as well as navigational issues in crowded straits and coastal waters near ports. Size also causes congestion at the port due to the scale, variety and complexity of cargoes; while most cargoes are containerised, there are logistics and documentation issues that arise from very large batches of containers. Handling the cargoes brought to ports is now a well-developed area in distributed management, though there is room for improvements in the regulatory aspects of customs and general security; these improvements are likely to involve cross-border co-operation and monitoring, partly dependent on standards, reworking of regulations and in the development of inspection technology.

The EU-supported MONALISA and MONALISA 2.0 projects enable the synchronisation of port-to-port journeys as well as the in-port management of cargoes, which in turn would be necessary for the introduction of fully-automated, autonomous ships. While these will require a support eco-system to support their reliable and resilient operation, these developments offer significant cost and time savings; they may also enable enterprises to be more robust against piracy and other attacks on the integrity of shipping systems, a factor likely to be of importance for insurers.

**Inland waterways**

Inland waterways in the EU comprise canals and rivers, in the main. These communication channels have been in the doldrums with regard to funding and innovation; it is estimated that they deliver less than 4% of the EU28’s cargoes, despite a network of 37,000 km spanning 20 EU member states and with good links to ports. There is considerable scope for an increase; the main advantages are:

- Waterways extend into the heart of cities and towns
- Transport by barge is much more sustainable than other forms of transport
- The introduction of container terminals on waterways has done much to integrate barge transport with local collection and distribution
- Utilisation of waterways can make a noticeable contribution to reducing congestion in other forms of transport, particularly by road
- While barge transport lengthens time to delivery, barges also represent convenient buffer stores for many distributed processes
However, there are a number of barriers that require mitigation, mainly to do with infrastructure:

- Narrow canals and locks impede the movement of large barges
- Lack of sufficient terminal facilities in important cities
- Fragmentation in the industry, hindering efficient planning and documentation, skills shortages, an aging workforce, low earning power reducing investment.
- Inland waterways are also natural ecosystems, with habitats that require protection against pollution, indicating extra regulations to the industry.

Recognising these barriers, the EC transport roadmap of 2011 (WP 2011) set goals for the inland waterway network:

- a 30% shift of road freight on journeys of over 300 km to other modes such as rail and waterborne transport by 2030, rising to 50% by 2050;
- stimulating the integration of inland waterways into the transport system, and eco-innovation in freight;
- ensuring that by 2050 all core sea ports are sufficiently connected to rail freight, and where possible, to the inland waterway system;
- between 2016 and 2020, examining mandatory application of internalisation charges on all inland waterways in the EU.

A number of programmes have since been created to help achieve these goals; NAIADES II, PLATINA 2, TEN-T, Marco Polo and Leonardo da Vinci. The steady increase in leisure activities on the waterways, whether by cruises or private leisure activities is certainly creating an environment conducive to investment.

**Rail transport**

- The Thalys high-speed train through France, Belgium, Germany and the Netherlands has to adapt to seven different signalling systems. The EU currently uses seven gauge sizes and seven types of electric currents (with different voltages and frequencies, and alternating or direct current, etc).
- High-speed trains are the preferred passenger choice. When Spain’s high-speed Madrid-Seville line was launched in 1992, the route’s market share for rail rose from 19% to 53%. The Barcelona-Madrid link saw its share rise from 13.7% before it opened to 45.6% in 2010.
- Train journeys can be faster than short and medium distance flights. This applies in particular to high-speed lines over distances of up to 800 km. A 400 km journey by high-speed train can be up to an hour faster than covering the same distance by plane.

Railway networks are of increasing importance in the EU28, in view of their potential for safety, efficiency and sustainability. Recent announcements of high-speed rail links from China to the EU and to other Asian countries, coupled with the big increase in passenger traffic in member states within the EU28, all indicate a revival in the future of rail. Furthermore, the significant funding in the H2020 programme for rail and the creation of the ‘Shift2Rail’ Joint Undertaking (EUCReg64252R 2014) indicate extensive support for rail developments. This is fortunate, given predictions of rising traffic demand; (freight transport is projected to increase, by around 40% in 2030 compared to 2005 and by about 80% by 2050; passenger traffic is expected to grow by 34% by 2030 and 51% by 2050). In addition, the linked challenges of congestion, fuel security, CO2 emissions and the need to create an efficient transport infrastructure to underpin growth in the European economy also provide drivers for better utilization of railways.
Current aims for rail transport in the EU28 include the creation of a Single European Railway Area, greater efficiency and effectiveness, greater competition among rail companies to drive down lifecycle costs, and a better end-to-end travelling experience for users.

To accomplish this there are large investments in electrification of the railways, expansion of rail networks, improvements in both trains and fixed infrastructure, and a big investment in information networking. The development of good rail links to Asia indicates that goods transport by rail may gain a much larger share of rail usage than indicated above, mainly at the expense of sea transport. Furthermore, the recent identification of 54 city-to-city pairs for high speed rail links indicates that railways will challenge many short-haul air links.

A number of market barriers have been identified; for example slow progress in some member states to open their railways; and some documentation biases still exist.

Road transport

- Electric cars could contribute to savings of 5 Mt CO₂/year if the national and regional objectives of 5 million electric vehicles on the market by 2020 is met.
- Navigation devices can make car journeys shorter. In a study for TomTom, researchers found km savings per journey of 6-16% and time savings of 11-18%. With nearly 40 million “sat nav” users across Europe, this represents a saving of 10 million hours in traffic and more than 100 million vehicle km.
- In London, Cologne, Amsterdam and Brussels, drivers spend 50+ hours a year in road traffic jams. In Utrecht, Manchester and Paris, it is more than 70 hours.
- The share of road transport in intra-EU long distance freight transport is around 33%; rail and inland waterways jointly contribute less than 20%. The poor environmental performance of the transport system is linked to greener rail and inland waterways transport not exploiting their potential in longer distances.

Including short journeys, road transport carries about 40% of freight and the majority of passenger journeys involve road transport. Not only is it a major industry in the EU28, it is one in which much change is happening. Firstly are the changes in vehicles to hybrid power-trains, fuel cells and fully-electric automobiles, recognising the need to reduce emissions. Uptake has been slow, but this trend is rapidly increasing as the technology matures and support networks are set up. Secondly, the growth of IT in the vehicle, which shows no sign of stopping, has changed the vehicle to a mobile node in an information and control network. The progress towards fully-autonomous road vehicles emphasises the importance of this networking across the EU28, providing information to passengers and to vehicle control systems, and using information from both of these to manage traffic systems. In principle, it is a small step to move further and link these networks to others for rail and air transport to optimise the journey experience both for goods and for people.

A second benefit from these networks is the potential to change business models; to move much more to a service orientation, where leasing or hiring vehicles rather than outright personal ownership is the goal. Already, early forms of this exist; UBER is perhaps the best-known example for joining itinerant drivers with intending travellers. It is likely that the automotive OEM’s will move rapidly to enter this market as well over the coming decade.

A secondary benefit is the potential for reductions in traffic congestion. All the different progresses mentioned above will help to reduce congestion; the move to a service model with much greater utilisation of individual vehicles will be of considerable help. Since this business model has several
other benefits, such as encouraging more reliable vehicles of much greater longevity and near-zero emissions, as well as releasing parking lots for building, there will be good progress on air quality and better conditions for people.

3.4.2 Revision of the requirements

In the subsection on urban mobility, it was said that mobility constitutes a system of systems with a tangled and convoluted collection of feedback loops within and between the systems, with a multitude of different goals for the community and for the individuals within, and that this is a description of a wicked, non-stationary problem. This wicked problem grows in size once the supply lines are included.

It was also stated that finding some form of co-ordinated, sustainable solution must be brought about incrementally. The sheer scale of investment, spread over many years; the resources to realise the solution(s) are distributed between the EC, member states, research institutions, manufacturers, civil engineers, and transport organisations. For example:

- The cost of EU infrastructure development to match transport demand is estimated at over €1.5 trillion for 2010-2030. Additional investment of a trillion euros in vehicles, equipment and charging infrastructure is needed to achieve emission reduction goals. Completion of the TEN-T network requires €550 billion by 2020, of which €215 billion to remove the main bottlenecks.
- The average lifetime of a plane is around 30 years, of ships around 28 years and train rolling stock is replaced approximately every 35 years.
- It takes up to 20 years to build a motorway, from planning to construction. Average cost per km depends on the location and complexity of the route; between €7.1-26.8 million.
- It is estimated that the present value of investments to developing the electric road transport infrastructure in the EU would be in the range of €80-140 billion.

Three strands of development seem evident.

1) The development of sustainable vehicles with extensive intercommunication capabilities.
2) Most modes of transport will require changes to the infrastructure, both to extend their routes and to enable better intercommunication.
3) Governments at many levels of the EU28 act to create a regulatory environment that creates incentives to deliver the development in strands 1 and 2, and to address public acceptance.

Taking the last of these first, generating a shift in the public's attitudes to transformed mobility will require a concerted attempt for people to adopt the health benefits of human-powered motion and to give up the notion of vehicle ownership.

The first two strands offer the best hope of producing this transition. The arrival of better vehicles, offering benefits over those on offer, and their gradual percolation into service, coupled with advantages on journey times through intercommunication will help. Self-evidently, they will have to happen in parallel and in concert, to create both the feeling and the evidence of significant technical advances.

In addition, there will necessarily be government involvement in adjusting the legal framework that covers transportation and safety in transport, ensuring commonality across jurisdictions, and in protecting individuals against the power of the large organisations that will probably dominate the transport sector.
Summarising the comments above,

1) The technologies to address most of the vehicle and infrastructure issues are almost available (all at TRL 5 or above); there are the social and political issues of public acceptance, infrastructure funding, legal and regulatory adjustments, and issues of insurance still to be solved. There is a joint role for government and industry to deliver solutions to these, at European and member state levels.

2) Given the complexities involved and the multitude of constraints, requirements, desires and goals that will apply to future transportation, a gradual approach to implementations will likely produce the best results. Because transport will serve smart communities in the future, test cases and extended pilot implementations based on smart communities may present the best incremental way forwards. At a later stage, connecting these together may be a good way to grow our understanding of future transport and in gaining acceptance from the public.

3) Transport does not recognise borders (except for legal reasons), so action at the Commission level is necessary, even fundamental to success. Initiatives such as ERTMS in railways, SESAR for air transport, TEN-T for waterways and ERTA for roads have created frameworks, but member states have important roles to play in removing commercial barriers to progress.

4) Transport is a domain in which a multitude of small enterprises coexist with large firms. Among the former, the awareness of future change appears limited, coupled with fierce competition for markets. This combination can produce fear of the future, leading to resistance to change and a demand for protection from change. These two factors will need some inducements and incentives to overcome these barriers, again indicating a need for positive action by governments and trade association in combination.

5) Future changes, involving a heavy reliance on software, will require transport organisation to become adept in new skills, both to exploit the opportunities that embracing CPS will provide, and in maintaining their own capabilities to prosper.

3.4.3 Non-technology elements

There are a number of important non-technical issues that require attention, mainly because of the disruption effects of transport technology, leading to business winners and losers, on a large scale. These include sustainability issues, agreements on the legal aspects of interoperations of platforms to enable the creation of transport ecosystems, new business models appropriate for these ecosystems, and the removal of national constraints that hinder more rapid progress. Dealing briefly with each of these in turn, while recognizing the links and parallelisms among them, the following can be said.

1) Sustainability. Currently, transport has a large influence on sustainability, through its emissions and through the sheer numbers of vehicles being produced around the world, as developing countries move to modern forms of transport. Emissions reduction targets will necessitate investments in alternative forms of motive power, such as electricity and hydrogen power; however, although great strides have been made in the technologies, with more to come, there are financial, legal and business models issues still to be addressed adequately. The move to non-fossil-fuel systems represents a significant disruptive change to national economies that will require time for change. The number of vehicles is also a potent driver of emissions; however, the rapid development of autonomous control of vehicles, coupled with the development of new business models as represented by firms such as Uber, Lyft, and others, turning into transport –as-a-service (“mobility by the minute”) is expected to lead to a reduction in the number of vehicles produced and recycled through more efficient utilization and better design necessitated by the new business models. Nevertheless, this again represents a major disruption to national economies, so we may expect slower progress towards the benefits. Firstly, there are issues of social acceptance of these new technologies
by the population. For example, for many people, driving is a form of self-expression and of relaxation after a period of stressful work. For others, the ownership of a prestigious, perhaps old, vehicle is a status symbol (for example, there is an expanding market for expensive mechanical watches), and for still others driving represents freedom from timetables and pre-planned routes. Secondly, there are significant economic effects on jobs. The transport sector in the EU provides about 12 million jobs, many of which are likely to disappear as new technologies are introduced. Of those remaining, there are likely to be required skills changes, to accommodate the new technologies; it is not obvious that current incumbents of these jobs will be able to acquire these new skills easily since the educational base required may be too different.

It should be noted that less vehicles on the roads has benefits for smart cities, both for reducing the need for parking spaces (for example, an OECD study indicates that 90% of parking space could be recovered\(^\text{56}\)) and for assisting the energy sector by buffering electrical energy storage, both of some importance for the delivery of a sustainable society. One other aspect that has big implications for sustainability is what is known as ‘weightless manufacturing’, typified, for example, by new additive manufacturing technologies, commonly known as ‘3D-printing’. This technology indicates that the movement of goods may be heavily reduced, since almost any device can be manufactured locally. As with all the examples in this section, this will be disruptive to business models and trade, so we may expect slower progress than is possible.

2) Platforms and ecosystems. Platforms are the basis for new business models, as evidenced by the platforms owned by Google, Apple, Facebook and Amazon, which have been very successful in opening new business opportunities. However, the transport domain has other characteristics such as real-time operation and great requirements for connectivity, indicating that transport platforms necessarily must interoperate, both at the technical, business and strategic levels. Security and legal issues abound in this, again indicating that progress might be slower than expected, particularly when these issues cross national borders. Furthermore, because of the close interconnections between transport and most other domains of human personal and societal activity, it is likely that transport platforms will be rapidly combined with other platforms to create extensive eco-systems, functional across borders and jurisdictions. However, the need for standardization for this goal to be reached indicates that delays will be inevitable.

3) Legacy issues. Transport has been around since pre-history, so we may expect that there will be a multitude of legacy issues from the past. Within the EU-28, these have been surfaced by the movement towards a Transport Single European Area, as discussed above. These legacy issues range from hardware problems (e.g. different rail systems, different canal specifications etc.) through software and business issues (e.g. documentation, tickets, etc.) to human and cultural issues (e.g. suspicion of and resistance to automation and the pressures for conformity, the emotional involvement with old transport devices, etc.)

4) There are significant ethical issues to be addressed when implementing the technologies and approaches discussed above; these are mainly to do with responsibilities and trust. At a basic level, trust between drivers and autonomous vehicles will be important for the prevention of accidents, as will trust between all transport users and the infrastructure of communications on which they will all depend; gamification is likely to be an issue here, leading to something considerably less than a Nash equilibrium. Likewise, given the plethora of independent actors

---

in the transport sector, all necessarily interacting to provide a comprehensive service to society while maximising their own system benefits, there is the potential for a less-than-optimal outcome, absent the presence of trust between the actors. Contracts do not provide a sufficient constraint on ‘selfish’ behaviour; there is a need for a ‘partnering’ approach, going beyond the details of contracts and ably described by Paul Coelho\(^\text{57}\). Given that the transport CPSoS is extremely complex and in continual flux, any actor within the network with a limited view of the network’s functionality is likely to be confronted by continual changes of strategy without obvious causes being evident, may become subject to frustration leading to behaviour characterised as the ‘Tragedy of the Commons’\(^\text{58}\).

All of these elements have deep connections with society and the way individuals like to live their lives. Consequently the processes of bringing about extensive change will require small, co-ordinated steps across many domains mentioned above to achieve a sustainable, efficient and effective society and transportation infrastructure within the EU28. Technologically, most of the requirements are already available, so in theory progress could be fairly swift. It is the investment costs and disruptive effects that will mean that progress is slowed to a pace of change that the EU28 can absorb.

3.4.4 Mapping of requirements into technology

As indicated in the section above, the problem is not so much the mapping of requirements into technology; much more it is the management of technology into society. Most of the relevant technology components are already at TRL6 and above; it is issues of standards, laws, regulations, and the acceptance of change by populations that are the constraints on progress. Complicating these issues is that transport is an individual thing, albeit created and operated by large organisations. The implication of this is that actual progress will be brought about by bottom-up developments leveraged by governments and large organisations, assisted by Joint Undertakings and Large Scale Pilots; the projects 3Ccar and MANTIS within the ECSEL programme are examples of the former, in which in which the issues in this section are being addressed. Large Scale Pilots will include concepts of the Smart City; as these are realized across the EU28, so transport will be realized simultaneously, to power local economies and to provide citizens with the mobility they and their business interests will need. Without doubt, there will need to be Grand Projects as well, such as the Chinese plans for new East-West railway links, with the benefits that one can foresee.

3.4.5 Timeline – Definition

This exercise in bottom-up progression to a sustainable transport future has all the hall-marks of a ‘wicked problem’, especially when combined with the requirements for transport endemic to the other domains discussed in this deliverable. As said above, it is not developments in the technical elements that will determine a timeline for progress; it is the non-technological requirements that will determine progress, and these are likely to be solved piecemeal and in distributed fashion across the landscape of cities and regions. Therefore, we may expect progress to be continuous, punctuated, distributed and determined, fitting more or less into the EC’s transport plans, and without definite milestones. It is for this reason that the transport Roadmap at the top of this chapter has only the one entry.


Nevertheless, many technologies and regulatory developments will be necessary:

<table>
<thead>
<tr>
<th>Technology and Application</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop reliable, safe, in-vehicle autonomous navigation &amp; control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated applications for continuous Big-Data-based situation awareness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of distributed High Performance Computing technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Architecture for support infrastructure for autonomous vehicles and for non-oil power units</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation of reliable, safe, support infrastructure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of IoT, incorporating new technologies (e.g. 'Fog computing') for efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop modelling &amp; simulation environments for control and interoperation of transport networks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creation of regulatory environment to enable &amp; implement autonomous transport networks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop business models for autonomous transport networks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>develop near-field communications for autonomous transport networks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 23 development timelines for strands of ‘Smart Transport’
3.5 Smart Energy

3.5.1 Introduction
The move towards sustainable society will impact heavily on the energy sector (Anderson et al 2008, Centre for Strategic and International Studies 2009, PriceWaterhouseCoopers 2010). We discuss here some major challenges for energy – concentrating on electricity, but also considering heat, oil and gas – and technologies under development.

Aging infrastructure
Much of Europe’s transmission network is ageing and inefficient (Hashmi 2011). Significant capital investment is required to increase its capacity, capability and efficiency. Newly developed and upgraded infrastructure must be future-proofed as far as possible, with increased capacity and greater resilience than ever before, to cope with projected environmental effects of changes in climate and weather patterns, which affects both the security of the infrastructure and generation capacity as well as patterns of demand.

Changes in energy generation
Europe has committed to decarbonised electricity production by 2050 (European Climate Foundation 2009), as outlined in European Directive 2010/40/EU. This mandates migration away from carbon-based energy sources to renewable energy sources (RES) (Centre for Strategic and International Studies 2009). When coupled with requirements for increased resilience, this forces major changes in how electricity grids are currently organised – for both the technology used and the market structure. Current energy transmission and distribution infrastructure assumes a small number of large-scale power producers and many small-scale consumers (e.g., homes and offices), with energy generally flowing in one direction from producer to consumer (Hashmi 2011, acatech and EIT ICT Labs 2012). RES do not always conform to this expectation (ASME 2009) and often involves larger numbers of widely-distributed, small-scale generators (GRID+ 2013, acatech and EIT ICT Labs 2012), with energy not limited to a uni-directional flow from high voltage producer to low voltage consumer. Power producers and consumers may not be separate organisations and production facilitates may not be sited close to population centres. Small-scale wind turbines or solar panels can be installed on many private or public buildings, resulting in buildings that sometimes draw from the grid, and sometimes supply excess power back. Actors which can shift role from consumer to producer and back again affect the design and implementation of Demand-Side Management (DSM) policies, which are used to smooth peaks and troughs in energy demand, as well as affecting the economics of the market structure (we discuss this later). Many RES experience marked fluctuations in ability to generate (ROAD2SOS 2013, acatech and EIT ICT Labs 2012), driven by climactic conditions which are difficult to predict far in advance. As a result, conventional techniques for ensuring that energy demands are met must be adapted to accommodate less predictable and less controllable generation methods. A new model of how to cope with unexpected events and/or unusual weather patterns (GRID+ 2013) is needed, including unpredictable events such as storms or floods that threaten infrastructure, with redundancy and resilience built into the system. Finally, there are few metrics and standards for describing and comparing disparate energy sources and integrating them (ASME 2009).
Changes in demand

Energy demand has increased in recent decades and is expected to continue (European Climate Foundation 2009); some predictions suggest an increase of somewhere between 45% (Centre for Strategic and International Studies 2009) to 60% (Battaglini et al 2009) before 2030. Reasons include:

- Increasing adoption of electronic and CPS devices.
- Substantial increase in smaller households, especially single-person households (Torriti 2012). Each separate household imposes extra energy overheads.
- A preference for electricity rather than hydrocarbons (e.g., for heating and transport), because electricity can potentially be generated using non-polluting, sustainable methods. For example, requirements to charge electric vehicles (EVs) regularly and meet heating requirements in a decarbonised European energy economy will place substantial extra demand on electricity suppliers (acatech and EIT ICT Labs 2012).

Load balancing challenges

Supply must be matched to demand in order to prevent network instabilities or black-outs, with sufficient energy at peak times and minimal surplus at times of low demand. Conventional techniques for managing load balancing have been based on large central generation and controllable industrial load (GRID+ 2013). Load forecasting involves producers contracted in advance to generate more power when large demand is anticipated. These techniques are not sufficient to cope with the evolving infrastructure (GRID+ 2013) and changing patterns of demand as production methods are diversified and RES which deliver fluctuating power (Battaglini et al 2009, European Directive 2010/40/EU) are increasingly exploited (ASME 2009). Load balancing is particularly challenging when generation and demand are both fluctuating and not synchronised (acatech and EIT ICT Labs 2012).

3.5.2 Revision of the requirements

Key market needs relevant for CPS in the energy domain include the following.

1) Energy produced meets demand
2) The energy sector can cope with distributed and diverse sources of energy
3) Infrastructure is self-healing, fault tolerant and secure
4) Heat demands are met in a decarbonised infrastructure
5) Energy is affordable for domestic and industrial consumers
6) Decision support is available based on real-time information
7) The sector delivers effective load management
8) The marketplace incentivises and rewards investment

3.5.3 Technological and non-technological elements

In this section we describe future expected developments for addressing the above challenges. Many strategies are require technological advances as well as socio-technical developments.

Managing demand

Strategies for load balancing include “Demand Side Response” (DSR) strategies, to influence consumer behaviour (Torriti 2012, GRID+ 2013, Hashmi 2011), usually via financial premiums or discounts applied at certain times to match current demand with current supply. CPS technologies are key to implement this on a large-scale. For example, operators setting DSM pricing policies need a real-time view of the
current grid status (i.e., whether there is a current surplus or a deficit). In addition, consumers need information on current pricing in order to make decisions; this can be provided by smart meters. “Smart” charging technologies are also useful; e.g., a charging station capable of monitoring current DSM policies and making intelligent decisions about when to begin charging a large battery could help to achieve optimal load balancing, particularly if it’s possible to negotiate with other similar nodes in the local area to ensure that the demand for power is distributed evenly. Smart metering technologies will support the development of an engaged and informed consumer base and increase the effectiveness of DSR.

Changes in the marketplace

A well-designed energy market incentivises appropriate stakeholders to make the necessary capital investments to ensure efficient, clean and cost-effective energy generation, transmission and distribution (acatech and EIT ICT Labs 2012), allowing them to recoup the capital costs, whilst motivating all stakeholders to participate in global efficiency moves. In recent years, deregulation of the energy markets has created a complex and rapidly-evolving sector (CPSoS 2015), where traditional roles are subject to significant change, and new roles and stakeholders emerge to make key contributions. Real-time electricity markets and aggregators have appeared, and now play a potentially important role in load management strategies - as long as the need for improved data exchange, real time control and real-time economic models can be achieved (CPSoS 2015). Changes to the energy marketplace have dramatically increased the amount of energy transmitted between regions (Hashmi 2011). Market liberalisation and “unbundling” of previously centralised structures has created a landscape where processes that were once centralised are now implemented by independent and distributed stakeholders (ROAD2SOS).

Roles are evolving in other ways, and are not consistent across all European member states. For example, Transmission System Operators (TSOs) manage fixed, wide-area infrastructure, whilst distributors manage and maintain the infrastructure required to transport energy from the wide-area grid to final consumers. Distributors are increasingly expected to adopt the role of facilitating effective and well-functioning retail markets for energy (eurelectric 2010), effectively evolving their role from a conventional Distribution Network Operator (DNO) into that of a Distribution System Operators (DSOs). DSOs provide active system management to co-ordinate energy sources and energy demands within the local region, to “control networks capable of intelligently aggregating many different geographically dispersed inputs” (Malot 2014). Currently the range of roles and capabilities of energy distributors varies across Europe, with some regions relying heavily on DNOs (e.g., in the UK), whilst distributors in other regions exhibit DSO-style capabilities to varying extents. This variation can complicate deployment of new technologies, since implementations need to account for regional variations.

Distributors increasingly need to provide options for consumers to choose the best supplier as well as allowing suppliers to offer a range of services (eurelectric 2010). However, the traditional energy market does not provide distributors with a wide-area network view of the current market conditions. Market results (i.e., prices and supplies agreed in advance after a round of forecasting and bidding activities) are conventionally communicated to the TSO only (evolvDSO 2014). Increasingly, stakeholders and generators connected to the DSO networks can bid and participate in the energy markets, (evolvDSO 2014) and need access to this data.
Collecting real-time data and developing a global view

With the “big-picture” view at its disposal, the TSO traditionally has responsibility for coping with detected failures or other problems, making requests to DSOs when necessary, but these roles may need to evolve further to ensure that smart grids are flexible and resilient and distributors can react to local conditions. It needs to be easier to generate a systems view, in real time, of current demands, supply and pricing, for all relevant stakeholders (e.g., to support application of effective DSR or for fault tolerance purposes). Currently this is difficult and the lack of information hinders the application of many important techniques and strategies, such as DSM and dynamic configurations. There are several reasons why this is difficult:

- Co-ordination between necessary stakeholders is sometimes hindered by variations in such a complex cross-border marketplace
- Large quantities of data are needed to support this process and there is no installed infrastructure capable of transmitting this data at high speed
- The infrastructure for generating this data (e.g., smart metering) is not fully installed, and the progress towards this varies across the member states currently
- There is considerable heterogeneity in the approaches towards monitoring network state – e.g., distributors and TSOs collect very different data about current state, and at markedly different intervals/granularity

The current, highly-fragmented value chain needs to be closed, and an increased amount of interoperation between the different types of operators to enable this systems-wide view. Techniques for modelling, planning and understanding the implications for the wider region for decision-making and cost-benefit analysis are needed (European Climate Foundation 2009). An anticipated increase in the use of sensors within infrastructures (ROAD2SOS 2013) will mean more information can be made available to planners and decision makers.

Smart Grids

A smart grid (Fang et al 2011, Hashmi 2011, Giordano & Bossart 2012) is an energy grid which is extensible, reliable, optimised, secure, resilient and flexible enough to cope with many small and large scale producers as well as with demand variations (Hashmi 2011, Coll-Mayor et al 2007). An optimised smart grid will rely on sharing large quantities of data generated from distributed units over large regions, in order to monitor current network conditions and co-ordinate the current power supplies. A smart grid employs a bidirectional flow of information and/or energy, and may apply intelligent strategies to ensure any or all of: improved grid reliability; improved control; improved infrastructure for generation, transmission, metering and consumption (Fang et al 2011, Centre for Strategic and International Studies 2009), as well as full cyber-security (Giordano & Bossart 2012). In contrast, a traditional grid is uni-directional, transmitting energy from high voltage suppliers to low-voltage consumers, with limited flexibility and limited access to real-time network information. Smart grids may be implemented by combining one or several CPS technologies, including: smart meters which support two-way communication (ROAD2SOS 2013); smart monitoring for assessing grid status; and phasor measurement units to ensure reliable power transmission (Fang et al 2011). Data shared in this way must be up-to-date in order to generate and distribute policies that help the grid achieve its real-time, current objectives, requiring high speed communications to meet the global grid real-time requirements (REServiceS 2014, evolvDSO).

A smart grid aims to adapt to demand response (GRID+ 2015) and increased flexibility will be needed in each local area. This can be achieved through DSR and smart metering to some extent, but other
techniques will also be needed. Energy storage is important (acatech and EIT ICT Labs 2012), and is currently subject to significant research investment, although large-scale, industrial-scale energy storage is still in its infancy. The demand for storage has generated many research projects which are largely non-synchronised, funded by various separate bodies, covering a diverse range of technologies (GRID+ 2015, Coll-Mayor et al 2007).

Smart grids are frequently viewed as a largely small scale, localised solution, which is not readily scalable. However, key problems of addressing demand/supply disparity and congestion could also be tackled through much larger, interconnected wide-area power grids, capable of delivering surplus from one area over large distances. Due to small differences in climate, time zones and cultural practices, actual peak demands across Europe do not coincide exactly and a very large grid connecting many countries allows these regional variations to absorb differences in demand hour-by-hour (Battaglini et al 2009, ROAD2SOS 2013). A European “super” grid could even connect European and North African countries (Battaglini et al 2009, Torriti 2012). However, current infrastructure does not yet permit such a flexible wide-area flow of energy. The European energy system is divided into five interlinked (via subsea cables) but separately managed grids with each potentially further partitioned into national areas. Congestion arises at many national or grid borders (PriceWaterhouseCoopers 2010) where interconnection capacities are limited (European Climate Foundation 2009, Coll-Mayor et al 2007) and the installed infrastructure cannot cope with moving significant amounts of power sufficiently quickly from one grid to another. What is needed is a smart grid of large scale, but this goal faces substantial scalability challenges, since there is little experience in handling the millions of bi-directional data nodes involved (Fang et al 2011). In addition, the emergence of flexible smart grid technologies is expected to result in a move towards decentralised architectures, but reliability and security in decentralised control algorithms are not yet well understood. There is, furthermore, considerable uncertainty about how decentralised control will scale to a commercial energy infrastructure. Large-scale grids may face problems of efficiency, since energy is lost when transported over long distances.

Quality of Service

Quality of service (QoS) is an important consideration for building an effective market structure; key QoS indicators include voltage quality and continuity of supply (evolvDSO 2014). The evolving energy marketplace must ensure that it is economically possible to deliver a high quality network. There must be capability to monitor this effectively and respond when QoS is not met. Some regions within Europe take QoS indicators or cost-effectiveness into account in the market structure already, but increased take-up of RES is likely to challenge current market incentives, since a rapid adoption of RES on a large scale will require DSOs to cope with variable generation that can lead to instability or network overloading (evolvDSO 2014). There’s a need for metrics and standards for describing, comparing, and integrating disparate energy sources, including discussion of QoS elements. Greater use of probabilistic techniques will be employed in the future to model and plan infrastructures, including calculations on appropriate levels of redundancy which will be required. Current techniques rely heavily on deterministic modelling, but this can result in too little or too much redundancy in order to meet the twin goals of affordable energy & infrastructure on the one hand, and sufficient resilience and QoS guarantees on the other.

Meet heat demands in a decarbonised energy sector

Heat demand exceeds electricity demand in many European regions. For example, heat is the single biggest energy use in the UK (Chaudry et al 2015), exceeding electricity demand by 5 or 6 times during
peak months (Maclean et al 2016). Shifting heat generation to decarbonised sources will place a major demand on alternative sources of heat to replace the combustible sources currently used. Heat demand is mostly driven by heating for buildings and generating hot water, and so technologies to improve building and water efficiency will become particularly important (MacLean et al 2016), including both new buildings and retrofitting older buildings. A range of solutions will be needed to meet this demand, potentially including: electrification of the heat supply; district heating; biomass and biogas; solar thermal; and repurposing gas grids with hydrogen (MacLean et al 2016). All of these solutions will require significant technology infrastructure, including development of technologies (including CPS enabled technologies) to cope with seasonal variations in demand, and heat storage.

**Oil and gas**

Much of the discussion in this chapter is directed at electricity generation, but can also be applied to the oil and gas sectors as well. Adoption of digital technologies and advanced analysis in the oil and gas industry is considered to lag behind other industries (Larsson 2014, Blanter and Chidambaram 2016). The oil and gas sector shares an increasing pressure to improve operational efficiency and responsiveness, across the oil & gas value chain: upstream operations (exploration and production), mid-stream (transportation) and downstream (refining and retail). Cost and capital investment are significant in this sector, as they are in electricity generation, and as a result there’s great interest in improving efficiency by optimising the supply chain and maximising productivity. As with the electricity market, gas and oil infrastructure is in many cases aging (GE 2014), and the marketplace is beginning to see more flexibility in traditional roles (although not the same extent as the electricity sector). We describe here challenges and CPS applications specific to the oil and gas sector.

Upstream stakeholders in oil and gas are interested in analysis of diverse sets of data, including physics and cross-disciplinary data, to improve knowledge (Slaughter et al 2015). CPS technologies can make contributions here, by supporting advanced multi-paradigm modelling. Hydrocarbon extraction sites are increasingly likely to move to locations which are hostile and complex or difficult to access (e.g., in deep water or requiring substantial drilling), which become economically-attractive only after more readily-accessed reserves have been tapped. At the same time, existing large extraction sites have significant maintenance requirements (Slaughter et al 2015). For these reasons, increased automation – including robotics, autonomous devices, and advanced sensing and analysis - is needed at very exploration and extraction sites, to reduce costs and improve safety. Supervisory control and site management systems can make use of CPS technologies for gathering environmental data and making decisions to improve productivity, accuracy and safety, although the range of proprietary tools and platforms which are available can become a barrier to adopting CPS methods. Open standards to share this type of data would improve interoperability across an increasingly complex range of tools and data types in use, including both new tools and legacy systems (Slaughter et al 2015).

Mid-stream stakeholders (responsible for transportation) are increasingly dealing with variable volumes and grades of product, transported from multiple locations to varying markets and users (Slaughter et al 2015), which represents an increase in flexibility compared to previous decades. The sector particularly suffers from aging pipelines and manual legacy systems. Data-enabled infrastructure can use advanced sensing equipment to monitor pipelines intelligently (Slaughter et al 2015). For example, advanced collections of diverse sensors (TransCanada 2014) and “smart pigs” (Snyder 2014) can be used to improve detection of external leaks. Some estimates suggest that modern, smart pipelines which make use of industrial internet sensing and analysis technologies are capable of generating 10 terabytes of data for each 150,000 miles of pipeline (GE 2014). Although the
oil and gas network is not experiencing a market restructure in the same way as the electricity sector, midstream operators can leverage the large amount of data generated from across their networks to collaborate with downstream operators to develop new value chains, including finding and exploiting new markets; pricing incentives may even be used to even out peaks and troughs in demand (Slaughter et al 2015). To be effective, this typically requires integration of large amounts of highly diverse data, including from sensors in the network, weather and information from logs.

Downstream operators (refiners and retailers) have strong economic incentives to ensure that production and operations are efficient. Ineffective maintenance, for example, can result in expensive unscheduled shutdowns (Slaughter et al 2015). CPS technologies based on sensing devices, wireless communications, open protocols and advanced analytics permit maintenance to be planned in a more effective way, by studying performance and state of components to identify areas where inspection and maintenance are needed and prioritising maintenance schedules accordingly (Slaughter et al 2015). Data is also used heavily to optimise the oil and gas supply chains. In some markets this has led to greater flexibility between the supply chain operators, with refiners (for example) in the US switching away from buying medium and heavy crude oil under long-term contracts to flexible arrangements for buying more diverse crude blends dynamically (Slaughter et al 2015). The complete supply chain can include retailers and even automotive suppliers, using CPS technologies to build in-car platforms that can nudge drivers towards particular brands or behaviours.

Workforce skill

The energy sector as a whole currently lacks staff with experience and training in CPS technologies and fields; most technical staff will have training and expertise in engineering or in computer science, but not both. However, techniques for designing and analysing energy infrastructures which are resilient, secure and fault tolerant will require considerations of the physical properties of the infrastructures alongside greatly enhanced digital capabilities. Technical staff with appropriate skills will be in increasing demand.

3.5.4 Mapping of requirements into technology

Technology is described here, and linked to requirements. A much more detailed mapping is provided in Figure 20.

- Large-scale European grid capacity should be increased with new long-distance transmission lines across national borders to avoid congestion and improve load management (acatech and EIT ICT Labs 2012, PriceWaterhouseCoopers 2010, European Climate Foundation 2009, Coll-Mayor et al 2007) (Requirements 1,5,7)
- Grid infrastructure must be adapted to cope with many distributed sources of energy, as well as distributed co-ordination and optimisation activities (ROAD2SOS). Grid infrastructures must be capable of coping with supply chains where many participants may be either consumers or producers and a bidirectional flow is needed. (Requirements 1,2,3,7)
- There’s a need for increased interaction between different types of operators (e.g., aggregators which can ease harmonisation of local supply and load (GRID+ 2013)) and wider adoption of ICT communications technologies to share real-time network status and pricing information. Common market-specific communication and data management systems are needed (eurelectric 2010) (Requirements 1,3,6,7)
More uniformity in regulation and in strategic planning is needed (GRID+ 2014a, METER-ON 2014, Hashmi 2011, acatech and EIT ICT Labs 2012) so that effective strategies can be implemented across Europe (evolvDSO 2014). (Requirements 2,5,7)

Figure 24 Mapping of requirements into technology. Smart Energy

- Standardisation is needed across national boundaries (Hashmi 2011, Coll-Mayor et al 2007). This includes data formats, platforms and procedures used to exchange forecasting data (REserviceS 2014). Product standards are needed to avoid expensive incompatibilities (REserviceS 2014) and to ensure interoperability. Standardisation is needed not only for communications, but also for ICT components, energy data semantics and harmonised smart grid processes (acatech and EIT ICT Labs 2012). (Requirement 2, 3, 5,6,7)

- Metrics and standards are needed for describing and comparing disparate energy sources and integrating them (ASME 2009). (Requirement 2)

- A real-time systems view must be possible, to share current network status across wide regions (COMPASS 2014) to enable pricing models to adapt to demand (ROAD2SOS 2013). Visualisation tools for decision support are needed (ROAD2SOS 2013). (1,3,5,6,7)

- DSR policies should be exploited to a much greater extent. This requires an ability to provide real-time pricing to consumers so that they can respond immediately. Data communications which are real-time, high speed are needed (see above). (1,7)

- Further research is needed on cost-effective, efficient means for energy storage (CPSoS 2015), including heat. Research would benefit from increased co-ordination efforts between national and European funding bodies. (1,4,7)

- Investment is needed into technologies that allow energy to be consumed on demand, regardless of where it was produced. An efficient management platform is needed to identify the optimal routes, dynamically updating depending on current global and local conditions.
Advanced software tools are needed to develop appropriate control algorithms (RESserviceS 2014). (1,7)

- Improved probabilistic planning and/or forecast methods are needed (RESserviceS 2014 acatech and EIT ICT Labs 2012) to help with demand management. Forecasting is currently a key tool used by TSOs to ensure that demand is harmonised with supply, but must be adapted as predictable outputs of large-scale carbonised power stations are replaced with distributed RES. (1,3,6,7)

- Tools and techniques must be available to ensure the security of the increased data communications for smart, flexible grids (METERON 2014, ROAD2SOS 2013). This can include techniques drawing on cyber-security, architectures, and regulatory frameworks to clarify privacy and security requirements. (Requirement 3)

- Models and techniques are needed to allow DSOs to design resilience policies in light of the expected new grid topology that will emerge. Generic, systems-level views of resilience are needed in addition to domain-specific models of infrastructure (COMPASS 2014) and views to allow local smart grids to react flexibly to local situations. Stochastic models integrated into the verification and analysis tools will allow unusual events to be simulated and analysed (COMPASS 2014). Technologies for self-monitoring and self-healing are needed to improve the resilience of the infrastructure (CPSoS 2015). (Requirement 3)

- Design approaches that can integrate the demands of a varied range of engineering, ICT, marketplace and climactic domains are needed (COMPASS 2014). This is likely to require incorporation of hybrid modelling approaches, including continuous-time, discrete event and market modelling approaches, for example, as well as the need to incorporate stochastic elements (COMPASS 2014, CPSoS 2015). (Requirement 1,2,3,4,7)

- Where possible, energy consumption should be reduced. Energy consumers must be engaged and well-informed. Devices and equipment must be efficient. Continuing advances in smart and efficient power electronics can help to improve energy usage and efficiency. Techniques for harvesting energy and re-using “wasted” energy can help. Technologies and techniques to improve building heat efficiency or hot water efficiency are particularly important given the scale of heat demand compared to electricity. (Requirement 1,4,5,7)

- Advances in big data will be necessary to underpin the increasing reliance of the energy sector on smart digital technologies. Within millions of devices communicating in real-time, the data infrastructure used by the energy sector must be capable of transmitting and processing large quantities of data and conducting analyses to produce decisions and recommendations, and this must be conducted quickly enough that decisions are still relevant. (Requirement 6)

- Decentralised architectures are increasingly likely in large area networks. These must be reliable, scalable and efficient. Dynamic reconfiguration is a technique for continuing to offer services (possibly with reduced QoS guarantees) when parts of the energy infrastructure is compromised; there is a need for dynamic reconfiguration which can be deployed quickly, with high confidence in its reliability and security (Requirement 3)

3.5.5 Timeline – Definition

The timeline for achieving change in the energy sector is very long, for a variety of reasons. Significant marketplace changes are required alongside major building and installation projects. As a risk-averse, safety-critical industry, innovations affecting the physical infrastructure do not tend to receive commitment until there is high confidence that they can deliver minimum standards of safety and reliability. Consequently, expected timelines for the changes discussed in this chapter are expected to
be delivered over decades rather than years. Below we suggest some aspects which are achievable by 2020.

- Strategies and technologies to reduce energy consumption are already making gradual progress, via innovations to reduce power consumption of existing devices, and via educating energy consumers about energy-saving practices.
- Smart meters are scheduled to be available to all consumers by 2020 in many areas of Europe. Once completed, availability of smart meters can support reduction of energy consumption by placing real-time information about current energy usage at consumers’ disposal. Smart meters are a key enabling technology necessary to begin implementing large-scale reactive DSR policies and pricing strategies.
- Availability of smart meters is also a key enabling factor that will support evolution of distributor roles, allow various stakeholders to develop a systems-wide picture of the current status of the grid, and facilitate better sharing of data between stakeholders. Development of this technology will take a step forward when smart meters are widely available by 2020, although other advances (e.g., in marketplace roles and the availability of an appropriate data infrastructure) are also necessary, which are likely to be delivered after 2020.
- Technologies to make increased use of “waste” energy are expected to make improvements by 2020.
- Technologies to improve energy storage are expected to deliver pilot results by 2020, although large-scale commercial deployment will be much longer.
- CPS technologies such as big data and advanced modelling and analysis techniques are currently being deployed to many areas of the oil and gas sector, which lags other sectors, and this is expected to increase installed capability by 30% in the next five years (Blanter and Chidambaram 2016). This will improve the industry’s flexibility and efficiency; smart detection of pipeline leaks, informed maintenance for refineries, and platforms to “nudge” users developed in collaboration with retailers and automotive manufacturers are likely to be early adoptees.

<table>
<thead>
<tr>
<th></th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce energy consumption e.g. through education, better building insulation, improving efficiency of existing devices, better power electronics etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Smart” grids (enabled by widespread deployment of smart meters, upgraded infrastructure, platforms &amp; data exchange) (electricity)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evolution of market roles, particularly distributor roles, enabled by better ICT infrastructure (electricity)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make increased use of “waste” energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.6 Smart City

3.6.1 Introduction

Smart City is a concept that appeared around two decades ago when cities started to become worried about the sustainability problems they were causing; problems basically linked to areas of energy and transport, without forgetting the phenomenon of the great deal of people moving from rural to urban areas. Urban populations will grow by an estimated 2.3 billion over the next 40 years, and as much as 70 percent of the world’s population will live in cities by 2050. In a general context where population is increasing sharply and the global climate is warming, cities consume 75 percent of the world’s energy and produce 80 percent of its greenhouse gas emissions. At the same time, the population is ageing: By 2050 the number of people over the age of 60 is expected to triple and will outnumber children under 15 for the first time in history.

Smart Cities must be ready to respond to the demands of today’s population and in the long term they must have a global perspective that includes, on the one hand, people and the fact of having an ageing population with their respective needs and on the other hand, an efficient management of resources and all of this within a dynamic city that is forever becoming more technological.

In this sense and due to growing global needs to create more liveable urban spaces, Smart Cities are emerging as a priority for research and development in Europe and around the world. Smart Cities require more than just technological solutions; they must be human-centric and built for the sustained, optimal livelihoods of their inhabitants. The vision of Smart Cities therefore calls for collaborations among engineers, architects, social scientists, and educators.

The CPS research and education communities will play a key role in Smart Cities R&D. Digital technology enhanced city to improve performance and wellbeing, to reduce costs and resource consumption, and to engage more effectively and actively with its citizens.

Smart Cities are associated to different types of technologies, but those that stand out the most are IoT and CPS. This is due to the fact that IoT and CPSs are designed to support applications that can manage enormous amounts of data and a wide variety of data from the environment. Thus, CPSs can

<table>
<thead>
<tr>
<th>Large-scale energy &amp; heat storage solutions, more flexible grids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big data techniques &amp; improved sensing -&gt; more efficient maintenance schedule (oil, gas, electricity)</td>
</tr>
<tr>
<td>Improved safety through increased automation (oil &amp; gas)</td>
</tr>
<tr>
<td>Real time market pricing &amp; demand management incentives (electricity) enabled by better ICT infrastructure</td>
</tr>
</tbody>
</table>

Figure 25 Timeline definition (Smart Energy)
boost the smart city vision by using information and communication technologies for more efficient and effective resource management. Smart cities focus on providing innovative and better quality services to its citizens by improving the infrastructure of the city while reducing the overall costs.

Smart cities can be seen as wide-scale cyber-physical systems, with sensors monitoring cyber and physical indicators and with actuators dynamically changing the complex urban environment in some way. Governments, organizations, and technology industries are rising to the challenges of increased urbanization, working to improve urban life by offering improved efficiencies with energy utilizations or services, for example.

The Challenge Communities ranging from small towns to megacities are looking to the power of emerging Internet of Things technologies to better manage their resources and improve everything from health and safety to education and transportation. They can meet their smart city needs with cyber physical systems (CPS) — interconnected hybrids of engineered and IT systems — if certain engineering. CPSs often support real life processes and provide operational control of Internet of Things objects, which allow physical devices to sense the environment and modify it.

On the other hand, and as in most sectors and aspects of life, Smart City transformation is essentially economically-driven in principle. With the components of the Smart City ecosystem, and the sectors in which these components form a platform for planning the transformation of the Smart City, it is necessary to adopt a realistic and pragmatic vision of such transformation according to priorities. Smart Cities do not appear overnight and their transformation entails costs that must be planned in short, medium and long term with a comprehensive perspective.

An added value of smart cities and an innovative market opportunity for cities is to monetize the amount of data collected. Big data players such as Amazon, Uber, Airbnb seek information that enhance the performance of the algorithms they run for improving the services they are offering. Smart city paradigm can complement the resources of these companies use directly from the city's platform. The deal among them (private companies and municipalities) offers cities an extra possibility for the sustainability of the smart city infrastructure.

3.6.2 Revision of the requirements

The requirements and needs within the Smart Cities domain are directly linked with the PERSON, who can ultimately take advantage of all of the different technology and developments that comprise a SmartCity. A city is intelligent when it is capable of responding to the needs of its citizens in terms of efficiency and when increasing their quality of life; this also includes economic sustainability in the long term and environmental sustainability, which directly affects the quality of life of a city's citizens. For all of this it is therefore necessary to gather information identifying the profiles of the users and their needs and generate forecasts and improve the efficiency in city management.

Efficiency and sustainability are transversal elements, essential in SmartCities and they affect all of the areas managed by the city, such as:

- Improved transportation, avoiding traffic congestion and improving fluidity and intermodal transport that is perfectly connected helping urban mobility to be more sustainable and reducing the length of journeys and waiting times. Information about the citizens, as the basis, but also the information of the citizen to the SmartCity expressing their needs and providing
information that will help to improve how to plan means of transport and communication routes.

- Management of resources: water, electricity and waste are cornerstones in city management. Water is a scarce resource that needs regulating, intelligent irrigation systems in public areas and the individual management of water in homes are essential elements. SmartGrids are important elements for energy efficiency that must be occur both at city level and also on an individual basis. Improve waste collection routes, encourage recycling, etc.

Aspects that result in air quality, pollution and noise reduction and consequently an improvement in quality of life. The creation of a single management ecosystem where all systems are interrelated and interact with each other, is where CPS has a great task to implement, and this is also where the awareness of politicians and citizens is a key instrument for success. In this field, comprehensive city management platforms are the ideal solution to take full advantage of the data, increasing efficiency and improving decision making.

### 3.6.3 Non-technology elements

In line with what has been stated above, non-technology elements are directly related with the human centric approach of all actions and policies implemented in cities.

The Public Authorities play a key role in guaranteeing the rights and obligations of the citizens and their role in managing resources is also essential. In this regard, the authorities also establish the legal framework within which SmartCities can be developed, paying special attention to the protection of the privacy and confidentiality of the data to be addressed.

On the other hand, SmartCities do not just suddenly appear out of the blue; the process implies a significant economic investment and this promotes the transformation towards a SmartCity model. Private-public partnerships are the current solution to the challenges that exist in cities and the private sector works together with and develops joint projects with the public authorities in a win-win relationship to promote developments in cities making them smart and improving the citizens’ quality of life.

All over the world there are a great deal of SmartCity initiatives that are more or less successful and this means a great amount of knowledge has been gained and can be shared by the different public authorities that manage cities. Learning from the mistakes made by other cities can lead to a successful implementation of a SmartCity model. Bearing in mind that SmartCities are configured by their unique characteristics and citizens, and can therefore not be copied, they must be adapted so that citizens feel the cities are theirs and to respond to real problems and needs.

Finally, SmartCities are not isolated territories; they interact beyond their borders, in fact, aspects such as the environment know no borders, a means of transport does not stop because it is moving from one territory to another; these and other aspects entail the need for cross-border cooperation among different cities and this will be essential to not generate isolated sectors and to improve the citizens’ quality of life.

### 3.6.4 Mapping of requirements into technology

Those identified requirements can be addressed through a combination of technological and non-technological elements. CPS’s challenge is to promote a new paradigm of SmartCities where the solution is not only technology and its interoperability, but also the interaction with non-technology
elements. The combination of both is to achieve a city that is really smart and capable of increasing the quality of life of its citizens.

The technologies to be implemented are the combination of those currently known and that will evolve throughout time. Interoperability among them and with those implemented in other SmartCities will be the key to success.

It has thus been identified that:

1) Experience sharing-collaboration, is related with an increase in a city’s efficiency, sustainability models and citizens/politicians awareness. The technologies to be implemented are CPS and CLOUD and the non-technological elements with Legislations, Financial Aspects and Cross-border collaboration.

2) Technologies interoperability is related to sustainability models, Data and Creation of inclusive ecosystems, being IoT technologies, platforms, cloud, CPS and Big Data.

3) Scarcity resources are related with the increase in a city’s efficiency, sustainability models and citizens/politicians awareness, technology to be implemented is BigData and non-technological elements are human centric legislation, quality of life and cross-border collaboration.

4) Data Driven sustainability is related with an increase in a city’s efficiency, sustainability models, Data and citizens/politicians awareness, the technologies being Platform, BigData, real-time and the non-technological aspects being public administration, quality of life and cross-border collaboration.

5) Digital divide overcome is related with an increase in a city’s efficiency and citizens/politicians awareness, the technologies being platform, HMI and non-technological elements being human centric, public administration, quality of life and cross-border collaboration.

6) Innovation ecosystem building related with sustainability models collaboration, data and Creation of inclusive ecosystems, all technology is implicated and the non-technological aspects are legislation, PPP, public administration and cross-border collaboration.

As seen, efficiency is a constant that appears repeatedly in practically all points, so, as already stated, efficiency and sustainability are transversal elements to be taken into consideration at all times.
3.6.5 Timeline – Definition

The following table shows the first draft of the timeline for the Smart City domain. Regarding the starting point, it is planned the evolution of some factors during the next year (such us CPS integration in city utilities, Security and privacy or Digital divide break), on the other hand, there are two factors that are scheduled to start in 2018, this is the case of Large scale deployment and Big data application for the optimization of city procedures. Finally, there are three factors that are scheduled in a mid-term (starting in 2019, Integration of emerging transportation system in city decision making, Citizen seamless and active participation through CPS and Interoperability of multiple city services).

<table>
<thead>
<tr>
<th>Requirements</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration in Utilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emerging transportation systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citizen engagement and digital divide break</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security and privacy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Big data exploitation for city planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interoperability of legacy smart vertical domains</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large scale deployment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.7 Conclusion

This section provides the main messages derived from the analysis of the different domains covered by Road2CPS. The main information gathered is presented in two tables. On the one hand, the main
drivers and barriers, on the other hand the main messages, in both cases the information is classified by domain.

In addition, previous results have to be taken into account. Below are presented some common requirements that have to be addressed for a better market adoption of CPS technologies according to the conclusions of deliverable D2.2[1].

- The elaboration of regulatory frameworks for the different domains
- It is necessary to train and educate labour force and traditional companies in IT and create strategies with the objective to attract talent to the EU.
- The implementation of open solutions and standards will facilitate interoperability and facilitate the integration of SMEs and innovators in the ecosystem.
- Security and privacy issues must be addressed by providing technological tools and also a legal framework that protects companies investing in innovative solutions.
- The fostering new business models and a culture of innovation/entrepreneurship should be enhanced.

What are the key drivers and barriers that have been identified in the Application Roadmap? The next table contains this information classified by domain.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Drivers</th>
<th>Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart Health</td>
<td>Reduction in cost&lt;br&gt;Development of cloud technologies (storage + processing)&lt;br&gt;Commoditization of AR and VR&lt;br&gt;NFC technology deployment</td>
<td>Security and privacy for dealing with sensible data&lt;br&gt;Patient acceptance of disruptive applications&lt;br&gt;Heterogeneous health systems and regulations across Europe</td>
</tr>
<tr>
<td>Smart Manufacturing</td>
<td>Reduction in cost&lt;br&gt;Development of cloud technologies (storage + processing)&lt;br&gt;Deployment of new wireless communication technologies&lt;br&gt;Increasing computing capability of embedded devices</td>
<td>The manufacturing industry has a lot of legacy equipment which needs to be adapted/retrofitted&lt;br&gt;Connected equipment increases need for trust and security concepts and solutions&lt;br&gt;Increased interoperability requirements for connected equipment</td>
</tr>
<tr>
<td>Smart Transport</td>
<td>CPS enabling autonomy in vehicles&lt;br&gt;Sustainability agenda driving adoption of CPS&lt;br&gt;Potential benefits in information, quality, performance from CPS</td>
<td>Safety, bureaucracy and regulatory issues still to be solved&lt;br&gt;Slow change of alternative power infrastructure away from oil&lt;br&gt;Resistance to disruption of established</td>
</tr>
</tbody>
</table>

[1] Road2CPS D2.2 Report on Market Requirements and Socio-Economical Needs
### D2.3 Road2CPS Technology and Application Roadmap

<table>
<thead>
<tr>
<th>adoption</th>
<th>business models and relationships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adoption of ‘smart community’ measures to improve quality of life for EU citizens</td>
<td>Emergent, disruptive effects because of sensitivity of transport to changes in other sectors</td>
</tr>
<tr>
<td>Willingness of governing bodies to create validation environments despite legal constraints (e.g. RATP demonstrations in Paris)</td>
<td></td>
</tr>
</tbody>
</table>

### Smart Energy

| Aging infrastructure is required to improve efficiency, capacity & resilience (applies to electricity, oil & gas) | Oil & gas: many proprietary tools & platforms for automated extraction, data collection & decision-making - impedes adoption |
| Changes in energy demand, e.g. electric vehicles & decarbonised heat | Electricity: “smart” grids which are resilient, bi-directional & flexible require major infrastructure upgrades, including real-time monitoring, smart meters, storage, big data... |
| Less controllable, highly distributed renewable generation techniques for electricity | Market structure must ensure stakeholders can benefit if they invest in infrastructure |
| Many small producers/consumers (instead of small number of big power stations) | Electricity: Difficult to access a system-wide view of current conditions, difficult to react |
| More flexible markets needed to support dynamic pricing, incentives etc (applies to electricity, oil & gas) | Electricity: market changes required to support flexible grids. Many regional variations in market roles/structure, data standards, which must be taken into account currently |
| Hydrocarbon extraction sites become smaller, more challenging & variable in quality | Industrial scale energy & heat storage currently in infancy. Research not well co-ordinated |

### Smart City

| Development of city ecosystems – needs - providers – solutions - all local | Security and privacy for dealing with sensible data |
| Development of cloud technologies (storage + processing) and big data application | Digital divide + citizen engagement |
| Interoperability providers | Heterogeneous regulations across Europe |

Finally, the table below summarizes the main messages derived from the analysis of the domains covered by the project.
<table>
<thead>
<tr>
<th>Sector</th>
<th>Main Message</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Smart Health</strong></td>
<td>CPS technologies are a key factor in the Smart Health Sector. Through using existing technologies such as cloud computing, social networks or big data, health care services will offer many potential benefits to patients and doctors. On the other hand, it will be needed to overcome barriers, such as legislation and regulation disparity, in order to encourage the collaboration between private and public providers. The expected evolution in the following years indicates that in the short-term smart health sector will be evolved through CPS technologies providing new functionalities that optimize processes and patient information delivery.</td>
</tr>
<tr>
<td><strong>Smart Manufacturing</strong></td>
<td>Some of the manufacturing requirements identified can be mapped to already existing technology. For instance, collaborative environments between the actors and engineering solutions can be provided by a number or platforms like Virtual Fort Knox, FIWARE, FITMAN and the Industrial Data Space. In addition, RAMI 4.0 and IIRA are the two largest undertakings to provide a CPS or IoT based reference architecture and common framework for manufacturing and other industrial sectors. The development of common framework and standards will boost the massive roll-out of CPS in industrial environments. Moreover a bigger barrier is in the social aspects of trust in cloud solutions. This will require a huge effort in the education activities building awareness and trust on such solutions.</td>
</tr>
</tbody>
</table>
| **Smart Transport** | Regarding Smart Transport, it seems that the problem is not so much the mapping of requirements into technology. Much more it is the management of technology into society. This means that non-technological requirements are a key factor in Smart Transport, so it is issues of standards, laws, regulations, and the acceptance of change by populations that are the constraints on progress.  

The social consequences of technological advances have very large implications for society, particularly with respect to road transport. The advent of autonomous vehicles, coupled with transport applications such as Uber and Lyft (two leading travel share companies in USA) have the potential to drastically reduce personal vehicle ownership, with strong consequences for the automotive industry, employing about 12 million EU citizens. Secondly, the reduction in parking space requirements will release a significant proportion of real estate in cities and towns for other uses. Thirdly, traffic-optimising applications, combined with the developments above, promise to reduce congestion, energy consumption and emissions, in turn leading to a more healthy, sustainable environment. Other benefits accrue as well; the release of capital otherwise tied to vehicle ownership has evident benefit to the local economy.  

From a Smart Communities perspective, the opportunities presented by technology developments in transport are considerable. Firstly, there is a realistic opportunity to develop multi-mode, delay-minimising, solutions for journeys, whether of people or goods, or both. Secondly, the release of capital and spending power could enable the provision of other aspects of the Smart Community concept, to the benefit of citizens (e.g. moves towards a circular economy). Finally, the reductions in atmospheric pollution will be a health benefit for all. |
These benefits apply to other transport sectors as well, to a lesser extent. There are, of course, costs; nothing comes for free. There is a significant problem for employment, since transport skills do not easily transfer to other sectors. Likewise, the creation of a widespread alternative energy network may be expensive. Thirdly, governments rely to a significant extent on tax receipts from the transport sector to fund the infrastructure of civilized society, which will have to be found elsewhere. Fourthly, there are many legal and other regulatory issues to be solved, and solutions to these may come slowly, because of their complexity.

The adoption of common solutions will facilitate the replication of solutions thus boosting the development of products and services on top of available resources pushing smart transport sector beyond current applications.

It is clear that potentially there are great benefits from the technical developments for transport currently in progress, as outlined above. But they represent a considerable upheaval to the current status and expectations in society, and it is this that thought to be the biggest challenge to the introduction of new technology.

| **Smart Energy** | According to the analysis, the plan for smart energy could be divided into two periods. In a mid-term there are some aspects which are achievable by 2020. CPS technologies such as big data, advanced modelling and analysis techniques are currently being developed in order to improve the industry’s flexibility and efficiency in a few years. On the other hand, predicted timelines for main changes in the energy sector are expected to be delivered over decades rather than years. |
| **Smart City** | CPS’s challenge is to promote a new paradigm of SmartCities where the solution is not only technology and its interoperability, but also the interaction with non-technology elements. The combination of both is to achieve a city that is really smart and capable of increasing the quality of life of its citizens. The technologies to be implemented are the combination of those currently known and that will evolve throughout time. Interoperability among them and with those implemented in other SmartCities will be the key to success. |
4 Summary and overall Conclusions

The key outcomes and conclusions of the Road2CPS technology and Application Roadmap are summarised as below:

- As CPS combine a huge variety of technical, industrial and business domains, many different standards within and between different industries as well as along the value chain and at different vertical levels exist that inhibit interoperability between different systems and between components within a given system. In future, a variety of redundant reference architectures and platforms should be avoided and the access to these should be easy for a huge number of organisations and companies. Approaches that support open standards and reduce vendor lock-in should be in focus. Furthermore, interoperability between platforms and between devices should be promoted.

- Modelling and simulation solutions have become an important element in the area of engineering, and will be essential for CPS, particularly for those CPS that cannot be switched off, because they are safety-critical, and for those that are not fully configured until run-time. The advantage of M&S is the potential reduction of effort in terms of costs and time and the potential for improved performance or better quality designs. However, adoption of modelling and simulation solution in SMEs is still not fully exploited. Modelling and simulation face further challenges such as heterogeneity in modelling notations and high requirements from CPS-side for fault tolerance, resilience, and dynamics. The increasing role of human aspects as well as consideration of autonomous systems is also an aspect of M&S, which are not sufficiently considered currently. Multi-domain, multi-dimensional, and multi-objective approaches of modelling and simulation should be more in the focus of future work.

- Safety, security, and privacy aspects that are considered as hot topics for many domains should be addressed by CPS solutions – the development of security algorithms is one module of many others. Cyber-Physical Systems as a key enabling technology for many application fields such as infrastructure requires key properties like safety, security, and privacy of systems. Without addressing these aspects the establishment of CPS in many sectors will be delayed significantly – especially in traditional sectors like manufacturing. Approaches for ensuring either security or safety in a CPS need to consider challenges from the hardware or the software of a CPS, evolving into holistic techniques that consider the properties of the complete system end-to-end. Certification, regulation, and standards are valuable concepts for dealing with safety-critical issues.

- Through the significantly growing number of connected devices and sensors, the generation of huge amounts of data is a challenge and a great opportunity at the same time. Not only the generation of big data, but also storage, preparation, analysis, usage and the seamless integration of new techniques like edge computing are important fields for future research and enable novel business opportunities. To cope with big data real-time analysis in a digitized and data driven economy, data and information exchange processes will occur in near real-time – which means that big data analytic tools need to address this challenge. Besides velocity, volume, variety, veracity, and value are further properties that are highly relevant and thus form quality criteria for the big data value chain as a whole.
Autonomous systems are becoming more and more omnipresent; autonomous transport systems like the DLR in London or the google car are two examples of Cyber-Physical Systems that support humans and help in terms of decision-making processes. Ubiquitous autonomy could lead to finer control over manufacturing, transport and logistic processes and will help to monitor and track unique elements as well as complex products. In an ideal autonomous environment, CPS take on jobs that are repetitive, dirty, dangerous, debilitating, boring and which are currently done by humans. While this is a clear benefit, there are social challenges that must be addressed, such as job loss, job displacement, continuous retraining, and the provision of a living wage for all.

The topics human machine awareness and human-in-the-loop are becoming increasingly more important in all respects – e.g. controlling of machines by humans is more complex in a cyber-physical world. CPS can have, depending on the type and adjustment, a certain level of autonomy that requires suitable solutions considering complex human behaviour. The emergence of cobots, as an example for machines working together with humans, show the challenges that arise in the field of human and machine awareness aspects. Furthermore, ethical questions such as how a CPS should behave in a complex, critical situation that include humans are still not ultimately answered.

The degree of automatization within the manufacturing industry is already at a high level – nevertheless the step towards a mainly digitised sector still needs to be done. Some demands from the industry for technologies are already met, but a broad variety of different standards at different levels of the value chains hamper the interoperability and lead to a more or less fragmented domain. Platforms are one instrument to overcome these issues and the most important approaches that foster the development of a common framework are the RAMI 4.0 and IIRA reference architecture models. RAMI 4.0 is linked to the Industrie 4.0 initiative and IIRA to the US-based Industrial Internet Consortium. A challenge in manufacturing is to convince the more conservative decision-makers concerning IT-based products such as cloud solutions. Recognising that change is endemic to society and that errors will always occur, the assurance of resilience in systems is intertwined with automation.

The transport domain, more than the manufacturing and compared to the energy sector, is to a higher degree connected to human-specific aspects. The human-in-the-loop topic is more central, which means that not only safety, security, and privacy aspects are especially of prime importance, but also non-technological questions that are not easy to measure nor to calculate. Awareness building and acceptance for CPS by all layers of the society are necessary actions that need to be taken to overcome diffuse barriers and challenges.

The energy sector is evolving from a marketplace oriented around small numbers of large providers into a domain with many smaller stakeholders with flexible roles. This includes more and different stakeholders such as policy-makers, energy aggregators, advanced energy distributors with increasingly flexible roles, application developers and IT and telecommunications providers, in large and small companies newly entering the market as well as end users who are better informed than ever before about their energy usage requirements, thanks to smart meters. CPSs enable this trend, which also leads to generation of more data than before. A higher degree of interconnections and communication processes result in a higher degree of complexity – aspects of self-healing infrastructure, integration of...
diverse renewable and fossils sources as well as decision support mechanisms based on real-time information will gain importance in the future.

- Similar to the transport domain, the city planning field, and considering especially the smart city approach, is to a higher degree dependent on non-technology elements like acceptance of a CPS environment. Monitoring systems, autonomous controlling systems, and robots in fully automated automotive factories need to convince influential sceptics and of course must be accepted by the population. As the smart city domain is a combination of different sectors such as transport, building industry, energy, and infrastructure for instance the degree of complexity is even higher. Modelling and simulation solutions, similar to the above mentioned domains, could help to reduce costs in the long run.

- Cyber-Physical Systems are valuable to support the different stakeholders in the health domain. As safety, security, and privacy are always of crucial importance, these issues need to be guaranteed in particular in the context of healthcare and different states of health of patients. In addition, the legislative and regulatory framework has to be adapted to CPS-based healthcare systems considering not only the already existing technologies, but also the new and future cyber-physical solutions.

- All domains have in common that a lack of IT is observed which need to be overcome by promoting education and skills with relation to CPS. Education programmes need to address these challenges and measures to train the labour force in traditional sectors and firms in terms of IT skills supported by awareness building processes involving the broader society. Additionally, talented professionals outside the EU should be attracted by targeted policy and by industry and research institutions.

- New business models will arise in the wake of the paradigm shift towards a CPS-based economy and society, but support is needed to foster entrepreneurship and mentality to generate radical and disruptive innovations. Further promotion of SMEs and start-ups through targeted incentive programmes as well as knowledge and technology transfer measures will be necessary to cope with competitors from North America and East Asia.

In summary, progress in the key technological fields identified, will help to fuel the development of modular, secure and trustworthy Cyber-Physical Systems of the future. As many similar challenges and opportunities exist in different application domains, a cross-disciplinary, multi-domain approach should be pursued. The involvement of and dialogue with the society is seen as key to make CPS a success and to best benefit economy and society as a whole.

As an overall conclusion, it is clear that the funding that has been provided for the development of CPS technologies has delivered useful and significant results from a technological perspective. However, there are many technical extensions still required, justifying funding. There is also evidence that there should be a shift in focus towards the many industrial, business and community issues involved in the adoption of CPS technology. The latter are now becoming urgent as barriers to the adoption of CPS within the EU community.
5 References


Eurocontrol13 (2013). Challenges of growth 2013; Task 4 European Air Traffic in 2035, Eurocontrol, BE.


