Deliverable 1.5
Programme Achievements, Exploitation Opportunities, and Impact Multiplication Activities

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<td></td>
</tr>
<tr>
<td><strong>Institution:</strong></td>
<td>Steinbeis-Europa-Zentrum</td>
<td></td>
</tr>
<tr>
<td><strong>E-mail:</strong></td>
<td><a href="mailto:Reimann@steinbeis-europa.de">Reimann@steinbeis-europa.de</a></td>
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The Road2CPS project is co-funded by the European Community’s Horizon 2020 Programme under grant agreement no. 644164.

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## Consortium Information

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<thead>
<tr>
<th>Name (and contact data)</th>
<th>Institution (incl. address)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. Reimann</td>
<td>Steinbeis-Europa-Zentrum</td>
</tr>
<tr>
<td><a href="mailto:reimann@steinbeis-europa.de">reimann@steinbeis-europa.de</a></td>
<td>Erbprinzenstrasse 4-12, Karlsruhe, DE</td>
</tr>
<tr>
<td>M.J.D. Henshaw</td>
<td>Loughborough University</td>
</tr>
<tr>
<td><a href="mailto:m.j.d.Henshaw@lboro.ac.uk">m.j.d.Henshaw@lboro.ac.uk</a></td>
<td>Ashby Road, Loughborough, UK</td>
</tr>
<tr>
<td>J. Fitzgerald</td>
<td>University of Newcastle</td>
</tr>
<tr>
<td><a href="mailto:john.fitzgerald@ncl.ac.uk">john.fitzgerald@ncl.ac.uk</a></td>
<td>King’s Road, Newcastle upon Tyne, UK</td>
</tr>
<tr>
<td>David Servat</td>
<td>Commissariat à l’énergie atomique et aux energies alternatives, Paris 15, 75015, FR</td>
</tr>
<tr>
<td><a href="mailto:david.servat@cea.fr">david.servat@cea.fr</a> @cea.fr</td>
<td>Fraunhofer IPA</td>
</tr>
<tr>
<td></td>
<td>70569 Stuttgart, DE</td>
</tr>
<tr>
<td>Daniel Stock</td>
<td>Anysolution SL</td>
</tr>
<tr>
<td><a href="mailto:daniel.stock@ipa.fraunhofer.de">daniel.stock@ipa.fraunhofer.de</a></td>
<td>07010 Palma de Mallorca, ES</td>
</tr>
<tr>
<td>D. Ordóñez</td>
<td>Atos España SA</td>
</tr>
<tr>
<td><a href="mailto:dom@anysolution.eu">dom@anysolution.eu</a></td>
<td>Madrid 28037, ES</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>Murray Sinclair</td>
<td>Loughborough University</td>
<td><a href="mailto:M.A.Sinclair@lboro.ac.uk">M.A.Sinclair@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>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>Claire Ingram</td>
<td>University of Newcastle</td>
<td><a href="mailto:claire.ingram@newcastle.ac.uk">claire.ingram@newcastle.ac.uk</a></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>Daniel Stock</td>
<td>Fraunhofer IPA</td>
<td><a href="mailto:daniel.stock@ipa.fraunhofer.de">daniel.stock@ipa.fraunhofer.de</a></td>
</tr>
<tr>
<td>Benjamin Götz</td>
<td>Fraunhofer IPA</td>
<td><a href="mailto:benjamin.goetz@ipa.fraunhofer.de">benjamin.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>
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Executive Summary

The document at hand aims at reporting on and analysing the Road2CPS activities carried out to assess and disseminate the ‘programme achievements’, identify ‘exploitation opportunities’ and facilitate ‘impact multiplication’. Most Road2CPS activities are directly linked to or naturally support these endeavours:

- Analysing the impact from past and ongoing projects, identifying the gaps and bridging efforts
- Bringing related projects together and disseminating the programme achievements widely
- Developing technology, application and innovation strategy roadmaps for CPSs to serve as a catalyst for early adoption of CPS technologies
- Developing recommendations for future research priorities as well as implementation strategies
- Enhancing CPS implementation and demonstrating business opportunities through case studies
- Building a CPS constituency by bringing together key players (from academia, industry and policy making) from a broad range of technology and application domains, and across the value chain

This document aims at giving an overview focussing on the first and second objective above, and provides links to more in depth analysis’ in the various publically available Road2CPS documents. Moreover, it provides an assessment of the approach and recommendations for future programmes.
1 Introduction

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:

![Figure 1: Road2CPS objectives](image)

The document at hand aims at reporting on and analysing the Road2CPS activities carried out to assess and disseminate the ‘programme achievements’ and identify ‘exploitation opportunities’ and facilitate ‘impact multiplication’. The activities can mainly be placed within the first pillar of the graph above, but are naturally supported by all pillars and activities of the Road2CPS project.

Within this document a synthesis of outcomes along with an assessment of activities and recommendations for future projects is given. Details on the methodology and supporting data creating the results can be found in the annexes of this document.
2 Overview on Activities Performed and Results Available

As most Road2CPS activities can be related to the aims of this deliverable, a first overview is given on the results obtained and delivered through detailed, individual documents that are publically available on the Road2CPS website: http://www.road2cps.eu and direct links in the reference section of this document.

**Programme Achievements**

1) Activities are centred around a custom made tool (Vulture tool) to collect, analyse and evaluate programme achievements, assess specific impacts and identify gaps
   - D1.1 State of the Art and current impact report
   - D1.2 Gap analysis report
   - D1.3 Impact assessment

2) Activities focussing on the dissemination of achievements from the programmes projects
   - D1.4 Summary of programme achievements and impact
   - D6.5 Catalogue of programme achievements
   - Report on ICT-1 Clustering and Communication event / Portfolio analysis

**Exploitation Opportunities**

1) Activities are centred around case studies
   - D3.2 Case studies report

2) Activities are centred around roadmaps and recommendations
   - D2.3 Technology and application roadmap
   - D2.4 Strategy roadmap
   - D4.1 Recommendations on research priorities, innovation strategies and business opportunities
   - Reports on Roadmapping and Strategy Workshops

**Impact Multiplication**

1) The Vulture tool
   - https://vulture.road2cps.eu/

2) Activities are centred around Constituency Building WS
   - D5.1 Task Force Action Plan
   - D5.2 Report on Constituency Building Workshops
   - Individual Workshop Reports, Results from Discussions and Interactive sessions at workshops
3 Main Road2CPS Activities and Results

In the following sections, the main results regarding the assessment and dissemination of ‘programme achievements’, the identification of ‘exploitation opportunities’ and facilitation of ‘impact multiplication’ along with an evaluation of the approach and recommendations derived are presented.

3.1 Analysis of Project Achievements, Identification of Gaps and Impact Assessment

This section relates to the project objectives contributing directly to:

- Impact assessment of past and ongoing projects pursued by internet search, interviews with relevant stakeholders and project coordinators
- Gap analysis analysing the top-down (theoretical CPS) view and map it with the industrial / application-oriented (bottom-up) view in order to identify gaps to be filled on both sides so that CPS applications become practice in the future
- Impact multiplication pursued by identifying overlaps and connections to fill gaps, bringing knowledge together and matching technology push and market pull.

The following Road2CPS documents give in depth information on the outcomes (D1.1 State of the Art, D1.2 Gaps Analysis, D1.3 Impact Assessment, D1.4 Summary of Programme Achievements)

Moreover, Road2CPS recommends to directly explore the data and results within the ‘Vulture Tool’: https://vulture.road2cps.eu/ (please find more details in the Annex of this document)

3.1.1 CPS related Projects analysed

The Road2CPS analysis of projects focussed on a specific set of both completed and on-going Commission-funded projects in FP7, H2020 and ARTEMIS/ECSEL, related to the domain of CPS:

7th Framework Programme Projects (different shades of blue in table 1 below):

- ‘Embedded systems design’: EMBOCON, ENOSYS, ERA, GENESI, GRENEERBUILDINGS, HYCON2, HYDROBIONETS, KARYON, MADNESS, MAKESENSE, OPENCOSS, SPRINT, TERESA, VITRO
- ‘Monitoring and control’, ADVANCE, AGILE, AUTOPROFIT, BALCON, BEMO-COFRA, CLAM, CONSERN, EC-SAFEMOBIL, IMC-AESOP, MoVeS, PAPYRUS, PLANET, SCUBA, WIBRATE
- ‘System-of systems’ AMADEOS, COMPASS, CPSoS, CyPhERS, DANSE, DYMASOS, Local4Global, Road2SoS, T-AREA-SoS, VERDI

H2020 projects (ICT-1 2014 call SmartCPS, running in parallel to Road2CPS, in black and bold in table 1)

- AXIOM, COSSIM, CP-SETIS, CPS-SUMMIT, CPSE LABS, EOT, EUROCPS, IMMORTAL, INTO-CPS, Road2CPS, SAFURE, SCORPIUS, TAMS4CPS, TAPPS, UnCoVerCPS

ARTEMIS/ECSEL projects (added during the Road2CPS lifetime, in July 2016, purple in table 1)

- 3CCar, ACCUS, Almarvi, ARROWHEAD, CONCERTO, COPCAMS, CRYSTAL, DEWI, E-SCOP, EMC2, Exist, HOLIDES, InForMed, MANTIS, RS-COP, RobustSENSE, SWARMs, WITH-ME
A list of 54 EU-funded projects FP7/H2020 projects assessed at the project start. After the mid-term review a further 18 ARTEMIS/ECSEL (purple) were added and summing up to 72 projects. The projects in bold are funded under the same call as Road2CPS and have the strongest relation to the project.

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| Table 1: List of projects assessed during the Road2CPS project. |

3.1.2 Analysis of Programme Achievements

Before considering the analysis of the data, if is helpful to review a few of the success stories to set some context and to help appreciate the diverse nature of the projects under review.

Success stories

The following subsection summarises a few success stories uncovered during the preparation of this report. Full versions and links to sources are also available on the Vulture Tool.

EMBOCON

All the achievements of the project were highly mathematical in nature, and related to finding optimum solutions to systems and control problems. The application of these algorithms was demonstrated in software developed within the project.

This type of problem relates to many real-world problems, and the algorithms and associated software have found real world commercial applications. Subsequently, a spin out company, Embotech, has been founded and is making commercial sales based on the technology developed within the project.
This achievement is an excellent example of the application of abstract mathematical concepts to solve problems that would only be noticed when solutions do not exist.

**AGILE**

Within the project AGILE, a ground-breaking system/tool has been developed for the fully-automated calibration, maintenance and renovation of the operation of generic TMS. The most important aspect of the AGILE system/tool is that it is of "plug-n-play" nature: all the TMS operator has to do is to just plug the AGILE system to the TMS without the need of any modelling, analysis or other tedious preparatory or interfacing effort.

The real-life results after implementing AGILE, indicate that AGILE was able to provide around ~70% improvements. This suggests in more typical cases where the TMS is not that well-designed the improvements would be quite higher. Moreover, quite conservative calculations based on the above-mentioned improvements indicate that the AGILE leads to annual fuel cost savings of around 2-3 Million Euros for an urban area of 100,000 people.

**COMPASS**

Model based engineering methods and tools for Systems of Systems (SoSs) developed in the COMPASS project ([http://www.compass-research.eu](http://www.compass-research.eu)) were evaluated by Bang & Olufsen (B&O) using a set of case study aspects representing the company's development process challenges regarding SoS engineering. The development process includes SoS requirements engineering, SoS conceptual modelling, SoS verification and SoS testing.

Case studies included models of AV data streaming, leader election and service discovery in networks. The modelling of methods used were assessed using a bespoke set of COMPASS-specific Technology Readiness Level(s) (TRLs).

The conclusions, based on TRL evidence suggested that the methods and tools (based on SysML, the formal modelling language CML, and tools based around the COMPASS Symphony IDE) met B&O’s SoS engineering needs.

B&O reported that the semi-formal COMPASS technologies were already adopted by B&O. Techniques and tools base on more formal techniques were regarded as applicable, and the verification results demonstrated in the studies would not have been achievable using conventional non-formal methods and tools. However, the comparative immaturity of the tools and the need for specialist formal methods skills.

**WiBRATE**

WiBRATE’s key innovation lies in the development of a self-powered, vibration monitoring and control platform. Unlike existing vibration monitoring devices available in the market that operate as individual entities, WiBRATE’s unique approach is based on individual intelligent sensor-actuator nodes that communicate wirelessly to collaboratively predict impending failures, perform fault diagnosis or provide real-time feedback. This feedback can then be used to further minimise vibration levels using distributed and autonomous micro-actuators that are capable of carrying our robust, distributed control. The use of robust wireless communication strategies ensures that the system is highly flexible and allows for a new class of monitoring and control applications that are not possible using traditional wired systems. Apart from measuring and controlling vibration levels, WiBRATE’s platform also harnesses the vibration itself thus resulting in a system that is both maintenance free and environment friendly.
Less than two years into the project and the WIBRATE consortium has been rewarded with one of its first industrial contracts for the sensor system, from South Eastern Railways in the United Kingdom; this has allowed to further enhance the prototype and convert it into a product.

Project Analysis

Next to an analysis of project achievements in terms of impact, level of maturity and targeted domains the projects were analysed according to correlations to their size, amount of funding, relation to infrastructure, NCOIC interoperability scale and grouped into specific clusters.

Projects observations made in the earlier Road2CPS propose that there are four clusters:

- **Systems-of-Systems** (High level activities where the component parts are also systems)
- **CPS Support Ecosystem** (A broad range of activities that engage with technologies and services to support CPS. i.e regulation, standards, enabling technologies to support communication between systems etc.)
- **Strategic Technology Research** (Strategic activities including building collaborative networks of expertise)
- **Technology Implementation** (Activities typically focussed on hardware or software for CPS)

Deliverable D1.1 ‘State of the Art report’, presented a representation of the CPS project space linking ‘Infrastructure’ to the ‘NCOIC Interoperability Scale’ and ‘Domains’:

![Cube 2.0 from Road2CPS SoA Report](image)

This view was based on the outputs of ARTEMIS, and emphasised the domain independence of the projects reviewed. This initial view has been supported by a more detailed heat map. The horizontal boundaries between the clusters System-of-System, CPS Support Ecosystem and Technology projects,
is very clear. An analysis comparing the different axes and relating them to project funding, size, TRL is given in the annex of this document.

Key Observations from Project Analysis

**Overall Project Achievements:** Some projects have succeeded in making the journey to commercialisation in a remarkably short time, however, it is not at all clear that this could have been predicted at the project proposal stage. For example, the highly mathematical concepts researched with EMBOCON quickly found commercial application in helping to optimise real world control systems through a spin out company, while the tools developed in COMPASS were taken up by project partner Bang & Olufsen. This illustrates just two of the many possible routes towards commercial outcomes of CPS projects. In deliverable D1.4 the 72 projects were reviewed in detail and attempts to assign a Technology Readiness Level (TRL) to provide a developmental context to the achievement. With respect to TRL it is important to note that high classifications are not normally a primary project objective, and that the path from concept to commercial application is fraught with difficulty at every level. Thus, even apparently small achievements may lay solid technical foundations for subsequent projects.

**Impacts:** Some projects have achieved remarkable impacts since their conclusion. What is striking is the diversity of projects’ range of outcomes. Nevertheless, not all domains are equally covered by reported achievements. It is notable that healthcare lags in this regards, possible because of its highly regulated nature. The high TRLs reported for Manufacturing and IT&C are perhaps explained by their commercial value. The lagging of Security is without obvious explanation, given its self-evident importance.

**Relation between Achievement and Impact:** Based on our initial examination of the data collected, the relationship between the achievements of a project and the impact is difficult to directly relate. A project may deliver one or more high achievements while making little or no impact. As a hypothetical example, a project may demonstrate a highly effective and compact power source technology suitable for discrete distributed sensors under laboratory conditions. This is a high achievement with no direct impact. A second project, perhaps with different collaborators, may assemble the technical and commercial expertise to package that same technology into a commercial application. This demonstrates fairly high achievement and impact. A third project may assemble a consortium with the expertise to transform the now proven technology into a commercial product that may be used widely throughout industry in many different applications. This is a low achievement, but demonstrates very high impact. This finding suggests that projects should always be considered as part of the overall technical and commercial ecosystem to ensure that their contribution to commerce and well-being are properly appreciated.

**Domain independence:** Independence from domain has been a common thread while examining the collated data. This indicates that CPS challenges might best be addressed by providing instruments not tied to domain specific challenges.

**Domain coverage:** Transport related projects are well represented in the dataset of CPS projects, followed by ‘Manufacturing’ and ‘Energy’ while ‘Healthcare’ and ‘Security’ are clearly gaps in the coverage. These gaps have been observed throughout the Road2CPS project.
Size of funding is worthy of further examination. Small CPS projects do seem to be capable of returning excellent value for money. Their relationship to previous larger projects is unknown, so caution is needed when drawing conclusions.

Data analysis: The Vulture tool and high level network diagrams may also be useful in interpreting large quantities of data. Indeed, as the number of projects increases such diagrams may represent the only way to summarise the information in a human readable format.

3.1.3 Gaps analysis and Impact Assessment

A gap analysis has been performed for the 72 projects, revealing 75 gaps which have been categorised in terms of an interoperability scale, closely related to the NCOIC Interoperability Framework. The summary below is further detailed in Annex 2 of this document, where each gap is described in more detail and the impact for eliminating it is assessed.

**Political/ Economic/ Regulatory/ Business Board level**

**Description:** Technology addresses needs and opportunities that should be addressed either by government (e.g. creating regulations, programmes, agencies, etc.) or by the board of a company (e.g. recommendations that affect why the company exists and what it does; governance, legal and financial aspects). Discussion of pre-requisites for business models to be successful. Gaps include:

- Few International Agreements
- Security Issues
- Digital Divide
- Social Acceptance of CPS
- Cross Sector Interaction of CPS
- Need for CPS Trained People
- CPS Education and Training
- Evaluation Methods for IoT
- CPS Failure Fall-Back Plans
- Societal Responsibility Regulations
- Engineering Governance
- Regulations for CPS Information Privacy
- Regulations for Sustainable CPS
- Scalable Socio-Technical Models
- Single European Area
- Regulations for Autonomy
- Human Connectivity to IoT
- CPS In Agriculture

**Business objectives: strategy & policies level**

**Description:** Technology helps formulate the plans which government/ industry/ companies should develop to reach desirable business objectives; may also indicate how to implement the plan(s) in order to avoid unwanted side-effects and consequences. Evaluation of business models. Gaps include:

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- QoS and CPS
- Trade Space Tools
- CPS Strategy
- CPS Trained Workforce
- Assure Ethical CPS
- Cross Disciplinary Autonomous CPS
- V&V for Large-Scale CPS
- Health Monitoring” of CPS
- Safety and Security of CPS
- CPS Life-cycle Management
- Domain Specific CPS Architectures
- CPS Authority and Responsibility
- Resilience and Brittleness of Evolving CPS
- Consequences of Contracts for CPS
- Impact of Learning and Autonomous CPS
- CPS for Waste Management
- CPS Interoperability Standards
- Model Based Control of CPS
- Safe CPS for Remote Healthcare
- Regulation for Bionic Devices

**Business context: aligned procedures level**

**Description:** Technology addresses the procedures within a function (such as manufacturing) that can be matched better with the goals of the function (e.g. to make savings in time, costs, waste, efficiency, etc.) Technology may address the alignment of procedures running across several companies. Standards and codes of practice are also important. Gaps include:

- Better Broker-Type Architectures for CPS
- Verification of Hybrid CPS
- Modelling of Hybrid CPS
- Tools for Scalability of CPS
- Run Time V & V for Continuous CPS
- V & V for Autonomous Component Systems
- Resource Efficient Large-Scale CP
- M2M Communication for CPS
- Deep Human System Interfaces for CPS
- Tools for Managing Legacy CPS
- Methods for Human Roles in CPS
- Tools for Ultra Large Scale SoS
- Tools for Trustworthy CPS
- Tools for Continuous Change in CPS
- Energy Storage for CPS Components
- Carbon Free Energy Storage for CPS
- Recycling for CPS
- Platforms for Domain Specific CPS
Semantics: knowledge & sharing of knowledge level

Description: If the technology allows or recommends adoption of, or suggests changes to, ontologies, taxonomies, thesauri, or discusses knowledge sharing (e.g. IPR agreements) among different groups, companies, etc., then it is at this level. Gaps include:

- Situation Awareness for Autonomous CPS
- Human Automation Communication
- Cross Disciplinary Knowledge Base for CPS
- Metadata for Standard M2M Communication
- Metadata for Standard Operating Procedures
- Human Avatars for Building CPS
- CPS for Bio-Energy Harvesting

Semantics: information & interoperability level

Description: Understanding of concepts contained in messages passed between interfaces. Technology may deal with glossaries, or classes of information, in the context of transferring meaning from one head to another, or between CPSs or software agents. Discussion of protocols would also indicate this level. Gaps include:

- Big Data Approaches for CPS
- Big Data Visualisation
- Sensing for Human-Automation Interface
- Ultra-Reliable Technology for CPS
- Network Security Technologies for CPS

Syntactic interoperability

Description: Technology addresses formats, compression techniques, encryption and other ways of representing knowledge, information and data for transfer between functions, organisations, etc. Standards and codes of practice regarding interfaces and message structures are indicators of this level, as is discussion of integration of models. Gaps include:

- Alternative Approaches to Network Security

Network interoperability

Description: Enables the exchange of messages between CPSs across a variety of networks. Technology addresses networks and networking, interface descriptions, and analysis of network architectures. Gaps include:

- Communication Technologies and Standards
- 5G Technologies for CPS
- Improved Network Architectures for CPS
- Enhanced Distributed Data Storage for CPS

Physical interoperability level

Description: Technology /Mechanisms to establish physical and logical connectivity and which address issues of physically connecting together devices, using Ethernet cables, plugs sockets, wireless, or transferring pieces of paper. Gaps include:

- IoT Interconnection Standards
- Low Power Miniature Sensors
A graphical presentation and interconnection of these gaps is shown below. The different interoperability levels are presented in different colours.

Figure 3: All 75 gaps and links, from the Gephi database. Nodes (gaps) are colour-coded by interoperability level (see legend), sized by the number of edges (links).

The diagram above, Figure 2, was produced by inspection of each gap turn and noting which other gaps it might be considered to link with. This process was manual and depended upon the expertise and opinion of the reviewers. We therefore held a review process and debated the logic of including each gap in turn to produce a consensus result. Although, the process might be automated by using keywords, it was felt that the manual process provided a baseline for such a novel approach. In this figure, each of the nodes is coloured to represent its position in the classification hierarchy as shown in the legend. To produce the final figure as shown the following process was applied:

- Apply a random arrangement to the nodes.
- Apply a Force Atlas algorithm. Essentially, this applies a repulsion effect to each node and an attraction effect to each edge (link). Thus, nodes with many links end up closer than those with few links.
- Rotate the final arrangement so high level classified gaps (Green) are close to the top.
“Big Data” type visualisations are more appropriate as the quantity of data increases along with the increased number of cross linkages. These have been used to good effect within deliverables D1.2 *Gaps Analysis* and D1.3 *Impact Assessment*. As the number of projects has increased to 72 and the number of linkages increased to over 2500, only a network type visualisation as presented in the figure above can capture the overview in a single diagram.

Next to the presentation of gaps and connections between them, the projects analysed have also been included into this graph (in grey – see next figure).

![Figure 4: Overview of Project links to Gaps](image)

It should be borne in mind that not all Deliverables from each project were consulted, and that many projects are still in progress, and not all Deliverables are available. Some links between projects and gaps may be missing.

Within the figure above projects are closest to identified gaps which they address. As stated above, the placement has been generated entirely through the use of an algorithm which seeks to minimise the distance closely linked nodes. The linkages may be interpreted as the potential each project has to make and achievement or impact. Thus projects such as this one, Road2CPS, CPS-SUMMIT and BALCON are towards the top of the diagram close to the high level Infrastructure gaps they serve.
Conversely, projects such as CPSELABS, U-TEST and SPRINT are close the technological gaps that they address. HYCON2, already noted as a project with wide ranging potential impact and achievements, has gravitated to the middle of the diagram. Overall many similarities can be observed with the “Cube 2.0” diagram of D1.1 State of the Art Report.

We speculate, that if it were possible to apply this type of representation to many hundreds of project and gaps and their associated linkages (representing impacts and achievements) the diagram would tend towards many clusters, such as the one represented here.

The figure below shows an excerpt of the figure above, an example for the ‘GAP: Platforms for domain specific CPS’, its neighbouring gaps and linked projects:

**Figure 4b: Filtered version of Figure 1 with Gap 57 ‘Platforms for domain specific CPS’ as the focus of this plot, and showing its local interconnected neighbours.**

- This plot reflects the importance attached to platforms by the EC and by industry, as evidenced by the 12 H2020 projects and the 12 ARTEMIS/ECSEL projects involved in this topic.
- The wide range of Gaps identified in this plot together with the high degree of linkage among the Gaps indicates the sophistication and complexity of this Gap. This nexus of Gaps indicates that large projects, of the scope of ARTEMIS or ECSEL projects, is necessary to deliver substantial progress. While there is scope for smaller projects with a focus on an identifiable generic issue, such projects should attend closely to the requirements that emerge from the
larger projects in order that the contribution of the smaller projects is properly usable.

- It is laudable that the EC and industry jointly is prepared to invest so heavily in this domain to ensure future competitiveness; however, it does raise questions of overlap of focus and work, and whether there is enough co-operation and concertation among these 24 projects in the planning and utilisation of outputs, albeit respecting the importance and ownership of IPRs.

The amplitude of links indicates a strong role for standards and semantics; this might be one of the important side-benefits of the work in generating platforms.

The figure below shows the gaps currently addressed by the 72 projects, and how many projects address a specific gap (and it would be possible to derive an individual plot for each of those):

<table>
<thead>
<tr>
<th>Count of Projects Targeting Gaps</th>
<th>Count of Projects Targeting Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gap Number and Name</strong></td>
<td></td>
</tr>
<tr>
<td>IoT Interconnection Standards</td>
<td>25</td>
</tr>
<tr>
<td>Platforms for Domain Specific CPS</td>
<td>24</td>
</tr>
<tr>
<td>Low Power Miniature Sensors</td>
<td>22</td>
</tr>
<tr>
<td>Improved Network Architectures for CPS</td>
<td>22</td>
</tr>
<tr>
<td>Resource Efficient Large-Scale CPS</td>
<td>21</td>
</tr>
<tr>
<td>Social Acceptance of CPS</td>
<td>17</td>
</tr>
<tr>
<td>Ultra-Reliable Technology for CPS</td>
<td>17</td>
</tr>
<tr>
<td>Tools for Ultra Large Scale SoS</td>
<td>17</td>
</tr>
<tr>
<td>Big Data Approaches for CPS</td>
<td>15</td>
</tr>
<tr>
<td>Model Based Control of CPS</td>
<td>12</td>
</tr>
<tr>
<td>QoS and CPS</td>
<td>11</td>
</tr>
<tr>
<td>Domain Specific CPS Architectures</td>
<td>9</td>
</tr>
<tr>
<td>Better Broker-Type Architectures for CPS</td>
<td>9</td>
</tr>
<tr>
<td>CPS Interoperability Standards</td>
<td>8</td>
</tr>
<tr>
<td>Engineering Governance</td>
<td>7</td>
</tr>
<tr>
<td>Situation Awareness for Autonomous CPS</td>
<td>7</td>
</tr>
<tr>
<td>Tools for Trustworthy CPS</td>
<td>7</td>
</tr>
<tr>
<td>Verification of Hybrid CPS</td>
<td>6</td>
</tr>
<tr>
<td>Network Security Technologies for CPS</td>
<td>6</td>
</tr>
<tr>
<td>Resilience and Brittleness of Evolving CPS</td>
<td>6</td>
</tr>
<tr>
<td>M2M Communication for CPS</td>
<td>6</td>
</tr>
<tr>
<td>Assure Ethical CPS</td>
<td>6</td>
</tr>
<tr>
<td>Regulations for Autonomy</td>
<td>6</td>
</tr>
<tr>
<td>Tools for Scalability of CPS</td>
<td>6</td>
</tr>
<tr>
<td>V&amp;V for Autonomous Component Systems</td>
<td>5</td>
</tr>
<tr>
<td>V&amp;V for Large-Scale CPS</td>
<td>5</td>
</tr>
<tr>
<td>Regulations for Sustainable CPS</td>
<td>5</td>
</tr>
<tr>
<td>5G Technologies for CPS</td>
<td>5</td>
</tr>
<tr>
<td>CPS Strategy</td>
<td>5</td>
</tr>
<tr>
<td>Safety and Security of CPS</td>
<td>5</td>
</tr>
</tbody>
</table>
The top 10 gaps addressed by the 72 projects analysed, revealed to be: IoT Interconnection Standards, Platforms for Domain Specific CPS, Low Power Miniature Sensors, Improved Network Architectures for CPS, Resource Efficient Large-Scale CPS, Social Acceptance of CPS, Ultra-Reliable Technology for CPS, Tools for Ultra Large Scale SoS, Big Data Approaches for CPS, Model Based Control of CPS. These topics
had probably been identified for the work programme and promoted within the calls of the projects analysed. Gaps that were covered by a small number of projects included themes around education, human in the loop and societal responsibility/divide, which have been identified as topics that need more attention in many Road2CPS activities. Gaps not addressed by any of the projects include: Few International Agreements, Scalable Socio-technical Models, Need for CPS Trained People, CPS Trained Workforce, CPS for Waste Management, Recycling for CPS, Enhanced Distributed Data Storage for CPS.

The figure below shows how many gaps a specific project addresses (shown for projects addressing many gaps in parallel).

<table>
<thead>
<tr>
<th>Projects</th>
<th>Count of Gaps Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYCON2</td>
<td>26</td>
</tr>
<tr>
<td>EMC2</td>
<td>15</td>
</tr>
<tr>
<td>HOLIDES</td>
<td>15</td>
</tr>
<tr>
<td>R5-COP</td>
<td>14</td>
</tr>
<tr>
<td>ACCUS</td>
<td>12</td>
</tr>
<tr>
<td>CRYSTAL</td>
<td>12</td>
</tr>
<tr>
<td>E-SCOP</td>
<td>11</td>
</tr>
<tr>
<td>InForMed</td>
<td>11</td>
</tr>
<tr>
<td>RobustSENSE</td>
<td>11</td>
</tr>
<tr>
<td>SWARMs</td>
<td>11</td>
</tr>
<tr>
<td>ARROWHEAD</td>
<td>10</td>
</tr>
<tr>
<td>CONCERTO</td>
<td>10</td>
</tr>
<tr>
<td>Local4Global</td>
<td>10</td>
</tr>
<tr>
<td>MANTIS</td>
<td>10</td>
</tr>
<tr>
<td>SCORPIUS</td>
<td>10</td>
</tr>
<tr>
<td>3CCar</td>
<td>9</td>
</tr>
<tr>
<td>ADVANCE</td>
<td>9</td>
</tr>
<tr>
<td>COPCAMS</td>
<td>9</td>
</tr>
<tr>
<td>DEWI</td>
<td>9</td>
</tr>
<tr>
<td>Exist</td>
<td>9</td>
</tr>
<tr>
<td>WITH-ME</td>
<td>9</td>
</tr>
<tr>
<td>Almarvi</td>
<td>8</td>
</tr>
<tr>
<td>DANSE</td>
<td>8</td>
</tr>
<tr>
<td>Road2CPS</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 3: Number of gaps addressed per project

**EXAMPLE HYCON2:**

The gaps addressed by HYCON 2 cover multiple NCOIC levels and the breadth is such that there is little suggestion of domain specificity of the gaps covered. This is also consistent with the observation from “D1.1 State of the Art Report” that CPS gaps are very loosely tied to application domain.

This work is not in a position to evaluate how reusable the results are from HYCON2, given its focus on theoretical understanding. However, it seems reasonable to assume that the addressing of multiple levels of gaps will achieve wide ranging impacts; the ‘Local4Global’ project, which has HYCON2 as one of its fore-runners, provides a good example of the implementation of theoretical understanding in engineering projects. As such these wide ranging projects may be regarded as highly strategic in their focus whose benefit will take time to be realised.
Key Observations from GAP Analysis and Impact Assessment

For the strategic gaps (Political/ Economic/ Regulatory/ Business Board level – green in fig. 3) a more detailed analysis was performed and the messages and related impacts were derived.

Key messages about strategic gaps and impacts

- Each of the 18 targeted, strategic gaps has neighbouring gaps that contribute to closing the gap. This indicates that projects focused on a single gap are unlikely to deliver the scope of benefits that are possible.

- Political and societal strategic gaps have more links to other strategic gaps than do technological strategic gaps. Given the pervasion of CPS into society, this indicates that the projects focussed on technology goals may reduce their effectiveness by not including more societal goals.

- Most of the 18 plots link technology gaps to gaps concerned with human involvement. This implies that technology projects should become more socio-technical; the pervasion of CPS technology into the life of people requires this.

- 46 of the 75 gaps were addressed; some of them many times (e.g. Gap 51 ‘Tools for ULSS’ was addressed by many projects. There was no obvious co-ordination in this.

- Several groups of gaps recur in the strategic plots. These gaps should be addressed collectively soon, particularly since CPSoS are expected to operate permanently in a fault state.

- Modelling and simulation tools, methods and approaches that embody a socio-technical perspective should be developed, to ensure that the needs, fears, and support of individuals and communities are addressed.

- ‘Cross-domain knowledge’ occurs frequently, needing a strong commitment of resources to it. Conservation of knowledge is complex and never-ending; its architecture and processes involve IT&C, organisational design, operations, personal roles, workable policies, educated people and wisdom. Closing this gap will provide a key resource for the EU28 into many future decades

- ‘Single European Area’ occurs in most of the strategic plots. It remains an important goal for the EU28

- ‘Road2CPS’ is a small-scale project. Nevertheless, its evidence-based focus on projects and their gaps indicates that useful feed-back for EU RD&I planners can be generated.

- The plots for all 18 strategic gaps overlap to some extent. This emphasises the connected nature of CPS research. EU Large Scale Pilots will explore this connectedness from a CPS/CPSoS viewpoint; but there is a need for community-oriented pilot projects as well, providing another perspective on connectedness.

- Given the need for the EU28 to reach a sustainable economy and lifestyle, it may be that directing both LSPs and the community-oriented projects mentioned above towards the instantiation of the ‘Circular Economy’ as an important goal would be doubly beneficial for the EU as a whole.
3.1.4 Conclusions

The overall approach used has created powerful visualisations summarising the CPS projects reviewed. Some results are confirmation of that which might be expected area such as: IoT, Low power sensors, Reliability, hold no surprises. More broadly, four main groupings are proposed:

- Systems-of-Systems
- CPS Support Ecosystem
- Strategic Technology Research
- Technology Implementation

The lack of coupling to application domain was a surprise, but represents a view supported by other workers in the field. It may be that the number of projects targeting domain specific CPS are an artefact of the past scope of EU project calls, rather than an application driven need. Further work is needed to clarify these speculations.

Amount of project funding is an area worthy of further exploration as some small projects have had remarkably high impacts. However, their relationship to larger projects was not captured, so caution is needed when interpreting this observation.

Road2CPS Recommends:

- Earlier work in this project has shown that CPS projects are only loosely coupled to domain, so the focus for RD&I should be towards addressing coherent sets of gaps as a general problem, with the solutions tailored subsequently to fit domain instantiations.
- Future EU interventions should be designed to address coherent sets of gaps as vertical, horizontal, or both, with the sets classified by the NCOIC framework.
- Technology projects that tend to focus on lower levels of the NCOIC scale should also consider the higher level impacts. There are interconnections between the levels.
- EU interventions should be designed to cover the whole spectrum of gaps within the CPS domain to maximise the impact from those interventions.
- The structured approach to collating data and visualising the results in this project could be applied both in more detail and more widely to other EU domains to maximise the planning of future benefits of interventions.
3.2 Dissemination of Programme Achievements and Impact Multiplication

3.2.1 The Road2CPS Catalogue of Programme Achievements


A Catalogue of Programme Achievements including details on the aims, results achieved and impacts of projects gives stakeholders a good overview on the progress and also collaboration opportunities.

3.2.2 The Road2CPS Clustering and Communication Event

**Context:**
The Road2CPS Clustering and Communication Event brought together over 120 experts from the fields of Cyber-Physical Systems (CPS) and the Internet of Things (IoT) and presented 16 projects that had been funded under the first call of Horizon2020 complemented by three ARTEMIS and ECSEL projects. The meeting was very successful in raising awareness of the activities being performed and highlighted that the areas being addressed within the project portfolio provide good coverage of the research, development and innovation needs across the domain. The timing of the meeting was also very pertinent with the launch of the new ARTEMIS-IA Strategic Research Agenda and the Digitising European Industry initiative. Many synergies with the findings of Rad2CPS were apparent.

Notably there was a mix of higher TRL activities being addressed by the ARTEMIS-IA and ECSEL large scale projects addressing key industrial topics such as integration of tools for safety-critical systems development, interoperability, factory automation and maintenance systems. Underpinning and extending this H2020 projects are performing novel work in the areas of verification and validation to deal with the new reality of not being able to predict all eventualities in autonomous applications such as cars, and to deal with key issues such as guaranteeing safety and security in a world which is becoming increasingly vulnerable to cyber-attack. A number of projects are addressing multicore processors to maximise application performance and to provide trusted computation when mixed-criticality applications are implemented.

**Outcomes:**
To get past the valley of death and successfully introduce technologies it is notable that the CRYSTAL and CP-SETIS projects that address interoperability and standardisation provide a model for similar proposed actions within the agenda for Digitising European Industry. Likewise the Innovation Hubs projects, CPSE Labs and EuroCPS, that target engagement with SMEs to raise awareness, transfer skills and provide access to the latest technologies, also directly support Europe’s goal of Digitising European Industry.

Looking to the future the roadmapping activities being performed in projects such as Road2CPS and CPSoS have an important role to play in bringing together the constituency around CPS and in providing recommendations for future research needs. The markets for CPS are global and the CPS Summit and TAMS4CPS projects are identifying areas within CPS where it may be possible to collaborate with the US to tackle common problems and work jointly to bring together critical mass. Here it is also important to address barriers that exist to technology roll out through harmonisation of standards, regulation for privacy and approaches to liability at a world-wide level.
Portfolio analysis:

An overview with key points of the 15 H2020 and three ARTEMIS pilot projects presented is given in Figure 5. On the top left industry engagement is being led by the ARTEMIS-IA. This is driving ARTEMIS large-scale projects addressing key topics such as Factory Automation and Maintenance systems in the ARROWHEAD and the ECSEL MANTIS projects. Supporting this is the H2020 project EoT which is addressing a specific technology of visual processing which has application across a number of application domains.

Development environments are a key concern in industry and the CRYSTAL project is a major initiative to address the integration of tools for safety-critical applications. The interoperability specification (IOS) allows integration of tools from many vendors. Underlying this is an Innovation Action to develop and promote the IOS standards to the wider community. The H2020 projects IMMORTAL and INTO-CPS are also addressing aspects of tool integration. Verification and validation is also a key need in the safety-critical application domain and notably here new novel approaches are being investigated to deal with the new reality of not being able to predict all eventualities in autonomous applications such as cars (projects UnCoVerCPS and U-TEST). Hardware and software development is being directly addressed in a number of projects exploiting the use of multicore processors reflecting the trend towards increasing numbers of cores. Simulation is being addressed in one project, COSSIM, and notably this project is also considering safety as a key requirement. Underpinning the adoption of networked systems is the increased vulnerability to cyber-attack. Here foundational work on safety and security is being performed by SAFURE and TAPPS. In particular, dealing with the reality that Apps with little or no provenance are being increasingly downloaded onto hardware, e.g. in the automotive domain, the TAPPS project is developing trusted execution areas to protect systems of higher criticality.

Notably the H2020 projects EUROCPS and CPSE Labs target at engaging with SMEs. As SMEs are the “powerhouse” of Europe these are important in raising awareness, transferring skills and providing access to the latest technologies. This directly supports Europe’s goal of Digitising European Industry. There are also two key roadmapping activities. Road2CPS has an important role to play in bringing
together several roadmapping activities that have been performed previously and to create a constituency around CPS. At the Systems of Systems level the CPSoS project is putting forward recommendations that deal with the human and complexity aspects of large, highly distributed systems such as sociotechnical issues (e.g. trust for increased autonomy) and cognitive features to manage increased complexity. These are areas which are not represented in the current portfolio but which must be addressed in order for the technology to be adopted.

The CPS Summit and TAM54CPS projects address both joint EU and US collaboration, one specifically on modelling and simulation and the other in a wider sense identifying areas within CPS where it may be possible to collaborate. It is clear that the problems being addressed are global problems which need to be tackled jointly to bring together critical mass. Here trustworthy CPS is an area which is being promoted. Looking beyond this there are many opportunities for standardisation. This has been demonstrated successfully by CRYSTAL and CP-SETIS for tool interoperability but is also required in other areas such as interoperability and standardisation for CPS and IoT more generally as highlighted in the agenda for Digitising European Industry. Finally, in order to enable successful uptake of technologies there is a need to remove barriers to commercialisation through harmonised regulation for privacy and liability.

In the main part of this report the strategic context of EU level support for Cyber-Physical Systems is presented along with summaries of the project presentations. The results of the discussion session and conclusions are also described. Project facts including partners, abstract, objectives and highlights are referred to in the Catalogue of programme achievements.

3.2.3 The Road2CPS Constituency Building Workshops

Three constituency building events were held during the course of the Road2CPS project:

1. The “Future platforms” workshop in Turin, Italy, October 2015
2. The “Smart Cyber-Physical Systems Clustering and Communication Event” in Vienna, Austria, April 2016
3. The “Smart Destinations Workshop: Digitising European Business and Society”, in Palma de Mallorca, Spain, October 2016

The three workshops enabled to establish a committed community of experts from various fields and backgrounds, interacting throughout the project lifetime. Some of them were recurrent participants in the Road2CPS events, others joined along, amounting to almost 120 persons with a fairly equal repartition between academia, industry (of which 30% SMEs) and administration/ funding agencies. The repartition between countries was the following: Austria (3), Belgium (6), Estonia (1), Finland (6), France (13), Germany (23), Greece (2), Ireland (1), Italy (8), Netherland (3), Norway (2), Poland (1), Portugal (3), Romania (1), Spain (28), Sweden (6), Switzerland (1), Turkey (1), UK (8), USA (1). The workshops held half-yearly enabled an assessment of findings and revise directions accordingly.

In the first roadmapping workshop held in Paris (June 2015) the concept of platforms was acknowledged as having a tremendous role in the structuration of the CPS field as such and of the domains Road2CPS intended to investigate (energy and transport, smart cities, health and manufacturing), as well as on the structuration of business ecosystems. It was thus decided to focus the first constituency building workshop to be held in Turin on this key notion (Future Platforms Workshop). It provided an interesting opportunity to enable cross-fertilisations between platform offers and demand side needs. The position of Europe was deemed threatened by US pervasiveness in
the field of consumer platforms. Although Europe features already promising assets, these need to be federated behind major industrial actors. Platform offers need to gain outreach towards SMEs. Programs such as I4MS promise to help in that direction, indeed acting as matchmaker between supply and demand sides to form the premises of sustainable ecosystems at regional level.

During the second workshop (SmartCPS Clustering Event), these findings were discussed with ongoing ICT and IoT projects under the H2020 and Artemis/ECSEL umbrella. The event took place in Vienna soon after the release of a new version of the ARTEMIS-IA Strategic Research Agenda (SRA), offering strong momentum to this meeting. The focus was on assessing the coverage of the current EU project portfolio and the means to inducing a stronger cooperation between projects (and platforms) across Europe. First of all, it was underlined that large Innovation Action projects do provide valuable impacts in tool integration, interoperability, or advances in heterogeneous systems, to name a few. These have both vertical (domain) and horizontal (value chain) impacts. Sustained by high TRL funding, their respective platforms are starting to gain attraction from SMEs through the open calls of cascade funding projects (see e.g. EuroCPS). Important steps have been taken towards building a more efficient research-to-innovation pipeline. The very ends of the pipeline (research and commercialisation) however do remain in need for important deliberate funding supports. Too much focus on higher TRLs could have detrimental effects in the long run on research projects at lower TRLs for the CPS field (or ICT in general). Turning to existing dedicated instruments (e.g. FET), which feature sizeable amounts of funding but have broad scopes and very high expectations for disruptive advances, is not an easy target to help carrying on the fundamental technological research which the CPS challenges ahead call for (e.g. formal validation of security and trust for autonomous systems). In addition, if platforms are attractive seeds from which to grow ecosystems, one should not miss to remember their attractiveness is subjected to a continuous intake from novel users, business models and ideas. To this aim, it is needed to help continuous education and professional skill learning, as well as ways to grant European user/customer an important involvement level in these experiments all along the pipeline (as the GAFAs have understood perfectly). Now, clear instruments lack to help in this direction. The EC is believed to have an important role here to find the appropriate balance for a smooth uptake of novel ideas and improvement in practices, skills, standards and usages.

At the time of the SmartCPS Clustering Event (April 2016), the reflection on Digital Innovation Hubs and Competence Centres (DIH-CC) was soon to be given a strong impulse with the launch of the Digitising European Industry program. Acknowledged as being pivotal in the dissemination of platforms and know-how, the DIH-CC usually grow from existing research and technology structures and clusters active at regional level. The EC objective here is to federate the efforts among these initiatives and help those at lower development stages gain quicker momentum. Methodological guidelines and best practices need to be gathered to accelerate the process across the EU28. To this aim the Road2CPS consortium thought a relevant case study would consist in understanding the evolution of a novel sector, which has so far not been under the direct umbrella of the Digitising European Industry (in contrast to transport, manufacturing or health). The purpose of the third and last constituency building event was thus set to reach out to the stakeholders involved in the emerging Smart Tourism / Smart Destinations area. The domain was chosen for its very high rate in new technology adoption and business model ongoing evolution. Also thanks to the Road2CPS consortium network there was a very nice opportunity to successfully gather all the actors of a particularly relevant initiative in Spain called Smart Destination, developed in coordination with regional and local administrative, research and technology public and private actors. The workshop was held in Palma de
Mallorca at the heart of the implementation of this initiative for the Balearic Islands. This event also complemented the Road2CPS community with experts from the Smart Cities and IoT related domains.

From the presentations given during the Smart Destinations Workshop, the tourism sector appeared to be exemplary of the digitisation taking place: large deployment of device-centric infrastructures, gathering massive amounts of data, guided with the ambition to turn this data mining into informed decision-support models, while caring for a balance between legitimate economic growth goals and the well-being of citizens and our environmental preservation. The close, important links to local SMEs to help them make use of the data, and to create their own local consortia offering services to tourists is an outcome from which other industries could learn. This was an ideal field of investigation for DIH-CC. Two main recommendations could be formulated: 1) what prevents a profitable coordination between initiatives and the uptake of a strong service-oriented business sector is the data model and infrastructure fragmentation. It is one of the major challenges ahead, which can be assigned to the DIH-CC network in general: working on pragmatic solutions towards common capabilities to enable information extraction from data, across systems and for all digitising domains. This calls for a shared semantics framework among data producers and consumers (multimodal transport, waste management, tourist needs and behaviours, resident feedback, energy grids, etc.). 2) the second recommendation is to mitigate the potentially detrimental societal impacts created by our current hasty pace in technological adoption and infrastructure deployment. The subsequent risks are the digital divide among the population and the overall rejection from a distrustful society. In response to these 2 aspects, some foreseen funding lines are: 1) to enable the sustainability and evolution of both infrastructures deployed and the emerging ecosystem throughout their lifetime, 2) to give citizens an edge in the digitisation process to seize opportunities for an improved well-being, a cleaner environment and jobs/professional skills enhancements.

In summary, these workshops brought participants of many EU countries, different types of organisations, different backgrounds together, to discuss various perspectives on the CPS field, leading to an enhanced overall understanding of goals, motivation, challenges and solutions.

3.2.4 The Road2CPS Roadmapping and Strategy Workshops

The Roadmapping activities build one of the main pillars of the Road2CPS project and are reported on extensively in many other deliverables. Still, it has to be mentioned, that these activities brought together a ‘foresight community’, including members from ARTEMIS-IA, EFFRA as well as IoT representatives, which shared their views and visions in a very intense and fruitful way during the project lifetime. Reports on the specific events are available here: [http://road2cps.eu/events/wp-content/uploads/2015/12/Road2CPS-WP2_Roadmapping-WS-Paris_2015-06-24-Report-V11-Public-Version.pdf](http://road2cps.eu/events/wp-content/uploads/2015/12/Road2CPS-WP2_Roadmapping-WS-Paris_2015-06-24-Report-V11-Public-Version.pdf)


3.2.5 The Road2CPS Case Studies

Road2CPS has created a brochure of 10 case studies, performed in mainly SMEs, serving as a guide to Guide to Cyber-Physical Systems Engineering. The brochure presents ‘case studies from real-world businesses’ and explains in an easy to understand language what CPSs are and how they can be of benefit for businesses (by reducing costs, improving efficiency or products and services).
Cases studies and success stories are a good tool to promote CPS via ‘real life examples’, and alleviate concerns and motivate especially in SMEs and mid-caps.

4 Conclusions, Evaluation of Approach and Recommendations

The Road2CPS consortium and the evaluation of feedbacks from experts/participants in Road2CPS activities revealed, that the activities described above are of great value and importance for the community. Giving the different stakeholders of the Cyber-Physical Systems ecosystem, the opportunity to share, compare and analyse the related results and to come together to discuss, collaborate and plan activities is giving a support action like Road2CPS an invaluable benefit. The links within the ICT-1 project community but also within the overall CPS/IoT/FoF ecosystem could be strengthened. Moreover, stakeholders from the demand and supply side, from technologies and application domains as well as along the value chain could be brought together successfully in a productive and open atmosphere to exchange ideas and discuss future directions.

A catalogue of programme achievements and project activities, updated on a regular basis, a project portfolio analysis and dedicated events give a good basis and overview for all involved participants and the overall community.

The in depth analysis of 72 CPS related projects using a sophisticated custom made tool, which can be explored by anyone interested to find out more about the projects, provides a very valuable means to become informed, select specific projects of interest and relate aims and results on an individualised basis.

The gap analysis performed can be used to identify gaps not targeted by current projects, visualise related gaps and asses projects covering specific gaps. The vulture tool has innumerable possibilities to select and relate different characteristics of the data set (growing with the number of project details included) and was used as the ‘project analysis tool’ in Road2CPS. Feeding the tool with relevant information of 72 projects of course is an effort (for a small CSA), but leads to a great pool of structured information. Many deliverables could be created on the basis of this tool, which again could provide the community with targeted information like existing gaps and opportunities of closing them. Many recommendations could be drawn by being able to compare many projects in a convenient way.

This tool and approach may be of interest to the Commission, especially those groups concerned with the planning, management and funding of RD&I projects. Development of this prototype to encompass the whole range of funded projects may provide very useful, multi-level, on-going feedback to the Commission for measuring the effects, successes, dead-ends and so on of the various programmes, leading to more finely-defined planning, greater efficiencies in support, and, eventually, more rapid progress in digitising the EU as a whole.

Road2CPS recommends:

- CSAs can have a great value in bringing the CPS and related communities together. Especially the organisation of concertation meetings for sharing results, identifying complementarities and collaboration opportunities should be taken into account in future work programmes.
- Federation of initiatives is necessary to exchange knowledge, align activities and avoid duplication of efforts.
- Specifically matching supply and demand (as performed in various workshops) is very important to align products to real needs. Moreover, the involvement of end-users in all stages of a project is seen as crucial.
- An analysis of past and ongoing projects builds a good baseline for all stakeholders. Tools like the ‘vulture tool’ could become a generalised approach, being continued by the following projects / CSAs to not start all work from scratch.
- The vulture tool should be further exploited by successor projects.
- A catalogue of Programme Achievements including details on the aims, results achieved and impacts of projects (of the same call/ same programme) gives internal and external stakeholder a good overview on the progress and also collaboration opportunities.
- Cases studies and success stories are a good tool to promote CPS, and alleviate concerns especially in SMEs and mid-caps. The Road2CPS cases studies (10 case studies) could be translated into a broader format.
5 References

The following references have been considered for the development of this document:


https://dspace.lboro.ac.uk/2134/20817

Road2CPS deliverables:


More related Deliverables (which are elaborated in parallel to this document, e.g. D4.1 Recommendations on Research Priorities, Business Opportunities and Innovation Strategies) can be found on the Road2CPS website: http://www.road2cps.eu/

Road2CPS Workshop Reports

Roadmapping and Strategy
Constituency Building


6 Annex 1 Methodology: Details on Data Collection and Analysis

6.1 Methods for Data Collection, Presentation and Exploration

A systematic approach was undertaken, modelled on the principles utilised by the Cochrane Collection in their detailed, evidence-based, biomedical surveys (Higgins and Green 2008), but adapted to the time frame and contents of this project (their core process of Concepts, Studies, Results and Conclusions). This approach, as adapted for this report, is developed in the following sections, but the key principle of collation of data for the study being independent of any expected conclusion has been followed. In fact, the geographically dispersed nature of the consortium has enabled access to a larger number of domain experts working independently of each other, which may be perceived as adding value to the quality of the data collation process.

Definitions

While the 72 projects mentioned above in Table 1.1 represent the projects sponsored by the EC within the sequence of Framework Programmes and in Horizon 2020, there are many other funded projects both within the EU and elsewhere around the world. The following definition of an Achievement was adopted to ensure consistency of recording: Within the context of the Road2CPS an Achievement is taken to be a tangible deliverable from a programme and is typically defined by an internal project plan and related documentation.

The State of the Art (SoA) is a description of greatest capability currently possible for a technology or application. Demonstrating a current state of the art is a program or project achievement. Such a demonstration may not necessarily result in an impact, although it may open the path to future impacts. Thus, all state of the art demonstrations are achievements, but are not necessarily also associated with impacts.

An Impact is taken to be the use of a programme achievement by one or more organisations that need not necessarily have been part of the original programme. Using this definition it follows that all impacts can be linked back to a source programme achievement. Thus, all impacts are associated with achievements, but not all achievements have associated impacts or SoA.

This relationship is used here to apply a qualitative measure to each achievement by assigning a Technology Readiness Level based upon an interpretation of the aggregated impacts associated with each achievement. By default all achievements are taken to start at TRL 1 and incremented up the scale on the basis of impacts. It is not possible to achieve TRL 5 or higher without validation within an external environment.

The Technology Readiness Level scale below is taken from the H2020 programme documentation.

<table>
<thead>
<tr>
<th>TRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>basic principles observed</td>
</tr>
<tr>
<td>2</td>
<td>technology concept formulated</td>
</tr>
<tr>
<td>3</td>
<td>experimental proof of concept</td>
</tr>
<tr>
<td>4</td>
<td>technology validated in lab</td>
</tr>
<tr>
<td>5</td>
<td>technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)</td>
</tr>
<tr>
<td>6</td>
<td>technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)</td>
</tr>
</tbody>
</table>
TRL 7 – system prototype demonstration in operational environment  
TRL 8 – system complete and qualified  
TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

As a convention, all projects were deemed to start at TRL 1. This convention simplified the assessment and placement of projects within the overall structure and presentation of reviews.

Finally, the narrative style used to report achievements should be descriptive, not unduly technical, and understandable by the informed public. The following guidelines may help:

- Abbreviations should be avoided, or defined when first used
- Technical terms should be explained
- Financial references should use Euros
- Links to SoA and Impacts snippets should be included
- Links to external sites should only be included if they help appreciate the achievement

Collation of Data from the 72 Projects Supplemented by other Relevant Information

The data collection focused on publicly accessible information on the 72 projects including EU websites, Project websites, academic publications and other online resources. Project documentation was also used, where available.

These deliverables were assessed by members of the Consortium, and condensations (“snippets”) were created as short descriptions of important findings and achievements of these projects, tagged for the three dimensions discussed above. These were entered into a database (the “Vulture”, described below in section 2) and subsequently analysed and rearranged to provide the results, as documented in this report. This analysis process was supplemented by the addition of extra, non-project information snippets from other organisations such as the IEEE Standards Association and Directives of the EC.

The essential aspects of the data collection protocol were:

- Assign each of the partners approximately 10 projects to review;
- Break each project into a series of “snippets” describing key achievements;
- Assign metadata to each snippet from a predefined nomenclature along with a short narrative about the snippet.

Results

The data was collated and presented “as-is”.

Conclusions

As in the case of the results, the conclusions are summarised and reported in the sections below.

The Vulture Tool

This description essentially replicates that provided in various Road2CPS documents/deliverables. It is provided here so this report can effectively stand alone, without the need for the reader to refer to other reports so that this one may be understood.
Why the need for a Tool
The agreed approach of breaking the data into small snippets and the categorisation of those snippets required the development of a custom software tool. The requirements for the tool were:

1. Collate text, files with associated custom metadata;
2. Usable by all consortium members with minimal training;
3. Permit analysis of the data and collation into a report;
4. Be quick and simple to implement;
5. Up-datable as required.

No existing software tool was known that could meet all these requirements, thus a custom tool was needed.

Implementing the Custom Tool
As the general purpose of the tool was to scavenge data, it was given the name “Vulture Tool”. Potentially there are many solutions to the simple requirements specification provided in section 2.1, but focussing on requirements 4 and 5, a physical implementation was realised:

1. Provide an internet based service using a LAMP (Linux Apache MySQL PHP) to enable all consortium members to access the tool;
2. Use DRUPAL to provide a custom graphical user interface for consortium members to input data;
3. Provide a path to publish a book style report on achievements.

It should be noted that the tool was not a monolithic piece of custom software: it was assembled from an array of software system blocks to meet the requirements of the task in hand. As such, the required functionality of this approach could have been met in other ways. However, the method chosen was very fast to develop and easy to modify so was entirely appropriate for the required application.

This particular deliverable did not require the use of R! for data analysis, although that remains available for additional in depth review. However, a path to publication quality output was needed. In due course this will be provided by linking Vulture output to the Scribus desktop publishing software. This linkage will be the basis for D6.5 A Catalogue of Programme Achievements.

Projects and Metadata
The previous subsections described the implementation of the Vulture Tool, but key to its usefulness was the pre-loading of the projects of interest and metadata definitions. For achievements the additional requirement was to adopt the H2020 Technology Readiness Level Definitions.

Entering the Data
To brief contributors on how to use the Vulture tool, and a set of instructions were developed (see: VultureGuidence.pdf) and two YouTube videos were recorded to assist with consistency of input:

- Introduction to Vulture (http://youtu.be/s7rF79A_HoI)
- Creating a SoA Snippet (http://youtu.be/7StyAVUjv4)

There were few queries from the expert contributors and this was taken to mean a general endorsement of the process and terminology.
Presenting the Results

The results of this work are presented as a document, however the Vulture Tool at http://road2cps.tech-trends.co.uk offers a highly effective way of browsing all the collated project snippets, project websites and other relevant on-line resources. The following subsections describes features available within the Vulture tool that add value to the data.

Collation of Data by taxonomy term

Collation of Data by taxonomy term

![Home Page](Image)

Figure A.1: Home Page

The Vulture tool supports a rich array of user defined meta-data terms called taxonomy. The underlying CMS allows easy searching and viewing of data by taxonomy term and the user interface has been arranged to take advantage of this facility. Note that the user must be signed in to use see project data. All the source projects are taxonomy terms. From the home page the full list of Source Projects shown in the right hand column. Selecting “Advance” will display project details and all content associated with the Advance project. One can dig deeper into any content by clicking on the title or read more link on any item of content. Within the detail on the right further taxonomy terms
may be seen. Other content tagged with those terms may also be viewed by clicking on any of those terms. This form of *ad hoc* browsing of content permits a rapid overview of the data not easily captured on print. A more formal and repeatable analysis may be obtained through the use of an internal tool called "views".

Figure A.2 Result of Selecting Project Source Taxonomy Term
Predefined Data Views

All the data within Vulture is captured as text within fields incorporated into the mySQL server that comprises a system element of the Vulture Tool. The Views engine permits the creation of pre-defined subsets of the data and also allows certain operations on that data prior to its presentation. The views engine requires a certain amount of skill to drive, but is a semi-visual process comprising of selection of options with the ability to embed custom code on an ad hoc basis. The result is very rapid development of custom pages of data derived on the fly from the dataset.
Figure A.4 Creation of custom views

Describing some of the principal options in the creation of a custom view:

**Title:** A custom title for the view.

**Format:** Usually content or table format used.

**Fields:** All content is stored as fields or, in the case of images may be retrieved through content in fields. This section is used to select which content to display. Sub options may be used to control the viewing format and rules may be applied to rewrite the format or content.

**Filter Criteria:** Rules may be applied to filter the content on the basis of field content. Almost anything that may be verbally described may be encoded as a filter rule. Complex AND / OR conditions may also be created and applied. User definable options may also be encoded.

**Sort Criteria:** Usually content is best displayed in an order that makes sense in the context of the data being presented. User controlled sort options may also be encoded.

**Page Settings:** These include options relating to path, menu and access.

**Advanced Settings:** Complex features may be enabled here that require an advanced understanding of how the data has been captured. In this example **Relationships** have been established with **Project Source** and **Technology Readiness Level**. This enables filter and sort criteria to be created the act upon the relationships between fields and content in different tables of data.

Further types of action may also be defined under advanced settings including aggregation and counting of data.

Finally, towards the top of Figure 2.5.4 buttons for **Data export** and **PDF Page** may also be seen. These are special formats where the output data is displayed as a CSV file format or PDF file format respectively using the same criterion as the page displayed here.

Figure 2.5.5 shows how the data appears to a logged in user. Not the active links in blue that can be used to navigate to the detailed content or associated content.

The CSV output format is useful for transfer of content into external programs for further analysis. The format may be directly opened by spreadsheet tools and nearly all other data analysis tools.
Summary of the Vulture tool
The rich array of built-in search facilities, custom views and compatibility with external tools has added great value to the dataset collated within Vulture. The data collated has been annotated with metadata by members of the consortium, further adding to its value.

<table>
<thead>
<tr>
<th>Source Project</th>
<th>TRL</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMBOCON, 2010-01-15</td>
<td>8</td>
<td>Optimisation Software for Control Systems</td>
</tr>
<tr>
<td>to 2013-07-14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMPASS, 2011-10-01</td>
<td>7</td>
<td>COMPASS: Model-based SoS Engineering</td>
</tr>
<tr>
<td>to 2014-09-30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGILE, 2010-09-01</td>
<td>7</td>
<td>Plug-and-Play Control for Complex, Large-Scale</td>
</tr>
<tr>
<td>to 2013-11-30</td>
<td></td>
<td>Real-Life Systems</td>
</tr>
<tr>
<td>WBRATE, 2011-09-01</td>
<td>7</td>
<td>Wireless, Self-Powered Vibration Monitoring and</td>
</tr>
<tr>
<td>to 2015-02-28</td>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>HYDROBIONETS, 2011-10-01</td>
<td>6</td>
<td>Demonstration of Real-time microbiological</td>
</tr>
<tr>
<td>to 2014-12-31</td>
<td></td>
<td>wireless networked control system</td>
</tr>
<tr>
<td>ENOSYS, 2010-01-01</td>
<td>6</td>
<td>Trialed by Thales</td>
</tr>
<tr>
<td>to 2012-12-31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCUBA, 2011-11-01</td>
<td>6</td>
<td>SCUBA: results of pilot studies on systems co-</td>
</tr>
<tr>
<td>to 2014-12-31</td>
<td></td>
<td>ordination and control in large buildings</td>
</tr>
<tr>
<td>GreenerBuildings,</td>
<td>6</td>
<td>GreenerBuildings</td>
</tr>
<tr>
<td>2010-09-01 to 2013-10-31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GENESIS, 2010-04-01</td>
<td>6</td>
<td>Rome Underground Test-bed</td>
</tr>
<tr>
<td>to 2013-08-31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAPYRUS, 2010-09-01</td>
<td>5</td>
<td>Papyrus-RT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure A.5 Table View of Achievements

Limitations
The study outlined in this document presents a best effort to summarise the substantial achievements of recent research teams working in the CPS field. However, although the information produced is correct to the best of our ability, the study inevitably will have some limitations.

- Road2CPS researchers conducted all the searching and cataloguing, not members of the projects themselves. This does confer a certain amount of consistency on the approach and the standards applied. However, as external researchers, it’s possible that incorrect assumptions or misunderstandings have been made by Road2CPS staff who are not intimately familiar with each individual project.
- We’ve relied on publicly-available sources. It’s possible that significant impacts or achievements may have been achieved by a project, but are not identifiable via these sources. In particular, significant impact may be achieved after the project has completed, especially in cases where the project’s outputs continue to be adapted by the project partners. However, for many projects resources may not be available to continue updating the former project website long after the project’s conclusion.
6.2 Methods for Data Analysis and Visualisation

A useful new data visualisation has been the “heat map” table. This type of table is particularly useful for displaying data comprising of categories, as in the data collated by this project. A contingency table showing the count of occurrences of pairs of categorical values is produced and noted in each cell. For clarity, cells are shaded darker as the number of occurrences increases. A particular feature of this approach is that it fully supports data where multiple levels per category are permitted. For example, a project snippet might be marked as relating to several domains. This more relaxed approach to assigning categories, while increasing the complexity of analysis, better reflects the real world nature of projects and experts ability for categorisation.

Some examples for Project Analysis of Achievements, Gaps and Impacts

<table>
<thead>
<tr>
<th>1</th>
<th>5</th>
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Figure A.6 NCOIC vs Infrastructure (number of entries in Vulture within each category)
In the figure above, the bias of projects towards the lower levels of the NCOIC / Interoperability scale. Moreover, gaps in specific areas become visible.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Energy</th>
<th>Environment</th>
<th>Health Care</th>
<th>IT &amp; Domain</th>
<th>Manufacturing</th>
<th>Security</th>
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1. Political/Economic/Regulatory/Business Board level
2. Business objectives: strategy & policies level
3. Business context: aligned operations level
4. Business context: aligned procedures level
5. Semantics: knowledge & sharing of knowledge level
6. Semantics: information & interoperability level
7. Syntactic interoperability
8. Network interoperability
9. Physical interoperability level

**Figure A.7 Domain vs NCOIC (number of entries in Vulture within each category)**

In the figure above ‘Transport’ related projects are well represented in the dataset of CPS projects while Healthcare and Security are clearly gaps in the coverage. These gaps have been observed throughout the Road2CPS project.
### Figure A.8 Domain vs Infrastructure (number of entries in Vulture within each category)

The horizontal banding in the figure above suggests the association with the Infrastructure scale is reasonably independent of the Domain scale, supporting earlier assertions that EU CPS projects are largely domain independent.
“Big Data” type visualisations are more appropriate as the quantity of data increases along with the increased number of cross linkages. These have been used to good effect within deliverables D1.2 Gaps Analysis and D1.3 Impact Assessment. As the number of projects has increased to 72 and the number of linkages increased to over 2500, only a network type visualisation as presented in Figure 3.3 can capture the overview in a single diagram.
Within the figure above projects are closest to gaps which they address. The placement has been generated entirely through the use of an algorithm which seeks to minimise the distance closely linked nodes. The linkages may be interpreted as the potential each project has to make and achievement or impact. Thus, projects such as this one, Road2CPS, CPS-SUMMIT and BALCON are towards the top of the diagram close to the high level infrastructure gaps they serve.

Conversely, projects such as CPSELABS, U-TEST and SPRINT are close the technological gaps that they address. HYCON2, already noted as a project with wide ranging potential impact and achievements, has gravitated to the middle of the diagram. Overall many similarities can be observed with the “Cube 2.0” diagram of D1.1 State of the Art Report.

We speculate, that if it were possible to apply this type of representation to many hundreds of project and gaps and their associated linkages (representing impacts and achievements) the diagram would tend towards many clusters, such as the one represented here.
### 7 Annex 2 Table of Gaps and Impact eliminating them

<table>
<thead>
<tr>
<th>Interoperability level</th>
<th>Description</th>
<th>Gap</th>
<th>Value of eliminating the gap</th>
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</thead>
<tbody>
<tr>
<td>Political/ Economic/ Regulatory/ Business Board level</td>
<td>Technology addresses needs issues and opportunities that should be addressed either by government (e.g. creating regulations, programmes, agencies, etc.) or by the Board of a company (e.g. recommendations that affect why the company exists and what it does; governance, legal and financial aspects). Discussion of pre-requisites for business models to be successful.</td>
<td>1. Lack of international agreements to facilitate supply chain operation across legal boundaries</td>
<td>1. Removal of barriers will facilitate and improve international operations of CPS; important for governance</td>
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<td>2. Security issues abound, indicating the need for international agreements and standards</td>
<td>2. Improved overall security and safety of CPS networks; also important for governance. Certification of CPS networks for dependability will be important</td>
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<td>3. Within EU28, different rates of adoption of IoT and CPS may exacerbate the ‘digital divide’ between member states and between their people. Internationally the ‘digital divide’ persists between developed &amp; less developed states.</td>
<td>3. General improvements to EU commerce, and improved quality of life for EU citizens. Also, general improvements to international commerce, and improved equality of life for all citizens of the world</td>
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<td>4. Need for concerted, integrated, co-ordinated efforts by governments and other agencies to bring about cultural, social &amp; educational change to encourage wide adoption of CPS and overcome poor social acceptance of and trust in the steady pervasion of CPS within and across society; inability to assure CPS will exhibit ethical behaviour; lack of a regulatory regime and good practice code to</td>
<td>4. Improved quality of life for citizens, through improves social acceptance of the changes CPS represent; improved trust in and hence participation in and use of CPS will result in better quality of life for citizens, through improved social acceptance of the quality of service provided by CPS</td>
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<td>Interoperability level</td>
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<td>enforce ethical operations by CPS in all domains</td>
<td>5. [EMPTY; merged with 4]</td>
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<td>Poor understanding of how CPS in different sectors interact; lack of modelling &amp; simulation capability to mitigate possible clashes.</td>
<td>6. The close-coupling of systems characteristic of CPS imply that ‘normal accidents’ will happen, and may have extensive effects. The probability of these will be reduced.</td>
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<td>Wide-spread need for more CPS-trained, competent people to manage, operate and maintain CPS.</td>
<td>7. A reduction in the occurrence of faults and breakdowns, improved resilience of CPS networks, increased commercial agility, greater reliability of service</td>
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<td>Provisioning of education systems to ensure a continuous supply of a well-trained, competent workforce for CPS</td>
<td>8. A reduction in the occurrence of faults and breakdowns, improved resilience of CPS networks, increased commercial agility, improved quality of service, acceptance of CPS</td>
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<td>Paucity of evaluation methods, criteria and approaches to test the integrity of IoT networks &amp; communication patterns for critical industries and infrastructures (e.g. energy, transport)</td>
<td>9. Greater resilience and reliability of critical industries and infrastructures</td>
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<td>Assurance &amp; adequacy of fall-back plans for major CPS failures (e.g. energy)</td>
<td>10. Greater resilience when major incidents occur</td>
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<td>11. Lack of a regulatory and good practice infrastructure for Responsible Research and Innovation</td>
<td>11. Avoidance of inadvertent anti-social outcomes, better matches to societal needs, greater coherence and cooperation among CPS networks, better designed CPS networks</td>
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<td>12. Need for improved technical and engineering governance for critical CPS</td>
<td>12. Decreased development costs and improvement of Fitness for Purpose of CPS</td>
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<td>13. Need for regulations and good practice guides to enhance information privacy, protection, security and safety; this includes IPRs, commercial confidentiality, etc.</td>
<td>13. Improved acceptance of CPS by citizens; better service from CPS; brand enhancements for CPS. Note that the Smart City requires personalisation of data, so security certification of CPS will be fundamental</td>
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<td>15. Scalable socio-technical models of the economy to enhance/replace current economic models for forecasting purposes, to accommodate the tighter coupling of systems engendered by the spread of CPS capability</td>
<td>15. Better, more realistic models of society, enabling better predictions of future change, more useful economic models</td>
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<td>Interoperability level</td>
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<td>16. Continued development of ‘Single European Areas’</td>
<td>16. More efficient, reliable, resilient services for EU citizens, once security and comms issues are addressed</td>
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<td>17. Development of a regulatory environment to accommodate the roles in society of autonomous agents and systems, and their infrastructures</td>
<td>17. Greater safety and security for citizens as customers and co-workers; fewer instances of emergent, aberrant behaviour, better-designed CPS</td>
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<td>18. The gradual transformation of humanity into ‘cyborgs’, connected to the IoT through smartphones and other wearable devices, indicates the need for a comprehensive review of legislation and other instruments of government to fit the needs of society, and to facilitate the benefits that this connection offers.</td>
<td>18. Safer, more secure, reliable and dependable virtualisation of societal interaction with CPS and in social life in general</td>
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<td>19. For the ‘sustainability of society’, CPS have a large part to play in agriculture; on the farm and from farm gate to plate, together with the minimisation of waste. By extension, this includes the natural world. A co-ordinated effort, involving SMEs and LEs, is needed to maximise</td>
<td>19. Better, more careful agricultural practice, much less waste, improved quality of food supply to citizens, better resilience to food shocks from around the world, and better management</td>
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<td>Interoperability level</td>
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<td>Business objectives: strategy &amp; policies level</td>
<td>Technology helps formulate the plans which government/industry/companies should develop to reach desirable business objectives; may also indicate how to implement the plan(s) in order to avoid unwanted side-effects and consequences). Evaluation of business models.</td>
<td>food production and minimise waste.</td>
<td>of the natural world.</td>
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<td>20.</td>
<td>Theories of architecting, to enable better satisficing of networks and CPS to meet QoS and performance goals, including where legacy system are entrained into CPS</td>
<td>Better-designed CPS, better quality of service, reduced operational problems, improved acceptability of CPS</td>
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<td>21.</td>
<td>Tools &amp; applications for dynamic, scalable, trade space analysis to assist in architecting CPS, including legacy systems</td>
<td>Improved CPS delivered at less cost, improved QoS, improved entrainment and reliability of legacy systems</td>
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<td>22.</td>
<td>A range of domain-related strategies and road-maps for transforming current capabilities into CPS capabilities, including the retention of some legacy systems</td>
<td>Better-planned CPS able to deliver better services to citizens with greater reliability; savings for entrepreneurs and customers</td>
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<td>Availability of CPS-trained workforce to implement, operate &amp; adjust architectures</td>
<td>Fundamental step towards high-quality CPS</td>
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<td>Need for technologies to assure ethical behaviour in CPS, for reliability, safety, efficiency, trust &amp; social acceptance</td>
<td>Fundamental step particularly for social care and health care CPS; important for acceptance by most consumers</td>
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<td>Requirement for improved cross-disciplinary, theoretical understanding of autonomous behaviour in CPS</td>
<td>Essential for operational efficiency of CPS, and for their acceptance into society</td>
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<td>27.</td>
<td>Theories, tools, architectures and devices for continuous ‘health monitoring’ of operational CPS</td>
<td>27. Necessary to enable high quality of service for CPS in competitive, fast-changing environments</td>
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<td>28.</td>
<td>Improvements to, and formalisation of the Responsible Research &amp; Innovation initiative to permit greater interoperation and integration and to assure safety and security of CPS operating in society</td>
<td>28. Better strategies for CPS development, leading to better performance and better coverage of consumer needs, less waste and more attention to sustainability needs, both general and situation-specific</td>
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<td>Develop theoretical understanding of the relationships between CPS lifecycles, system certification, and CPS properties such as resilience, agility, robustness, etc.</td>
<td>29. Improved reliability security and dependability in operations of CPS</td>
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<td>30.</td>
<td>Characterisation of architectures for different industrial domains (e.g. health, transport, etc.)</td>
<td>30. Evolution of CPS pattern stereotypes, general and domain-specific</td>
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<td>31.</td>
<td>Theory and tools to explore architectures for the allocation of human authority and responsibility for CPS operations and behaviours: for legal and liability reasons</td>
<td>31. Well-designed, resilient CPS with clear lines of authority and responsibility, delivering services to consumers and better, more comprehensive environments for co-workers within CPS to manage systems and</td>
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<td>Interoperability level</td>
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<td>32. Theoretical understanding of emergence and resilience for business architecting of evolving CPS (i.e. the relationships between sources, sinks and bearers and the feedback loops between these involved in the transfer of material, energy and information that underpin both emergence and resilience), also addressing 'Normal Accidents' theory; tools to evaluate the brittleness of CPS where V&amp;V on components is incomplete, and for the brittleness of CPS networks (e.g. where several CPS have a common, key supplier)</td>
<td>Provision of the understanding necessary to deliver resilient, long-life, high-QoS CPS within changing environments. These analytics will lead to more reliable CPS, with better resilience for those situation where emergent, unwanted behaviour occurs; also addresses those situations where a key supplier’s problems cause extensive failures across many CPS; examples are Philips-Nokia-Ericsson chip supply; flooded disk drive factories in Thailand</td>
<td>devices; clearer legal boundaries established</td>
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<td>33. A means of assessing the consequences of the contracts and conditions that bind together the components of a CPS when the CPS is placed under stress</td>
<td>Large, extensive CPS will rely on network of contracts to deliver services; assessment of these will enable more robust designs of CPS, particularly when the environment is subject to change</td>
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<td>34. Understanding the impact of double/triple loop learning capability within autonomous systems on the</td>
<td>Design and operation of complex CPS including these systems will become less subject to emergent, perhaps unwanted, behaviour; behaviour itself will become more</td>
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<th>Interoperability level</th>
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<th>Gap</th>
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<td>behaviour, safety and security aspects of these systems</td>
<td>transparent</td>
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<td>35. Options and technologies for zero waste and mining landfill, as part of the circular economy.</td>
<td>Development of CPS for waste management will create a step-change in sustainability engineering and in materials conservation</td>
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<td>36. Interoperability standards required with further reach across industrial domains and more widely within them</td>
<td>Much better co-operation between CPS in different domains; improved within-CPS interoperability, more reliable and resilient design of CPS</td>
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<td>37. Development of both theory and software environments for model-based control of CPS</td>
<td>MBSE is the future of CPS; frameworks to build and instantiate models more readily will produce step-change advances in the engineering and operation of CPS and significant improvements in reliability.</td>
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<td>38. Need for architectures, infrastructures, and support for tele-health: since this will involve interaction with vulnerable people, perhaps with continually degenerating capabilities, the assurance of always-available, ethical care is a priority, there is a strong need for graduated control of the situation and for all aspects of safets &amp; security</td>
<td>Significant reductions in the costs of health care per person, but carrying significant infrastructure requirements</td>
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<td>Interoperability level</td>
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<tr>
<td>Business context: aligned procedures level</td>
<td>Technology addresses the procedures within a function (such as manufacturing) that can be matched better with the goals of the function (e.g. to make savings in time, costs, waste, efficiency, etc.) Technology may address the alignment of procedures running across several companies. Standards and codes of practice are also important</td>
<td>39. Generation of a regulatory regime and code of practice for bionic devices for human augmentation</td>
<td>39. Safer, more secure devices presenting fewer surprises for users, their families and for other people with whom users come into contact; reductions in health care costs</td>
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<td>40. Better Broker-type Architectures to entrain devices and applications into processes to deliver business goals; important for PnP-type CPS</td>
<td>40. Faster instantiation of CPS, with better-matching component systems, especially for those intended for short lives</td>
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<td></td>
<td>41. Verification methods together with modelling and simulation tools for hybrid models of CPS components</td>
<td>41. Of major importance for the design of safe, secure, efficient CPS within a given process environment</td>
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<td></td>
<td>42. Extension of modelling &amp; simulation environments for exploring behaviour of hybrid models of CPS components</td>
<td>42. Of major importance for the design of safe, secure, efficient CPS within a given process environment</td>
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<td></td>
<td>43. Few methods to tackle scalability problems of current tools and environments for large-scale CPS</td>
<td>43. Enables the principled, efficient design of large, complex CPS within a given process environment</td>
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<td>44. Need for run-time V&amp;V tools for upgrades to systems that cannot be switched off.</td>
<td>44. Permits necessary V&amp;V in a process context to ensure better, more reliable and safe CPS</td>
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<td>45. Develop methods &amp; tools for V&amp;V on autonomous CPS component systems</td>
<td>45. Permits assurance of performance by autonomous systems</td>
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<td>Interoperability Level</td>
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<td>46</td>
<td>Need for resource-efficient means of control, orchestration of CPS; especially computation and communication; also to address distributed control, local autonomy and ‘selfishness’</td>
<td>46. Necessary for management/operation of large-scale CPS, as in energy, health care, transport domains.</td>
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<td>47</td>
<td>Development of software technologies and languages to meet the needs of M2M communications between real-world CPS and their devices</td>
<td>47. Enables distributed CPS where time-sensitive coordination and operation is important</td>
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<td>48</td>
<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>48. Human control and co-operative working with CPS requires these to be developed to be able to execute authority and responsibilities within the CPS during operational processes</td>
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<td>49</td>
<td>Methods and tools for exploring and utilising legacy systems’ behaviour, security, etc. where documentation and/or relevant staff is/are missing</td>
<td>49. Enables ‘reverse engineering’ of legacy systems to establish current performance and constraints where documentation and operational knowledge may have been lost</td>
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<td>50</td>
<td>Methods and tools for the design of human roles within CPS (i.e. the deployment of human intelligence, wisdom, knowledge &amp; capabilities both to control and to co-work with CPS component</td>
<td>50. Humans are the final and best resources for resilience when unexpected or unwanted events occur; this enables the effective, early deployment of these</td>
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<td>systems)</td>
<td>51 Methods and tools for the control of Ultra-Large Scale Systems of Systems (ULSS) composed of networks of many CPS (e.g. energy supply); likely to include hybrid models for control</td>
<td>resources to restore ‘normal’ operations</td>
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<td>52 Methods and tools for the assessment of trustworthy behaviour within the CPS environment. This applies to trust between humans and CPS systems (in both directions); trust between organisations within the CPS; trust between systems and between devices within the CPS, particularly where autonomy and learning is involved</td>
<td>51. ULSS are typically socially-critical (and often safety-critical) CPS; these tools and methods will be important in their effective operations. Especially in the case of hybrid models for control; this is an ill-understood area.</td>
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<td>53 Methods and tools for the management of continuous socio-technical change in CPS</td>
<td>52. Trust is a cornerstone of CPS. Given their pervasion into society, the assurance of trustworthy behaviour is of fundamental importance to ensure uptake and safe, ethical operation</td>
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<td>54 Development of better energy storage systems</td>
<td>53. Neither CPS nor the personnel responsible for their operation will remain the same; nor will their operational environments. These methods and tools will enable the maintenance of safety and performance under changing circumstances</td>
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<td>54. Necessary for mobile components of CPS, and for those CPS that must be kept running when regular energy supplies</td>
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<td></td>
<td>Development of fuel cell and or carbon-free technologies</td>
<td>55</td>
<td>might fail</td>
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<td>Devices, methods and tools for recycling in the Circular Economy, including mining landfill</td>
<td>56</td>
<td>Necessary for mobile components of CPS, and for those CPS that must be kept running; for their contribution to sustainability</td>
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<td></td>
<td>Develop platforms and demonstrators for all domains (manufacturing, health care, etc) to provide infrastructure and tools to enable swift construction and operation of CPS, and to show benefits and approaches of CPS</td>
<td>57</td>
<td>Creates new revenue streams and commercial opportunities, as well as being fundamental for global sustainability</td>
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<td></td>
<td>If the technology allows or recommends adoption of, or suggests changes to, ontologies, taxonomies, thesauri, or discusses knowledge sharing (e.g. IPR agreements) among different groups, companies, etc., then it is at this level</td>
<td>58</td>
<td>Necessary if full benefits of CPS are to be realised, by making it easy for enterprises to design, operate and upgrade CPS. Furthermore, demonstrators will be necessary to engender take-up of the CPS approach; also to identify pitfalls and potential inefficiencies. Good way to show benefits of the circular economy</td>
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<td>Improvements to interfaces, tools and support software for better situation awareness for autonomous systems in CPS to achieve greater reliability, predictability &amp; safety</td>
<td>58</td>
<td>Removes the opportunities, occurrence and seriousness of emergent, probably unwanted, behaviour; better awareness of CPS component system operations may permit future efficiency gains through upgrades</td>
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<td>Development of ontologies for human-automation communication (e.g. SIRI, CORTANA)</td>
<td>59</td>
<td>Essential for easy verbal communication between humans and devices/software agents when co-working</td>
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<td>60. Development of a cross-disciplinary knowledge base (theories, expertise, etc.) for CPS design, development and operation</td>
<td></td>
<td>60. Necessary for a trained workforce across the EU and for maintenance of excellence in CPS utilisation. This will help organisations to cope with the inevitable imperfections of the models used on all layers (different accuracies, reliabilities and availabilities, models of processes, sensors and communications)</td>
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<td>61. Metadata ontologies needed for Standard Process Instructions and M2M communications; also for efficient ‘lending’ of CPS components between different CPS systems when required</td>
<td></td>
<td>61. Provides the basis for fast, efficient matching of devices and software to compose CPS as required for customised products and individualised services for consumers when combined with SOPs; also provides resilience in operations</td>
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<tr>
<td>62. Metadata ontologies needed for Standard Operating Procedures; also for efficient ‘lending’ of CPS components between different CPS systems when required</td>
<td></td>
<td>62. Provides the basis for fast, efficient matching of devices and software to compose CPS as required for customised products and individualised services for consumers when combined with SPIs; also provides resilience in operations</td>
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<td>63. Development of human avatars for MBSE design of CPS nodes and networks</td>
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<td>63. Avatars for variable human performance in operations, addressing combinations of fatigue, stress, workplace layout, task, job &amp; team design, job satisfaction, etc. will aid good architecting of CPS for performance, resilience, etc.</td>
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<td>64. Develop CPS devices, methods and tools for bio-engineering liquid wastes such as sewage, ground run-off, etc. for energy-harvesting</td>
<td>64. Creates new revenue streams and commercial opportunities, as well as being fundamental for global sustainability</td>
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<tr>
<td>Semantics: information &amp; interoperability level</td>
<td>Understanding of concepts contained in messages passed between interfaces. Technology may deal with glossaries, or classes of information, in the context of transferring meaning from one head to another, or between CPSs or software agents. Discussion of protocols would also indicate this level.</td>
<td>65. Improved architectures and analytics for ‘Big Data’ approaches for improved quality of data, for situation awareness &amp; for control of CPS</td>
<td>65. Creates new commercial opportunities for exploitation; necessary as an input to achieving a sustainable world</td>
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<td>66. Provision of visualisation tools to improve human understanding of Big Data patterns 67. Improved sensing (e.g. motion and posture-sensing) capabilities at the human-automation interface, for safety and efficiency</td>
<td>66. Enables organisations to find and exploit the commercial opportunities that Big Data makes available 67. Helps to ensure safety both for process co-workers and for end-users</td>
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<td>68. Understanding the technology for ultra-reliable devices and sensors connected to the network, and for the network itself</td>
<td>68. Fundamental for full exploitation of the IoT and CPS for the benefit of society</td>
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<td>69. Improved technologies to assure security of the network – encryption, quantum keys, etc., codes of practice to ensure conformance with regulations on privacy, protection, security, &amp;</td>
<td>69. Fundamental for trustworthiness of CPS &amp; IoT operations, realising the benefits that CPS and the IoT can bring to societies and hence a key enabler for the</td>
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<td>Syntactic interoperability</td>
<td>Technology addresses formats, compression techniques, encryption and other ways of representing knowledge, information and data for transfer between functions, organisations, etc. Standards and codes of practice regarding interfaces and message structures are indicators of this level, as is discussion of integration of models.</td>
<td>safety, etc.</td>
<td>acceptance and growth of CPS in society</td>
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<td>70. Development of Named Data Networks, Cognitive Networks, etc as alternative approaches to security, network traffic, etc.</td>
<td>70. New technologies for the Internet and the IoT can reduce communication load, reduce latency in the network, and enable better means to achieve high levels of security and trustworthiness that will be necessary in future</td>
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<tr>
<td>Network interoperability</td>
<td>Enables the exchange of messages between CPSs across a variety of networks. Technology addresses networks and networking, interface descriptions, and analysis of network architectures</td>
<td>71. Improvements to SDN and NFV technologies &amp; standards to present a smooth communications surface on which CPS components can interoperate, worldwide</td>
<td>71. Important for suppleness of the internet, and for flexibility and agility in CPS reconfigurations and in for meeting the customisation of products and the individualisation of services.</td>
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<td>72. Development of 5G technologies for better QoS, security, PnP capabilities (i.e. non-stationary CPS, BYOD), achievement of low latency comms, etc.</td>
<td>72. Significant for the transformation of humans into cyborgs, interoperating seamlessly with CPS; likely to be of importance in future health care; important for wireless control networks; and fundamental for dependability of the network</td>
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<td>73. Insufficiencies of architectures and tools to enable better management of the network, leading to improved reliability of service over whole network</td>
<td>Enables reduced communication load, reduced latency in the network, and enables better means to achieve high levels of security and trustworthiness that will be necessary in future</td>
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<td>74. Need for ‘Fog’ technologies (and similar) to supplement cloud computing &amp; storage</td>
<td>Important for time-sensitive CPS, and potentially to reduce communications load on the IoT</td>
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<td>Physical interoperability level</td>
<td>Technology/Mechanisms to establish physical and logical connectivity and which address issues of physically connecting together devices, using Ethernet cables, plugs sockets, wireless, or transferring pieces of paper</td>
<td>75. Standards for interconnection to the IoT, additional to IEC 61131 and 61499, particularly addressing long-latency issues, security, metadata and certification</td>
<td>Better, more reliable and trustworthy operation of the IoT and CPS. Important for dependability of CPS and the networks</td>
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<td>76. Lack of miniaturised, low power, long-life sensors in all categories &amp; sectors, particularly for Smart Communities</td>
<td>Creates the variety, volume, geographical distribution and detail of data on which Big Data analytics can operate effectively</td>
</tr>
</tbody>
</table>

Table A.1 Gaps and related impacts