Cyber-Physical Systems and Society: Some technology-based 'key messages' for ergonomics/human factors

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Abstract. The paper reports some of the findings for the H2020 project, Road2CPS. This project was intended to provide advice to the European Commission, based on the outputs of 54 FP7 and H2020 projects plus 18 ARTEMIS and ECSEL industry-based project consortia, all in the area of Cyber-Physical Systems. One of the goals of this project was to identify gaps in the knowledge and applications coverage of CPS and provide recommendations regarding these. The paper reports briefly on the methodology that was used, and the 'key messages' arising from the analysis that are relevant to CIEHF academics and pracitioners.

Keywords. Cyber-Physical Systems; practitioner needs; ergonomics; socio-technical systems.

1. Introduction

Cyber-Physical Systems are those where the hardware components have software embedded within and tightly linked to them for control purposes, with at least some potential for decision-making. Other software components for control of the system may also make autonomous decisions, changing the nature of human involvement. An autonomous automobile is a simple example of the concept. CPS are expected to dominate in most processes in most domains of economic activity, and be the main means of delivering global sustainability in coming decades.

This paper reports some findings from an H2020 project, 'Road2CPS'[1]. This was a 24-month CSA project, completed in February, 2017. Its remit was:

- Identify the gaps in current research in the realm of Cyber-Physical Systems (CPS)
- Analyse future research priorities and business opportunities
- Bring relevant stakeholders together to form an EU-based community of practice.

This paper reports on the first two aims above, in the form of 'key messages'. The main audience for these messages was the European Commission, especially the groups involved in formulating H2020 plans and funding Calls. However, implicit in these key messages are aspects of relevance to the E/HF profession, regarding its future involvement and contribution.

The paper is organized as follows. First, there is a description of some basic premises of the project. This is followed by a description of the methodology, leading to the caveats and assumptions involved that will help the reader to evaluate the contents of this paper. Some examples follow. Then the key messages relevant to the E/HF profession are discussed, and the paper ends with some broader conclusions.

1.1 Premises of the project

In an interesting approach, after the proposal with the aims above and proposed budget was signed-off by the Commission, the project was informed that the commission had a list of 54 CPS projects that it would like assessed. A year later, the Commission added a further 18 projects from the EU-funded ARTEMIS and ECSEL industrial application Joint

[1] http://www.road2cps.eu

Undertakings. This number of projects changed the original thinking on resource allocation fairly radically, leading to the caveats and assumptions discussed below to manage this volume of information within the time frame of the project. A data-scavenging tool (the 'Vulture') was created from open-source software components, and the open-source Gephi™ visualization package for networks was adopted to create plots of the data. For information on the development and functionality of Vulture, plus the internet location of the tool and its database, see (Palmer, Siemieniuch et al. 2016). A more detailed follow-up paper is planned.

1.2 Methodology to obtain the 'key messages'

The methodology described below refers only to the socio-technological aspects of implementing CPS within society, not to the business nor the political aspects, even though these are intertwined with the technologies.

Based on the list of 72 projects, their websites were accessed for Deliverables, and chosen snippets from these that referred to gaps, achievements and impacts were entered into the Vulture. This dataset was supplemented by snippets from other publically available reports and papers on CPS. The whole consortium of 12 people participated in this effort, and each snippet was classified on three orthogonal scales:

- Domain, using the ARTEMIS classification (Gide 2013, ART-IA 2016) already established (e.g. health care, manufacturing, etc.). Subsequent analysis showed that this axis was unnecessary; all the domains had common issues with respect to CPS technologies
- Infrastructure, including classes such as standards, regulations, business models, training, etc. This proved useful for classifying the gaps
- Interoperability, based on the NCOIC Interoperability Framework (NCOIC 2011) with classes such as strategic, business, semantic, etc. This proved to be by far the most important axis.

Other recognised sources on the state of the art in CPS (e.g. (Firesmith 2010, Duranton, Bosschere et al. 2015, Geisberger and Broy 2015) were also included in Vulture.

Based on this data repository, a table of 75 gaps and associated potential benefits was created. Using the interoperability scale as a guide, coupled with system engineering and ergonomics knowledge, these gaps were interlinked, using two types of links:

- 'Is a part of'; i.e. closing gap X contributes directly to closing gap Y
- 'Is a complement to'; i.e. closing gap X contributes/extends the effect of closing gap Y

The Gephi™ package was then used to visualise and filter the resulting network, as shown in Figure 1 below, to extract the key messages.

1.3 Caveats

The main caveats identified are as follows:

- While a total of 72 projects is a fairly large sample, it is EU-centric, and small in global terms.
- Many of these projects were still under way, with not much public information available
- Information retrieved from the projects was from their Deliverables. In view of the resource problem, no attempt was planned to interview representatives from the projects to elaborate the Deliverables.
- Not all the project Deliverables were in the public domain, and those that were

available may not represent the full information and outputs generated by the projects
- The analysis of the outputs was performed by ergonomists and engineers, using a systems engineering perspective. Other perspectives may reach different conclusions.

1.4 Assumptions

- The Deliverables produced by each project are an accurate record of the project
- The analysis of the Deliverables and the key messages are not domain-specific. All domains (healthcare, energy, etc.) have similar generic issues regarding CPS, albeit their resolution may require specific detail for a given domain
- Two classes of network links are sufficient to interpret the plots. This assumption is based on the benefits of simplicity.
- The focus on deriving key messages should be on the highest, 'strategic', gaps, since these will be of most interest to the Commission.
- Filtering the network in Figure 1 for each strategic gap and its nearest neighbours will reveal the key messages. Again, this is based on the benefits of simplicity. Figures 2 and 3 provide examples of this.
- The adoption of a bottom-up methodology based on project findings is enough to ensure that the key messages are evidence-based, not merely re-expressions of viewpoints already established in the general CPS literature.

2. Examples of the network analysis

Figure 1 below shows the network of gaps, links and projects, based on the 72 projects. The gaps are colour-coded by interoperability level, as shown in the key. Gaps are sized by the number of links. Brief labels for the gaps are given.

It will be noticed that in the bottom of the diagram there is a rich mix of coloured nodes, whereas in the top half the layers are more evident; none of the projects specifically addressed strategic issues, so this layer is distinct. It will also be noted that conveniently the projects have been sorted by Gephi™ algorithms to the outside. Less obviously, the ARTEMIS/ECSEL projects cluster towards the top of the network and the FP7/H2020 are located at the bottom half of the network. This observation is a reflection of the different nature of the two classes; the former aimed at implementation issues and the latter at technical research.

It is evident from Figure 1 that, apart from the observations above, the complexity of the network overwhelms visual analysis. For this reason, filtering was employed, to disentangle each strategic gap (green nodes) and observe its nearest neighbours. Figure 2 is an example for Gap 10: "CPS failure fall-back plans". This refers to the expectation that CPS, especially when they are linked into ever-larger networks as they increasingly pervade society (e.g. energy networks), will be operating most often in fault mode (Schätz 2014), and that fall-back plans will be needed to enable the fault(s) to be fixed with minimal disruption to the remainder of the CPS and its interoperating neighbours. It is for this reason, as well as others, that people always will be involved in the operations of CPS, making use of new skills in new types of jobs.

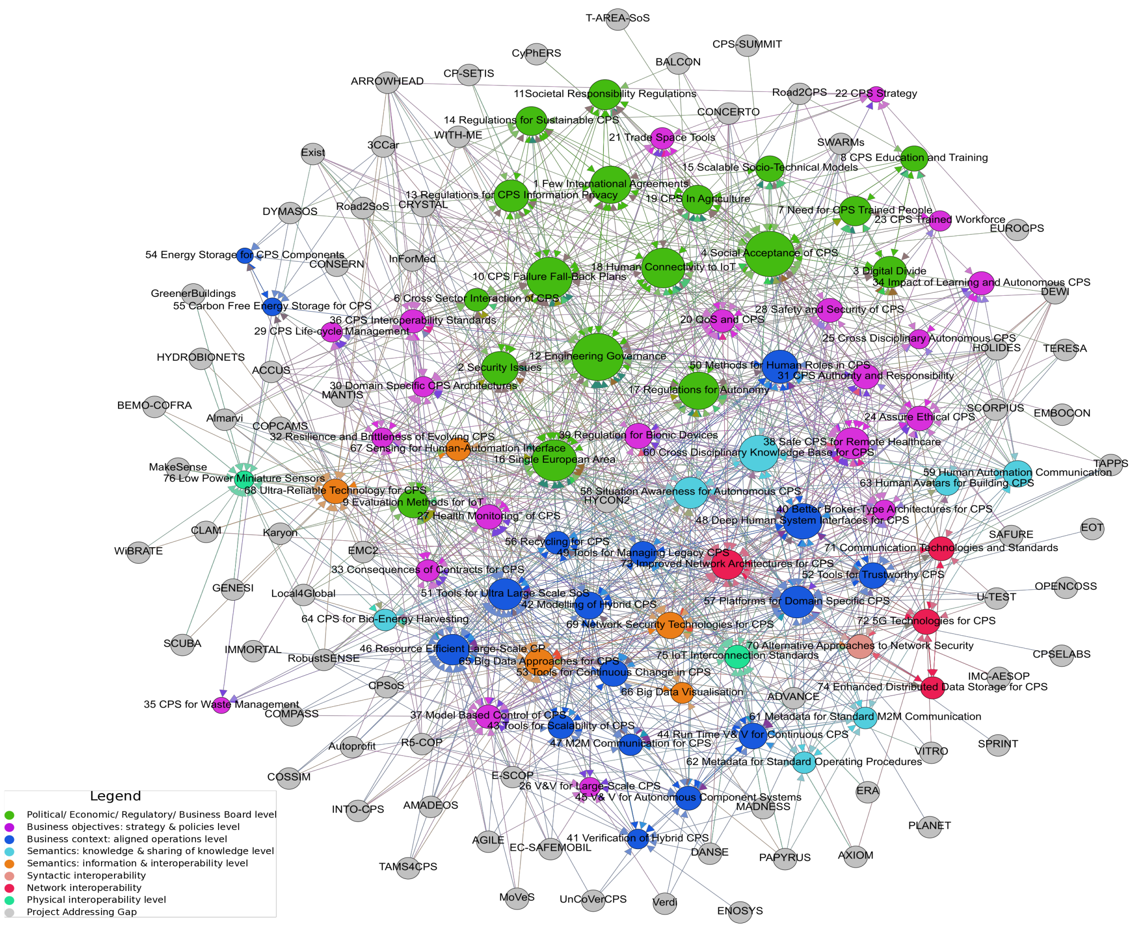

Figure 1. The complete network of projects and gaps, colour-coded by interoperability level

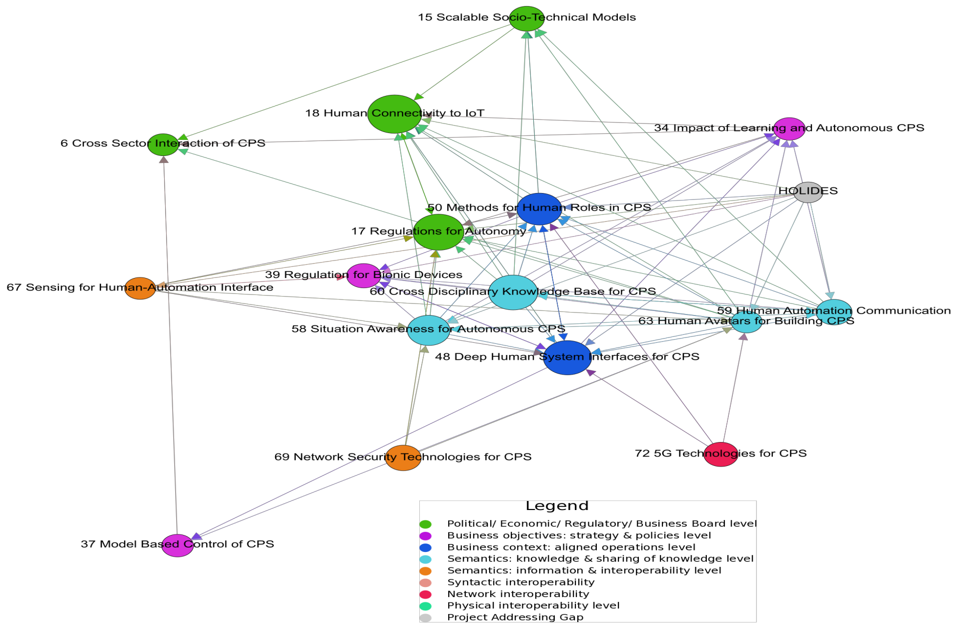

Figure 2, showing the filtering of the network based on gap 10 as the targeted strategic gap

Figure 2 shows the wide range of (non-green) gaps that need to be closed to enable good fall-back plans to be realised; likewise, the set of connected strategic (green) gaps indicate how the closing of gap 10 would contribute to the achievement of strategic goals for the EU.

Many of the gaps fall within the boundaries of the E/HF profession.

Figure 3 shows a filtering of a lower-level, business gap: 38 “Safe CPS for *[operation of]* remote healthcare”. As above, this shows the strategic gaps to which the closing of this gap would contribute, and also the wide range of other gaps that also need to be closed. There are two points that can be mentioned in relation to these other gaps; firstly, the wide range of these coupled with their inter-relationships, indicates we might be facing a ‘wicked problem’ (Siemieniuch and Sinclair 2014). Secondly, it is evident that many of these gaps require a large amount of ergonomics/HF knowledge and expertise. It is to be hoped that the CPS technology experts involved in closing these various gaps understand this earlier rather than later.
An advantage of this diagram is that it may be of assistance to the EC in writing future Calls, and in writing proposals to obtain funding for useful research. In the latter case, this also applies to national sources of funding.

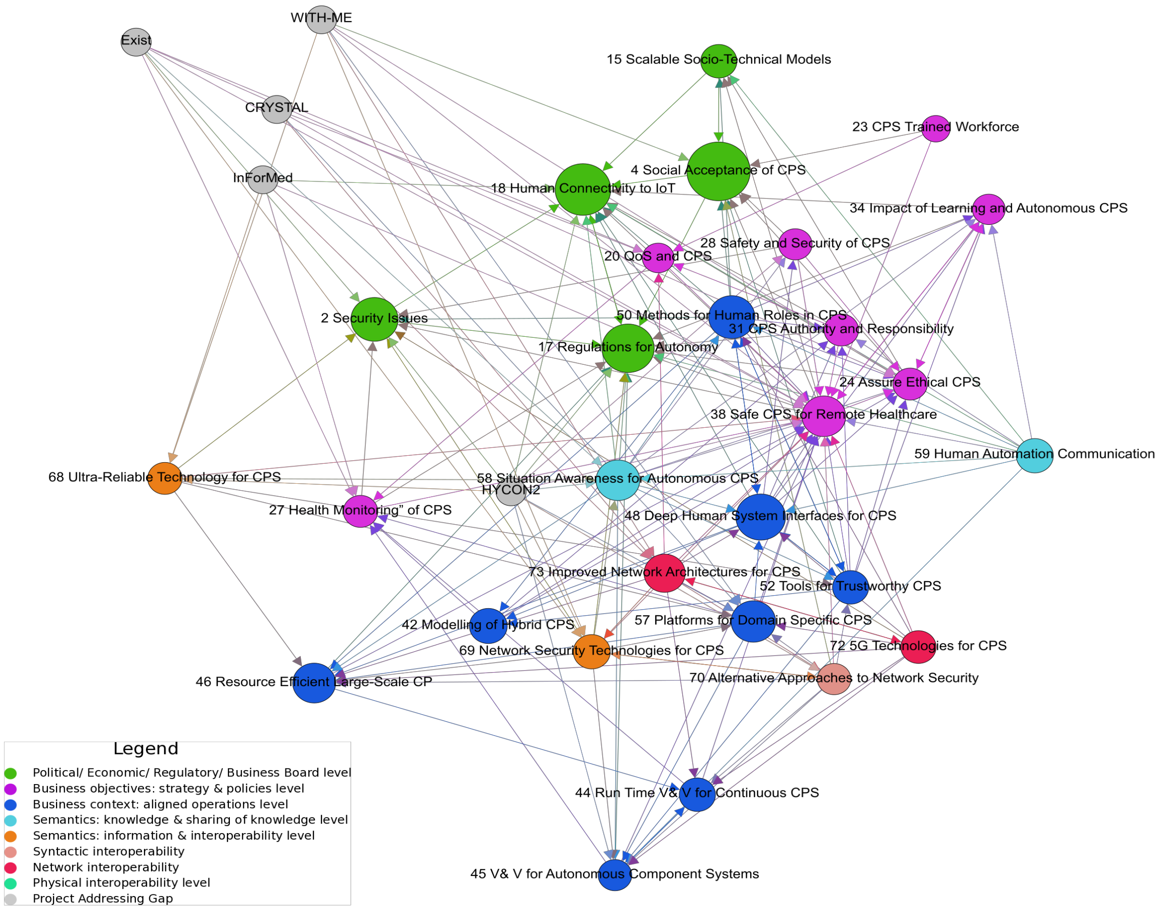

Figure 3, showing the network of gaps associated with developing CPS to assist in remote healthcare in society.

3. Key messages

The following key messages were included in Deliverables of the Road2CPS project, aimed mainly at the EC. These key messages, developed from the filtered set of plots, are concerned only with the socio-technical aspects of instantiating CPS widely in society to achieve strategic goals, addressing issues such as the sustainable society, the circular economy, and the security of citizens. Some key messages of interest mainly to the E/HF profession are also included.

3.1 Key messages for the EC

The key messages below emanated from the work described above, and in condensed form were included in the final Deliverable in January 2017, along with other key messages regarding business opportunities, etc.

- 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. This indicates that future Calls in H2020 (and its successor programmes) should have more broad scope.
- 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 be reducing 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.
- The plot, 'Gaps not addressed by the 54 FP7/H2020 projects' provides a perspective for future funding for R&I. These 29 gaps are significant in their own right and should not be overlooked.
- 46 of the 75 gaps were addressed; some of them many times (e.g. Gap 51 'Tools for ULSS' was addressed by 24 projects. There was no obvious co-ordination nor cross-referencing in the outputs
- Several groups of gaps recur in the strategic plots. These gaps should be addressed collectively soon, particularly since larger CPS 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 requirements, needs, fears, and support of individuals and communities are addressed.
- Gap 60, '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
- Gap 16, '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 (LSPs) will explore this connectedness from a CPS 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.

3.2 Key messages for the E/HF community

These messages are implications arising from the analyses reported above. Very few of the 54 projects mentioned E/HF issues and addressed them; those that did tended to take an engineering view ("of course, we must consider the human issues"; "there is always the issue of human error"; "user experience is important"), but little of substance was reported.

- Given the comment above, there is an obvious requirement for the CIEHF to be pro-active about the contribution it can make in the design and operation of CPS in society, especially to professional societies, technology associations, and government
- The Institute already has a synoptic view of the CPS domain and its likely role in society, coupled with a good appreciation of the likely interactions, concerns and values of the individuals and communities that will necessarily be interacting with this technology. However, the view seems dispersed among only some of its membership, and a wider degree of awareness, understanding and commonality of viewpoint would help to establish the Institute's role in the CPS world
- Many of the 54 projects included the need for an educated workforce for the CPS world. There appears to be three classes of people who will interact with CPS: Lay people who interact because they have to do so to accomplish a task, and have no interest in the CPS itself; operators/co-workers for whom the CPS is a valuable tool integral to their jobs; and gurus, who have close knowledge of the CPS, its strategies, and roles, and who can rearrange its capabilities for new or changing environments. The E/HF profession falls into the latter class, but it is not clear that there is adequate training provision and associated organised body of knowledge to turn out sufficient numbers of qualified personnel
- A future paradigm for which the E/HF community should be prepared is that of the distributed team carrying out co-ordinated, dependent tasks, where members of the tram are mobile. They interact with a CPS through distributed interfaces and through which their tasks are accomplished. The channels of information to these team members involve vision, audition and haptics (e.g. exoskeletons), mediated by simulations as well as direct vision, and the output channels to the CPS include gestures, postures, motion and locations in addition to the more usual channels. Furthermore, these interfaces must assure ethical behaviour (especially where components of the CPS have autonomous capabilities and have direct effects on people), and must facilitate trust by the team members in the operations of the CPS, and vice versa; two-way trust will be required. While there is knowledge within the profession for all of these characteristics, it is not commonly held, nor is it structured for teaching and application
- As Zink has cogently pointed out (Zink 2013), we are moving into a different world of work, and the nature of job design is changing as well. There is a need to revisit the practices that have been used for years to ensure that they deliver good jobs with relevant skills in this new world
- Finally, given the complexities associated with these messages, there is an urgent need for toolsets to enable comprehensive design, simulation and validation of our E/HF contributions to this new world of work.

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