Some implications of Software-Dominated Manufacturing for the ergonomics profession

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Abstract. Whether or not manufacturing moves whole-heartedly to the paradigm of Cyber-Physical Systems of Systems as indicated first in the 'Industrie 4.0' programme in the FRG, there is little doubt that manufacturing will become software-dominated by 2025. This will have significant implications for ergonomists involved in manufacturing: for the nature of roles and jobs, for the design of workspaces and workplaces, and for the design of the interactions between humans and automation. The paper explores some of these implications.

Keywords. Cyber-Physical Systems, manufacturing, workplace design, organizational design

1. Introduction

This paper is a follow-on to two previous papers (Siemieniuch, Sinclair et al. 2015, Sinclair, Siemieniuch et al. 2015), which explored some of the implications for the ergonomics discipline that may result from Cyber-Physical Systems (CPS) and software-dominated Systems of Systems (SoS) becoming significant processes in many of the basic functions of society, and particularly in manufacturing, by the year 2025. A definition of CPS follows (acatech-pos 2011):

> "*Cyber-physical systems are systems with embedded software (as part of devices, buildings, means of transport, transport routes, production systems, medical processes, logistic processes, coordination processes and management processes), which:*
>
> - *directly record physical data using sensors and affect physical processes using actuators;*
> - *evaluate and save recorded data, and actively or re- actively interact both with the physical and digital world;*
> - *are connected with one another and in global networks via digital communication facilities (wireless and/or wired, local and/or global);*
> - *use globally available data and services;*
> - *have a series of dedicated, multimodal human-machine interfaces.*

SoS extend this definition to the case where CPS and other classes of systems are 'owned' by different organisations, and are brought together into an SoS to perform some set of tasks. The key point here is that the systems that form the SoS can be managed and changed only by the 'owner' and in principle the only way in which the SoS can be managed is at the interfaces; however, the owners can change their systems in theory own interests and on their own timescales. Again in principle, information may not flow freely nor fully within the SoS due to protection of intellectual property and other commercial considerations.

2. Implications for Manufacturing Organisations

Arguably, SoS have been in existence since the time we all lived in caves and bartered goods and services. What has made them of importance in our modern world is the development and exploitation of Information Technology and Communications (IT&C): sensors, software, and actuators all bound together by the Internet to provide better sensing, data manipulation and activation across the globe. CPS in particular will make great use of IT&C, to the point where operations in manufacturing will be software-dominated, with people on the front line performing fewer manual tasks and ever-more management tasks in keeping the processes and other operations running. The advantages to manufacturers of moving to a software-dominated, reliable CPS environment are manifold, as addressed in the earlier papers mentioned above; briefly:

- their contribution to sustainability by better management of energy, water, emissions and materials
- the opportunities for social cohesion, jobs and materials conservation in moving to a circular economy
- much better control of processes, performance and quality
- moving from data flows to data floods and the advantages arising therefrom through the use of Big Data analytics

3. The nature of software-dominated manufacturing workplaces

The comments below are predicated on the CPS paradigm; whether or not an enterprise plans to embrace that paradigm, it is likely that all manufacturing organisations will move towards that goal, thereby encountering many of the issues discussed below. Figure 1 illustrates flows of material, energy and information (MEI) (Hinsley, Henshaw et al. 2016) within a manufacturing CPS in order to deliver products and/ or services to customers. Omitted from this diagram are the complexities of enabling this to happen; particularly the underpinning, manufacturing-oriented platform that provides the services that this paradigm requires: communications, security, management of data & information, and support for financial transactions, among many other supporting services.

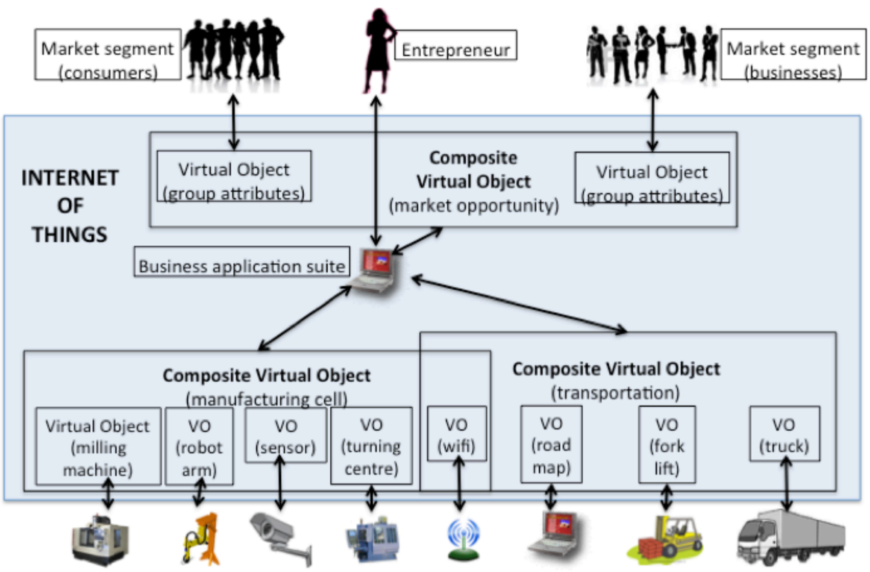

Figure 1: Illustration of a CPS-based manufacturing SoS, showing devices at the bottom represented in the internet as Virtual Objects (VO); these are then combined to create Composite VOs; these are then combined again with business software to create an enterprise. The enterprise may serve the consumer market (B2C), and/or other businesses (B2B). Complexities have been omitted. Diagram based on the CREATE-

NET project (Vlacheas, Giaffreda et al. 2013)

However, there are some complications in this picture of a gently-humming, highly-efficient, software-dominated future for manufacturing. Three comments about software are relevant (square brackets added by the authors):

- "For a useful perspective on the system design and engineering challenge, it is worth noting that the findings from Capers Jones, *[http://www.spr.com]*, and others indicate that deployed software systems contain approximately 0.4 latent faults per function point. To our knowledge, this indicator of dismal *[operational brittleness]* has improved only about three-fold in the last four decades." (Ring and Madni 2015)
- "In one case, we observed an outsourced application with 120 COTS products, 46% of which were delivered in a vendor-unsupported state. *[because they were four or more years old]"* (Yang, Boehm et al. 2005)
- "Due to the large scale and the complexity of systems of systems, the occurrence of failures is the norm *[to be expected]* in CPSoS" (CPSoS-D2.4 2015)

Then there are all the organisational complications of manufacturing as well, better-known to the ergonomics profession from past experience. However, there is one further complication that may become more prevalent, impacting very much on workplace design (Schätz 2014). There is much of ergonomics relevance in this lengthy quotation:

"Furthermore, CPS generally support critical processes, making it impossible to turn off the system to make changes and therefore, for instance, requiring (re-)configuration, (re-)deployment, (de-)commissioning, update, or enhancement during runtime. …

Finally, being large-scale and mission critical, CPS must [co-operate] with system engineers, operators, users, and other systems by actively supporting their processes, requiring autonomous capabilities of documentation, monitoring, optimization, healing, or adapting, among others. *[... the implications of these characteristics]* are that:

- a large range models of different domains, disciplines, and technologies are used, and
- the use of models is shifted from the design and implementation phase to the operation and maintenance phase.

we expect that

- the explicit use of models will play a dominant role in the engineering of CPS
- the traditional distinction between design/ implementation and operation/ maintenance of a system will be abandoned in favour of an integrated life cycle."

An implication that can be drawn from this lengthy quotation is that workplaces will embedded within close-coupled, fine-tolerance, time-sensitive, hybrid systems capable of producing a variable sequential flow of a wide variety of products.

4. Implications for the ergonomic design of CPS workplaces

Consequently, people at workplaces within a manufacturing enterprise will become co-workers with devices and hence with the software that provides their capability. This is in addition to the software that supports people that was present before. In this coworking mode, people are likely to have more of a supervisory/ managerial role, though they will still be performing manual tasks, and in this enhanced role they will have additional roles and functions to perform:

- situation-aware supervisors of work, the workplace and the environment, carrying responsibilities for operations, outcomes, safety and security.
- efficient, safe, effective co-workers co-operating with software systems and automated/ semi-autonomous agents to achieve goals. This includes working with uncaged robots - and within them too, when working within exoskeletons.
- discoverers and diagnosticians of emergent events, perhaps originating at some distance from their workplaces but with local effects.
- communicators, planners and initiators of resilient responses, perhaps affecting other workplaces and systems.
- Designers, implementers and co-ordinators of incremental improvements to operations.
- Maintainers of hybrid systems of blended software and hardware.
- Utilisers of modelling, simulation and visualisation tools and technologies for most interactions with automation. The use of virtual reality (VR) and augmented reality (AR) interfaces will be an important component of the workers' jobs.

What seems evident is that the old rubrics for workplace design are still relevant, but there needs to be some updating to reflect the close interoperation with extensive software capabilities. As was said in the earlier papers, the socio-technical principles as enunciated in years gone by are still relevant (because human beings are slow to evolve). However, the tools and techniques we use to diagnose and design workplaces will need some revision, to deal with the transfer of capability to software. Other changes are apparent as well:

- Interface channels of communication will adjust in importance; vision will always be the most important, but speech, gestures and haptics will likely increase in significance and usage due to the close co-operation with robots and other intelligent agents in workplace teams.
- The emergence of the co-worker as a cyborg, making use of mobile devices such as smartphones and tablets as major communication media will demand changes to our protocols and tools for interface design
- Given the amoral nature of software and the limitations of Artificial Intelligence (AI), the implications of functionality being increasingly transferred to software and the extended geographical reach that is thus made available mean that ethics becomes an important consideration in interface design, particularly in relation to safety and social responsibilities to the community
- The assurance of Informed Consent and Informed Command in the design and operation of workspaces and workplaces will be an important skill for the ergonomics/ human factors profession, as a means of ensuring ethical behaviour of the systems.
- Inevitably, there will be significant changes to the skills profiles of jobs in this new manufacturing paradigm. The roles of co-worker in a team, discoverer of emergent events, provider of resilient response, and incremental improver of the workplace are all present in the manufacturing jobs of today; however, the added complexities introduced by the heavy reliance on software systems with its attendant issues mean that these roles will all require competence in IT&C. Given that any team will include

individuals across the range of entry-level, efficient, expert and guru levels of operator knowledge and experience, the design of displays to enable sufficient situation awareness for informed command and consent will require that ergonomists have high levels of knowledge about software tools and applications, sound understanding of model-based systems engineering (MBSE), and the knowledge to co-operate closely with engineers.

- Some other aspects are apparent, too; the Big Data capabilities of the new manufacturing paradigm imply that much closer observation and micro-control of all co-workers will be possible. As one manger observed, "We operate a no-blame culture here, but the directors do like to know who we are not blaming". Policies, metrics, and the deployment of responsibilities and accountabilities all need reconsideration to embody the tenets of socio-technical systems theory.

The huge reliance on software in manufacturing, set to increase greatly, is a significant issue for traditional ergonomics. Within the Systems Engineering profession and other engineering professions they are already developing the knowledge and practice of MBSE for the benefits that this approach offers, and if the ergonomics profession wishes to be taken seriously by engineers, the discipline must develop its competence in these areas. The last quotation above (Schätz 2014) indicates that MBSE models and techniques will be used widely by co-workers on the shopfloor.

Exactly how this is to be achieved is a question that needs to be addressed by the formal committees of the professional associations. While it is possible to see how this could be done through CPD for existing professionals, there will be some difficulty in shoe-horning the necessary knowledge and practice into current academic programmes delivering ergonomics professionals.

5. Conclusions

Because of the huge potential benefits on offer to society from the adoption of CPS, it is likely there will be a strong technological push to implement the CPS approach. There are many barriers to this, both social and technological; as ever, these barriers meet at the interface between these two perspectives, right where our profession can have a huge impact. But, as the immediately-preceding discussion indicates, some fairly disruptive changes are needed to our traditional ways of delivering good solutions for the benefit of all. There is a real need to think ahead, now.

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