Skills Needs Analysis for “Industry 4.0” Based on Roadmaps for Smart Systems

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Abstract

The advent of a fourth industrial revolution has been suggested, based on distributed Smart Systems, integrated in the Internet of Things.

A methodology for skills needs analysis is suggested, containing the following steps. Firstly, roadmaps for Smart Systems are analysed, taking up documents provided by the European Technology Platform for Smart Systems (EPoSS), and the International Electrotechnical Commission (IEC).

From these roadmaps, first generic skills demands can be derived, serving as hypotheses for further analysis.

The next steps are organisation scenarios and technology/sector matrices as tools for qualitative and quantitative skills needs analyses.

Some of these steps have already been taken with respect to Industry 4.0, while others are suggested, providing examples from other contexts.

The whole methodology is embedded in an approach encompassing (technological) foresight, skills needs analysis, and development of educational frameworks, all within the context of R&D programme management.

Keywords:

skills needs analysis, Industry 4.0, smart systems roadmaps

1 Introduction

In this paper, a methodology for skills needs prognosis, based on technology roadmaps, is proposed. This methodology is conceptually applied to an innovation domain called ‘Industry 4.0’ in Germany.[1]

This methodology as a whole has not yet been applied in practice on Industry 4.0 or any other domain. In this regard, it is a proposal. It describes how skills needs prognosis, based on technology roadmaps, may be implemented in general, and how it could be applied specifically on Industry 4.0. Almost every methodical element, however, has been applied in various contexts. Thus, practical examples can be — and will be — provided for these steps.

In the following section, some context information on relevant aspects of the innovation systems in Europe and Germany is given. Afterwards, the conceptual application domain, Industry 4.0, will be introduced. As a description of the general landscape, foresight, skills needs analysis, and the implementation of educational structures, offers and programmes can be related to development phases of emerging technologies. This is addressed in section 5.

The main part of this paper is section 6. All steps of the methodology will be described, and all but one of them will be illustrated by practical application examples.

2 European and German context

This paper regards foresight, skills needs analysis, and the implementation of educational structures in the context of public R&D policies. To understand the lines of argumentation, it is useful to look at some aspects of European and German innovation systems.

European Technology Platforms (ETPs) play a crucial role in European research, development and innovation policies.[2]

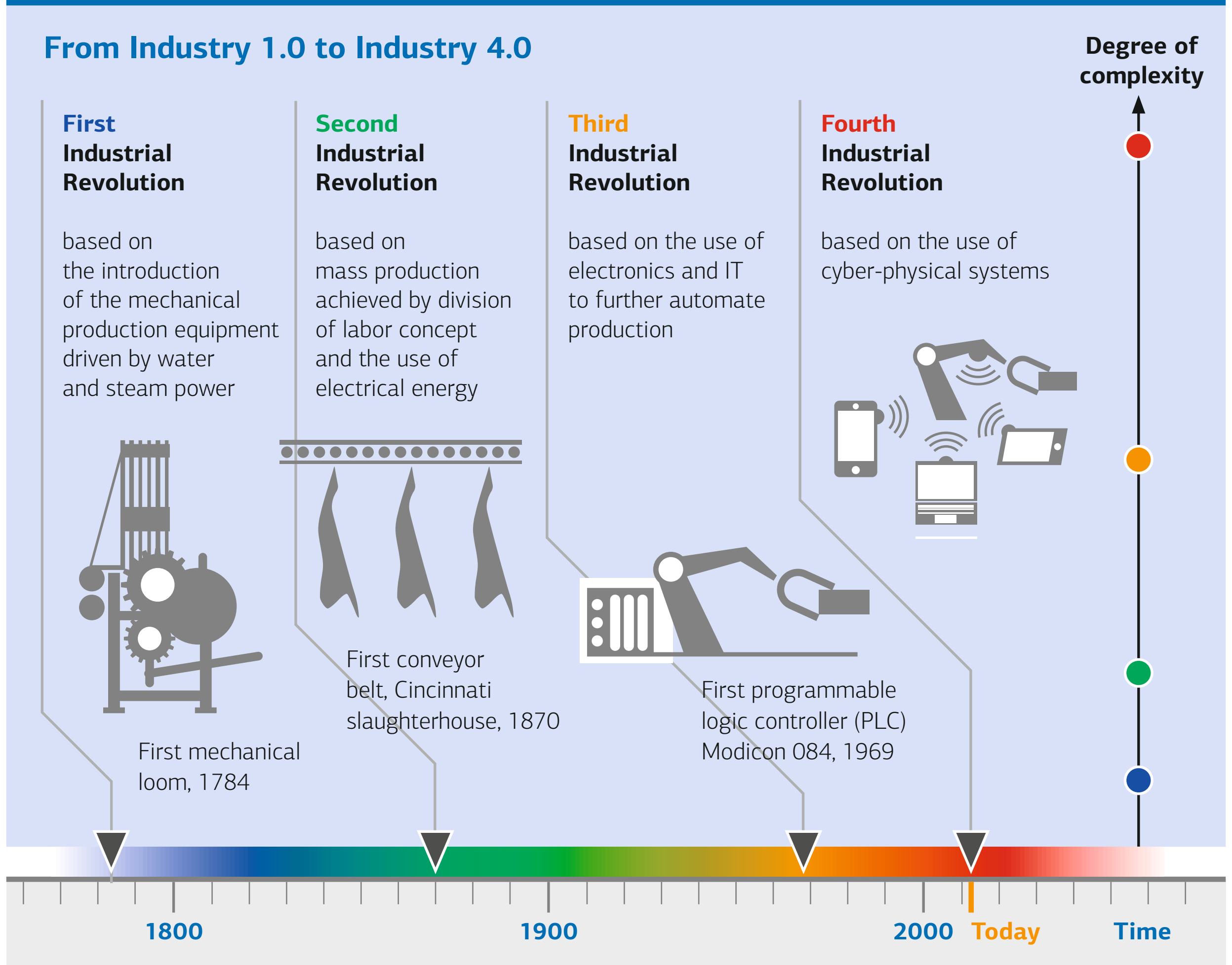
1 Promotorengruppe Kommunikation der Forschungsunion Wirtschaft — Wissenschaft (ed.) (2013): Deutschlands Zukunft als Produktionsstandort sichern — Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0. Abschlussbericht des Arbeitskreises Industrie 4.0, online: http://www.bmbf.de/pubRD/Umsetzungsempfehlungen_Industrie4_0.pdf
2 http://cordis.europa.eu/technology-platforms/

ETPs provide a framework for stakeholders, led by industry, to define research priorities and action plans on a number of technological areas relevant for European R&D policies. Some European Technology Platforms are loose networks that come together in annual meetings, but others are establishing legal structures with membership fees. Presently, there are almost 40 ETPs, in various innovation domains from energy and ICT to production technologies and transport.

ETPs set up Strategic Research Agendas (SRAs), which can contain technology roadmaps or at least material from which technology roadmaps can be (re-)constructed. For the purposes of this paper, the most important SRA[3] is the one published by EPoSS, the European Technology Platform on Smart Systems Integration,[4] playing a key role for Industry 4.0.

Within the German innovation system, shared-budget R&D programmes play a major

Figure 1: The fourth Industrial Revolution (DFKI/SIEMENS)



Source: DFKI (2011)

3 IRISS Deliverable 6.4 Strategic Research Agenda on Smart Systems Integration, to be published.
4 http://www.smart-systems-integration.org/public

role. These programmes are usually co-funded by public and private bodies. They cover a broad variety of domains, target groups, and purposes. There are technology and domain specific programmes addressing e.g. production technologies, electronics, or life sciences. Other programmes are provides for Small and Medium sized Enterprises, regardless of sector or domain.

These programmes are managed by Programme Management Agencies ('Projektträger' in German), on behalf of ministries and other public bodies.

Within the context of this paper, these programmes and agencies are relevant in (at least) two ways:

- Programme Management Agencies play a role in setting up roadmaps (or similar projections) regarding the R&D programmes and domains they administer. In this process, other roadmaps — e.g. those of related ETPs — are taken into account.
- Sometimes, measures to develop and implement educational structures, offers or programmes are parts of the programmes. This may relate to programmes explicitly tuned towards educational issues. But, and perhaps of more interest, this may also occur within technology or sector-oriented programmes, including measures to develop and implement the educational elements relevant for the respective technologies or sectors.[5]

3 The fourth Industrial Revolution

Recently, the Forschungsunion Wirtschaft — Wissenschaft, a consulting body relating to the High-Tech Strategy of the German Federal Government, has proposed 'Industry 4.0' as a crucial domain for future research, development, and innovation in Germany.

The future project Industry 4.0 relates to an approach to industrial history, proposing four industrial revolutions.

The first of these revolutions was based on the introduction of water and steam power. The second industrial revolution focused on electrical energy and industrial forms of organisation emphasising the division of labour. In a way, these two early industrial revolutions depend crucially on innovative form of power supply.

In contrast, the third and fourth industrial revolutions relate primarily to Information and Communication Technologies (ICT). In this context, the third industrial revolution used ICT for automatic control of production machinery. The upcoming fourth industrial revolution takes this to a qualitatively new level, which is characterised by the employment of Cyber-Physical Systems (CPS).

CPS are distributed smart systems — microsystems or MEMS (Micro Electro Mechanical Systems) — including electronic, mechanical and possibly also optical or fluidic components. They also usually include sensing, information processing and also often actuating functions. They are embedded in communication networks, this is also how CPS relate to the Internet of Things (IoT) paradigm.

They are able to perform processes in perception, cognition, and action which are said to become increasingly closer to human performance. The 'intelligent' capacities of CPS usually emerge from — more or less flexible — cooperation of distributed systems. In this regard, CPS are also related to the concepts of Pervasive Computing and Ambient Intelligence. There are broad potential domains for the application of CPS, including everyday life and housing, transportation and logistics, and health care.

Industry 4.0 is concerned with the implementation of CPS in industrial production. Beyond CPS themselves, aspects of Human-Machine-Interaction — or, eventually, even Human-Machine-Cooperation — new forms of industrial organisation, and more socio-economic phenomena need also to be taken into consideration for a successful implementation of Industry 4.0.

5 An example will be given in section 6.7.2

4 Development Phases of emergent technologies

Regarding the scope of this paper, three functions or processes need to be regarded:

- General foresight processes, concerning future developments, either in a more narrowly focussed on technological aspects, or embedding technology in a broader socio-economic framework
- Skills needs prognosis
- Development and implementation of education and training structures, offers and programmes

Over time, these three processes correspond to development phases of emergent technologies — from the initial technology trigger via market introduction to market saturation — as depicted in figure 2.

5 A methodological framework for skills needs prognosis

5.1 Overview

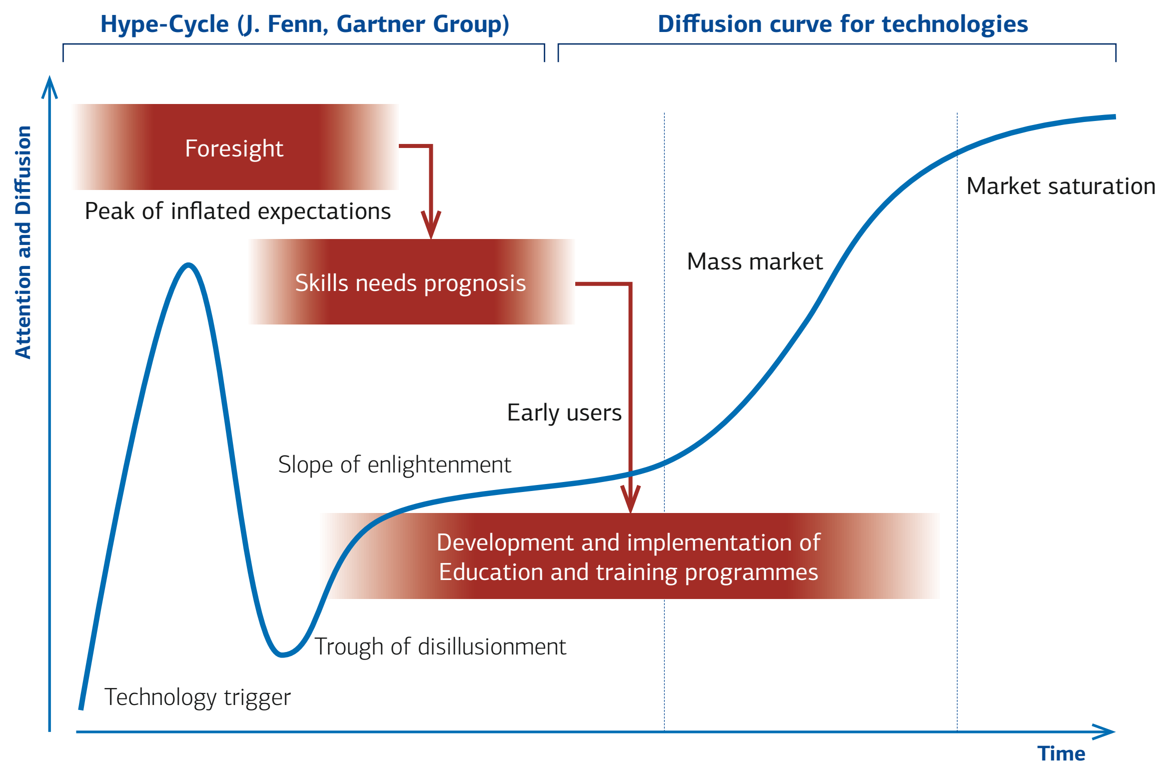
For skills needs analysis based on technology roadmaps, a methodological framework is proposed here. Figure 3 gives an overview of the individual steps. All these steps will be described and illustrated in the following sections.

5.2 Identifying and using technology roadmaps

5.2.1 Introduction

Usually, there are a variety of sources for technology roadmaps, and a variety of methods to develop and describe roadmaps. In the following, some examples of methods and sources — referring to Industry 4.0 — will be presented.

Figure 2: Development phases of emergent technologies



5.2.2 The Visual Roadmapping method

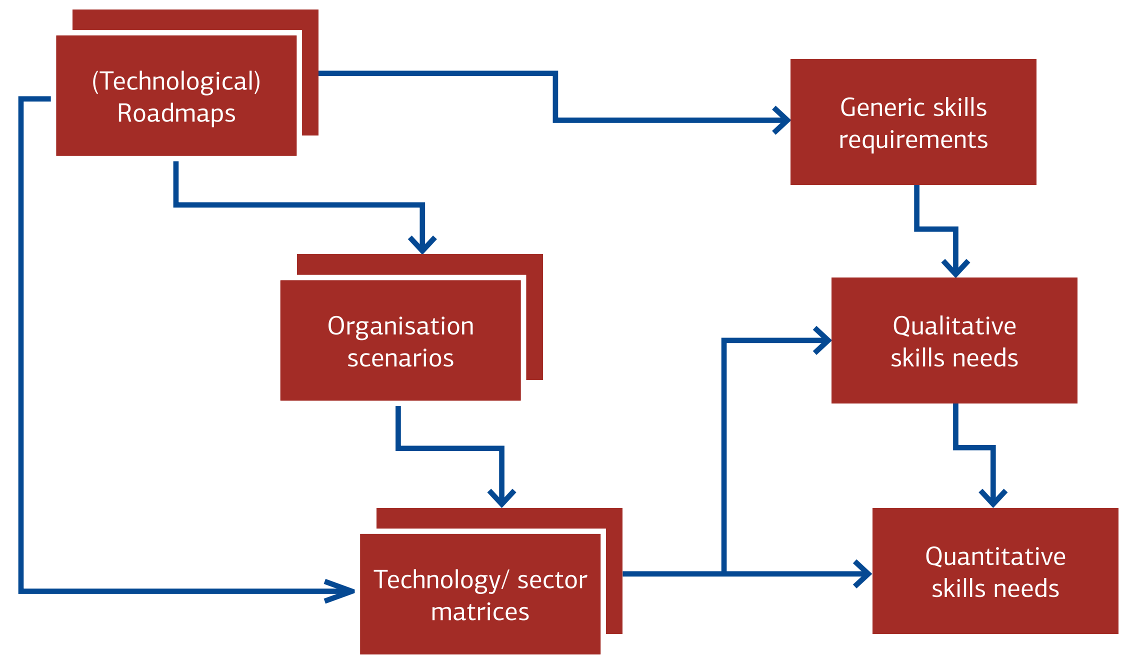
In order to archive a comprehensive overview on future changes and needs, a method is needed that allows to figure out even complex interplay of technological and societal developments/progress (co-evolution) in a clear and well-structured way. At the same time, the method should be sufficiently robust and efficient in order to generate reliable results. Following these preconditions, the Visual Roadmapping method has been developed and successfully applied in a large variety of projects.[6]

The Visual Roadmapping method is particularly suitable for the identification of perspectives and milestones along the way from "today" towards the future. The approach allows the identification of possible future options in "open" scenarios" as well as the outline of future pathways in "normative" scenarios (missions). Thus, the Visual Roadmapping method is an ideal tool that can be used in roadmapping and ex-ante evaluation of trends that facilitates the identification of key factors in future developments, the assessment of strategic potentials and the deduction of needs and actions to be taken.

Using the method, the complex interplay of the topic investigated and significant factors can be analysed regarding future developments. For this purpose, four relevant dimensions are represented in a visual roadmap:

- Socio-economic factors (legal, economic, social conditions),
- Enabling Technologies (scientific and technical progress),
- Development of the topic itself (central aspects and milestones),

Figure 3: A methodological framework for skills needs prognosis

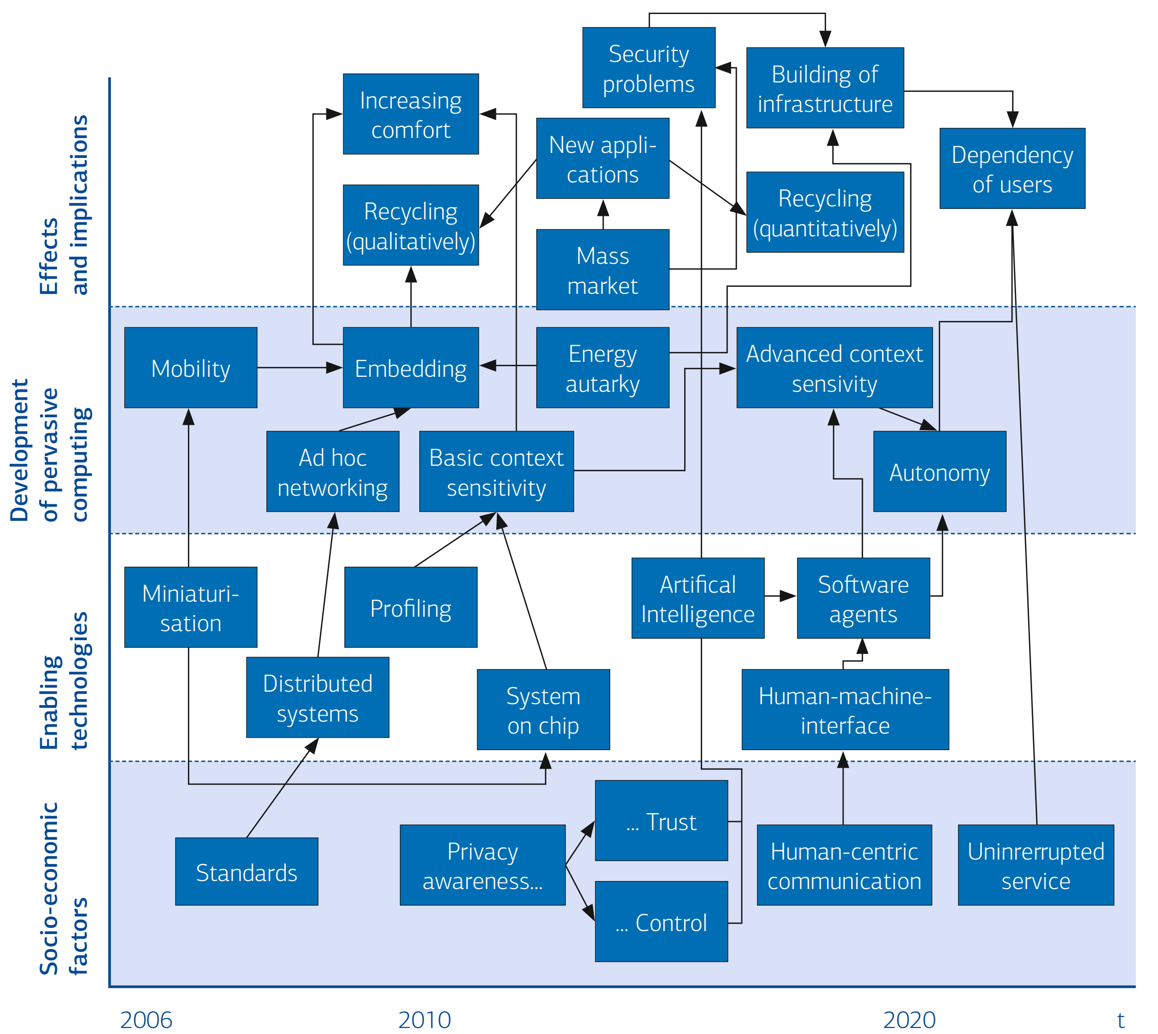


6 Kind, S., Hartmann, E.A., Bovenschulte, M. (2011): Die Visual Roadmapping Methode für die Trendanalyse, das Roadmapping und die Visualisierung von Expertenwissen. iit perspektive 4, Berlin/Germany

- Effects and implications (economic and social effects as well as new products and services).

The genesis of the roadmap is an expert based procedure that can be carried out with single experts or in groups of up to 10 persons. Starting with an empty matrix (the four dimensions versus a timeline of approximately 10 years from today), the experts are asked to discuss the topic and to identify single aspects/key issues of the future development concerning the four dimensions. These aspects and issues are written on “event cards” and placed in the matrix. Step by step, the matrix is filled with additional cards while existing cards can be rearranged or split-up (e.g. when an aspects needs to be divided into two distinctive sub aspects) etc. At the end of the session, the set of cards is final-

Figure 4: A Visual Roadmap for Pervasive Computing (Gabriel, Bovenschulte, Hartmann et al., 2006)



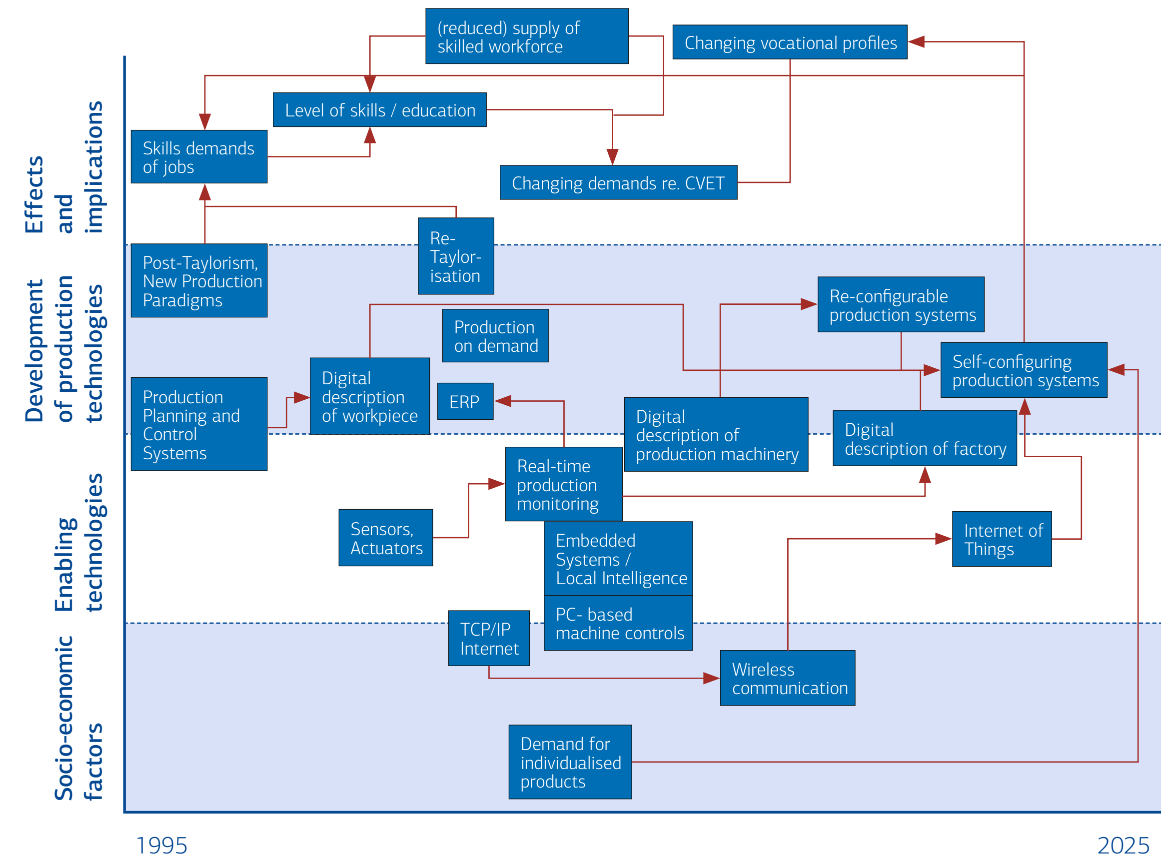
ised and prominent connections and dependencies — especially cross-dimensional ones — are indicated by lines and arrows.

With the described procedure, the implicit knowledge of experts can be extracted and clearly structured by relating different dimensions to each other. By using the matrix with corresponding “event cards”, there is the need to classify the identified aspects/issues in an unambiguous way (point in time, dimension) that enhances the informative value of the resulting roadmap.

Figure 4 provides an example of a Visual Roadmap concerning Pervasive Computing, a precursor of Cyber-Physical Systems.[7]

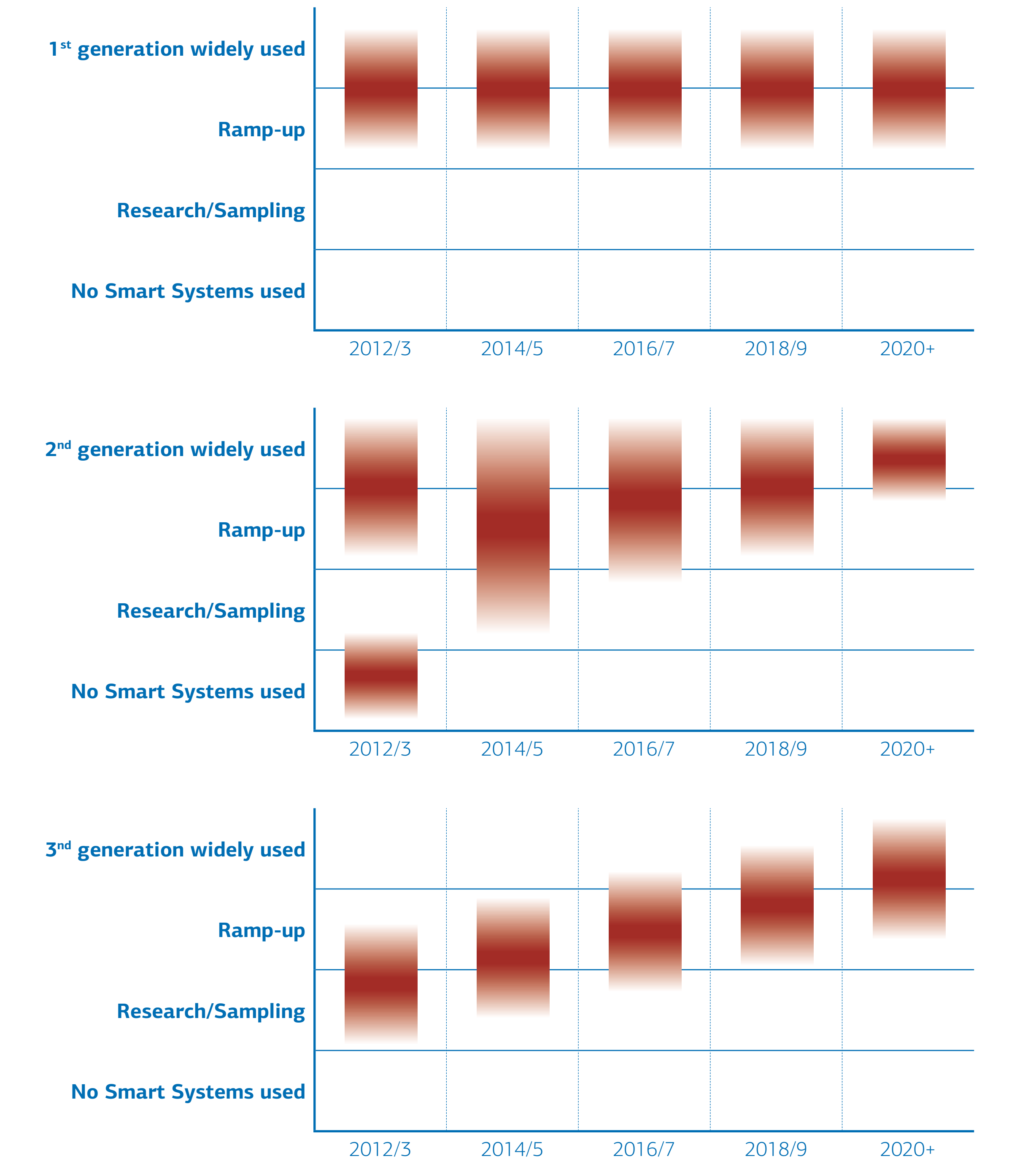
Figure 5 shows a Visual Roadmap for Production Technologies in a time course from 1995 to 2025.[8] Here, the general developments in the domain of Pervasive Computing — as shown in figure 4 — are regarded with respect to industrial production as application area. Also, developments specific for this domain are taken into consideration.

Figure 5: Visual Roadmap for Production Technologies (Hartmann, 2009)



7 Gabriel, P., Bovenschulte, M., Hartmann, E.A. et al. (2006): Pervasive Computing — Trends and Implications. Study of VDI/VDE-IT in cooperation with FhG-SIT and Sun Microsystems on behalf of the Federal Office for Information Security; SecuMedia Verlags-GmbH, Ingelheim/Germany
8 Hartmann, E.A.: Internet der Dinge-Technologien im Anwendungsfeld ‚Produktion — Fertigungsplanung‘; in: Botthof, A. & Bovenschulte, M. (Hrsg.) (2009): Das ‚Internet der Dinge’: Die Informatisierung des Alltags und der Lebenswelt. Hans-Böckler-Stiftung, AP 176, Düsseldorf/Germany

Figure 6: Smart Systems for Robotics / Factory Automation: Perspective (IRISS Deliverable 6.4)



5.2.3 Roadmaps from European Technology Platforms and the International Electrotechnical Commission

Visual roadmaps as described in the previous section are especially useful for a general, 'bird´s-eye' view of a domain. For more specific aspects, other formats and sources may be required. Concerning Industry 4.0, the Strategic Research Agenda (SRA) of EPoSS, the European Technology Platform on Smart Systems Integration, is specifically useful, as mentioned before. This SRA, developed in the IRISS project,[9] covers a broad range of application domains. For the purposes of this paper, the section on industrial production is relevant; this section covers the following sub-domains:

- Manufacturing equipment
- Process control
- Robotics & Factory automation
- Prototyping equipment
- Test & Inspection

All these domains are described according to a common framework of 'generations' of smart systems. Put simply, the first generation refers to cutting-edge automatic control technologies for automated production as used today. Second generation technologies will, for example, include more advanced features of machine learning. Finally, the third generation will be characterised by functions close to human perception, cognition, and behaviour.

In the five sub-domains as described above, different dynamics of development are predicted. With respect to third generation smart systems, the sub-domain 'Robotics & Factory Automation' is regarded as especially dynamic (figure 6).

Some additional aspects concerning the implementation of Smart Systems in the domain of Robotics / Factory Automation can be found in the SRA provided by EUROP, the ETP for robotics.[10] Here, future scenarios are provided for several sub-domains. Especially interesting among these are 'Cooperating Robots & Ambient Intelligence' and 'Planning'. Specific features of future robotic technologies in these regards include:

- Distributed control
- Inter-agent communication
- Application of swarm theories / swarm intelligence
- Skill based / learning based automation
- Autonomous planning for tasks of high dimensionality
- Interactive learning from human partners

Finally, some more developments are covered in a recent study performed by VDI/VDE-IT on behalf of the International Electrotechnical Commission (IEC)[11]. A 'technology radar' developed in this study predicts, for example, the following developments in the domain of Smart Systems:

- Artificial Organs
- Multi-Material Hybrid Organic / Inorganic
- Cognitive Based Control Systems
- Muscular Interface
- Neuro-Interface
- Bio-Engineering
- Bio-Electronics

This very brief overview of technology roadmaps may give a first impression of how these different sources and formats look, and which kind of information they convey. A first comparative analysis of the different sources provides a high degree of consistency. The preliminary results therefore indicate a robust and reliable future perspective for the development of central building blocks for industry 4.0. In the following, it will be discussed how this information can be used as basis material for skills needs prognosis.

5.3 Generic skills requirements

An integrative view across the technology roadmaps allows the identification of some generic skills requirements. One of these requirements relates to the convergence between mechanical / electronic / software-based components or systems, which will be occurring across scale

9 http://www.iriss-csa.eu
10 http://www.robotics-platform.eu/cms/upload/SRA/2010-06_SRA_A3_low.pdf
11 IEC Study: Evaluation of roadmaps, technology trend studies, and research agendas — Final Report; not yet published.

levels (macro/meso/micro). A focus domain of these developments appears to be robotics, with core aspects such as cooperating robots and 'soft automation' (e.g. inherent safety by soft and flexible actuators of robotic systems). Furthermore, bionics will probably play a more pronounced role in developing future robotic systems with human-like perception, cognition and behaviour.

Regarding a flexible division of work between human and robot in the context of Human-Machine-Cooperation, safety-related competences will become more important: When there are no fixed processes, safety considerations need to be part of the work process itself re-considering every situation anew according to safety aspects.

5.4 Qualitative skills needs

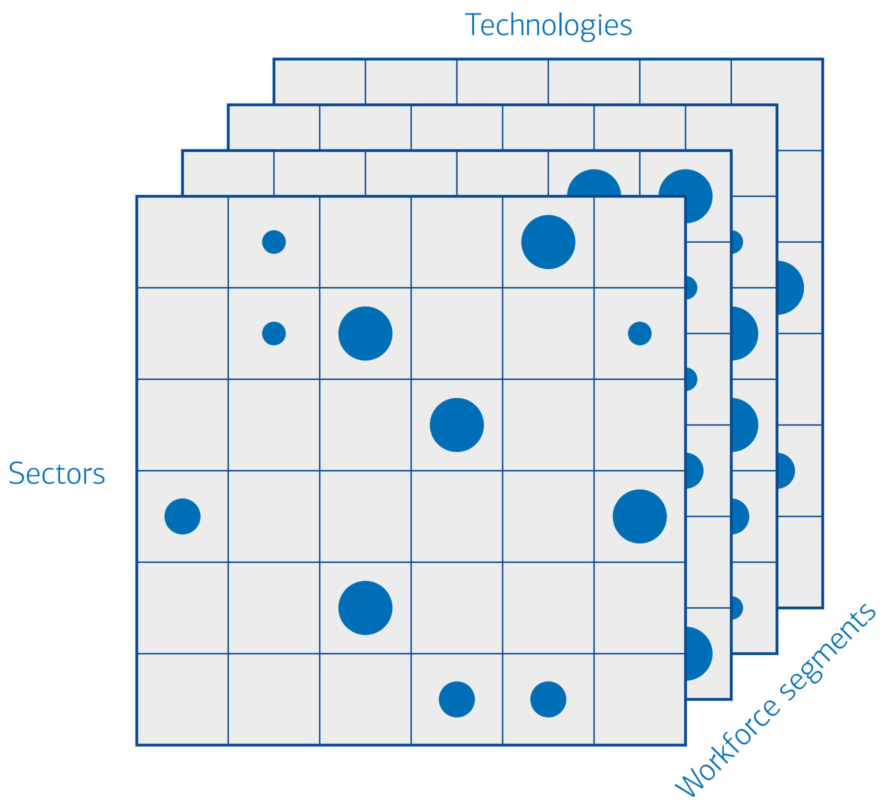
With respect to these generic skills requirement, some first hypotheses can be set up regarding qualitative skills needs.

In the German context, a to-be-developed vocation might be the Industrial ICT Specialist, combining expertise in electronics and ICT (hardware/software). Open questions would concern the relation of this new vocation to the already existing Mechatronics Specialist. Furthermore, it might be asked whether this should be an initial vocation, or a qualification to be gained within CVET, e.g. as a continuing education perspective for Mechatronics Specialists.

Within Higher Education, a future specialisation — e.g. as a Master programme — could be something like 'Industrial Cognitive Sciences', with distributed sensor/actuator networks, robotics, perception (e.g. 3-D vision), cognition (e.g. action planning, cooperation; swarm intelligence) as focus domains.

Similarly, a programme called 'Automation Bionics' might also cover robotics, with emphasis on actuators (e.g. artificial muscles, limbs and organs), and perception/cognition aspects, but rather from a biological perspective, in order to facilitate an "organic" cooperation between humans and machines.

Figure 7: Technology / sector matrix



5.5 Organisation scenarios

As a basis for skills needs analysis, organisation scenarios are required. Different paradigms of industrial organisation will yield very different skills needs, as the following fragments from organisation scenarios may illustrate. These texts are taken from a study by iit for the Confederation of German Trade Unions (DGB).[12] Among more fact-oriented material, a 'storytelling' element was also included, describing a fictive dialogue between shop stewards around the year 2020, exchanging experiences from their different kinds of 'smart factories'. The first one would tell this story:

"I'll explain it referring to our machine setters. They've all got smart glasses' now. If something's to be done anywhere, the setters will get a message displayed in their glasses, e.g. 'go to unit 13, milling machine'. When they arrive there, all the tools they need will already be there on automatic trolleys. They don't need to think very much anymore. The tools they will need next are highlighted in their glasses. If they need any more information, it will also be displayed there. In a way, these colleagues are now remote-controlled by their smart glasses".

His colleague from another company would answer:

> „We don't have specific machine setters. All colleagues in our production team can do the setting-up, and also some maintenance. Because everything's connected to everything, we can pretty well monitor, at our info-terminals, what's going on in production. Even better: What will be going on, we will see whether our supply parts are still on the motorway, or already in our company. Thus, we can organise and coordinate our work just fine."

From these examples, it should become obvious that even very similar or identical technologies may be embedded in very different organisational environments, implying different skills needs.

5.6 Technology/sector matrices

Finally, skills needs analysis has to take into account different effects of the same technologies in different sectors. This may, firstly, concern different organisational paradigms, as presented in the previous section, which may occur more or less frequently across sectors. Furthermore, technologies will lead to different skills needs in sectors producing these technologies, as opposed to those using them; some sectors might be producers and users at the same time. Within the sectors, the skills needs might — and will most probably — differ between workforce segments (e.g. R&D vs. production; vocationally vs. academically educated staff, etc.). To our best knowledge, a systematic technology/sector analysis, with respect to skills needs, has not yet been undertaken. Thus, this methodical element is, for the time being, a mere proposal.

6 Implementation within R&D programmes:

6.1 Introduction

Results of skills needs analyses may be used in different contexts, driven by different users. In Germany, a typical use context would be within vocational education. Social partners might pick up results from such analyses (in fact, they sometimes do) and ask the Federal Institute for Vocational Education and Training (BIBB) to facilitate a process leading to a modification of an existing, or the creation of a new vocation.

Another context might be publicly funded programmes, either such tuned towards educa-

12 cf. footnote 8

tional issues, or others covering (technological) innovations. The following example stems from this latter context.

6.2 Training and qualification for age-related assistive systems

Being one of the countries that is most affected by demographic change, Germany seeks for solutions to cope with the impact of this exceptional challenge. Apart from "classical" issues concerning education, social and pension systems, work force development, child care etc., one option is to make use of the potential of high technology to contribute to a society of longer life expectancy. This technology oriented perspective which gained European and international attention is known today as Ambient Assisted Living — AAL. AAL encompasses advanced computer technologies, software developments, interface design and robotic approaches in order to assist older people leading an independent and self-determined life. To a certain degree, AAL can be seen from a technology point of view as the "caring & living" counterpart to industry 4.0/Cyber-Physical Systems for production.

Due to the development of advanced technological solutions and their embedding into for example, existing caring scenarios, AAL systems require state of the art knowledge concerning operating, maintenance and interaction in a traditional "low tech" environment. Many of the systems are still prototypes that wait for a broad market roll-out (final hurdles are less technical specifications but missing business models).

Regardless of the sketched situation, experts from academia and enterprises expect a broad introduction of AAL systems within the next few years. To make these systems a success, a technologically qualified work force has to mirror technological progress. A central issue in this context is that the existing professional careers have to be widened in order to include sound knowledge on AAL. This means that nurses using the systems and craftsmen installing and maintaining AAL solutions need skills complementary to their existing professional expertise; an aspiration that is not accomplished so far.

In order to react to this foreseeable qualification shortfall, since 2011 the German Federal Ministry of Education and Research (BMBF) has promoted nine interdisciplinary educational and training projects that aim at conceptualising advanced training courses in higher education for non-academics and academics. The overall budget for these projects amount to up to 5 million Euros.

Based on an analysis of future technological developments, future needs mainly arise in sectors of care and handicraft. After the validation of the identified and qualified tendencies and elaborated roadmaps, a set of curricula for extra-occupational and full-time training (theory and practical elements) has been developed. Professionals as well as undergraduates and post-graduate students can achieve a Master of Science in Ambient Assisted Living or be trained as consultants for Ambient Assisted Living in their special fields of work.

7 Conclusions

A proposal has been made here for skills needs analysis/prognosis based on technology roadmaps. It has been conceptually applied to Industry 4.0 as an important future innovation field. A similar approach has been applied to AAL.

Within this scope, it was argued that existing technology roadmaps from different sources and in different formats provide substantial input for skills needs analysis.

Two aspects were specifically emphasised. Firstly, organisation scenarios are a necessary element of skills needs prognosis, because there is no 'technological determinism': Similar technologies may lead to different skills needs, depending on the organisational environments.

Secondly, a technology/sector-matrix should be used as conceptual grid to address different skills needs in different workforce segments in different sectors depending on different subsets of the technologies under consideration.

Finally, among various contexts for using results of skills needs analyses, publicly funded (innovation) programmes have been identified as promising 'biotopes'.

Source/Citation:
Hartmann, E. & Bovenschulte, M. (2013): Skills Needs Analysis for "Industry 4.0" based on Roadmaps for Smart Systems. In: SKOLKOVO Moscow School of Management & International Labour Organization (ed.) (2013): Using Technology Foresights for Identifying Future Skills Needs. Global Workshop Proceedings, Moscow; p. 24-36